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ARCOM Declaration:

The papers in these proceedings were double-blind refereed by members of the scientific committee in a process that involved, detailed reading of the papers, reporting of comments to authors, modifications of papers by authors and re-evaluation of re-submitted papers to ensure quality of content.

Foreword

Welcome from the Chair – 41st Annual ARCOM Conference

Professor Craig Thomson, Glasgow Caledonian University

Following several years influenced by the need to rebuild from the pandemic and last year's celebration of our 40th anniversary, the 41st ARCOM conference provides for a more thematically directed forum where together we can explore the need for our cities to embrace a regenerative future. This is challenging and represents a paradigm shift from our traditional development model with the built environment playing a key part in its delivery. Such a future requires planning, design, construction, maintenance through lifecycle approaches, innovation and importantly collaboration with a wide range of stakeholders.

The construction sector will be key in the delivery of regenerative environments, and a multi-disciplinary approach is required not only for professionals but also amongst researchers. Dundee as our host city provides an exciting context due to a remarkable transformation through a long-term regeneration programme centred on its waterfront. From the reconfiguration of transport infrastructure and the creation of new commercial, civic and public spaces to the construction of the iconic V&A Dundee and the recent approval of the Eden Dundee project, the city exemplifies the evolving nature of urban regeneration.

These developments reflect a shift from traditional socio-economic objectives to more holistic approaches that integrate placemaking, environmental stewardship, and nature-based solutions. However, delivering a more regenerative approach faces considerable challenges which require all researchers in our field of construction management to contribute as this vision should increasingly frame all our work, and increasingly seek collaborations with researchers in other disciplines. The conference is structured around a keynote lecture, and two panel discussions designed to explore the scale of the challenge.

The ARCOM conference also provides a focus for wider themes, and through this reflects a coverage of the research currently being undertaken within our field of construction management as it has done since 1984. It is a privilege to work alongside Dr Chris Neilson to co-edit the proceedings for this conference, and we are proud to present a collection of papers that reflect the diversity, depth and dynamism of our field.

The journey began for our authors straight after the 40th conference last September as they started the process of developing their abstracts to meet the January submission deadline. This year we received 294 abstracts which although slightly down from our record number of 339 in 2024, was comparable to our 2023 conference and provides a strong foundation for the conference. 180 papers were submitted which again was comparable with our 2023 conference, with 147 (100 indexed and 47 working papers) being accepted following our 2nd stage review which is in line with our 2024 conference. This represents a stronger conversion rate which is down to the hard work of our Scientific Committee and the time that they spend on reading the papers and crafting thoughtful review comments which aim to challenge the authors to question and improve their papers.

What makes ARCOM special is the commitment of the authors to work with the reviewers to improve their papers, a process which can be challenging but rewarding.

The evidence would suggest that authors are increasingly up for the challenge, and the reward is an increasing number of authors who receive an invitation to present their work at conference.

ARCOM remains committed to being an inclusive and supportive platform for academic development. We aim to provide not only a venue for showcasing high-quality research but also a space where delegates—whether early career or established scholars—can grow, connect, and contribute to the future of our field in a friendly and welcoming environment.

The publication of the Proceedings of the 41st Annual ARCOM Conference and the production of our 2025 Working papers compendium takes a lot of effort. Firstly, I would like to thank my co-editor, Dr. Chris Neilson who organised, liaised, copy-edited, and sometimes nudged authors, reviewers and even me. Cath O'Connell who promptly dealt with all IT matters and who continues to improve our website and its associated conference management system. The Organising Committee who reviewed all the abstracts received and subsequently joined the members of our Scientific Committee to review papers at both initial and final review stage.

With the number of submissions this year, our review process has required a big effort by everyone, and this did not go unnoticed. I would also like to thank all the submitting authors, as without you we would not have a set of proceedings or indeed, a conference.

Finally, I would like to thank everyone at Abertay University for providing an excellent venue for our conference.

I hope you enjoy the papers,



Professor Craig Thomson

ARCOM Chair

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Table of Contents

Foreword 5
ARCOM Committee for 2024/2025 7
Scientific Committee 2024/2025 9
Table of Contents 11
AI / BIM / Digitalisation 17
Developing a Digital Twin-Enabled Cost Management Framework - Abdulrasheed Madugu Abdullahi, Muhammad Abdullahi and Rilwan ShuaibAbdulrahman 19
Digitalisation in Regenerative Cities - Debs Harding and Phillipa Boyd 29
Assessing the Impact of Level of Detail for Planning of Tunnelling Projects Using Building Information Modelling - Quentin Chevrier and Alireza Moghayedi 39
Artificial Intelligence Within the South Australian Architecture, Engineering, and Construction Industry - Emily Temby, Martin Jade and Nicholas Chileshe 49
Exploring Data Readiness for AI Adoption in the Construction Industry - Dinara Davletbayeva, Stuart Tennant and Ashwini Konanahalli 59
An Exploratory Study on Expectations from AI-Based Automated Scheduling - Irem Dikmen and Murat Cevikbas 69
Evaluating the Impact of Gen-AI on Improving Communications in Construction Projects - Atieh Dini and Ehsan Asnaashari 79
AI-Powered Auto-Scheduling of Construction Projects for Improved Efficiency - Shingai Chigangacha, Christian Henjewele, Hussein Adebayo Ibrahim and Nam Bui 89
Construction 4.0 Adoption in Vietnam's An Phu Project -Nam Bui, Christian Henjewele, T Huynh-Xuan, T Ngo-Thanh and Huy Q Truong 99
Trapped in Technocentric Thinking? - Léon olde Scholtenhuis and Ranjith Kuttantharappel Soman 109
Digital Disruption and Transformation in Project Cost Management in Developing Countries - Molusiwa Stephan Ramabodu 120
Deploying Industry 4.0 Enabling Technologies in Construction Projects - Liliyana Makarova Jørsfeldt, Anne Klitgaard, Rene Dahl Jeppesen, Carl Redmond and Lasse Justesen 129
The Application of BIM for Construction Circular Economy - Xiaobo Rong, Jingyu Zou, Saeed Reza Mohandes 139
Exploring the Role of Digital Twin Technology in Achieving Net Zero Buildings - Yifei Sheng, Saeed Reza Mohandes, Amir Rahbarimanesh and Kamal Qazi 149
Artificial Problems with Artificial Solutions? – Fred Sherratt 159
Exploration of Socio-Technical Approach for Implementation of Digital Twins for Predictive Maintenance in the UK - Modupe Sobowale, Faris Elghaish and Tara Brooks 169
Contract management 179

From Adversarial to Collaborative - Abiola Aderibigbe, Nnedinma Umeokafor and Yog Upadhyay....181
Digital and Collaborative Contract Management Practices in the Danish Construction Industry - Christian Laustsen and Lasse Fredslund....190
Exploring Stakeholder Collaboration in the Development of Baseline Schedules - Anthony McElwee, John P Spillane and James G Bradley....200
Advancing Construction Contract Risk Management Through NLP - Saad Rasool, Yuting Chen, Chika Udeaja and Daniel Fong....210
Design and technology....221
Exploring the Potential of Virtual Reality in Cross-Border Construction Projects - Sylvester L Manege, Ajay K Aravindakshan Abba T Mahmud and Newton Kiwia....222
Feedback-Driven Design Framework to Bridge the Gap Between Building Design and Operations - Miyami Dasandara, Ali Rashidi, Sahar Soltani and Duncan Maxwell....232
Integrating Sustainable Design and Responsible Project Management - Yiting Zhao, Lihong Zhang and Eunice Maytorena-Sanchez....242
Disaster management and resilience....253
Building Organisational Resilience - Zamageda Zungu....255
Equality, Diversity and Inclusion....265
Breaking the Concrete Ceiling - Tabarak Ballal....267
An Exploratory Study on Gender-Balance Influence on Hiring and Promotion in Construction Companies - Aine Harrison, Kate O'Connell, John P Spillane and James G Bradley....277
A Just Green Transition - Richard Brett, Barbara Vohmann and Sarah Strachan....287
Assessing the Roles of Emerging Technologies on Disability Inclusivity in the Construction Industry - Ernest Kissi, Clinton Aigbavboa and Evans Kwesi Mireku....297
Health, Safety and Wellbeing....307
Bridging the Gap - Emmanuel Aboagye-Nimo, Mansi Jain and Danstan Chiponde....309
Influence of Safety Climate on Safety Behaviour - Eunice Achina Agyemang and Emmanuel Adinyira....319
An Exploration of Condom Use among Male Construction Worker Clients of Female Sex Workers in the Western Cape - Paul Bowen, Kamal Yakubu and Rajen Govender....329
Reporting of Work-Related Stress - Patrick Bruce, Victor Hrymak, Jimi Johnston and Carol Bruce....339
How Do Organisations Respond to Major Regulatory Change? - Liam Webb, Selcuk Cidik and Vivien Chow....349
Drive-in Drive-Out Work and Temporary Accommodation - David Moloney, Michael R Curran, John P Spillane and James G Bradley....359

An Exploratory Study into Construction Health and Safety Practices and Digitalisation in South Africa - Emmanuel Itodo Daniel, Christiana Adah, Fidelis Emuze, Ezekiel Chinyio, Abimbola Windapo, Comfort Iyiola, Olalekan Oshodi and Amanda Filtane 369
Everything in Its Right Place - Sinead Gilmour, Simon David Smith and Faye Wade 379
The Interplay Between Stress, Anxiety, and Depression in the Construction Industry - Cillian Keane and John P Spillane 389
Workplace Incident Reporting - Charles Okafor, Ravi Rangarajan, Abdulla Ansari and Haruna Musa Moda 399
Digitalisation of Occupational Safety and Health in Construction - Jaemin Jeong, Clara Man Cheung, Daeho Kim, Saeed Reza Mohandes, Dongmin Lee, Patrick Manu, Akilu Yunusa-Kaltungo, Sarah Haines and Changbum Ahn 409
Building a Safer Tomorrow - Che Khairil Izam Che Ibrahim, Patrick Manu, Sheila Belayutham, Clara Man Cheung, Mazlina Zaira Mohamad, Akilu Yunusa-Kaltungo, Shafienaz Ismail, Nor Syamimi Samsudin, Abhinesh Prabhakaran, Pablo Perez, Abdul-Majeed Mahamadu and Azman Hussain 419
Accidents Analysis in Construction Road Projects - Hadi Sarvari, David J Edwards and Iain Rillie 429
The State of South African Construction Health and Safety – John Smallwood .. 438
A Systematic Review of the Application of Industry 4.0 Technologies in Construction Safety Management - Jingyu Zou, Saeed Reza Mohandes, Clara Cheung and Amir Rahbarimanesh 448
Human Resources Management 459
The Functions of Project Management Office Models for Construction SMEs - Mohammed Alghaseb 461
An Exploration of Interpersonal Conflict Causation Factors in the Built Environment - Tadhg O'Neill and John P Spillane 471
Personality Trait Distribution of Construction Managers in the Republic of Ireland - Tadhg O'Neill and John P Spillane 481
Strategic Succession Planning of SMEs in the Built Environment - Marc Tracey and John P Spillane 491
Infrastructure Development 501
A Review of Value for Money Assessment Approaches in Public Private Partnership Projects - Agnes Kaima, Sam Zulu and Neema Kavishe 503
Program Management of Construction Projects - Alberto De Marco, Massimo Rebuglio, Concetta di Napoli 512
Platform Thinking in Construction - Daniel Woodier, Julia Köhler and Christian Thuesen 522
Law 533
A Legal Scoping Review of UK Law Governing Green Building - Diane Dickson 535
Offsite construction 545

Industrial Housing as European Crisis Response - Christian Koch 547
Policy Purpose and Effect on the Use of Modern Methods of Construction in the English House Building Sector - Jonathan Morgan, Chris Goodier, Robert Schmidt III and Kudirat Ayinla 557
Advancing Offsite Construction Practices - Aaron D O'Neill, John P Spillane and Michael R Curran 567
No More Cursory Summaries - Léon olde Scholtenhuis, Tom Coenen, Andreas Hartmann and Ramon ter Huurne 577
Pedagogic research 587
Navigating Bias in Apprenticeship Research - Elma McMahon, John Spillane and James Bradley 589
Examining the Perception of Quantity Surveying Students During Measurement of Construction Works Workshop Sessions - Amina Nazif, Bert Young, Rafiu Seidu, Abigail Amoah-Korsah and Frank Ghansah 597
Shaping Sustainability Minds in Construction Education - Aysar Dawod Selman and Evelien Verdonck 607
Innovative Pedagogies in Construction Project Management Education - Mehran Sepehri, Murat Ayhan, Don Samuel and Mark Allinson 617
Performance 627
Deciphering Frameworks for Work Breakdown Structure Development in Complex Construction Projects - Anthony McElwee, John P Spillane and James G Bradley 629
Towards an Optimised Taxonomy of Errors in Construction - Rokhsareh Mohammadkhani, Theopisti Papadopoulou, Gordon Hunter and Ted Donchev ... 639
Stakeholder Salience in Managing Intragroup Conflicts in Australian Construction Projects - Nilmi Bhagya Senarath, Nilupa Udawatta, Gayani Karunasena and Salman Shooshtarian 648
Trust, Control and Performance in International Joint Ventures - Leonardo Sedevich-Fons 658
Critical Success Factors May Be "Sufficient" But Are They "Necessary" for Project Performance or Success? - Martin Morgan Tuul 668
Aggregated Annual Profit Analysis Method - Stephen Urquhart and Andrew Whyte 678
Indonesian PV Power Plant Performance - Andrew Whyte and Yusuf Ramadhan 688
Procurement 699
Inter-Firm Conflict and Project Delay in Malaysian Construction Sector - Abdul Azri Bin Abu Hasan, Peter Fenn and Elika Aminian 701
Examining Social Procurement Policy - Jemma Bridgeman 711
Building Better Futures - Joshua Shedrack Mangvwat, John P Spillane and James G Bradley 721
The Influence of Project Manager Capability on Project Governance - Doug Wheeler, Timothy Rose and Stephen Kajewski 731

Sustainability 741
Determinants of Material Reuse in a Restorative Circular Economy in the Building Sector - Jieling Huang, Mohamed Abadi and Jillian Yeow 743
A Framework of Maturity Levels for Building Firms to Inform the Strategic Transition to Smart Circular Construction - Oluwapelumi Abiodun, Mohamed Abadi, Obuks Ejohwomu and Patrick Manu 753
Exploring Stakeholder Strategies for Circular Economy Adoption in the Welsh Construction Industry - Overcomer Agoi and Adetola Oguntade 763
Building Obsolescence - Azlan Shah Ali, Zakaria Norhanim, Zulkifly Umi-Kalsum and Zaki Faiz 772
Organisational Responses to Sustainability Demands - Jan Bronke 782
Opportunities and Challenges for Project Based Organisations in light of Climate Change - Danstan Bwalya Chiponde, Barry Gledson, David Greenwood, Emmanuel Aboagye-Nimo 792
From Clauses to Carbon - Ariana Darvish and Mehran Sepehri 802
A Mixed Methods Approach to Developing a Framework to Manage the Legal and Contractual Risks in Green Building - Diane Dickson 812
Organisational Collectives for Sustainable Change: Hope or Hoax? - Nicolaj Frederiksen, Stefan Christoffer Gottlieb, Andreas de Gier, Rasmus Holmegaar, Christian Koch and Martine Buser 822
Regenerative Cities in Action - Devindi Geekiyanage and Amila Liyanage 832
A Regenerative Strategy for Civic Precinct, Newcastle, NSW, Australia - Bob Giddings, Marcus Jefferies and Robert Rogerson 842
Perceptions of Sustainability from Small German Construction Firms: An Autoethnography - Henning Grosse 852
Supportive Hero and Troublemaker? - Stina Hellsvik and Petra Bosch-Sijtsema. 862
Circular Building Going in Circles: Challenges in Circular Business Model Implementation in the Danish Construction Industry - Rasmus Holmegaard, Martine Buser, Christian Koch, Stefan Christoffer Gottlieb, Nicolaj Frederiksen and Andreas de Gier 871
Revitalising Building Production Through Regeneration - Dimosthenis Kifokeris, Daniella Troje, Radhlinah Aulin and Henrik Linderoth 881
Transforming the Design of Resource-Intensive Load-Bearing Structures into Regenerative Practices - Dan Lange-Kornbak and Ali Kadum Hassan 891
Motivational Factors for Circular Economy Design Knowledge Management in Construction and Demolition Waste Sector - Malsha Nadeetharu, Nilupa Udawatta, Gayani Karunasena and Glenn Costin 900
Sustainable Low-Carbon Housing Retrofitting in the UK - Mohd Farhan, Serik Tokbolat and Carlos Osorio-Sandoval 910
Constructs and Indicators for Assessing Stakeholder Behaviour in Adopting the Circular Economy in Construction and Demolition Waste Management - Anne Dilogini Rex Ashokkumar, Gayani Karunasena, Nilupa Udawatta and Chunlu Liu 921

Public Clients' Transition Towards Circular Practises in Infrastructure Projects - Shaun Alex and Ad Straub 931

Prioritising Sustainable and Low-Carbon Transport Indicators in Infrastructure Transition Using Pairwise Comparisons - Swaroopa Rani Sunkari and Simon David Smith 941

Developing a Conceptual Framework to Embed the Social Cost of Carbon in Cost Estimation for Commercial Buildings - Ziru Tao, Paul Baguley, Obuks Ejohwomu and Rashid Maqbool 951

The Role of Digital Technologies in Advancing Circular Economy Practices in the Australian Construction Industry - Sivanuja Thirumal, Nilupa Udawatta, Gayani Karunasena and Al-Ameri Riyadh 961

Reused or Used Up? - Dimosthenis Kifokeris, Daniella Troje and Kristina Mjörnell 971

Evaluating 1960s-1970s Ageing Concrete Buildings Through Documentary Analysis for Renovation and Demolition Decisions – Xiao ma, Dorsa Fatourehchi, Kirsten Day, Paulo Vaz Serra, Nilupa Herath, Ali Yaghoubzadehfard and Priyan Mendis 981

A Model of Social Value Maturity for Benchmarking Construction Contractors - Greg Watts 991

From Strategy to Site - Sean Elliot Wisse, Lovisa Bjurgård Fagerlund, Daniella Troje 1000

Assessing the Salvage Value of Green Components in Malaysian Buildings - Norhanim Zakaria, Azlan Shah Ali and Umi Kalsum Zolkafli 1011

Index of Authors 1021

Index of Keywords 1025

AI / BIM / DIGITALISATION

DEVELOPING A DIGITAL TWIN-ENABLED COST MANAGEMENT FRAMEWORK: A STRUCTURED APPROACH

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The Architecture, Engineering, and Construction (AEC) industry is plagued by poor cost performance, with most construction projects experiencing cost overruns, delays, and poor efficiency and performance. Traditional cost management methods often fail to provide timely insights and accurate predictions, aggravating this issue. This study explores the integration of digital twins with cost management, leveraging Building Information Modelling (BIM) data, as a potential solution. Building upon the synchronisation approach of the orthogonal synchronised digital twin (SDT) model, this study adopts a design science research (DSR) approach, combining a comprehensive literature review with semi-structured interviews with industry experts, to develop a digital twin-enabled cost management framework. The proposed framework consists of four key components: (1) Digital Twin Component, (2) Cost Management Component, (3) Data Analytics Component, and (4) Integration Component. The proposed framework enables real-time cost data analysis, simulation, and optimisation. This study addresses a significant research gap and provides a foundation for future research and practice in digital twin-enabled cost management.

Keywords: digital twin; cost management; construction industry; data analytics; building information modelling

INTRODUCTION

Cost overruns and inefficiencies are a persistent challenge in the Architecture, Engineering, and Construction (AEC) industry and significantly impact project success (Durdyev, 2020). These challenges frequently arise from the complexities inherent in construction projects, including fragmented workflows, diverse stakeholders, and dynamic environmental conditions (Omotayo *et al.,* 2024). Traditional cost management methods often struggle to provide accurate and timely cost information throughout the project life cycle. This is defined by their reactive nature, lack of real-time information, and reliance on fragmented data (Sepasgozar *et al.,* 2022; Tuhaise *et al.,* 2023). Cost estimation, control, and reporting are often fragmented, relying on static inputs and periodic updates that fail to reflect real-time site conditions or operational performance. As a result, potential cost deviations are

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recognised lately, hindering proactive decision-making and leading to inefficient practices with significant cost repercussions (Sepasgozar *et al.,* 2022).

Digital Twin (DT) technology offers a potential solution by enabling real-time data synchronisation and informed decision-making (Tuhaise *et al.,* 2023). DT generally has three primary components: the physical environment, its digital representation, and the continuous flow of data and feedback that links the two, facilitated by data sensing technologies, artificial intelligence capabilities, and high-speed networking (Grieves, 2014; Jiang *et al.,* 2024; Tuhaise *et al.,* 2023). DTs have been implemented to resolve persistent issues related to productivity, efficiency, and value (Moshood *et al.,* 2024).

Previous research has shown significant advancements in the application of DTs in the construction industry, moving from conceptual models towards practical implementations across various project lifecycle phases (Su *et al.,* 2023; Yang *et al.,* 2024). Initially, DTs, often integrated with Building Information Modelling (BIM) and 4D simulations, were used for constructability analysis, safety management, and progress monitoring during the planning and construction phases (Nguyen and Adhikari, 2023; Sacks *et al.,* 2020). The integration of Computer Vision (CV) and Real-Time Location Systems (RTLS) enabled near real-time updates of digital representations and facilitated tasks like activity recognition, productivity analysis, and safety management on construction sites (Huang *et al.,* 2021). Furthermore, advancements include the development of frameworks for generating DTs by integrating BIM with emerging technologies like the Internet of Things (IoT), Artificial Intelligence (AI), and Blockchain (Boje *et al.,* 2020). Research has explored DTs for specific applications such as precast concrete element production (Kosse *et al.,* 2024), infrastructure management (Hakimi *et al.,* 2023), and building lifecycle management, including predictive maintenance and anomaly detection (Lu *et al.,* 2020). The concept has evolved towards semantic digital twins leveraging Linked Data and ontologies for enhanced data integration and interoperability (Boje *et al.,* 2020). Moreover, advancements in visualisation technologies like Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) are being integrated with DTs for improved interaction and understanding of project status (Prakash *et al.,* 2024).

Despite advancements in DT within the AEC sector, there remains a critical gap in the development of integrated cost management frameworks that fully leverage the capabilities of DT and BIM. BIM effectively serves as a comprehensive data repository, capturing detailed geometric and functional information of assets (Sacks *et al.,* 2020). However, its limitations become evident when dynamic real-time data integration from the physical environment is required (Tuhaise *et al.,* 2023). DT technology addresses these limitations by connecting physical entities with their virtual models, enabling bidirectional data flow and continuous updates to the BIM model with real-time information (Tuhaise *et al.,* 2023). Current practices often fail to consistently harness the real-time data synchronisation offered by DTs specifically for cost management purposes. This lack of integration presents a clear need to explore how to achieve seamless and timely updates of cost-related information derived from both the evolving digital models and the ongoing physical construction activities. Therefore, this research aims to address this gap by developing a structured framework for integrating DT technology with cost management practices in construction projects. The proposed framework has the potential to foster enhanced cost control through real-time insights, proactive risk management, and optimised resource allocation.

LITERATURE REVIEW

Construction Cost Management

Construction cost management is the process of controlling costs within an approved budget throughout the lifecycle of a construction project (Vigneault *et al.,* 2020). It involves processes such as quantity take-off, cost estimation, cost budgeting, cost monitoring and control, life cycle cost analysis, and claim management to ensure that the final construction cost remains within the client's approved financial limits (Vigneault *et al.,* 2020). Effective cost management is crucial in the construction industry to mitigate cost overruns, which remain a key risk in construction projects (Omotayo *et al.,* 2022).

Research in construction cost management has focused on identifying factors that contribute to cost overruns (Oyegoke *et al.,* 2022; Sepasgozar *et al.,* 2022). For example, studies have aimed to determine the main and sub-attributes that influence cost control practice (Adjei, 2020). The effectiveness of different cost control techniques and factors affecting their selection have also been examined (Oyegoke *et al.,* 2022). Another research compared traditional cost management processes with those enabled by digital technologies such as BIM (Vigneault *et al.,* 2020). These comparisons aim to identify how digital tools can address the limitations of conventional approaches and improve efficiency and accuracy in cost management. The integration of cost management with broader industry trends like Industry 4.0 is also receiving attention (Sepasgozar *et al.,* 2022).

Digital Twin Technology in Construction

A digital twin is a dynamic digital representation of a physical asset, process, or system, updated with real-time data to achieve cyber-physical integration (Grieves, 2014). In the construction industry, a digital twin can update a BIM model with real-time data from sources like sensors and IoT devices, enabling real-time monitoring of assets and activities and improving decision-making (Tuhaise *et al.,* 2023). The application of digital twins in construction is still in its early stages but is steadily growing (Tuhaise *et al.,* 2023).

The core elements of a digital twin typically include the physical entity, its digital replica, and the data connection facilitating the flow of information between them (Grieves, 2014). Research has identified key technologies used in the development of digital twins in construction, spanning data acquisition, data transmission, digital modelling, data/model integration, and services (Tuhaise *et al.,* 2023).

Studies have explored the potential of digital twins across different phases of a building's lifecycle, including planning, design, construction, and operation and maintenance (Long *et al.,* 2024). However, current research predominantly focuses on the construction and operation and maintenance phases (Long *et al.,* 2024). Different models for digital twins exist, with the five-dimensional model (physical entity, virtual model, service, fusion data, and connection) being commonly adopted (Jiang *et al.,* 2024). While drawing inspiration from manufacturing, construction digital twins have distinct characteristics due to differences in the working environment, scale, project timespan, granularity, stability, and capacity size.

BIM-based Cost Management

BIM is a process supported by technology for creating and managing information about a construction project across its lifecycle (Eastman *et al.,* 2011). In cost

management, BIM enables the association of cost-related information with the digital model elements (5D BIM), facilitating more accurate and efficient cost-related processes. BIM-enabled cost management leverages the information-rich BIM model for tasks such as quantity take-off, cost estimation, cost control, and cost reporting (Sepasgozar *et al.,* 2022). These capabilities have led to increased efficiency in early-stage planning and automation of routine cost functions.

Despite these advances, BIM-based cost practices often remain fragmented and static. Processes such as estimation and control are typically executed in isolated stages, relying on periodically updated inputs that do not reflect real-time project dynamic. Robson *et al. (*2016) have argued that cost should be seen as contextual information formed by stakeholders, project circumstances, and contractual procedures. The research described cost figures are typically "surrogate numbers," hiding performance and decision-making dynamics. This suggests that while BIM and related tools can automate cost functions, they may unintentionally replicate flawed assumptions if cost is not treated as a dynamic narrative linked to actual production.

While BIM provides a detailed digital representation of a project, its effectiveness is constrained without real-time feedback from construction activities. The integration of BIM with emerging technologies like the Internet of Things (IoT), Artificial Intelligence (AI), and Blockchain is being explored to create more dynamic and intelligent cost management systems (Boje *et al.,* 2020). The evolution towards semantic digital twins, leveraging linked data and ontologies, also aims to improve data integration and interoperability in BIM-based cost management (Abdullahi *et al.,* 2023; Boje *et al.,* 2020). Overall, the integration of DT with BIM will aid in overcoming these limitations by embedding real-time data from the physical environment, including resource utilisation, material flow, and progress monitoring, into the virtual model. By aligning physical performance with digital records, cost data can more precisely represent current project reality.

METHOD

Based on the principles of Design Science Research (DSR) (Hevner *et al.,* 2004), this study adopted a structured methodology for developing a digital twin-enabled cost management framework for the AEC industry. DSR is particularly suited for creating innovative artifacts, in this case, a framework to address significant problems within a specific domain (Calvetti *et al.,* 2025). Therefore, this research combines a rigorous comprehensive literature review with empirical data gathered through semi-structured interviews with industry experts to develop and propose the intended framework. The methodology was implemented through four iterative stages (Peffers *et al.,* 2007): (1) Problem Identification and Research Objectives Definition, (2) Framework Design and Development, (3) Evaluation and Validation through Expert Interviews, and (4) Framework Refinement.

A thorough literature review identified AEC cost management issues and a critical research gap in integrating DT technology with cost management processes in stage 1. The literature review process ensured a thorough understanding of the existing knowledge base and the identification of a well-defined research problem. This review defined the research objectives by emphasising the need for a structured, real-time, digital twin-enabled cost management framework.

In stage 2, insights from the literature review and prior theoretical developments in digital twins (Calvetti *et al.,* 2025) were used to design the initial conceptual

framework, incorporating four primary components: the Digital Twin Component, Cost Management Component, Data Analytics Component, and Integration Component. The design phase involved systematically mapping interactions and data flows between these components, leveraging BIM (Nguyen and Adhikari, 2023) and emerging DT technologies, such as IoT sensors, real-time data analytics, and predictive modelling techniques (Hu and Assaad, 2024).

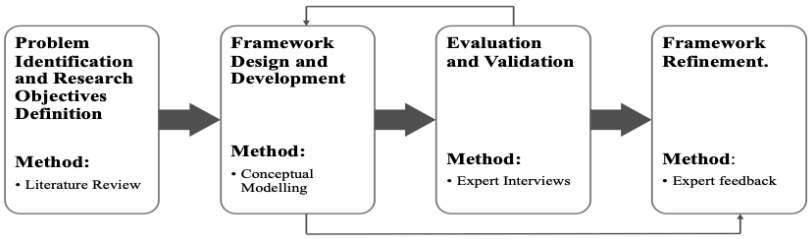


Figure 1: The research framework based on DSR (Peffers et al., 2007)

In stage 3, which is the evaluation and validation stage, semi-structured expert interviews were conducted to validate and refine the framework's conceptual components and practical applicability. Each expert was provided with the conceptual framework (including diagrams and descriptions) in advance and subsequently engaged in individual validation sessions lasting between 1.5 and 2 hours. Participants included professionals with substantial experience in construction management, BIM applications, and digital twin implementation within the AEC industry as presented in Table 1. During the sessions, the framework was discussed across five key evaluation dimensions: Alignment with current practices, integration and data flow, functional completeness, usability and accessibility, and future implementation. Interview data were analysed using thematic content analysis, facilitating the identification of common insights, critiques, and practical recommendations. Feedback from industry experts led to iterative refinement of the framework, ensuring alignment with real-world requirements and technological feasibility.

In stage 4, based on the rich qualitative data obtained during expert evaluation, iterative refinements were carried out to optimise interactions and data flow processes between framework components. This iterative process, a cornerstone of DSR (Calvetti *et al.,* 2025), focused on enhancing the framework's real-time analytics precision, interoperability among technological components, and ensuring the conceptual robustness and clarity of the framework.

Table 1: Summary of Expert Interviews Conducted

Expert Code	Background/Role	Experience (Years)	Number of Meetings	Total Hours of Interaction
A	Construction Cost Management expert	15	1	1.5
B	BIM and Digital Twin Expert	20	1	2
C	Construction Cost Management expert	20	1	2
D	BIM and Digital Twin Expert	15	1	1.5

Framework for Digital Twin-Enabled Cost Management

The proposed framework represents a structured approach integrating BIM and DT to significantly enhance cost management practices within the AEC industry. The

conceptual framework, as illustrated in Figure 1, comprises four interrelated functional layers; data sources, processing and integration, cost management, and integration and collaboration that operate concurrently to support real-time, lifecycle-oriented cost control. Rather than sequential phases, each layer performs a distinct role, yet their interaction is facilitated by real-time data flows and feedback loops. For example, data from sensors and site conditions (Data Sources) is processed and synchronised (Processing Layer) to inform dynamic cost functions (Cost Management), which in turn updates collaborative dashboards and stakeholder alerts (Collaboration Layer). These layers form a dynamic system enabling continuous data flow, stakeholder interaction, and adaptive decision-making. Cost, within this framework, is conceptualised broadly to include activities such as quantity take-off, estimation, and budgeting; post-contract processes like cost control, forecasting, and claims management; and life-cycle cost considerations such as maintenance, operational efficiency, and total cost of ownership supporting both strategic and operational financial decisions.

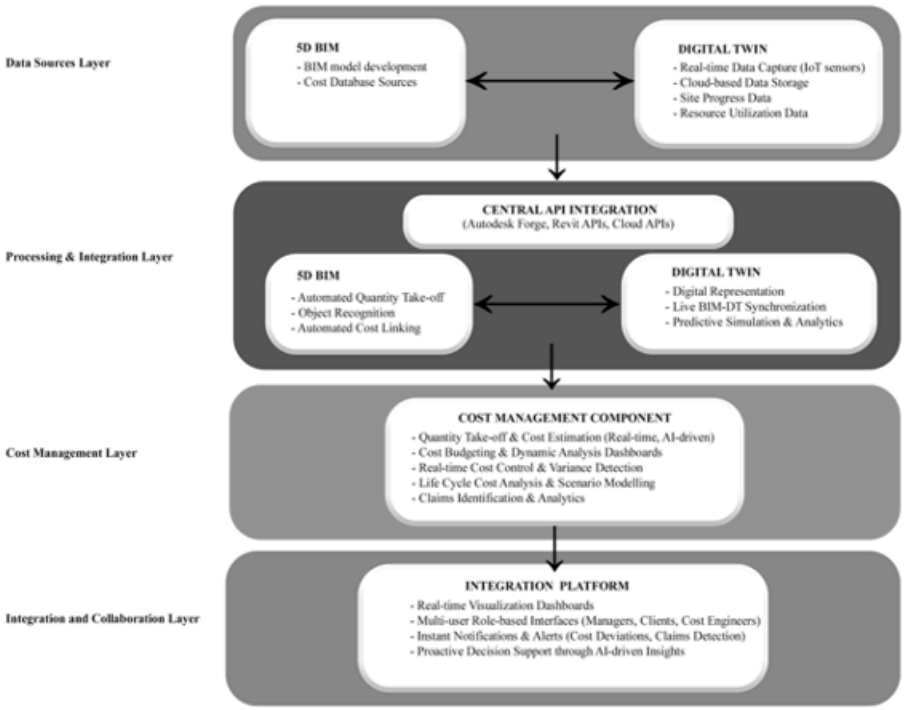


Figure 2: Proposed digital twin-enabled cost management framework

Data Sources Layer

The proposed framework integrates two foundational components: the 5D BIM component and the DT component. The 5D BIM component serves as a foundational data source, it encompasses the development of accurate BIM models via laser scanning technologies (scan-to-BIM), subsequently enriched by detailed construction specifications and comprehensive cost databases, including historical, market-based, and supplier-derived cost information. Concurrently, the DT component captures dynamic, real-time data using IoT sensors capturing construction site progress, resource utilisation, and environmental conditions. Such integration ensures high-quality, up-to-date data, thus enhancing the precision and reliability of subsequent analytical processes.

Processing and Integration Layer
This layer serves as the technological backbone of the framework, by synchronising physical and digital data streams for real-time cost management. This layer combines BIM and DT. BIM represents the project's geometry, construction components, and design specifications in a structured, static manner, whereas the DT component acts as a cyber-physical system. The digital twin dynamically synchronises real-time construction site data including resource utilisation, progress metrics, and environmental variables.

The integration component uses industry-standard application programming interface (APIs) like Autodesk Forge, Revit, and Cloud APIs to transmit data across the BIM and DT environments in real time. These send real-time site data from IoT sensors tracking resource use, progress, and environmental conditions to the DT's central data store. The DT system processes and visualises this data in connection to the BIM model, establishing a dynamic, bi-directional feedback loop between physical and digital surroundings. The DT component is a data ecosystem with sensor networks, cloud storage, and AI-driven analytics, not a live BIM model. This ecosystem's spatial interface and BIM, simplifies the interpretation and visualisation of cost performance data by linking physical components to their associated cost parameters.

Feedback from BIM and DT experts particularly underscored the importance of ensuring clear and robust API-driven interoperability. Consequently, the framework was refined to incorporate specific industry-standard APIs, ensuring compatibility and efficiency in practical applications. Furthermore, the 5D BIM component at this level provides for automated quantity take-off, object recognition, and cost linkage mechanisms, ensuring accurate quantification, cost estimation, and automated synchronisation across the digital twin and BIM environments. Meanwhile, the DT component provides predictive simulation and real-time analytics capabilities, critical for proactive project control and risk management.

Cost Management Layer
This constitutes the analytical core of the framework, synthesising integrated data inputs to facilitate comprehensive cost management tasks. It acts as a domain-specific instantiation of the general digital twin for the project. While the overall DT system may include data on safety, energy, environmental performance, or scheduling, the DT-Cost Model analyses cost-relevant parameters like real-time, AI-driven cost estimation and budgeting, automated variance detection, life-cycle cost analyses, and scenario modelling. Predictive analytics' capacity to anticipate cost overruns and dangers was highlighted in validation interviews with construction cost management professionals. Following expert advice, life-cycle costing was added to cost management assessments, expanding their scope and depth. Additionally, the inclusion of claims identification and analytics mechanisms within this layer was positively validated, offering a proactive approach to managing potential claims and financial disputes.

Integration and Collaboration Layer
This transforms the comprehensive data-driven analyses from previous layers into actionable insights accessible via a collaborative, cloud-based platform. This layer features real-time visualisation dashboards, multi-user role-based interfaces tailored for diverse stakeholders (clients, managers, and quantity surveyors), and instant notifications for critical cost deviations. Expert validation notably suggested enhancements to the user interface to ensure intuitive navigation and clarity,

particularly for stakeholders less familiar with complex BIM and cost data visualisations. The integration of proactive decision-support systems utilising AI-driven insights, as validated by experts, ensures the platform not only informs but also actively supports stakeholder decision-making processes, reinforcing effective project control and collaboration.

Framework Validation

To validate the relevance, alignment, and conceptual robustness of the proposed framework, semi-structured interviews were conducted with four industry experts (two specialising in construction cost management and two in BIM/digital twin technologies) as outlined the in the research methods sections. Drawing from a total of approximately 7 hours of expert interaction, this section discusses the framework's strengths and areas for refinement across five core issues: Alignment with current practices, integration and data flow, functional completeness, usability and accessibility, and future implementation.

The proposed framework aligns with industry standards and improves cost management through digital integration. Expert validation shows that the layered structure of Data Sources, Processing and Integration, Cost Management, and Integration and Collaboration reflects construction cost management decision-making stages. The framework's comprehensive functionality, including quantity take-off, AI-driven estimation, dynamic budgeting, cost control, life-cycle analysis, and claims management, garnered unanimous agreement for integrating both planning and operational elements, with a focus on life-cycle costing and predictive analytics for proactive financial decision-making.

The framework's focus on API connectivity for seamless real-time data interchange across BIM, Digital Twin, and cost management modules embodies true digital twin concepts by dynamically updating digital models based on physical site data. While technically strong, experts found role-specific dashboards and simplified visualisations to reduce information overload for non-technical stakeholders. Further definition of interoperability protocols and standards could facilitate implementation across varied software environments as the framework proceeds from conceptual development to real deployment.

Experts recommend pilot testing the framework in real construction sites from design to implementation phase. Practical testing will reveal workflow, data governance, and organisational structure compatibility improvements. To solve cloud-based, real-time data interchange problems, future development should include clear data privacy and cybersecurity protections. The framework's holistic approach to cost management and digital capabilities can improve financial decision-making throughout the construction lifecycle.

CONCLUSIONS

This study developed a digital twin-enabled cost management framework that reconceptualises cost as dynamic, real-time information rather than static numerical estimates, leveraging a structured and rigorous DSR methodology. The framework integrates BIM, IoT, and advanced analytics to support continuous feedback between the physical and digital environments. By doing so, it addresses limitations in traditional cost practices, particularly the detachment of cost figures from actual performance and offers a structured approach to enhance decision-making across the project lifecycle. Future research can focus on practical implementation and rigorous

validation in real-world projects, identifying gaps for further refinement and maximising its applicability and impact in practice.

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DIGITALISATION IN REGENERATIVE CITIES: OPPORTUNITIES AND CHALLENGES IN THE BUILT ENVIRONMENT

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The built environment increasingly focuses on delivering sustainable refurbishment and new-build projects to support regenerative city-building. Digitalisation is often positioned as a critical enabler through tools such as BIM, project planning software, and generative AI (GenAI). However, important questions remain about how these tools are used in practice and how professionals navigate emerging ethical and strategic challenges. This study explores how Built Environment Professionals (BEPs) engage with digital tools on live projects, including how professionals adopt, adapt, or resist GenAI in context. Guided by a Strategy-as-Practice (SaP) lens, the research draws on interviews, surveys, and two embedded case studies, one of which was led by a practitioner-researcher. Findings reveal that digitalisation is not experienced as a seamless transformation, but a situated, relational process shaped by professional judgement, discretion, and role-specific adaptations. While participants reported informal experimentation with GenAI, they also expressed uncertainty over authorship, accountability, and ethical use - particularly as AI functionality becomes embedded within everyday tools. These insights highlight the need to support digital tool adoption and the strategic enactment of digitalisation by professionals aiming for regenerative outcomes.

Keywords: digitalisation; GenAI; ethical frameworks; professional practices; technical competencies

INTRODUCTION

The ambition to build regenerative cities has reshaped construction discourse. Regeneration focuses on restoration, renewal, and the enhancement of ecological and social systems. Refurbishment and extension projects are critical to these efforts, particularly in urban contexts where reusing existing buildings reduces carbon, retains embodied value, and supports biodiversity and community resilience. These efforts increasingly rely on digital tools (e.g., GIS and digital twins) to address these complex ecological and social challenges with digitalisation enabling scenario modelling, participatory planning, and integrated decision-making (Moufid *et al.,* 2024). At the project level, the digital transformation of the built environment supports regenerative practices not merely through improved efficiencies, but also as strategic enablers of

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circularity, flexibility, and long-term value creation within construction and design workflows (Konietzko *et al.,* 2023). Regeneration is thus not only a design aspiration but a digitally mediated professional practice

While digitalisation is now central to construction discourse, how it is used in the everyday work of regenerative city-building remains surprisingly opaque. Little attention has been paid to how Built Environment Professionals (BEPs) engage with digital tools in complex, site-based practices. In projects that blend refurbishment with new-build elements, digitalisation unfolds not as a seamless system but as a situated, strategic activity shaped by professional judgement, improvisation, and collaboration. Despite growing enthusiasm for digital transformation in the built environment, there is limited understanding of how professionals implement digital tools within the messy, negotiated space of live construction projects. Digitalisation unfolds less as a formal rollout and more as a negotiated, professional activity - particularly in refurbishment and extension work. Renewal goals intersect with legacy constraints, fragmented systems, and interdisciplinary demands. Professionals must navigate diverse tools, shifting client expectations, and project-specific constraints. By investigating how Built Environment Professionals (BEPs) strategically implement digitalisation in refurbishment and extension projects that contribute to regenerative city-building, this study offers new insight into the strategic dimensions of delivering regenerative city-building in practice.

LITERATURE REVIEW

The following literature review situates this inquiry within broader debates on regeneration, digital innovation, and professional agency in construction.

The ambition to build regenerative cities has redefined urban development, shifting focus from growth and efficiency to long-term ecological renewal and social resilience. This paradigm reframes the built environment as a site of repair and restoration rather than extraction and expansion which prioritises biodiversity, adaptive reuse, and future-oriented architectural thinking. (Lehmann, 2019; Arup,2024). These perspectives challenge traditional notions of professional performance by shifting emphasis from delivering predefined outputs to enabling ongoing environmental and social regeneration. This reconceptualisation requires professionals to engage more strategically with adaptive reuse, stakeholder value, and long-term resilience - demands that digital tools must now support in practice, not just in theory.

Much of the academic literature on digitalisation aligns with this aspirational framing but often assumes digital tools can be smoothly adopted into practice. For example, GhaffarianHoseini *et al. (*2017) emphasize the environmental benefits of Building Information Modelling (BIM), framing it as a vehicle for high-performance design and cross-disciplinary integration. Similarly, Lu *et al. (*2017) highlighted BIM's potential for reducing waste and improving lifecycle decision-making. However, despite their sustainability focus, both studies are rooted in new-build contexts and rely on data consistency, controlled sequencing, and technical standardisation assumptions which are hard to apply in the context of refurbishments and retrofits (a fundamental component of building regenerative cities). These assumptions overlook the praxis of digitalisation - the situated, adaptive work of professionals dealing with legacy buildings, fragmented information, and evolving client needs.

This limitation becomes more apparent when digitalisation is examined through a sociotechnical lens. Dossick and Neff (2010), for instance, demonstrate that BIM does not eliminate professional silos but often reinforces them, requiring relational work to bridge institutional and cultural divides. Building on this, Forbes, and Ahmed (2021) argue that successful digital delivery is not just about systems, but the invisible, informal labour professionals undertake to align expectations, translate outputs, and resolve inconsistencies. These insights challenge the tool-focused assumptions of earlier work by reframing digitalisation as a negotiated and discretionary activity. These informal acts reflect not just workflow adaptations but practices - the shared norms and routines that shape how digital tools are enacted across project teams. Whyte (2019) extends this thinking by showing how digital information platforms reshape project delivery models, often redistributing responsibility and altering inter-professional boundaries. This repositioning creates opportunities and ambiguities, requiring practitioners to exercise judgement and strategically reinterpret their roles. Consequently, digitalisation becomes a technical shift and a reconfiguration of power, agency, and coordination - especially relevant in retrofit contexts where professional judgement must override rigid workflows. These evolving responsibilities highlight the importance of practitioners themselves - those actors who shape strategy not by following formal plans but by adjusting tools, translating outputs, and negotiating value in context.

Professional body guidance presents digitalisation as a structured and predictable process. The CIOB offers an Artificial Intelligence Playbook (CIOB, 2021) which links digital proficiency to sector-wide productivity and quality gains, while the UK Government's Construction Playbook (2021) frames digitalisation as integral to modern procurement reform. Although these reports offer valuable frameworks, they overlook the iterative and situational realities of project delivery, especially in non-standardised refurbishment projects. Their emphasis on compliance and optimisation leaves limited room for professional discretion, adaptation, or client communication, which are critical to regenerative outcomes. Recent guidance addresses these gaps by linking digitalisation with value and sustainability frameworks. For example, the UK Green Building Council (2022) connects digital workflows to whole-life carbon accounting and retrofit innovation. In contrast, the Construction Innovation Hub's Value Toolkit (CIH, 2021) promotes data-driven decision-making to optimise social and environmental value. Likewise, the CIBSE (2022) offers integration guidance for digital building services in complex environments. Despite expanding the discourse beyond efficiency, these documents rarely engage with the ambiguity and resistance professionals encounter when applying digital tools in practice.

From a theoretical perspective, Succar and Kassem (2015) proposed a multilayered model of BIM adoption that distinguishes multi-level project environments. Although this model acknowledges complexity, it still implies that alignment across these levels is possible through planning and coordination. In contrast, Orlikowski (2000) argues that technology use is not predetermined but emergent, constituted through users' situated actions and institutional contexts. This practice-based lens is especially useful in construction, where professionals regularly confront conflicting priorities and incomplete information, requiring responsive strategies rather than strictly adhering to tool logic.

While these sociotechnical and practice-based critiques have focused on BIM and conventional digital tools, the increasing presence of artificial intelligence (AI) - and especially generative AI (GenAI) - adds further urgency to these concerns. While

artificial intelligence (AI) refers broadly to technologies that simulate human intelligence, this study is particularly concerned with Generative AI (GenAI) - tools that produce new content such as text, images, or specifications, and are increasingly embedded in everyday software. Regona *et al. (*2022) showed that GenAI in construction is unregulated and adopted informally without ethical oversight. Similarly, Boyd and Harding (2025) examined how GenAI reshapes the traditional boundaries of authorship and expertise in PhD supervision. These insights are directly relevant to the built environment, where client trust, professional identity, and decision accountability remain central. Despite the growing interest in AI, few empirical studies have explored how it intersects with everyday projects in a regenerative context. Moreover, limited methodological research focuses on how digitalisation is enacted in real-time collaboration. Most existing studies rely on post-hoc surveys or implementation case studies, leaving the digital strategy under-examined.

These dynamics align with sociotechnical and practice-based perspectives, emphasising that digital tools are not neutral systems but are enacted through use. Orlikowski (2000) argues that the meaning and impact of digital tools emerge not from their technical features alone but from how they are embedded within local routines, user judgment, and organisational norms. Nicolini (2012) similarly highlights that professional practice is situated and contingent, shaped by how individuals interpret and adapt technologies within institutional and cultural settings. This perspective is particularly relevant now, as GenAI functionality becomes increasingly embedded within everyday software systems - often with little formal oversight or training. As digital tools evolve, professional discretion, informal adaptation, and ethical ambiguity remain central to how they are enacted.

METHOD

To understand how digitalisation is strategically enacted on the ground, this study follows the everyday professional activity of Built Environment Practitioners across live construction settings. It adopts a qualitative research design informed by the Strategy-as-Practice (SaP) framework (Jarzabkowski *et al.,* 2016), which conceptualises strategy not as a fixed plan but as a situated activity enacted through professional work The framework distinguishes between praxis (the activity through which strategy unfolds), practices (the tools, norms, and routines structuring work), and practitioners (the agents who bring experience and discretion). This allows digitalisation to be understood not as a static shift in tools or standards but as a live, negotiated process - produced through the situated actions of BEPs working in complex environments.

The research was conducted in three stages. First, 12 BEPs working in architecture, engineering, quantity surveying, and project management completed a scoping questionnaire. This provided initial insights into how the 3Ps played out in everyday work settings, helping to refine the interview focus and guide subsequent data collection. Secondly, 20 semi-structured interviews were conducted with professionals at varying levels of seniority. The interview guide was explicitly mapped to the 3Ps framework. Participants were asked to describe how they used digital tools on specific projects (praxis), how they navigated or adapted guidance such as BIM protocols or cost standards (practices), and how their professional judgment shaped or resisted standardised digital approaches (practitioners). Interviews were conducted via telephone and transcribed.

Thirdly, two embedded case studies were conducted in central Edinburgh. Each involved a refurbishment-led redevelopment project with full strip-outs, reconfiguration, and substantial new-build extensions. The first case study involved the full refurbishment and adaptive reuse of a Georgian townhouse in central Edinburgh, combined with major new-build extensions to the front, side, and rear. These additions significantly expanded the building's footprint and functional capacity. The project was privately commissioned and required strategic coordination across disciplines to retain heritage elements while supporting densification and improved energy performance key regenerative aims.

The second case study focused on the redevelopment of a city-centre property into fifteen studio apartments. This included a complete internal strip-out and spatial reconfiguration, supported by a substantial new-build extension. The hybrid nature of the project demanded close integration of architectural, structural, and services input within constrained site conditions. Regenerative value was delivered through reuse of existing fabric, increased housing density, and improved environmental performance targets. These cases offered insight into how digitalisation was enacted across professional roles and boundaries. The researcher worked as the contractor's Quantity Surveyor on both projects and maintained detailed reflexive notes capturing informal communication, tool use, and professional improvisation. While this insider role provided privileged, real-time access to strategic digital practices as they unfolded on live projects, it also required continual reflexivity to mitigate potential bias. All data were coded thematically using the 3Ps: Praxis captured situational problem-solving and tool improvisation; practices referred to workflows, standards, and team norms; and practitioners highlighted judgement, role tension, and collaboration. This structure supported a coherent analysis of how digitalisation unfolded as a strategic, enacted process within regeneration projects, rather than something imposed from above.

FINDINGS

Across the scoping questionnaire, 20 semi-structured interviews, and two embedded case studies, digital tools were found to shape - and sometimes constrain - professional judgement, collaboration, and communication in ways that diverged from their intended functionality. Rather than streamlining delivery, digitalisation frequently introduced friction, demanding informal workarounds and discretionary responses that exemplify praxis - the unfolding, situated activity through which strategy is enacted in everyday work.

Three strategies emerged from the data analysis:

Digital workflows

Digital tools were shaped more by individual workarounds and project constraints than by formal standards or shared protocols. In both case studies, professionals used a mix of software - AutoCAD, Revit, BIM, Excel, CostX, Microsoft Project, OneDrive, and Dropbox - without a unified digital environment. In Case Study 1, for example, the architect uploaded design models to OneDrive while the structural engineer worked independently in Revit. The client's Quantity Surveyor used CostX but generated outputs the client struggled to interpret. The contractor's QS, also the embedded researcher, translated these into Excel: "The client was confused by the CostX files - they simply didn't understand them. I had to rework everything into Excel so they could follow what was being costed and why." Although informal and often invisible, this discretionary labour was central to maintaining project momentum

and client trust. One architect said: "There's pressure to make the model think for us, but that's not how real projects work."

This emerging strategy shows that BEPs do not experience digitalisation as a standardised or universally enabling process. Instead, it is a context-dependent, relational practice requiring continual adaptation and negotiation.

Experimentation with generative AI

Another recurring pattern was the quiet, informal experimentation with generative AI (GenAI). Across roles, participants described unacknowledged but intentional use of GenAI tools. A graduate architect said: "Sometimes I use it just to shake up my thinking, though I'd never submit anything straight from it. "A Quantity Surveyor reported using GenAI to interpret manufacturer data and draft specification content: "It's helpful, but you have to check everything - I treat it like a junior assistant." A structural engineer described it as a "grey area - helpful, but I would not want to rely on it."

This quiet experimentation reflected a mix of curiosity, caution, and critical awareness. Participants viewed GenAI as a tool for creative prompting and productivity gains yet remained wary of its opacity and ethical implications.

Ethical consideration and professionalism

The final emerging strategy was navigation of ethical and professional issues concerning the use of GenAI. A project manager reflected: "There is no real rulebook. It's just… try not to cross a line, even though you don't know where the line is." Concerns over authorship, traceability, and professional deskilling surfaced across professions. One senior architect worried: "If younger staff get too used to relying on AI, what happens to their ability to problem-solve or think through a design on their own?" Participants also noted that software tools increasingly include AI-driven features without clear visibility. A QS remarked: "It's hard to tell what's the software and what's you anymore - there's no flag that says, 'AI did this bit.'"

These experiences pointed to more profound uncertainty. GenAI use was undocumented and rarely discussed, creating significant ambiguity.

Summary

Underlying all these observations was a clear display of strategic agency. Rather than implementing digital tools as instructed, professionals exercised discretion and judgment to adapt them to evolving site realities, client understanding, and interdisciplinary needs. These acts of adaptation and reinterpretation demonstrate the praxis of digital strategy: BEPs did not receive systems passively but actively shaped them in service of collaboration and regenerative intent. These findings raise important implications for professional judgement, ethical innovation, and digital agency - further explored in the following discussion.

DISCUSSION

What emerges from these findings is not a failure of digitalisation but a revealing portrait of how professionals actively shape it - quietly, experimentally, and sometimes uncomfortably. Rather than simply adopting tools, in the way described in literature (c.f. Ghaffarianhosseini, 2017), BEPs negotiate the space between possibility and responsibility, transforming digital friction into strategic opportunity. These findings challenge the assumptions of linear digital transformation. They show that digitalisation is not something received or implemented but something enacted. It is shaped by people, not platforms, and delivered through discretion, not directives.

BEPs are not simply adopting digital tools - they are strategically enacting them in response to complex project realities, professional responsibilities, and emerging ethical challenges. This supports and extends assertions that digitalisation can reinforce siloed approaches and relies on professionals to align expectations and resolve inconsistencies (Dossick and Neff, 2010; Forbes, and Ahmed, 2021) and shows that rather than experiencing digitalisation as a coherent, top-down transformation, participants described it as fragmented, improvised, and shaped by personal judgement. This reinforces the core argument of the Strategy-as-Practice (SaP) framework: that strategy is not held in documents or systems but is something professionals actively do in situated contexts (Orlikowski, 2000).

The use of tools such as Revit, CostX, Excel, and GenAI did not unfold in predictable or standardised ways. Instead, BEPs engaged in situated strategising - adapting workflows, translating outputs, reformatting content for client comprehension, and responding to the shifting demands of regeneration-led refurbishment. These examples align closely with the SaP concept of praxis: the lived, discretionary actions through which strategy unfolds in daily work. Unlike the sequential and stylised models of digitalisation described by professional institutions digitalisation was not implemented uniformly but flexibly adjusted to fit the nuanced realities of live construction sites, and the messy realities of refurbishment and retrofit projects.

Digital practices were also shaped by institutional expectations, cultural norms, and disciplinary routines, reflecting what SaP refers to as practices. Architects used GenAI for design ideation; Quantity Surveyors applied it selectively to aid specification drafting; engineers were more cautious, concerned about data accuracy and liability; and Project Managers navigated ethical uncertainty with little formal guidance. These role-based distinctions highlight how practices are informed by and constrained by professional identities, regulatory expectations, and risk tolerance.

Crucially, this study illuminated the importance of practitioners who exercise discretion to make tools workable. Professionals described developing informal workarounds, translating complex files into more accessible formats, and deciding when to trust or override digital outputs. These actions were not acts of resistance but of responsibility. One participant noted, “It’s hard to tell what the software is and what you are anymore.” Such reflections emphasize the ambiguity introduced by embedded AI features, where machine-generated content lacks visibility and traceability, leaving professionals accountable for validating outputs they did not fully author. These ambiguities resonate with Boyd and Harding (2025) findings on the ethical and practical complications of GenAI on relationships and authorship.

The increasing presence of GenAI embedded within standard platforms - often without clear labelling or oversight - exacerbates this uncertainty. Without dedicated training, ethical protocols, or institutional support, professionals are left to navigate AI-enhanced outputs using personal judgment and tacit knowledge. This demands more than technical competence; it requires ethical discretion, creative interpretation, and relational communication - mainly when outputs inform clients or coordinate teams. These behaviours show that digitalisation is not simply an input-output process but a socially and ethically mediated practice, supporting Regona *et al. (*2022) in showing that digitalisation tends to be unregulated and adopted informally without ethical oversight.

These dynamics are particularly significant in regenerative city-building, where project complexity, environmental goals, and client expectations must be continually

balanced. Regeneration is not delivered through tool adoption alone - it is enacted through the situated work of professionals negotiating between constraints, systems, and values. In these everyday acts of adaptation, clarification, and discretion, regeneration becomes real - not as an abstract ideal but as a collaborative practice grounded in the strategic work of BEPs.

Limitations

This study offers insights shaped by the specific context of refurbishment-led projects in central Edinburgh. While the findings are not statistically generalisable, they provide transferable insights applicable to similar construction settings - particularly those grappling with fragmented workflows, legacy systems, and the informal use of emerging digital tools.

Future research

Future research could extend these findings to other geographies, larger-scale infrastructure projects, or firms with more advanced digital strategies and formalised AI governance. Further studies might also incorporate perspectives from clients, planners, and regulators to understand better how digitalisation supports regenerative construction across the full project ecosystem. Exploring longitudinal impacts of GenAI integration, professional deskilling, and digital ethics in practice would also offer valuable contributions to the evolving discourse.

CONCLUDING COMMENTS

This study explored how Built Environment Professionals (BEPs) strategically implement digitalisation in refurbishment and extension projects that contribute to regenerative city-building. Guided by the Strategy-as-Practice (SaP) framework the research found that digitalisation is neither smoothly adopted nor categorically resisted. Instead, professionals navigating complex project realities actively interpret, adapt, and enact it.

The findings revealed that praxis - the situated doing of strategy - emerged through discretionary actions that made digital tools workable in live contexts. From reformatting technical outputs to bypassing rigid systems and favouring more responsive alternatives, these acts reflect strategic responsiveness to legacy conditions, fragmented workflows, and regeneration goals. Practices, including disciplinary norms and tool routines, shaped how digitalisation unfolded across professional roles. Architects, engineers, Quantity Surveyors, and Project Managers engaged with digital tools differently, reflecting their professional values, institutional expectations, and perceived risks. These role-specific patterns show that digital workflows are not standardised processes but socially constructed responses to contextual demands. Crucially, practitioners functioned as strategic agents, using judgement to bridge technical limitations and ethical uncertainty. This was particularly evident in GenAI's undocumented, experimental use and the growing presence of embedded AI within everyday software. Without clear authorship markers or institutional policy, professionals bore responsibility for interpreting and validating outputs - often relying on tacit knowledge, peer exchange, and instinct to maintain quality and trust.

This paper contributes to construction management literature by reframing digitalisation as a socially and ethically situated process - one that is shaped not by platforms or systems, but by the everyday work of practitioners. If digital tools are to meaningfully support regenerative city-building, policy, research, and practice must

move beyond top-down deployment to support the situated, discretionary, and strategic labour already being enacted by professionals.

By highlighting these situated adaptations, the research addresses the broader 'so what' question: Achieving regenerative city objectives depends heavily on strategically aligning digital practices across professional silos. This alignment would support more effective management of embodied carbon, enhanced lifecycle sustainability, improved stakeholder communication, and greater transparency in urban development processes. The study thus contributes to knowledge by demonstrating how digital strategy enactment - when strategically integrated rather than informally fragmented - can improve outcomes for regenerative urban development.

In direct response to the research question, the findings show that digitalisation is strategically enacted not through unified systems or prescriptive workflows, but through the situated, interpretive, and discretionary practices of BEPs. These acts of professional judgement and cross-disciplinary coordination are what enable digital tools - both established and emerging - to support regenerative city-building in complex refurbishment and extension projects.

More broadly, the research emphasizes the importance of acknowledging professional judgement, interpretive labour, and contextual responsiveness as key enablers of meaningful digitalisation in the built environment. It offers theoretical and practical insights into how regenerative ambitions can be more effectively realised in everyday construction practices, shaping more cohesive, resilient, and sustainable urban futures. It is not systems that deliver strategy - it is people.

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ASSESSING THE IMPACT OF LEVEL OF DETAIL FOR PLANNING OF TUNNELLING PROJECTS USING BUILDING INFORMATION MODELLING

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The use of Building Information Modelling (BIM) in tunnel projects is becoming increasingly common, but the impact of different Levels of Detail (LoD) on schedule accuracy remains underexplored. This paper investigates how LoD influences planning outcomes using two real-world tunnel projects, with a focus on schedule prediction. The findings show that higher LoD improves decision making but increases complexity, particularly in the early stages of design. 4D BIM further enhances planning by enabling spatial-temporal coordination of activities. Based on these findings, a phased approach to LoD implementation is recommended, applying higher levels of detail progressively as project complexity increases. The study also proposes LoD 2 as a baseline standard, with LoD 3 reserved for high-risk or sensitive phases. While limited in sample size and focused solely on schedule data, this research provides a replicable framework for broader validation using larger tunnel datasets.

Keywords: digitalisation; building information modelling; levels of detail; tunnel construction

INTRODUCTION

As cities become increasingly dense and the demand for underground infrastructure increases, tunnelling has emerged as an important strategy to support sustainable urban development. Tunnels enable efficient transport, energy distribution and utility networks, but their design and execution remain complex due to variable geological conditions, spatial constraints and the coordination of multiple stakeholders. Paraskevopoulou and Boutsis (2020) note that these challenges often lead to project delays, highlighting the importance of improved planning and risk mitigation strategies.

In response to these challenges, Building Information Modelling (BIM) has gained traction as a tool to support more reliable planning and execution of tunnel projects. BIM provides a collaborative, data-driven approach to infrastructure design, integrating geometric, temporal and geotechnical information in a shared digital environment. As highlighted by Lozano *et al. (*2023), BIM improves tunnel design by enabling predictive modelling and better geotechnical risk assessment, especially when combined with time-based (4D) simulation capabilities. By visualising

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construction sequences and identifying temporal conflicts in advance, BIM helps reduce scheduling uncertainties and optimise construction workflows.

A key factor in the effectiveness of BIM is the Level of Detail (LoD), which defines the depth and reliability of information included in the model at different stages of the project. Higher LoDs allow for more precise planning and sequencing of tasks but also require more extensive data and modelling resources. According to Abualdenien and Borrmann (2022), an optimal LoD strategy should balance modelling effort with project needs, ensuring that the right level of detail is used at the appropriate stage. For tunnelling projects, where minor deviations in excavation timing can cause significant disruption, matching LoD to project complexity and phase is particularly important.

The relevance of this study lies in the growing need to validate BIM design outputs against actual tunnel construction schedules. While the benefits of BIM and LoD are widely discussed, most studies remain theoretical or simulation-based and do not examine how predicted schedules generated at different LoDs compare with actual performance. Ergun *et al. (*2023) explicitly identify this gap and call for empirical studies that quantify the accuracy of BIM-derived predictions. Without such validation, it remains difficult for project managers and decision makers to determine what level of detail is most appropriate for effective planning.

This study addresses this gap by comparing the predictive accuracy of LoD 1, 2 and 3 models with the realised timelines of completed tunnel projects. The aim is not to confirm the intuitive notion that more detailed models are more accurate but rather to assess how each LoD performs in relation to design effort and output reliability. This approach recognises that higher LoD may not always provide proportionate benefits and that strategic use of detail could improve design efficiency without compromising project outcomes.

The primary research objective is to evaluate the impact of different LoD levels on the temporal accuracy of BIM-based design in tunnelling. This includes analysing how closely schedule predictions match actual project performance and identifying which levels of detail provide the most effective balance between modelling effort and design accuracy. By basing its analysis on real project data, this study contributes to the development of more evidence-based guidelines for the use of BIM in complex infrastructure contexts, helping practitioners to make informed decisions about model granularity throughout the project lifecycle.

LITERATURE REVIEW

The Importance of Tunnelling

Tunnelling has become a critical strategy in modern infrastructure development, particularly in densely populated urban environments. It allows for underground transportation systems, utility networks, and stormwater solutions, thereby relieving pressure on surface infrastructure. Tunnels also help to reduce noise and visual pollution, protect natural landscapes and promote sustainable urban growth by minimising surface land use. From a socio-economic perspective, tunnel projects contribute to regional development, reduce travel time and increase property values. Through a comparative economic analysis, Xie *et al. (*2021) demonstrated that tunnels often generate positive long-term net returns by increasing transport efficiency and stimulating economic activity in connected zones. The results reinforce the value of tunnels as a strategic urban policy tool rather than just an engineering solution.

Tunnel Construction Methods and Challenges

Tunnelling methods are typically divided into conventional and mechanised techniques. Conventional methods, such as drilling and blasting, involve sequential processes of excavation, mucking, and structural support installation. These methods are adaptable to different geological conditions but are often time-consuming and risky in complex ground conditions. In contrast, mechanised tunnelling using Tunnel Boring Machines (TBMs) allows for continuous excavation and immediate support installation, making it suitable for long, linear tunnels in consistent geological environments. As CETU (2016) notes, the use of TBMs requires significant upfront investment and precise geotechnical profiling to mitigate operational risks.

However, both approaches face significant challenges. Raza *et al. (*2023) analysed several large-scale metro projects and found that geotechnical unpredictability - such as water intrusion, unstable strata, or heterogeneity in rock strength - was a major cause of delays and budget overruns. These complications are often exacerbated by fragmented information sharing between stakeholders, lack of real-time monitoring and inadequate scenario forecasting. The authors recommend the adoption of digital planning systems capable of integrating geospatial, temporal and logistical data to improve proactive risk management and stakeholder coordination.

BIM Applications in Tunnelling

BIM has emerged as a promising solution to the coordination challenges of tunnel construction. By integrating geometric, geotechnical, time and financial data into a unified digital model, BIM allows for better project visualisation, simulation and analysis. In their case study of a metro extension, Lozano *et al. (*2023) demonstrated that BIM significantly improved geotechnical risk assessment, enabling early identification of potential soil-related hazards through model-based simulations. This capability supports a more responsive design process and risk-informed construction planning.

The utility of BIM is further enhanced by the integration of 4D (time) and 5D (cost) dimensions. Aredah *et al. (*2021) evaluated a tunnelling project where 4D BIM enabled real-time tracking of construction progress, identifying schedule conflicts well in advance and reducing on-site idle time. Their study showed that the integration of the construction schedule into the model promoted greater synchronisation between the excavation and lining teams.

Fugas (2022) adds that BIM, when properly implemented, becomes a single source of truth for all project stakeholders. In the tunnel environment, where design iterations, logistical constraints and safety considerations must be constantly reconciled, this shared platform helps maintain alignment between disciplines. The complexity of tunnelling increases the importance of tools that enable early detection of conflicts, minimise duplication of effort and support integrated decision-making.

Level of Detail (LoD) and Strategic Implementation

A key concept in BIM implementation is the LoD, which defines the depth and accuracy of information embedded in the model. LoD ranges from LoD 100, used for conceptual massing and alignment studies, to LoD 500, which reflects as-built conditions and includes precise materials and systems data. Abualdenien and Borrmann (2022) emphasize that while higher LoDs enable richer simulations and improved constructability assessments, they require significantly more data input and

modelling effort. This can reduce efficiency if not applied selectively based on project stage or complexity.

The International Tunnelling Association's Working Group 22 (2022) advocates the use of the Level of Information Need (LOIN) to guide the implementation of LoDs. Rather than applying a uniform level of detail throughout the model, LOIN encourages tailoring the level of detail based on the decision to be supported. For example, preliminary risk assessments may require only basic geometry and soil data (LoD 100-200), whereas excavation sequencing and logistics planning may benefit from LoD 300 or higher.

Empirical case studies reinforce the benefits of strategic use of LoDs. The West Block rehabilitation project in Ottawa, as reported by PCL (2024), used variable LoDs to address the coexistence of historic preservation requirements and modern building systems. By applying higher LoDs to critical zones and maintaining lower detailing in less sensitive areas, the team avoided over-modelling and maintained schedule discipline while ensuring coordination. Ninić and Koch (2017) similarly argue that LoD decisions should be revisited at key project milestones to ensure that modelling effort is proportionate to value added.

Despite these advances, the literature reveals a persistent gap: very few studies have tested the predictive accuracy of different LoD levels against actual construction outcomes. Most research remains theoretical or simulation-based, limiting the practical applicability of the findings. Ergun *et al. (*2023) explicitly call for comparative analyses that assess how closely BIM models at different LoDs align with actual construction timelines and performance metrics. This study responds to this call by comparing the results of LoD 1, 2 and 3 with real data from completed tunnel projects. In doing so, it contributes both to the empirical validation of BIM strategies and to the refinement of LoD planning in complex infrastructure projects.

METHOD

This study adopts a pragmatic research philosophy, combining empirical observations from real-life tunnel projects with theoretical insights to assess the role of BIM and LoD in schedule accuracy. A quantitative, data-driven approach is used to address the need to objectively assess how different LoDs affect the reliability of construction schedules. The research follows an abductive reasoning process, comparing modelled outputs with actual project schedules to test and refine the conceptual understanding of LoD performance in BIM environments.

Unlike previous studies based on simulated data, this research is based on real design and construction data from two completed tunnel projects provided by the Centre d'Étude des Tunnels (CETU). These real projects form the empirical basis for assessing the predictive accuracy of BIM-based design at LoD 1, 2 and 3. As cost data was unavailable or inconsistent across the projects, this study focuses exclusively on the time dimension - reflecting both the critical importance of scheduling in tunnelling and the availability of reliable as-built schedule data.

Modelling Planning of a Tunnel Project

This section looks at the methods used to produce accurate predictions using BIM software, specifically Revit and Dynamo, to generate parametric models. The tunnels are modelled as straight structures for simplicity, but hypothetical curves and slopes are included in the calculations for time estimation without being visually represented.

The methodology of time estimation differs according to the LoD. For this study, 3 LoDs (LoD1, LoD2 and LoD3) are introduced. While LoD 1 is relying on simplified assumptions based on general ground conditions and assigning corresponding TBM speeds. LoD 2 and LoD 3 offer more precise estimates by examining the project metre by metre, considering factors like TBM specifications, ground variability, excavation phases, and maintenance.

The Revit and Dynamo model formed the core of the methodology, automating the tunnel modelling process and creating a parametric design adaptable to different LoDs. The Revit model began by defining a ring family, the primary structural element of the tunnel, with parameters such as inner and outer diameter, thickness, and ring position. For LoD 2 and LoD 3, additional parameters, including volume, start and end dates, were calculated from imported data. Dynamo, a visual programming tool, was used to automate the modelling process by scripting tunnel parameters based on Excel inputs. This script assigned precise dimensions and properties to each ring, including material quantities and timelines, reducing the need for manual adjustments and ensuring accuracy. The integration of 4D BIM through Navisworks added time data to the model, enabling real-time construction scheduling.

Each model produced a 4D BIM output integrating timeline data, which was exported to planning tools such as Navisworks for comparison with actual project schedules. By aligning the predicted schedules from each LoD with the as-built timelines, the study quantified the deviation in planning accuracy at each level of detail.
In addition to the two validated case studies, a third hypothetical tunnel network was modelled to illustrate the functional benefits of LoD 3 in a more complex setting, particularly in terms of 4D coordination and conflict detection. Although this scenario is not part of the empirical validation, it showcases the potential of advanced BIM uses in complex planning contexts.
By grounding the methodology in real construction timelines and applying a consistent modelling framework, this research offers a robust basis for evaluating the trade-offs between modelling effort and planning accuracy. The insights gained aim to support more strategic decision-making around LoD selection in tunnel projects. Future extensions of this work will draw on a larger CETU database of over 150 tunnel projects, enabling broader statistical validation and deeper exploration of LoD applicability across various project types.

FINDINGS

This section presents the results of the comparative modelling performed on two completed tunnel projects, using three Levels of Detail (LoD 1, 2, and 3) to estimate construction timelines. The objective was to assess the extent to which increased modelling detail improves the accuracy of planning predictions when compared to the actual as-built schedules. The analysis was carried out exclusively on the temporal dimension, with all cost-related components excluded from the modelling and evaluation.

Each project was modelled in Autodesk Revit with parametric rings generated via a Dynamo script. For each LoD, the script adapted the level of input detail—from basic TBM speed assumptions at LoD 1 to detailed phase breakdowns, including logistics and maintenance, at LoD 3. The timeline data exported from the BIM model was visualised and analysed using 4D simulation in Navisworks, providing both a visual representation of progress over time and a structured schedule for comparison with real-world project data.

Project A: 4.7km main tunnel and 2.2 km service tunnel

Project A corresponds to the construction of a 4.7 km main tunnel and a 2.2 km service tunnel. The as-built records show an average excavation speed of 12.5 m/day with peaks up to 25.4 m/day.

Table 1: Project A, TBM 1 results

	Real project	LoD 1	LoD 2	LoD 3
Start date	03/09/2018	03/09/2018	03/09/2018	03/09/2018
End date	17/11/2020	07/03/2021	03/10/2020	12/09/2020
Planning variation in days		110	45	66
Planning variation in %		14%	6%	8%

Table 2: Project A, TBM 2 results

	Real project	LoD 1	LoD 2	LoD 3
Start date	06/04/2018	06/04/2018	06/04/2018	06/04/2018
End date	13/06/2019	10/04/2019	11/06/2019	04/06/2019
Planning variation in days		64	2	9
Planning variation in %		15%	0%	2%

LoD 1 applied a uniform TBM speed along the entire tunnel, which did not consider the transitions between different soil types, such as green clay and limestone. As a result, it did not anticipate changes in excavation rate or the influence of maintenance cycles, leading to an inaccurate and overly optimistic schedule.

LoD 2 introduced segmented TBM speeds by incorporating known ground conditions into the model. This adjustment improved alignment with actual performance by considering deceleration in difficult strata. However, the model still lacked explicit integration of operational pauses and logistical constraints such as TBM restarts or equipment adaptation periods. However, in this specific case, this did not change the estimates.

LoD 3 provided the most realistic schedule by integrating these critical variables, including three documented TBM stoppages for cutter head replacement and scheduled maintenance events. The modelling also considered minor phase conflicts with secondary works, making the forecast much more robust. Despite being underestimated by a few days, the model closely matched site reality, demonstrating the added value of high-fidelity time modelling. The 4D simulation also facilitated visual tracking of major slowdowns, allowing project managers to anticipate bottlenecks that could affect the continuity of the critical path.

This first project also shows that the more detailed the model, the more information it considers, but it is not necessarily the most accurate.

Project B: 3.2 km urban tunnel

The project examined a 3.2 km tunnel constructed under complex urban conditions, including two station crossings and multiple curved alignments. The project encountered highly swelling clay and logistical constraints related to limited working space. Real progress records indicate an average advance rate of 12.1 m/day, with 256 working days over the excavation period. The results are the following:

Table 3: Project B results

	Real project	LoD 1	LoD 2	LoD 3
Start date	18/05/2020	18/05/2020	18/05/2020	18/05/2020
End date	22/07/2021	10/11/2021	26/10/2021	02/07/2021
Planning variation in days		111	96	20
Planning variation in %		26%	22%	5%

LoD 1's simplified approach did not account for key disruptions such as TBM deceleration near station approaches, limited site logistics, or soil swelling phenomena encountered mid-alignment. Its reliance on average excavation speeds resulted in a substantial planning mismatch. The absence of any segmentation or task-level phasing further limited its reliability.

LoD 2 introduced variable TBM rates and partially accounted for hydrogeological variations. The model improved significantly over LoD 1 by factoring in specific zones with constrained advancement. However, it still missed the finer details of execution phasing, particularly in areas requiring reduced speed or split shift working cycles.

Then, LoD 3 integrated all major project constraints, including operational slowdowns during station bypasses, logistical downtime from limited shaft access, and reduced TBM productivity due to equipment repositioning. The model also allowed detailed sequencing of interface works, offering a temporally consistent projection closely aligned with the actual excavation sequence. The 4D output gave a clear view of complex interdependencies, enhancing the predictive quality of the planning process.

Project C: Hypothetical Complex Tunnel

To further illustrate the planning potential of LoD 3, a hypothetical multi-branch tunnel network was modelled, including intersecting alignments and overlapping excavation phases. Although not validated against real data, this scenario served to visualise how 4D modelling supports coordination, especially in identifying sequencing conflicts and simulating construction logistics. The outputs underscore the benefit of LoD 3 in planning-intensive projects.

In such complex projects, it is not enough to have only a 3D visualisation or only a temporal visualisation. A 4D BIM model is then required, and this implies a necessary high LoD (LoD2 or LoD3). For this scenario, the 5D model helps to understand the crossing of two tunnels. The model displays planning and cost information as shown in Figure 1, Figure 2, Figure 3 and Figure 4.

With the 4D model, it is much easier to understand the project, and it is also possible to identify time clashes. A 4D clash in BIM occurs when scheduling conflicts arise within the 3D model where construction activities are planned to take place in the same space at the same time, leading to potential problems with logistics, safety, and efficiency. These spatiotemporal conflicts can be identified early by integrating time into the 3D model, as can be done with LoD3 in this scenario, allowing project teams to adjust schedules, re-sequence tasks, and avoid delays.

By resolving 4D conflicts, projects benefit from better coordination, reduced risk, and optimised resource allocation while improving communication and decision-making between stakeholders, leading to more efficient and successful project delivery.

Cross-Project Insights

The comparative analysis confirms that higher LoD consistently improves schedule prediction accuracy. However, the results also support a more nuanced view: LoD 2 often offers a high return on modelling effort with significant improvements in forecast quality, while LoD 3 offers marginal gains that are justified primarily in complex or high-risk environments. LoD 1, while faster to produce, systematically underestimates durations and should be limited to preliminary studies.

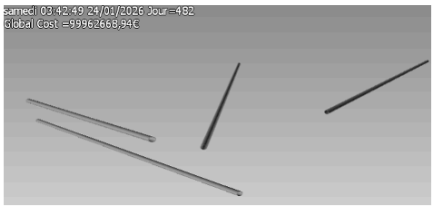


Figure 1: 4D view at day 482

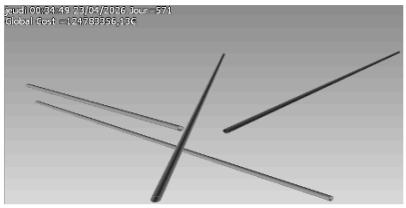


Figure 2: 4D view at day 571

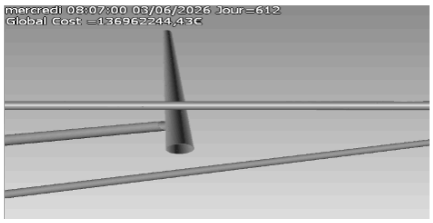


Figure 3: 4D view at day 612

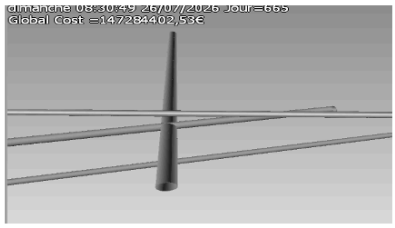


Figure 4: 4D view at day 665

Future Expansion and Dataset Scaling

This study forms the basis of a wider research initiative. The modelling framework developed here is currently being scaled up to analyse a dataset of over 150 completed tunnel projects held by CETU. Future work will focus on automating the comparative analysis of LoD predictions against realised durations, providing statistically robust insights into when and where higher LoD adds most value.

By grounding the analysis in real project schedules and combining this with structured 4D modelling, this research provides new empirical evidence for the effective use of LoD in tunnelling. It supports a strategic, risk-based approach to LoD selection, enabling project managers to optimise modelling effort relative to project complexity and constraints.

DISCUSSION

The case studies highlight the substantial impact of different LoDs on the accuracy and reliability of schedule predictions in tunnel planning. For the Project A, a relatively straightforward tunnel with constrained urban logistics, LoD 1 resulted in an error exceeding 120 days—demonstrating the limitations of average TBM speed assumptions. In contrast, LoD 2 offered a near-exact prediction, capturing basic zoning variations and thus validating its effectiveness for standard projects. The more detailed LoD 3 marginally improved this accuracy but at the cost of additional modelling effort, suggesting diminishing returns in low-to-moderate complexity contexts. The 4D simulation outputs reinforced the benefit of temporal visualisation for both technical planning and stakeholder coordination. By sequencing tasks along the project timeline and integrating ground condition data, higher LoDs provided clearer insight into risk points and logistics management. Although cost analysis was excluded from this study, previous findings (Aredah *et al.,* 2021; Butkovic *et al.,*

2019) suggest that integrating 5D BIM can further enhance project control when paired with high-fidelity LoD inputs.

These findings confirm that LoD should not be treated uniformly but adapted to project complexity. LoD 2 is suitable for baseline planning in most cases, while LoD 3 adds critical value in high-risk or phase-sensitive environments. A phased LoD strategy, escalating detail as the design matures, offers the most balanced and effective use of BIM in tunnelling.

CONCLUSIONS AND RECOMMENDATIONS

This study provides empirical validation of how different Levels of Detail (LoD) influence planning accuracy in tunnel projects using BIM. Through two real-world case studies, the research demonstrates that simplistic models like LoD 1 lack the precision required for execution planning and often produce significant errors. LoD 2 strikes a balance between accuracy and effort, proving sufficient for many tunnelling contexts. LoD 3, while demanding, becomes essential in projects involving complex geotechnical, logistical, or operational phases, particularly when supported by 4D visualisation tools.

The analysis supports a phased and adaptive approach to LoD implementation. Early planning stages can rely on lower LoDs to enable rapid decision-making, while critical sections of the project should progressively integrate more detail as risks and interfaces become clearer. This allows for targeted resource use, reducing unnecessary modelling effort and improving project efficiency.

Based on these findings, a phased and targeted LoD strategy is recommended: start with LoD 1 for concept design, shift to LoD 2 for baseline planning, and use LoD 3 only in instances where critical sections demand precision. LoD should also be adapted to the importance of specific project elements to optimise effort and impact. This strategic approach supports more efficient resource allocation and better decision-making in complex underground infrastructure development.

Nevertheless, the study has several limitations. It is based on a limited number of real projects, which may restrict generalisability. Only the schedule dimension was analysed, excluding cost-related data. In addition, the effectiveness of LoD 3 relies on access to high-quality, detailed input data, which may not always be available during early project phases. Future research will address these gaps by applying the methodology to CETU's broader database of over 150 tunnel projects, supporting the development of robust and scalable LoD strategies for infrastructure delivery.

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ARTIFICIAL INTELLIGENCE WITHIN THE SOUTH AUSTRALIAN ARCHITECTURE, ENGINEERING, AND CONSTRUCTION INDUSTRY: AWARENESS AND READINESS USAGE ASSESSMENT

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Artificial Intelligence (AI) has potential in revolutionising the performance of the construction industry. However current understanding, readiness, and awareness by South Australian construction practitioners is at the nascent stage. Therefore, this paper aims to examine the current awareness and potential applications of AI and assess the readiness of people and AI technology in the current industry. Data was collected from 34 construction professionals using a survey, with descriptive statistics and measures of central tendencies employed for the data analysis. The findings showed that although there was a higher general level of awareness of AI within the SA AEC industries, this was predominantly at the surface level only as there was a limited understanding of specific AI technologies or their applications. However, knowledge of current usage or available technology was limited with emphasis more on the potential of AI rather than actual technology which was currently under development. The findings of this study can help inform the construction practitioners on the adoption and usage of AI techniques by revealing the opportunities for improving its readiness and awareness.

Keywords: artificial intelligence; readiness; awareness; construction industry; South Australia

INTRODUCTION

Globally, the construction industry is inundated with challenges around productivity, labour shortages, cost and schedpule overruns, safety and grand challenges such as interconnected environmental cum social problems related to waste generation and its management. Digital technologies (DTs) such as artificial intelligence (AI) are proposed as the enablers to resolving and overcoming these challenges faced by the urban built environment (Regona *et al.,* 2024). For instance, according to the IT Brief Australia (2025), there is a rise in the application of Artificial Intelligence (AI) with 30% of Australian construction companies are now either trialling or using AI to combat industry challenges such as higher material costs, labour shortages, and disruptions in the global supply chain. AI is described as rapidly becoming a cornerstone in the construction industry, reshaping the entire project lifecycle from the

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design, construction, to the repair and maintenance stage (Regona *et al.,* 2024). According to the recent The State of Digital Adoption in the Construction Industry 2024 report (Autodesk and Deloitte, 2024), the main motivation for Australian construction companies in adopting AI is to combat industry challenges such as higher material costs, labour shortages, and disruptions in the global supply chain. The study by Perera *et al. (*2025) aimed at investigating the application, maturity and adoption interest of 14 Industry 4.0-related technologies in the CI (Con4.0-tech) in Australian construction firms also pointed out how the Australian construction industry lags countries like Germany, the USA and the UK regarding BIM adoption. In the U.K, it's not much different as studies have shown that there is a lack of research on the use of Artificial Intelligence (AI) within the construction sector (Jallow *et al.,* 2023).

However, as the construction industry is at an early stage of adopting AI, and traditionally, the construction sector field lags other sectors relative to DTs adoption (Chen *et al.,* 2024a; Zulu *et al.,* 2023), with the sector described as rather fragmented; and Industry 4.0 transformation which includes AI of construction enterprises lacks systematic guidance (Das *et al.,* 2023). Further, the uptake of DTs in the construction industry is described as has been limited and plagued with roadblocks (Chen *et al.,* 2024b). Equally, according to Zulu *et al. (*2023), the digital uptake amongst construction organisations is described as slow and ineffective, undermining a fundamental transformation and limiting construction firms from exploiting the digital benefits. Further, the move towards AI it is not well understood around the South Australian construction industry readiness and in general, and AI uptake in the Australian construction industry (CI) is also limited and with Australian businesses falling in the middle range for digital adoption, utilising an average of 5.0 technologies, increasing to 6.1 for medium and large enterprises (Autodesk and Deloitte, 2024). Therefore, to bridge the knowledge gap, this paper aims to: (1) examine the current awareness and potential adoption of AI techniques; and (2) assess the readiness of people and AI technology within the South Australian CI. To achieve the identified objectives, the following research question was proposed: "What is the current readiness and awareness level that the Australian architecture, engineering, and construction industries have for the adoption of Artificial Intelligence in South Australia?".

LITERATURE REVIEW

Awareness and potential adoption of AI techniques

There is a plethora of studies examining the awareness and potential uptake and adoption of AI techniques (Soltani *et al.,* 2024; Olatunde *et al.,* 2023; Perera *et al.,* 2025; Zhao *et al.,* 2025; Zulu *et al.,* 2023). For instance, within the UK construction context, Zulu *et al. (*2023) investigated the determinants of an effective digital transformation and identified leadership awareness among the determinants to effective digital transformation amongst construction organisations, and identified the leadership related cluster, i.e., awareness, attitude, approach, and leaders' characteristics as a determinant of DT. Olatunde *et al. (*2023) undertaken within the context of Nigeria found moderate awareness levels of Construction 4.0 technologies among the construction professionals. In Australia, Perera *et al. (*2025) and Soltani *et al. (*2024) have acknowledged the lack if industry awareness and underdeveloped applications for integrating them into construction workflows. Within the Chinese context, Zhao *et al. (*2025) established that perceived complexity negatively impacts construction companies' IoT technology adoption behaviour.

Readiness and usage assessment of AI

Several studies have explored the readiness and usage assessment of AI adoption across different sectors and industries (Olatunde *et al.,* 2023; Perera *et al.,* 2025; Nguyen, 2024; Zhao *et al.,* 2025; Zulu *et al.,* 2024). Zhao *et al. (*2025) explored the influencing factors and action paths of Chinese construction companies' IoT technology adoption behaviour and found the following critical factors: External environmental pressure, perceived benefit, top management support, company resource readiness, adoption intention, and perceived compatibility have a direct positive impact on adoption behaviour. In a non-AI related research, Nyugen (2024) examined the level of readiness for sustainable building materials (SBM) adoption in construction firms of varied sizes and identified 20 factors affecting the readiness which were then grouped into market, organisation, and employee readiness. The study also conceptualised readiness into market, employee (people) and organisational categories, with the employee readiness informed by The Theory of Planned Behaviour (TPB) whereas the IDT shaped the market readiness and the Resources-Based View for the organisational readiness. Within the Australian context, a study by Perera *et al. (*2025) aimed at investigating the application, maturity and adoption interest of 14 Industry 4.0-related technologies in the CI (Con4.0-tech) in construction firms found variations in the level of technology usage, and a direct correlation between technology maturity and its use. The AI technology as a suite of the Construction 4.0 technologies is identified as having the function of enabling, classifying, predicting, image processing, mining and problem-solving (Perera *et al.,* 2025).

Whilst the focus of this study is on the readiness and usage assessment of AI, review of the barriers (challenges) and drivers or enablers influencing its adoption (Chen *et al.,* 2024a, b; Klarin and Xiao, 2024; Wang *et al.,* 2024; Zulu *et al.,* 2024) were undertaken. According to Klarin and Xiao (2024), artificial intelligence (AI), provide promising avenues for the development of AEC, and potential for increasing productivity (Chen *et al.,* 2024b; Nnaji *et al.,* 2019; Manzoor *et al.,* 2021) as well as enhanced workplace safety and minimise worker injuries (Nnaji *et al.,* 2019). Other studies such as Wang *et al. (*2024) which identified, assessed, and categorised the barriers to digital transformation (DT) in the engineering and construction sectors and found the following 3 out 8 as most critical barriers: “lack of industry-specific standards and laws,” “lack of clear vision, strategy and direction for DT,” and “lack of support from top management for DT. Zulu *et al. (*2024) examined the barriers to digital leadership enactment in the construction industry on the basis that the slow rate of a fundamental digital transformation is being linked to the challenges facing an effective leadership. The findings resulted into a grouping of the following five themes: Leadership characteristics, management and organisational issues, resource constraints, technological issues and risk perceptions.

METHOD

To examine the current awareness and potential applications of AI; and assess the readiness of people and AI technology, a quantitative approach using questionnaire survey was used due to its ability to be able to count the frequency of occurrence of opinions, attitudes, experiences, processes, behaviours, or predictions (Rowley, 2014). The overarching research design includes the following three steps as employed by Wang *et al. (*2024): 1) conceptual study; 2) measurement instruments and data collection; and 3) data analysis

Conceptual study

A literature review was conducted on the awareness and potential adoption of AI techniques, and readiness and usage assessment of AI. Whilst the focus of this study was on the readiness, the connections to digital maturity research could not be overlooked and studies in that digital transformation (DT) such as Zulu *et al. (*2023); Wang *et al. (*2024) were also included in the review. For instance, Wang *et al. (*2024) categorised the barriers to DT in the engineering and construction sectors.

Measurement instruments and data collection

The measurement instrument comprised five parts. In Part 1, demographics such as age, education, and company size were sought. This was aimed at providing an in-depth description of the population of survey respondents, and education and organisation size are predictors of AI adoption (Schwaeke *et al.,* 2024). The groups classifications were determined based off the Australian Bureau of Statistics (2024). In Part 2, the focus was on the understanding of AI technologies and concepts and designed to assess the respondents' knowledge of AI. According to Rogers (2004), the first step in the adoption process is that of knowledge and this is where the individual is first exposed to an innovation but lacks information about the innovation. During this stage the individual tries to learn "what the innovation is and how and why it works" Therefore, the following two questions were posed: (1) In your opinion, is the construction industry ready to implement AI technology? and (2) do you believe your company is ready for adopting AI? The respondents were to rate their opinions on employee readiness and underpinned by the Theory of Planned Behaviour (Nguyen, 2024) using a Five-point Likert scale (1 = strongly agreed; 5 = strongly disagreed). In Part, respondents were asked on the advantages and difficulties of AI integration; the possible benefits (like cost savings and efficiency) and drawbacks (like job displacement and implementation issues) of AI, offering a fair assessment of its effects on this industry were assessed. As observed by Schwaeke *et al. (*2024), smooth integration of new technologies is essential for SMEs. In Part 4, the emphasis was on AI tools and practices and designed on the understanding that the assessment of the industry's level of AI integration and identification of innovation development needs could achieved through knowledge of AI tools and practices currently in use. Finally, Part 5, was focussed personal feelings and attitudes towards AI and included different social and personal aspects that impact the acceptance of AI, such as enthusiasm for technological developments or concerns about job security. The findings reported in this paper are from the first, second, fourth and fifth parts only as it is beyond the scope of this paper to report on the possible benefits and drawbacks (like job displacement and implementation issues).

A mixed purposive or authoritative sampling and snowball sampling techniques were adopted as, non-probability sampling technique was used as it based on researcher's knowledge and judgement, and snowball sampling relies on a few key individuals who are selected and asked to contact or recommend other relevant individuals (Rowley, 2014). A questionnaire survey (QS) as designed also included open ended questions and was distributed using the LinkedIn online platform as this is often utilised by corporations to announce upcoming events or advertise career opportunities and hence ensured adequate coverage. Furthermore, many companies have a profile on LinkedIn, and the application has a built-in messaging program for making contact. This data collection approach which revolves around sending a variety of companies a message through this service, with the goal of reaching a larger variety of different sized companies and has been used in AI related studies such as

Shang *et al. (*2023). This resulted in 34 responses, and the sample size is comparable to those of Nguyen (2024), and Yong and Mustaffa (2012) which had 29 and 14 valid responses respectively and used questionnaire surveys. Further, whilst the sample size might be considered as small, according to Coviello and Jones (2024), if high-quality survey data are obtainable from a smaller sample drawn using well-developed selection criteria, meaningful findings can still result. Furthermore, much lower samples sizes have been reported in construction management related research.

Data analysis

The measures of central tendencies and frequency analysis and descriptive statistics such as mean scores and standard deviations were utilised to analyse the quantitative data collected through the survey. According to Wang *et al. (*2024), these are the most used ranking method for measuring items

RESULTS AND DISCUSSION

Characteristics of respondents to questionnaire survey

The main respondents sampled for data collection were drawn from the following industry sectors: Construction (70.59 %; f =24), architecture (20.59 %; f = 7) and engineering (8.82%; f =3). Relative to the age of the respondent's position, the majority (64.71 %; f = 22) were drawn from the 25-39 years category followed by the 40-54 (17.65 %; f = 6); and 55-64 (14.71 %; f = 5). The minority (2.94 %; f = 1) were drawn from the 15-24 years category.

Awareness and potential adoption of AI techniques

According to Parida *et al. (*2019), the ecosystem readiness assessment is one such avenue that provides an important starting point for understanding the orchestration, defined as "a set of deliberate, purposeful action", and transformation processes for organisations. Therefore, the respondents were asked whether, in their opinion, if the construction industry ready to implement AI technology. The results showed that more than a third (38.2%, f =13) of respondents reported that their companies were ready, while (41.18%, f =14) acknowledged that the industry was ready for AI adoption. The implication of this finding is that difference shows a higher level of preparedness at a company level, even though only (20.59%, f =7) of respondents said their companies and the industry were very ready. To ascertain the respondent's knowledge of AI, the following question was posed: Do you know what artificial intelligence (AI) is? The results showed that the majority (82.35%, f =28) responded affirmatively. In contrast, the minority (17.65%, f =6) stated 'Maybe'. Respondents were further sked whether they had heard about AI and whether they know what AI is. The results also showed that one of the main barriers to AI being adopted is not due to the technology's readiness but rather the lack of enthusiasm to adopt new technologies. Therefore, the implication of this finding is that to overcome this barrier, further education and training around AI is needed as it will help increase awareness and understanding of AI. Construction organisations that are already ready such focus on gaining additional knowledge and confidence.

A word cloud was also generated from the opened end responses and using key phrases in response to the survey question 'What do you think Artificial Intelligence (AI) is regarding the construction industry?'. The results showed that some words such as 'unsure' were larger than others. The inference is that this might be just due to that word being a more common word choice. For example, optimise, efficient, and reduce time have all been separately mentioned but carry similar meaning in this context. The quantitative and qualitative findings in form of open-ended questions are

also consistent with the previous literature on awareness of AI adoption (Nguyen, 2024; Olatunde *et al.,* 2023; Shang *et al.,* 2023; Zulu *et al.,* 2023). For instance, Shang *et al. (*2023) identified lack of skilled employees trained in AI among the top to its [AI] implementation whereas Nguyen (2024) proposed the development of training programs and awareness campaigns tailored to employees as a strategy for ensuring that employees were equipped with the necessary knowledge and skills. Likewise, Bhatta and Shaha (2023) identified 'employee-tailored programs' as one of the items within the 'Positive Attitude towards change' factors that influence the acceptance of AI in HR practices. Therefore, drawing on Rocca *et al. (*2023), the awareness stage of any innovation is critical as at this stage, the individual or organisation approaching the innovation wants to understand what it is, how it works and why it is useful. The results and findings can also be interpreted through the Innovation Diffusion Theory (IDT) lenses advocated by Rogers (2004) which identified the following 5 stages of innovation occurrence: 1. Knowledge, 2. persuasion, 3. decision, 4. implementation and 5. confirmation. Thus, any adoption (or rejection) to have AI should be informed by appropriate knowledge of the AI technologies. The IDT is also associated with the market readiness. Further, application of technology adoption theories in construction management research is not new (Zhao *et al.,* 2025).

Readiness and usage assessment of AI

Readiness of people: The readiness to use AI was viewed through the technological and people aspects. Herein, the AI readiness to use technology also considers the readiness of the technology to be used. For example, not only do people need to be willing and capable of using Artificial Intelligence but the technology needs to be available to be used. Likewise, from the survey results individuals had more belief in their individual capabilities to use AI technology, however, when looking at the industries surrounding construction that differed. Regarding the industry, multiple responses acknowledged that they believed the industry was not ready and would take a while to implement the technology.

Readiness of technology: Regarding readiness to use the technology many of the responses indicate that the company the respondent works for may be ready, but the industry is not ready. This knowledge was confirmed by the survey results with multiple respondents acknowledging this difficulty. The findings around the readiness to use AI are also consistent with literature (Abioye *et al.,* 2021; Bhatt and Shah 2023). Literature agrees that one barrier the implementation of AI will need to face will be the cultural dislike of change (Abioye *et al.,* 2021). Likewise, Bhatt and Shah (2023) associated employee readiness and change acceptance to the organisational facilitation to change and situational factors. However, though some respondents revealed some insight into readiness of technology, the survey did not intentionally seek out to collect information about the technology readiness.

Usage: The results of the usage assessment of AI across organisations of different sizes as obtained from the questionnaire survey are summarised in Table 1. Examination of Table 1 shows that there was limited or no usage of AI in organisations with less than 20 employees, and one organisation stated that they were not sure. This implies that smaller companies might not have the resources or possibilities to use AI technologies and confirms Nguyen (2024) assertions that smaller firms may require additional support or incentives to enhance their readiness for sustainable building materials, as an illustration. However, AI adoption is more consistent for 'medium' organisations with 20-200 employees, and according to the Australian Bureau of Statistics (2024) classification. Nearly less than half of the

respondents (36.84%, f =7), reported that their organisations used. In contrast, 42.11% (f=8) reported as not using AI and the minority (21.05%, f =4) were not sure. The results reveal a balanced distribution suggesting organisations in the early phases of integrating AI. Table 1 also shows that the majority (55.33%, f =19) of the respondents were drawn from the 'medium' organisations with 20-200 employees' category. Further, of the large organisations (> 201 employees), the majority (58.33%, f =7) had the highest usage of AI compared with the 'medium' with only 36.84% confirming usage. This finding is consistent with literature with Nguyen (2024) acknowledging that medium-sized firms exhibit lower employee readiness than large companies primarily due to less extensive resources and structured hierarchies.

Table 1: Distribution of current AI usage by organisation size

What is your organisation size (employees)	*Does your organisation currently use AI technologies?*			*Grand Total*
	No	Not sure	Yes	
< 20	2	1		3
20-200	8	4	7	19
More than 201	2	3	7	12
Grand Total	12	8	14	34

The inference from this finding is that due to a greater focus on innovation, larger companies are more likely to have the technological infrastructure and resources necessary to successfully implement AI. However, the varying results across the respondents confirms Schwaeke *et al. (*2024) findings that organisational factors like company size appear to be less significant on the application of AI technologies. The findings on AI usage are also consistent with the previous literature (Nnaji *et al.,* 2019; Nguyen, 2024; Zhao *et al.,* 2025; Zulu *et al.,* 2023) and organisation size as a predictor of AI adoption (Schwaeke *et al.,* 2024). For instance, Nnaji *et al. (*2019) found that organisation size substantially influenced the level of importance given by employees when it comes to individual- and technology-related predictors. Using examples from the sustainable building materials readiness, Nguyen (2024) study aimed at examining the level of readiness for SBM adoption in construction firms of different sizes showed that large-sized companies demonstrated the highest level of readiness for SBM adoption, followed by medium-sized and small-sized firms, respectively. Likewise, Zhao *et al. (*2025) found organisation size and nature to positively moderate AI's positive effect on adoption behaviour. The implications emergent from this finding is that the adoption of AI in the construction industry is greatly impacted by the size of the organisation. Due to their more advanced resources, larger organisations are better able to use AI, however smaller companies have barriers including limited infrastructure and budgets. Affordable AI solutions with specialised training for small and medium-sized companies could help close this gap through encouraging adoption and increasing AI's potential in smaller companies.

Factors influencing the non-adoption of AI

The respondents were also asked as to what they thought was stopping them from the adoption of AI in the construction industry. The results showed that highest ranked reasons based on the frequency of responses were as follows: Lack of understanding (f = 30); Lack of training (f = 24); Lack of budget for software's (f = 20); Limited resources (f = 19); Cyber security (f =16) and Time impact to implement (f = 15). The least ranked reason was the impact on customers (f = 2). The findings from the factors influencing the adopting are also consistent with literature. As observed by Rogers (2004), "Awareness" is identified as one of the four main elements of the IDT.

Accordingly, from the innovation perspective, the "timing" decision as when to start the AI process as crucial to the success of that process, and hence 'Time impact to adopt' was among the factors identified in this study. Similar findings from non-AI related studies such as decisions to implement PPPs are equally evident in literature (Chileshe and Kavishe, 2021). Likewise, enhanced awareness is associated with increased knowledge required for adopting AI. Hence, it's hardly surprising that 'lack of understanding' was the highly ranked factor influencing the decision to adopt.

CONCLUSIONS

This paper has presented the perceptions of the stakeholders representing the construction organisations in South Australia regarding the current awareness, potential applications and readiness people for the AI technology. Data from 34 respondents showed that although there is a general awareness of AI within the SA AEC industries, the awareness is only surface level with limited understanding of specific AI technologies or their applications. However, knowledge of current usage or available technology was limited with emphasis more on the potential of AI rather than actual technology which was currently under development. The study also revealed the following as main influencing factors for no-adoption of AI: "lack of understanding", "lack of training", "lack of budget for software's ", "limited resources", "cyber security", and "time impact to implement". The following implications emerge for promoting the adoption of CE. 1) For policy makers, to increase awareness and uptake of AI, one such avenue would be to increase education to start introducing basic uses of AI to increase both readiness and awareness. People need to know more about the technology and how it can currently be used before it can be widely used. These companies should potentially focus of education to ensure a good knowledge basis for employees. The study's significant contribution is twofold: First, was to use the IDT to explain the readiness status of AI adoption. This was achieved through the study confirmation of the assertions of the Rogers' diffusion of innovation theory (Rogers, 2004) regarding the limited or rather AI knowledge exhibited by the South Australian construction practitioners, and Theory of Planned Behavior around people or employee readiness through knowledge and awareness of AI. Secondly, the findings contribute to research by building on the AI research agenda and provides implications for both practitioners and policy makers who might wish to channel their organisational energies toward the development of training programs aimed at raising the awareness of AI adoption, as well as equipping the construction practitioners with the necessary knowledge and skills AI implementation. This is germane as the AI is previously under-researched.

Limitations and future research directions

Whilst this study makes significant contributions in shedding light on our understanding of the current awareness, potential applications and readiness people for the AI technology, it is not without any limitations. The quantitative sample size was small (n = 34) and limited to South Australia. Therefore, future studies could employ larger sample sizes, across the different Australian states with varying AI adoption rates. Based on the conclusions, the study has established through exploring into the readiness and awareness within the AEC industries that the main barrier to readiness and awareness remains in willingness. Therefore, research should be focussed on improving the willingness of the industries to implement AI into more areas, and this may through further education support or workshops. Further, more research regarding effective introductions of new technology and systems into the

existing industries may reveal opportunities to improve the readiness and awareness. This may also speed up the process of integrating the use of AI into AEC industries.

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EXPLORING DATA READINESS FOR AI ADOPTION IN THE CONSTRUCTION INDUSTRY

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A primary driver for AI adoption in construction is enhanced productivity and efficiency. Building Information Modelling (BIM) may be observed as a convenient foundation for AI adoption offering a common source of readily available and structured data. The concept of BIM data readiness as a prerequisite for AI adoption in construction is explored through a Systematic Literature Review. The initial search revealed 33 potential sources of relevant literature. After careful filtering, screening and review, 9 articles were identified and studied in detail. The findings reveal several fundamental data readiness components for AI adoption. First, BIM-AI integration requires robust data acquisition, interoperability and development practices to ensure data quality; second, awareness of distinct project life-cycle requirements and third, the necessity of customised industry standards that would steer and inform AI adoption, addressing data security, ethics and sustainability issues. Though most papers recognised and emphasize the importance of data management strategies, key areas of ethics and level of development received scant attention. Understanding BIM as a source of structured data offers a pragmatic milestone in the journey towards AI adoption in construction.

Keywords: data readiness; AI adoption; artificial intelligence; building information modelling; construction industry

INTRODUCTION

Whilst there has been considerable interest in the impact of artificial intelligence (AI), there has been limited exploration regarding the groundwork and readiness of industry to adopt AI procedures and practices to ensure that the utility and promise of AI is realised. It is essential that key aspects of AI, knowledge and development and the speed of change do not outpace key infrastructure requirements. In short, the construction industry needs to learn to walk before it can run. This is arguably one of the most pressing issues to date (Re Cecconi *et al.,* 2024). If construction industry readiness for AI adoption is not appropriately evaluated there remains an inherent risk that the speed of change will overtake industry capacity and capability to appraise, prepare, develop and embrace AI in a meaningful and fully integrated manner (Jäkel *et al.,* 2022, Jäkel *et al.,* 2024, Regona *et al.,* 2022). Stakeholder disappointment and underperformance may only reinforce long held perceptions of the construction industry as backward and resistant to change (Re Cecconi *et al.,* 2024).

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Davletbayeva, D, Tennant, S and Konanahalli, A (2025) Exploring Data Readiness for AI Adoption in the Construction Industry, *In:* Thomson, C and Neilson, C J (Eds) *Proceedings of the 41st Annual ARCOM Conference,* 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 59-68.

Whilst the definition of AI remains contested (CIOB 2024), it is from concepts of machine learning (ML) that current understanding of AI resides. The UK Government's 2023 policy paper on a pro-innovation approach to AI regulation defined AI systems or AI technologies as products and services that are 'autonomous' and 'adaptable'. This definition was further explained by (Gajjar 2023) stating that "the 'autonomy' of AI refers to some AI systems that can make decisions without the intent or ongoing control of a human… The 'adaptability' of AI refers to AI systems, after being trained, often developing the ability to perform new ways of finding patterns and connections in data..." According to Chui *et al. (*2023) AI may be defined as "the ability of software to perform tasks that traditionally require human intelligence". For the purposes of this paper, encapsulating the essence of ML and adaptability will be utilised, as it captures the capabilities of AI, the idea of autonomous learning and the importance of data.

One area of notable development for the construction industry over the past two decades is Building Information Modelling (BIM) (Gholisadeh *et al.,* 2018). This has promoted ever-increasing use of information communication technologies (ICT) and ongoing digitalisation of project information in a manner that is consistent, coherent and transferable across project and organisational boundaries. The UK Government played a major role in sponsoring BIM adoption, including mandatory use for publicly funded construction projects (UK Government 2015). BIM and the digitalisation process have made it possible to automate design, construct virtual models and integrate various stakeholders into the project process, improving the construction outcome (Gholisadeh *et al.,* 2018). The concept of extending and aligning BIM knowhow and AI innovation into contemporary construction processes will not only reduce the time spent on routine actions, but also to optimise administration, produce cost savings and increase efficiency across a range of tasks (El Jazzar *et al.,* 2021).

Despite the ongoing debate about the definition, utility and impact of AI, especially in relation to disrupting existing work patterns, transformation will require significant technological, organisational and cultural shift (Angstroem *et al.,* 2023). Interestingly, Jäkel *et al. (*2022) identified four levels that will be affected and need to be changed when implementing AI in a construction setting: (1) the process level, (2) the organisation level, (3) the application system level, and (4) the data level. Reviewing the four levels identified by Jäkel *et al. (*2022), it is important to comment that AI adoption is not inextricably linked with BIM. BIM and AI are not symbiotic and there are likely to be many process, organisational and application situations where AI adoption remains independent from the BIM framework. Nonetheless, AI and data are symbiotic (Angstroem *et al.,* 2023, CIOB 2024). Therefore, it may be posited that BIM offers a convenient source of data readiness as a prerequisite for AI adoption in the context of the construction industry. The aim of this paper is to explore industry research/practice and enabling AI in construction in terms of data readiness. This will envisage the first steps of a coherent and logical route for meaningful AI adoption.

LITERATURE REVIEW

To date, a large amount of research literature is focused on what impact AI will have on the design, construction, operate and management of a building and the built environment, as well as barriers to AI adoption (Regona *et al.,* 2022). One of the most promising directions is the introduction and subsequent integration of BIM with AI (Du *et al.,* 2024, Pan and Zhang 2023). Zhang *et al. (*2022) explored examples of

BIM-AI integration across various construction project phases including planning, design, build and operate, in addition to automatic modelling and sustainable development applications.

Whilst early indications are promising, there remain many challenges to be addressed. One headline challenge is data (Hiniduma *et al.,* 2025). The literature underscore issues such as data acquisition, data interoperability and data transferability between different construction databases and data formats as problematic (Wang *et al.,* 2024). Regardless of efforts to overcome these barriers via fresh concepts, new model and innovative methods (El Jazzar *et al.,* 2021, Wang *et al.,* 2024), development and progress remain protracted (Sacks *et al.,* 2020). An inability to adequately address these barriers will hinder AI adoption. In addition, practical results have not yet yielded sufficiently reliable outcomes for the widespread implementation of AI (Pan and Zhang 2023, Zabin *et al.,* 2022). Given that AI implementation requires integration of databases (Angstroem *et al.,* 2023), BIM and the utility of digital data stored is arguably the beating heart of successful construction industry process and readiness strategy for AI adoption.

Building Information Modelling (BIM)

Two decades of BIM development has contributed significantly to the ongoing digitalisation and automation of the construction process. Today, BIM contains information not only on the 3D model, but also the project schedule (4D), project cost information (5D), supports the energy efficiency of the model (6D), and further expands its functionality to collect data from sensors, to support safety and the principles of lean construction (CIOB 2014, Koutamanis 2020). Expanding the dimensions of BIM and using its full potential will allow extracting structured data for analysing the corresponding parameter. The most common format for BIM data extraction is Industry Foundation Classes (IFC) (Du *et al.,* 2024). Therefore, a prerequisite and readiness criteria for the adoption of AI and supporting digital transformation in a construction setting is the presence of BIM as a foundation (RIBA 2024, Jäkel *et al.,* 2024, Sacks *et al.,* 2020).

BIM contains consistent and structured data, and each construction project will develop its unique BIM Execution Plan where all specifications, requirements, data ownership and other parameters are established. The Level of Development (LOD) specification outlines requirements for data sets and defines information requirements which fluctuate throughout the construction project lifecycle. The growing maturity of BIM Level 2 to Level 3 provides great advantages of real-time data access (UK Government 2015). In other words, BIM can act as a convenient reservoir of structured data which AI models can access, utilise and exploit across the project life cycle, from generative design to facilities management (Zhang *et al.,* 2022).

Project Life Cycle

As hinted, BIM already represents an extensive digital environment that supports the primary stages of the construction project lifecycle (design, construction and operate and management) and has capability and capacity to contain more information with dimensions expansion (Koutamanis 2020). Recently, Zabin *et al. (*2022) reviewed machine learning (ML) techniques that utilise BIM-generated data for various tasks across the construction project life cycle, with the design phase benefiting the most from applying ML techniques to BIM data. The construction phase, whilst offering AI opportunities, appears to remain cautious in its data readiness for AI adoption.

Nonetheless, improved efficiency and optimisation of processes through BIM data analysis (Zhang *et al.,* 2022, CIOB 2024) is undoubtedly emerging.

In contrast to the construction phase, the operate and management (O&M) phase and especially growing awareness of intelligent buildings, smart cities, smart infrastructure and concepts of big data exhibit considerable promise for BIM-AI integration. This facet of BIM-AI adoption will encapsulate and pull together key low-carbon, low energy sustainability standards including environmental (energy, water, waste), social (productivity, health, well-being) and smart (ICT, deep learning, robotics and persuasive computing) criteria (Worall 2018). Collectively, the BIM-AI integration supports a construction project cradle to grave concept.

Governance

AI tools are highly depended on the quality of data and can only work efficiently with well-structured data (RIBA 2024). The compliance of all construction stakeholders with the concepts and principles of governance, data security and data management is of great importance. Jäkel *et al. (*2024) highlight data management aspects such as data governance, timeliness of data, data quality, data storage, data value and data security for evaluating construction company digital transformation readiness and maturity. A data readiness for AI framework developed by Hiniduma *et al. (*2025) exhibits many similarities with Jäkel *et al. (*2024) and underscores four main data readiness metrics: data quality, data understanding and usability, data structure and organisation, and data governance. Data quality includes data accuracy, completeness and consistency, while data governance ensures data security and its ethical use. All construction company data including BIM databases contains valuable information on strategic construction projects, clients and intellectual property.

Organising robust information and data management in both an organisational and project setting is arguably a critical prerequisite for successful adoption of AI in construction (Angstroem *et al.,* 2023). Indeed, ISO 19650 establishes universal rules for information management for the entire construction industry, offering understanding and guidance to help navigate the complex information flow of a construction project (Abanda *et al.,* 2025). Strict compliance with governance and information management standards will facilitate the most complete and timely information possible for the project. This will ensure the required specification for data quality and facilitate subsequent training of AI algorithms and tools (Jäkel *et al.,* 2024). Transforming data stored in BIM and other databases into a form that can be used by AI remains problematic (Wang *et al.,* 2024, Sacks *et al.,* 2020). Consequently, AI adoption will require data modification and conversion to ensure consistency, interoperability and common standards of governance.

Summary

Successful AI adoption in construction may be evaluated through the data readiness of BIM as a construction project source of digitalised information with the ability to transfer data use for AI applications. The flow of data undergoes significant transformations as it travels from one system to another during the lifecycle of a construction project. Therefore, data at the design, construction and operate and management stage have different levels of detail and information (Abanda *et al.,* 2025). Combined with the data requirements for AI, this data will undergo changes and processing of a rather different nature, depending on type of data and purposes (Hiniduma *et al.,* 2025, Wang *et al.,* 2024). To take these changes into account, a framework for BIM data preparation was developed which incorporates key data

readiness categories (BIM, Project Lifecycle Stages and Governance) and their prerequisites - see Table 2. The following section, Research Strategy will focus on a systematic literature review to offer detailed insight for digital data management and the data foundation predicted for AI readiness in construction.

RESEARCH STRATEGY

For this exploration, BIM is considered as a reliable source of structured data for construction projects. Using a Systematic Literature Review (SLR) method presents an opportunity to obtain transparent and replicable results in searching large volumes of literature to identify and evaluate articles that deal with data preparedness for AI adoption. Two scientific papers databases were used to find all the relevant and high-quality literature: namely, Web of Science and Scopus. The search fields were set with keywords corresponding to the database and main data format, technology, data readiness component and industrial context. The search was conducted in title, abstract and keywords. The results were filtered by category, article, review and conference paper and limited to English language. No date range was set. Table 1 lists all keywords used to perform the search. These concepts are components of BIM/IFC data readiness for enabling AI adoption in construction.

Table 1: Literature search for review

Source	Web of Science (WoS), Scopus
Database or Data Format	"BIM" OR "building information model*" OR "IFC" OR "industry foundation class*"
Technology	AI OR "artificial intelligen*" OR "computational intelligen*" OR "data mining" OR "neural network*" OR "machine learning" OR "ML" OR "deep learning"
Industry	"construction industry" OR "construction engineering" OR "architecture, engineering and construction industry" OR "construction management" OR "AEC*"
Data Readiness	"data preparation" OR "data preparedness" OR "data readiness" OR "data quality" OR "data transfer*" OR "data processing" OR "data conversion" OR "data structure" OR "data compatibility" OR "data integration" OR "data interoperability" OR "data transform*"

The study employs the PRISMA 2020 approach (Page *et al.,* 2021) to report the process of SLR. The search was performed on March 7, 2025. As a result of the search, a total of 46 papers were identified: 28 papers in Scopus and 18 papers in Web of Science. After removing duplicates, 33 papers were subjected to an initial abstract screening for compliance with the aim of the study. After collective review and discussion of the 33 papers, the number of relevant papers selected for further study was reduced to 14. After a final screening of the 14 selected papers, only 9 papers met the criteria for analysis of data readiness for AI adoption in construction.

Key inclusion criteria were as the following: papers which use BIM as a source of data for AI algorithms, carrying out data transformation, or in-depth analysis on the data readiness. Exclusion criteria were as the following: the usage of BIM as only a receiver of external data in the processes as Scan-to-BIM, Digital Twins and generic discussions on AI usefulness within construction. It is acknowledged that there are other sources which may inform this study, and subsequent generalisations would benefit from a more detailed and expansive exploration of theory and practice.

FINDINGS AND ANALYSIS

SLR analysis was mapped to identify vital components/dimensions of BIM data readiness for AI adoption in construction. The process reveals several key areas of

interest. Although BIM and AI technologies have existed separately for some time, the practical use of BIM data as a foundation for the adoption of AI in the construction industry began relatively recently. All articles selected for the study are published between 2020 and 2024.

Nonetheless, there are a few surprises. Firstly, the unexpected low number of academic publications. After a structured selection and filtering process followed by a careful review of content and evaluation of 'relevance', only 9 papers from an initial pool of 33 papers were judged as appropriate for inclusion in this review. Secondly, mapping data readiness criteria against the selected papers discloses potential proficiency gaps in construction industry data readiness for AI, see Table 2.

Table 2: Data readiness framework

	DATA READINESS									
	BIM				PROJECT LIFECYCLE STAGES			GOVERNANCE		
Prerequisites / Paper	Maturity	Dimensions	Level of Development	Data Format	Design	Construction	O&M	Standards for BIM-AI	Ethics/ Data Security	Data Management
1 Pan & Zhang (2021)	●	●		●		●				●
2 Koo et al. (2021)		●		●			●			●
3 Li et al. (2024)		●		●	●					●
4 Du et al. (2024)		●		●	●	●	●	●		●
5 Pino Alvarez et al. (2024)					●					●
6 Cheng et al. (2020)		●		●			●			●
7 El Asri et al. (2024)						●				●
8 Ryu et al. (2021)		●		●						
9 Sellberg et al. (2022)				●						●
Total	1	6	0	7	3	3	3	1	0	8

Data readiness criteria are grouped under three broad themes: namely, BIM, Project Stages and Governance. Each theme is broken down into key 'proficiencies' or 'prerequisites' that would assist successful AI adoption. In total, there are 10 prerequisites, 4 for BIM, 3 for Project Stage and 3 for Governance. From the mapping exercise, 4 of the 9 papers only cite 2 of the proposed prerequisites. Indeed, 8 out of 9 papers address 5 or fewer prerequisites. Interestingly, the paper with greater than 5 prerequisites (7 / 10) is the solitary paper to explicitly address the concept of readiness as a precursor to AI adoption. This outcome may suggest a construction industry keenness to focus on the implementation period and the promised benefits of AI with very little consideration of readiness.

Exploring the 3 broad data themes and associated 10 dimensions of readiness reveal a spectrum of construction industry interest and subsequent focus. Key dimensions of readiness currently attracting industry interest include 'data management' with 8 out of 9 papers, 'data format' with 7 out of 9 papers and 'BIM Dimensions' with 6 out of 9 papers. Most researchers work with geometric data in 3D format, only a small part of the studies (Pan and Zhang 2021) is on the way to increasing the maturity of BIM using cloud BIM allowing real-time collaboration.

Given that the overarching research focus is data orientated, this is both anticipated and reassuring that key aspects of AI readiness are being actively explored. At the opposite end of the spectrum, important readiness criteria such as maturity and the level of development of BIM received almost no substantive attention in the studied papers. A similar situation is observed in the field of ethics and data security, as well as the standards for the integration of BIM and AI. Data security is not discussed in any of studied papers, BIM-AI standards received attention in only 1 paper (Du *et al.,* 2024) out of the 9 selected. This is a slightly worrying disclosure.

Neglecting 'level of development' is likely to hinder the overall effectiveness and utility of AI adoption. This may cause false starts leading to repeat work, an underutilisation of AI as well as diminished trust in the technology. The lack of attention regarding ethics and data security is troubling given widespread industry awareness and corporate implementation of GDPR (2018). From an AI readiness outlook, this fundamental prerequisite would appear to be largely ignored.

DISCUSSION

Adoption of AI in construction requires careful preparation and a minimum standard of 'readiness' to mitigate the risks and maximise the opportunities for a successful outcome. This study identified key prerequisites from both the literature review and the SLR that contribute to the understanding of data readiness for AI adoption in the construction sector. Whilst the study readily acknowledges the opportunities for AI, it remains mindful of an industry resistant to change (Re Cecconi *et al.,* 2024). While there are attempts to comprehend how to apply AI to the data contained in BIM, researchers face similar difficulties, such as quality of data, data transformation issues and others. Individually and collectively, this may significantly slow down progress in this direction and reveal the state of readiness of the industry to adopt AI at the present time. Data management is an important aspect for obtaining high-quality data. In this regard, bringing data within the BIM to the proper level is a priority.

The problems of data interoperability in BIM-IFC mapping (Koo *et al.,* 2021) and BIM-ERP systems (Pino Álvarez *et al.,* 2024) force the use of AI methods aimed not at improving the efficiency of the construction process, but at eliminating technical difficulties and shortcomings in relation to data management. Although the functionality of the IFC format is gradually improving, it no longer fully meets the needs of today's technologies. The necessity for further expansion of its capabilities is beyond doubt (Koo *et al.,* 2021, Cheng *et al.,* 2020).

Technical aspects of BIM-AI data transformation are considered in Ryu *et al. (*2021) and Sellberg *et al. (*2022), focusing on the speed of writing and loading a file into an AI algorithm or model, the quality of the extracted data from BIM. All these parameters are important for calculating computing power and data storage capacity, which directly affect sustainability, energy consumption and emissions into the environment. Both Sellberg *et al. (*2022) and Cheng *et al. (*2020) emphasize the need for standardised approach for appropriate algorithm selection, otherwise, this choice is influenced by subjective preferences and experience of a developer. In this light, the standardisation of AI technology selection and the corresponding transformation of BIM data can be formalised in future industrial policies aimed at optimisation and alignment with emission reduction policies. However, this issue is not explicitly discussed in any of the reviewed sources and may have overlooked and/or underestimated the difficulty of standardisation in a highly fragmented sector.

Another barrier to embracing of AI in the construction industry is the challenges of accessing open datasets of real project models for training AI algorithms (Sellberg *et al.,* 2022). AI models trained on large number of datasets increase reliability of output, and as a result, their trustworthiness in real-world working conditions (Cheng *et al.,* 2020, Ryu *et al.,* 2021). Most of researchers work with small datasets as they must augment, process and convert data manually (Koo *et al.,* 2021, Du *et al.,* 2024, Ryu *et al.,* 2021). It is unlikely that the large data of BIM models can be subjected to any significant transformations without the availability of automatic tools for such transformations (Du *et al.,* 2024).

With the emergence of data-driven technologies such as AI, data has a pivotal role to inform readiness for adoption. It must be recognised that extracting, transforming and storing data from real BIM models can be associated with certain risks (Das *et al.,* 2021, Zabin *et al.,* 2022). Therefore, aspects of data ethics and security must be properly developed and regulated. Perhaps this factor would contribute to greater openness of construction data and, consequently, to more reliable AI models specifically customised for construction industry. In this matter, professional organisations and academics may play a central role, indicating directions for the legislators to regulate the development of AI in the construction sector, improving its outcome and continue a trajectory towards sustainable development.

Special industrial standards for BIM-AI data transforming, as well as the defining of responsibility for data and its ethical use would give the start for accelerated implementation of AI and the achievement of desired improvements in the construction industry. Despite the availability of a general AI standard from ISO organisation, there is a necessity of industrial AI standards which consider all specific characteristics of the industry and available digital data sources such as BIM, and which would smoothly steer the process for BIM-AI data management and governance practices.

There are noteworthy attempts by professional bodies to address the rapidly changing landscape in the application of digital technologies. For example, RIBA has developed the Smart Building Overlay. This recommends data management according to ISO19650 for security, data storage when working with Smart Building technologies and offers users to develop protocols for interaction between systems. Just as the implementation of RIBA BIM Overlay and Digital Plan of Work helped with understanding the requirements for information fluctuating across the project lifecycle. Presently, there is a need to develop a new document that will clarify the requirements for digital data at each stage of a project using AI. Of course, this requires collaborative work with IT professionals, but they will not do this work themselves if it is not initiated by the industry and there is no clear demand for it.

CONCLUSIONS

Whilst AI in construction cannot be ignored, AI success in achieving enhanced construction performance cannot be deemed inevitable. There are many benefits associated with AI adoption in construction namely, simplified procurement, generative design, predictive maintenance, automated performance tracking, hidden pattern discovery, knowledge management, to suggest a few. Nonetheless, there are certain prerequisites required to avoid “painful” mistakes that may lead to under-utilisation, disappointment and potential rejection.

A key staging post for enabling AI in construction is data readiness. Only through robust data management, establishing standards for BIM-AI adoption, refining transformational processes will construction data meet the performance requirements of a modern digitalised industry. Although data readiness is important, it is only one of several readiness criteria for the successful implementation of AI in construction. This paper is focused only on data preparedness, further avenues of research should explore and elaborate on other constituents of successful technology implementation, such as ethics, data security and the socio-technological tensions likely to emerge. Awareness of prerequisites will provide strategic direction for the pragmatic adoption of AI by all stakeholders, stimulating widespread use with demonstration of successful examples.

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AN EXPLORATORY STUDY ON EXPECTATIONS FROM AI-BASED AUTOMATED SCHEDULING

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Scheduling is a complex process that requires information from several sources, coordination between teams, and experience of using various methods and tools. Automated scheduling (AS) may facilitate the process and provide a potential solution for the skills gap experienced in the construction industry. In this paper, we will present initial findings from a funded research project about development of an AI-based AS tool for building projects. As a part of the needs analysis, semi-structured interviews were conducted with 12 construction professionals to identify challenges with the traditional scheduling process, requirements from, and potential concerns about an AI-based AS tool. Unavailability of data, procedural difficulties such as extracting information from several documents and poor communication between different disciplines were highlighted as the current challenges. Major expectations from the tool are primarily about automated analysis of various documents and better coordination of information exchange. Judgemental reasoning required for scheduling tasks and limited explainability of AI raise concerns about the performance of a fully automated tool and decreases trust.

Keywords: Artificial intelligence; construction planning; digital technology; time

INTRODUCTION

Scheduling is a data-driven process that requires information retrieval from different sources and communication within the company as well as project stakeholders (Soman and Molina-Solana, 2021). Standards, technical specifications, project reports and company guidelines are among the several documents that are used in developing baseline schedules. Information extraction, interpretation and categorisation process requires significant amount of time. Due to fast-track projects increasingly seen in the construction industry, preparation of a baseline schedule that effectively reflects the project scope and meets stakeholder expectations is challenging, often leading to planners overlooking critical project details and input from different disciplines. Project disciplines are often reluctant to contribute to the planning process due to their workload (Winch and Kelsey, 2005). Project planners are expected to manage the complex information gathering process, utilise effective methods and tools for scheduling, and ensure effective collaboration between project teams despite time related and organisational challenges (Abou-Ibrahim *et al.,* 2019). Scheduling involves development of a work breakdown structure (WBS), identification of

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activities, estimation of durations, defining relations and constraints, resources levelling and carrying out network calculations using methods such as Critical Path Method (CPM). Processes are iterative, require different types of data and knowledge and optimisation. Scheduling is an exercise under uncertainty which requires forecasting and incorporating risk impacts into time plans. Forecasting is another knowledge-intensive process that requires information gathering about project, company and external factors and collaborative efforts to make sense of uncertainty. Artificial intelligence (AI) may provide a possible solution to deal with complexity and uncertainty in projects, increase efficiency and effectiveness of scheduling tasks.

AI is defined as systems that display intelligent behaviour by analysing their environment and taking actions with some degree of autonomy to achieve specific goals. AI provides a solution for automating data-intensive tasks such as scheduling because it can handle large amounts of data with speed, accuracy and consistency. It can process thousands of documents in seconds, analyse and learn from data. For example, for scheduling purposes, AI can carry out document analysis to understand scheduling requirements and be trained on labelled data where experts have previously applied preferred scheduling principles. If optimisation is required, AI can balance trade-offs by using constraint-based optimisation models. Based on their findings from a Delphi study with a panel of 52 project management experts who reflected on future potential AI applications in project management, Holzmann *et al. (*2022) argue that top-ranked functions for AI integration are mainly about scheduling such as creating a Work Breakdown Structure (WBS), project budget, updating project progress, identification of scope deviations, and allocation of tasks to project teams. Pan and Zhang (2021) also demonstrate through empirical research that AI can handle operational challenges of scheduling. Felicetti *et al. (*2024) suggests that AI is moving beyond solely enhancing operational efficiency to changing the cognitive tasks in project management.

Müller *et al. (*2024) argue that integration of AI into project management is a transformative trend that is reshaping the industry by referring to findings of a questionnaire that 76% of the participating professionals agree that AI will reshape project management. According to this study, project scheduling is one of the primary areas through which AI impacts efficiency, accuracy, and decision-making. Although there are several studies reported in the project management literature about AI applications for scheduling, majority is technology oriented and demonstrate how an AI method or algorithm can be used for a specific scheduling task. One popular area of research is duration prediction by AI. Among these studies are artificial neural networks (Pewdum *et al.,* 2009), and hybrid AI models (Yaseen *et al.,* 2020). Another research area is using AI methods to support a single scheduling task, such as WBS development. Amer *et al. (*2022) developed a deep learning-based natural language processing (NLP) tool to learn relations between activities. NLP that enables computers to understand, interpret, generate and respond to human language is a widely used AI method to extract key information from reports, topic detection and classification, understanding trends and detection of contradictions and similarities. The requirement of considering several reports at different stages of the scheduling process makes NLP an appropriate method to for scheduling purposes. Several researchers demonstrated how NLP can be used for scheduling such as Wang *et al. (*2022) for information extraction from BIM, Hassan *et al. (*2023) to digitise scope of work requirements and Dikmen *et al. (*2025) for automated contract analysis to estimate risk in projects.

Although there are individual applications of AI using specific documents for a given scheduling task, research on expectations of schedulers from an AI-based automated tool, and perceptions on its potential challenges and benefits are missing. An AI based tool can analyze and interpret project documentation, extract information from relevant databases to estimate scheduling variables, can be trained to identify patterns/rules, and facilitate collaboration between project stakeholders. However, identification of which "documents", "information" sources, scheduling "variables", "rules of thumb" and "processes" that can be facilitated by AI and perceptions on risk and benefits of project schedulers, require further research, which is the aim of this paper. AI-based models that are not just adding to the body of academic knowledge but can also be applied in real-world practice are needed (Darko *et al.,* 2020). Within this context, this research was designed using a design science paradigm that aims to understand needs of potential users to develop an AI-based tool that would provide value for practitioners.

METHOD

Initial findings of an on-going research project that aims to develop an AI-based automated scheduling tool are presented. Design science paradigm that is extensively employed in information systems research (Hevner *et al.,* 2004) serves as the methodological framework for the project to develop a tool through iterative steps guided by practice. Using the practice theory, the research investigates the actuality of project-based working as proposed by Cicmil *et al. (*2006), particularly project schedulers' tasks, context-specific routines and rules of thumb. The research process unfolded across three steps: problem identification and goal setting, development of the tool and evaluation. In the initial step, needs assessment was conducted via interviews with 12 construction professionals experienced in scheduling. The findings from needs assessment are used to determine required functions of the tool and AI methods appropriate for these functions. Research questions at this step are R1. What are the processes, data/documents, and principles used by schedulers? R2. What are the current challenges of scheduling process? R3. What are the expectations of users from an AI-based automated scheduling tool? R4. What are the perceptions of users on benefits and challenges of an AI-based tool?

Experts were selected based on their experience in scheduling, particularly in international projects. The criteria used were minimum bachelor's degree in construction engineering and management related fields, minimum of 5 years of hands-on experience in scheduling, and minimum of 3 years of experience in international markets where the experts were selected by non-probability sampling. 25 experts who meet these criteria that have either existing professional relations with the research team or those identified from professional social networking platforms were invited. The profile of 12 scheduling experts who accepted to participate in this study is given in Table 1.

Semi-structured interviews were conducted online with participants who are in different parts of the world (in English). Initially, a definition of AI is given with a couple of examples of AI methods such as NLP, ML and GenAI. The questions were directed to experts in three different sections. Section 1 requested demographic information, Section 2 asked about current practices of scheduling, utilisation of data and documents, and challenges of the scheduling process. Section 3 explored their expectations from an AI-based automated scheduling tool, as well as possible concerns. On average, an interview took approximately 90 minutes. Interviews were

conducted till the data saturation was reached, recorded and converted to text. A manual thematic analysis was conducted. Spreadsheets are developed to organise quotes according to the identified “process/task”, “documents and data” and “requirements” as “themes”.

Table 1: Profile of the experts participating in semi-structured interview (IC: Experience in the International Construction, PE: Experience in Planning)

Expert ID	Personal profession	Education	Years of experience	Location
E1	Executive manager	Civil Engineer	IC: 30, PE: 25	Turkey
E2	Project manager	Civil Engineer	IC: 28. PE: 25	Turkey
E3	Technical office manager	Civil Engineer	IC: 10, PE: 12	Turkey
E4	Planning manager	Civil Engineer	IC: 12, PE: 20	United Kingdom
E5	Senior associate	Civil Engineer	IC: 26, PE: 22	USA
E6	Contract manager	Civil Engineer	IC: 22, PE: 12	Saudi Arabia
E7	Planning manager	Civil Engineer	IC: 08. PE: 03	Saudi Arabia
E8	Senior planning engineer	Civil Engineer	IC: 06. PE: 03	Turkey
E9	Program Controls Director	Civil Engineer	IC: 14, PE: 14	Saudi Arabia
E10	Senior consultant	Civil Engineer	IC: 13. PE: 13	United Kingdom
E11	Director	Mechanical Engineer	IC: 15, PE: 45	United Kindom
E12	Cost control manager	Civil Engineer	IC: 15. PE: 12	Qatar

FINDINGS

Documents and information sources used for scheduling

Table 2 depicts findings structured in a way that it summarises the "processes", "documents and data" and "principles/requirements" as stated by the participants. It demonstrates that different types of information sources and documents are used for each scheduling task. There are fundamental documents as well as others that provide useful information on requirements, preferences and control points. For example, for WBS development, Bill of Quantities (BoQ) is the core source of information. However, if a BoQ is not prepared according to standards such as the Master Code or the New Rules of Measurement (NRM), WBS development becomes challenging. Laws and regulations, tender schedule and previous project data are used to develop WBS. Use of contract documents are mentioned by all the interviewees at almost every phase of baseline scheduling, mainly General Conditions of Contract (GCC), Particular Conditions of Contract (PCC), Questions and Answers at the tendering stage, BoQ, Specifications, Drawings, Tender Schedule, Method Statements (MSs) and Scope of Work (SoW). Reports prepared for the project, such as the Lenders’ Report, cash flow analysis and estimated budget, Environmental Impact Assessment Report are also among the documents used to develop the baseline schedule. Company procedures and guidelines for scheduling (if they exist), scheduling standards and principles (e.g., Society of Construction Law), laws and regulations such as Labour Law and Customs Law are mentioned as critical documents that are used by the schedulers while preparing the baseline schedule, especially during duration estimation and defining constraints and activity relations. Minutes of Meetings (MoMs) between project stakeholders, especially with the Client are also used to extract critical information about constraints and preferences. Majority of the interviewees referred to company databases and historical records to estimate durations and contingency. Expectations from an AI-powered tool is primarily to analyse and interpret several documents to facilitate project understanding.

Use of BIM for scheduling

11 out of 12 interviewees mentioned that usually BIM is not ready at the baseline preparation stage, and it is not used. Schedulers also pointed out that using 4DBIM

software capability is limited, it requires more data and not practical. Specific software, such as Primavera, is usually defined in the contract, thus must be used as a contractual obligation.

Table 2: Requirements for scheduling tasks

Tasks	Requirements
Developing the Work Breakdown Structure (WBS)	• Use WBS – if standard formats are used. • Optimise level of detail – neither too detailed nor too broad • Check any contradictions between Bill of Quantities (BoQ) and other documents • Ensure that WBS and CBS are similar for better cash flow management • Learn from previous projects that are similar • Support collaboration between different project disciplines and stakeholders • Take consent of the owner • Check consistency of WBS with tender schedule, laws and regulations
Identification of activities	• Use Technical Specifications for activity names • Use minutes of meetings (MoM) for owner requirements • Consider all relevant laws and regulations
Activity milestones and constraints	• Use contractual documents to identify any constraints • Use the tender schedule for milestones • Use MoMs to identify constraints imposed by the owner
Allocation of resources	• Calculate the quantities and check consistency of measurements • Refer to method statements (MS) for resource requirements
Assignment of costs	• Check the type of payment method (unit price or lump-sum) • Check with the cash flow submitted to owner and financer
Calculation of duration (using productivity rates and based on time constraints)	• Use local laws and regulations (E.g. Labour Law) • Use company procedures and guidelines for constraints • Rules of thumb • Use of historical data to estimate productivity rates and adjust according to current project
Risk assessment and contingency estimation	• Check method statements to identify risks • Use laws and regulations to identify specific risks such as environmental, health and safety and social risk • Add contingency due to weather conditions. • Use previous project data to estimate delay. • Use risk register to incorporate risk impacts on durations.
Identification of relationships (hard and soft logic)	• Identify relations using contract documents and technical specifications • Use company procedures about scheduling principles • Use MoMs with owner and other project stakeholders • Check standards (eg. Society of Construction Law) • Use data/input from different disciplines • Refer to regulations (such as safety permits) and laws
Setting the calendar	• Use the labour law (working days and holidays) • Understand owner requirements from MoMs
Adjustments considering the contractual completion date and milestones	• Take the milestones and completions dates from contractual documents • Carry on iterations to meet the contractual completion date and milestones
Resource levelling	• Learn resource limits and preferences for different project disciplines using MoMs • Check the capacity and resource availability in the company • Check with allocated budget and cash flow in pre-project documents

Requirements and expectations from AI for different scheduling tasks

Automated WBS development require using several documents including BoQ, technical specifications and coordination between different project disciplines to check its relevance. It also requires input from users for optimum results such as level of detail. "Determining the level of detail in the work schedule is a critical issue. If it is too detailed, the work schedule becomes unmanageable in a very short time. However, if the level of detail is too low, the critical path loses its significance. Therefore, WBS levels should be optimised to ensure that the project can be effectively controlled and monitored." (Expert 2)

> Expert 5 highlighted that they try to create a WBS that closely resembles CBS for better project control and management. Consistency of WBS with other contract documents such as the tender schedule should be also checked (Expert 3).

Some companies use historical project data to develop the WBS and then organise coordination meetings to check whether it reflects requirements of different disciplines and stakeholders.

> "We take advantage of similar projects we have undertaken to develop the WBS levels. WBS of a similar project, if exists is a good source for understanding the nature of a project. Then, we conduct workshops with different project disciplines in the company and meetings with project stakeholders before we finalise the WBS. This is a must to maintain alignment, coordination, and commitment throughout the project execution." (Expert 9).

The importance of the role of coordination and communication was mentioned by all of the experts almost for all steps of scheduling, which is also found as one of the challenges. Experts agree that the biggest challenge they face is to bring the project disciplines together and hold Baseline Schedule Meetings. Expert 5 also mentioned that even if they manage to organise these meetings, meetings are not productive as "divisions are reluctant to take responsibility, and they do not have enough knowledge of the project." The same kind of problem is expressed by another interviewee as follows:

> "It is very difficult to bring people together in meetings and discuss the baseline schedule efficiently because of lack of expertise, communication skills, sometimes conflict of interests between divisions and stakeholders exacerbate this problem. As the project grows, these problems increase geometrically, not linearly." (Expert 6)

Experts agree that relevant laws and method statements play an important role in defining the project scope, but due to time challenges, sometimes these are ignored.

> "Method statements include details of materials and equipment such as mobile cranes and drills to be used, which are critical for duration estimation and resource planning, however, these documents are usually overlooked due to time limitations." (Expert 3)

Estimation of durations using productivity rates is an exercise that requires several types of data. The expectation from the automated tool as mentioned by most of the interviewees is to learn from similar projects. However, data is limited.

> "A project in Algeria may not have the same man-hours as a project in England. Moreover, even in the same location, we may not be able to pour a cubic meter of concrete at the same productivity rate during different external factors. Unit man-hours vary depending on the region, the type of job, local worker productivity and site constraints. I believe that an AI-based tool that can learn from data and analyse the factors affecting productivity rates to identify patterns can provide much more reliable estimates to be used in baseline schedules." (Expert 3)

Experts also mentioned about different company guidelines and procedures, such as procurement procedures (Experts 3, 4) and scheduling handbook (Experts 10,12) that are used while assigning durations, as well as rules of thumb, as given below:

> "Activity durations should be manageable. Long-duration activities are difficult to monitor and control. I avoid using long durations for activities, such as no longer than two weeks." (Expert 9)

As indicated by Expert 10, "if the company does not have a database, the scheduler's experience becomes extremely important". An expectation mentioned by Expert 10 is a rule-based system where the rules are either learned by AI or set by experienced schedulers themselves.

Another data-driven process is risk assessment. Following are some quotes from the interviewees about documents containing relevant risk information.

> "Method statements should be referred to identify risks and add contingencies. e.g., if a method statement indicates that work is to be carried out with a crane, windy weather can be a risk." (Expert 2)

> "In the UK, law and the EIA regulate the protection of wildlife and nature during the construction process, number of badgers, water voles, etc constitute a source of delay risk." (Expert 10)

Expert 6 mentioned about challenges of organising risk workshops to assess project risks considering different aspects of the project such as technical, contractual and economic to provide useful input to estimate buffer.

Assigning relationships between the activities require consideration of several documents, as Expert 3 explains as below:

> "Contract documents and company scheduling procedures determine the relationship types to be used in scheduling. Additionally, meetings conducted with the owner may establish rules for relationship types. We use specific standards such as the Society of Construction Law, … In most of our projects, the use of the Start-to-Finish (SF) relationship is prohibited, as stated in the IMP/IMS Guide, as well as by the Society of Construction Law. (Expert 3)"

Soft logic, also known as preferential logic or discretionary dependencies, is based on best practices, preferences, expert judgment and usually decided by a consensus between different project teams. Setting the soft logic requires consensus between members.

> "Technical specifications may regulate mandatory relationships among activities. For example, fire alarm system and CCTV tests cannot be performed without permanent energy. While the planning department assigns mandatory physical relationships between activities using technical specifications, discretionary relationships (soft logic) are usually set through meetings with project disciplines." (Expert 2)

All interviewees explained scheduling as an iterative process that involves teams coming together to discuss resource allocation options, which cannot be done effectively due to time limitations. Checking the integrity of baseline schedule includes review of several issues as well as experience, judgemental reasoning.

> "As a common practice, schedulers check the project longest path, near critical paths, activities without predecessors, activities without successors, activities with constraints, negative lags, etc. to check whether the schedule makes sense given the project nature before finalising it." (Expert 10)

Benefits and concerns about using AI for scheduling

All the interviewees mentioned about "automated document analysis" as the major benefit. Expert 8's comment shows that even the whole scheduling process is not automated, there can be some time and cost savings valued by the scheduler by some level of automation.

> "We spend enormous amount of time for discussing the activity relationship in meetings with other departments. The meetings are not result-oriented sometimes departments try to establish dominance over other teams. Even if only relationships like hard logic can be linked automatically by the AI-based tool, time and money lost in meetings can be reduced and more consistent work programs can be created." (Expert 8)

One of the interesting discussions in interviews was about availability of data and whether an automated tool can be ever possible without enough data to train the AI. Four of the interviewees raised their concerns about lack of data in construction, unreliability of AI trained with limited data leading to lack of trust. Concerns were about whether AI can mimic human decisions that require judgmental reasoning. This

group of experts including Expert 4 and Expert 5 raised serious concerns about a fully automated scheduling tool.

> "There are several documents in construction projects, significant or less important, and sometimes maybe conflicting that are used to develop the work schedule. For example, if we want artificial intelligence to use every file to determine the constraints, AI can assign constraints to jobs that should not be there. Human input will be needed to prioritise factors and make reasonable adjustments" (Expert 4)

Another concern was about lack of explainability and uncontrollability of the tool leading to serious consequences, which have been reported by other researchers (Kumar *et al.,* 2023). The "black box" nature of AI makes it a possible source of unpredictable errors.

> "As a disadvantage, the schedule created by this type of tool may not be sufficiently checked, errors may be noticed too late, potentially leading to problems, cost increases and conflicts between the parties. For example, a purchase item that has a wrong date may result in serious cost and time implications" (Expert 3)

The other group of experts, smaller in number including Expert 6 and Expert 8, were very positive about AI. This group trusts that AI can interpret the information, identify patterns and relations that could not be done by humans due to complexity, thus positive about an AI tool with minimum human input. This aligns with a previous study by Dacre and Kockum (2022) that as the complexity in projects increases, perceived benefits of using AI gets higher as it is assumed that AI reduces some of the unknowns.

DISCUSSIONS AND CONCLUSIONS

Based on the findings from interviews, the major processes that can be supported by the AI-based tool are identified as; retrieval of documents and other information sources needed for a given scheduling task, automated document and data analysis to estimate scheduling variables such WBS, activities, durations, relations, constraints and buffer, carry out iterations to optimise time and resources, check consistency with documents such as standards and company procedures and also rules of thumb learnt by AI and/or set by the users to make necessary adjustments (R1). Major challenges are document analysis and collaboration (R2). Findings summarised in Table 2 provide the information required for the forthcoming steps of the research project (R3). For example, selecting the AI methods to be used for different purposes, such as NLP for document analysis, a rule-based system and/or deep learning methods to understand scheduling patterns from previous projects. Concerns such as lack of transparency mentioned by the schedulers highlight Explainable AI as a possible solution. Use of GenAI and chatbots to facilitate task automation, information retrieval and team communication will be considered. Findings from this study can be used by other researchers aiming to develop similar tools. However, it should be mentioned that findings reflect opinions of only limited number of project schedulers and cannot be generalised. We are planning to conduct action research in a construction company to understand how schedulers act and learn in practice and the role of institutional, cultural and behavioural factors in the next steps of the artifact development.

As a summary, AI is considered as a powerful technology to automate some of the critical tasks of scheduling with reasonable or no human input leading to significant time savings and increased efficiency. However, there is a considerable distrust among project schedulers in AI mainly because they suspect that AI may not perform well as it lacks judgmental reasoning and cannot be trained due to limited amount of

data (R4). Our findings highlight that human intervention is still needed for scheduling where AI is conceptualised as a collaborator for increased productivity rather than a manager with full automation. As Lavagnon and Pinto (2025) highlights future research is needed for deeper understanding of the "complementary" role of AI, which is also demonstrated by our findings. Other research avenues about use of AI in scheduling could be exploring cultural and organisational contexts for AI adoption, alternative models of human-AI teaming in projects, possible change in project management roles and demonstrating actual benefits and challenges of using AI in practice.

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EVALUATING THE IMPACT OF GEN-AI ON IMPROVING COMMUNICATIONS IN CONSTRUCTION PROJECTS

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Effective communication in any construction project, including city regeneration, plays a crucial role in aligning diverse stakeholders, fostering community trust, and achieving shared goals while addressing complex social, economic, and environmental challenges. Leveraging emerging digital tools, such as generative AI, offers potential to refine and enhance communication process. This study explores the role of ChatGPT in supporting written communication within this complex environment and examines variations in performance between ChatGPT 3.5 and the more advanced ChatGPT 4o. Using a simulated scenario, 20 participants, comprising general contractors and client representatives, engaged in two rounds of email exchanges and subsequently evaluated three emails against seven communication criteria: clarity, conciseness, completeness, call to action, courtesy, personalisation, and composition. Preliminary observations suggest that ChatGPT 3.5 may have advantages in clarity and conciseness, while ChatGPT 4o appeared to generate more comprehensive content, though it was relatively less preferred by participants. Factors such as clarity, calls to action, and conciseness emerged as potentially influential in crafting prompts for improved email effectiveness. These findings provide initial insights while highlighting the need for further exploration in broader contexts.

Keywords: artificial intelligence; ChatGPT; generative AI; miscommunication; written communication

INTRODUCTION

To achieve meaningful progress and address critical challenges, it is essential to prioritise areas with broad and lasting impacts across multiple domains. In the context of urban regeneration, the scope of relevant topics is extensive and deeply interconnected. Among these, effective communication is fundamental, shaping success in areas such as contract management, human resources, sustainability, equality and diversity, and health and safety. In the construction industry, communication is defined as the mutual exchange of information between senders and receivers to create a clear and understandable platform between construction parties

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(Dainty *et al.,* 2007). Various studies highlight the importance of effective communication for a wide range of reasons, such as project implementation (Zulch 2014), collaboration, reducing costs, preventing time overruns, and improving work quality (Zulch 2014), performance quality, managing safety, completing projects within budget (Coopers 2012), achieving coordinated results, managing change, motivating employees, and understanding workforce needs (Armstrong and Taylor 2020), and reducing project failures and increasing transparency (Hoezen *et al.,* 2006).

Despite its importance, extensive research by scholars and industry professionals has highlighted poor communication as a significant issue in the construction industry. According to the report produced by PMI (2013), ineffective communication contributes to 56% of the total risk of a project cost overrun. Communication networks in construction projects face growing complexity and inefficiency due to temporary design processes, increasing project sizes, and fragmented teams, different roles and supply chain, the involvement of numerous stakeholders, and regulatory bodies, increasing the complexity of maintaining clear and consistent communication (Zulch 2014). Among the various forms of communication, written communication stands out as a highly feasible method that aligns well with the requirements of an effective system and platform (Zadrozny and Lai 2023).

Email communication remains the predominant formal system for group information exchange and record-keeping. A recent study analysing the transmission and content of email communication found that emails strongly represent underlying activities and offer insights into the engineering processes behind their creation (Snider *et al.,* 2017). a project manager on a construction site spends three to three-and-a-half hours each day handling work-related emails (Soni 2022). Du *et al. (*2020) focuses solely on email logs, phone interviews were conducted with each 80 participating companies to confirm that email was the primary communication tool for the given project (Du *et al.,* 2020). However, email is not without its challenges, including ambiguity, tone and emotion, cultural differences, grammatical errors, assumptions, formatting issues, reader's mood and perspective. Email needs to be enhanced with innovative approaches to help stakeholders fully leverage its valuable features and mitigate poor communication in construction projects.

Beyond the established technologies, there is growing interest in the potential of artificial intelligence (AI) and machine learning to further enhance communication in construction. Generative AI (Gen-AI) is a specialised branch of artificial intelligence that focuses on creating new content based on learned patterns from existing data. The primary objective of this research is to assess the potential of Gen-AI tools, specifically ChatGPT, in reducing miscommunication within construction projects. To achieve this, the research outlines the following objectives: (i) evaluating ChatGPT's impact on enhancing written communication across various criteria, (ii) comparing the efficiency and effectiveness of different ChatGPT versions, highlighting their key strengths and weaknesses, and (iii) Identifying and prioritising the key communication criteria valued by stakeholders, enabling a deeper understanding of the relative importance of ChatGPT's strengths and weaknesses.

LITERATURE REVIEW

As a leading Gen-AI tool, ChatGPT is a state-of-the-art large language model (LLM) and has revolutionised natural language processing (NLP) by generating human-like text with context and coherence., ChatGPT possesses numerous features that make it a strong candidate for this research. ChatGPT's extensive Massive Data Training in

collaboration with OpenAI and Microsoft enables it to understand and generate a wide range of textual content. The use of Transformer Architecture further enhances this by enabling the model to generate responses that are more human-like (Nazari and Saadi 2024)., making written communication feel more natural and engaging. This is particularly beneficial in maintaining the tone and formality required in external communications between contractors and clients. Algorithm Optimisation for deep learning allows the model to be both efficient and effective in generating responses. Continuous Fine-tuning and Reinforcement Learning from real-world interactions ensures that the AI evolves and adapts to different communication styles, improving over time and becoming more adept at handling various scenarios (Roumeliotis and Tselikas 2023). Lastly, the focus on Ethical and Bias Mitigation Efforts means that the AI-generated communication is more likely to be fair, unbiased, and professional (Shakya *et al.,* 2023), which is crucial in maintaining the integrity and trustworthiness of communications in sensitive or high-stakes environments like construction projects.

Recent studies reveal Gen-AI's broad potential in the construction industry. The integration of Gen-AI with Building Information Modelling (BIM) has enhanced information retrieval, boosting search speed, accuracy, and user experience (Zheng and Fischer 2023). In safety training, the use of Gen-AI in virtual reality environments has helped overcome linguistic and literacy barriers, offering real-time guidance to migrant workers (Hussain *et al.,* 2024).

The interest in Gen-AI tools for enhancing written communication continues to grow due to their numerous benefits. Previous research has highlighted the capabilities of Gen AI-enabled chatbots in offering immediate feedback, personalisation, and customisation opportunities, delivering linguistic input, and facilitating daily writing practice (Guo *et al.,* 2023). ChatGPT can provide real-time, contextually relevant feedback on written content, assist users in refining grammar and syntax, and offer practice opportunities through interactive writing exercises (Zadorozhnyy and Lai 2023). It enhanced writing skills, particularly clarity and coherence, in both business and language learning contexts (Slavych *et al.,* 2024; Zadorozhnyy and Lai 2023). ChatGPT also boosted corporate communication by enhancing response times and decision-making (Fauzi *et al.,* 2023) and outperformed existing methods in email summarisation (Bhuvaneswari and Tharaniesh 2023). Despite extensive research on ChatGPT in various fields, there is a lack of studies focused on its impact on communication within the construction industry.

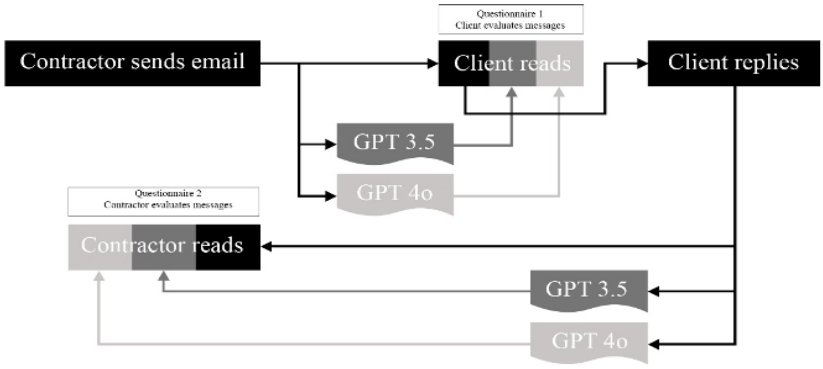
METHOD

The Sender-Message-Channel-Receiver (SMCR) model of communication, also known as the or Berlo's model (Stead 1972), offers a structured approach to analysing communication processes. In this study, a fictitious scenario was used to apply the SMCR model to email communication between a contractor and a client's representative during a construction project. This approach ensures the confidentiality of sensitive data while enabling a controlled examination of information sharing and decision-making. The fictious scenario is a construction company in London, hired to excavate a site for a new commercial building, discovered old structures and unusual fibrous material while digging. Suspecting the material to be asbestos, the contractor halted the project and informed the client's representative via email.

Data Collection Process

The following methodological pathway was designed to navigate the research objectives creatively (Figure 1).

Figure 1: Data collection process



The detailed steps of the methodology pathways will be presented into 8 steps:

1. The study involved 20 industry professionals, including geotechnical engineers, civil engineers, and other construction-related professionals. Participants were divided into two groups (contractor and client representatives) assuming roles as senders and receivers. Randomly participants (10 each) were paired.

2. Participants confirmed their 15-minute availability, then received a fictitious scenario by email and responded within 10 minutes. The time limit ensures comparability, as ChatGPT generates responses quickly.

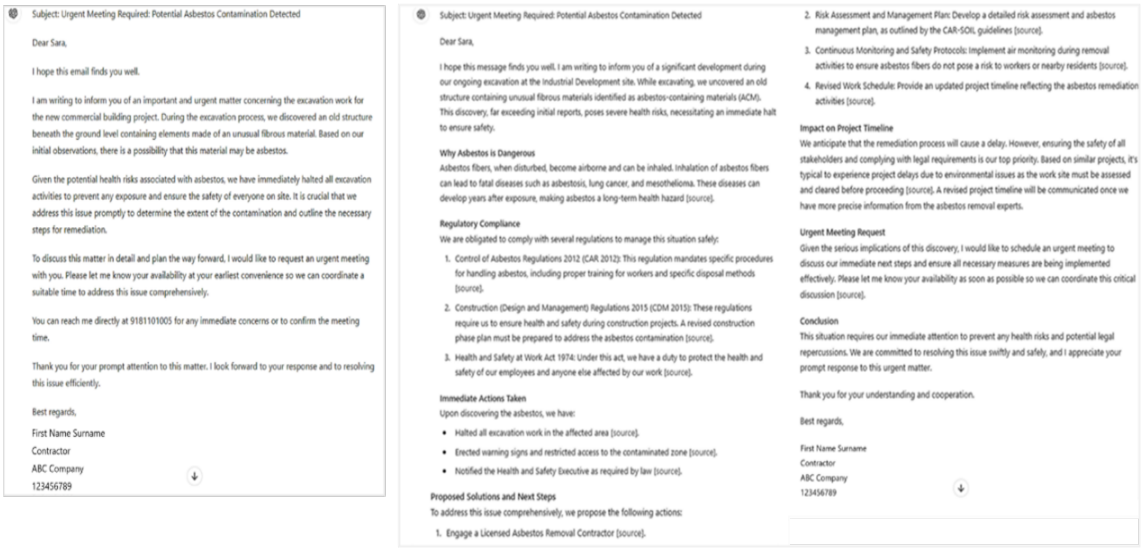
3. Step 3 includes all necessary inputs for ChatGPT models to generate emails from contractor to client rep. This involves selecting training materials for ChatGPT4o (subscription: £19.99/month) based on topics such as asbestos, contaminated soil, and health and safety and a suitable prompt, outlined in the left column of Table 1.

4. Following the upload of materials to ChatGPT-4o and the submission of the prompt to both versions, two emails were generated as responses (Figure 2)

Table 1: Prompts given to ChatGPT for steps 3 and 7

From contractor to client rep	From client rep to contractor
Role: You are a contractor (First Name Surname) from a construction company (ABC Company) based in London. **Scenario:** While excavating, you discovered an old structure beneath the ground level with some elements built with an unusual fibrous material. Suspecting it is contaminated with asbestos, you immediately halted the project. **Task:** You need to inform the client's representative, Sara Jackson, by writing an email and requesting an urgent meeting. **Type of Output:** This email should be written in a polite manner and an adequate number of words. **Adjustment:** If I provide you with other data (such as articles, books, or websites) to use in writing this email, please refer to them using the word "source." If no additional data is provided, there is no need for referencing. **Extra Information:** Your contact information is 123456789. **Audience:** The client's representative, Sara Jackson.	**Role:** You are a client representative (First Name Surname) who was informed about an on-site health and safety issue by a contractor via email. **Scenario:** During the excavation, the contractor uncovered old construction debris along with an unusual fibrous material. Suspecting it to be asbestos, the contractor promptly halted the work and informed the client representative via email. The client representative then received this email and responded accordingly, which will be presented in the following: Email written by each participant. **Task:** Your task is to read the email in the scenario and write a new email based on this context. **Type of Output:** This email should be written in a polite manner and an adequate number of words. **Adjustment:** If I provide you with other data (such as articles, books, or websites) to use in writing this email, please refer to them using the word "source." If no additional data is provided, there is no need for referencing. **Extra Information:** Your contact information is 987654321.

Figure 2: AI-generated emails – ChatGPT 3.2(left) and trained ChatGPT 4o (right)



Subject: Urgent Meeting Required: Potential Asbestos Contamination Detected

Dear Sara,

I hope this email finds you well.

I am writing to inform you of an important and urgent matter concerning the excavation work for the new commercial building project. During the excavation process, we discovered an old structure beneath the ground level containing elements made of an unusual fibrous material. Based on our initial observations, there is a possibility that this material may be asbestos.

Given the potential health risks associated with asbestos, we have immediately halted all excavation activities to prevent any exposure and ensure the safety of everyone on site. It is crucial that we address this issue promptly to determine the extent of the contamination and outline the necessary steps for remediation.

To discuss this matter in detail and plan the way forward, I would like to request an urgent meeting with you. Please let me know your availability at your earliest convenience so we can coordinate a suitable time to address this issue comprehensively.

You can reach me directly at 9181101005 for any immediate concerns or to confirm the meeting time.

Thank you for your prompt attention to this matter. I look forward to your response and to resolving this issue efficiently.

Best regards,
First Name Surname
Contractor
ABC Company
123456789

Subject: Urgent Meeting Required: Potential Asbestos Contamination Detected

Dear Sara,

I hope this message finds you well. I am writing to inform you of a significant development during our ongoing excavation at the Industrial Development site. While excavating, we uncovered an old structure containing unusual fibrous materials identified as asbestos-containing materials (ACM). This discovery, far exceeding initial reports, poses severe health risks, necessitating an immediate halt to ensure safety.

Why Asbestos is Dangerous
Asbestos fibers, when disturbed, become airborne and can be inhaled. Inhalation of asbestos fibers can lead to fatal diseases such as asbestosis, lung cancer, and mesothelioma. These diseases can develop years after exposure, making asbestos a long-term health hazard [source].

Regulatory Compliance
We are obligated to comply with several regulations to manage this situation safely:

1. Control of Asbestos Regulations 2012 (CAR 2012): This regulation mandates specific procedures for handling asbestos, including proper training for workers and specific disposal methods [source].
2. Construction (Design and Management) Regulations 2015 (CDM 2015): These regulations require us to ensure health and safety during construction projects. A revised construction phase plan must be prepared to address the asbestos contamination [source].
3. Health and Safety at Work Act 1974: Under this act, we have a duty to protect the health and safety of our employees and anyone else affected by our work [source].

Immediate Actions Taken
Upon discovering the asbestos, we have:

- Halted all excavation work in the affected area [source].
- Erected warning signs and restricted access to the contaminated zone [source].
- Notified the Health and Safety Executive as required by law [source].

Proposed Solutions and Next Steps
To address this issue comprehensively, we propose the following actions:

1. Engage a Licensed Asbestos Removal Contractor [source].
2. Risk Assessment and Management Plan: Develop a detailed risk assessment and asbestos management plan, as outlined by the CAR-SOIL guidelines [source].
3. Continuous Monitoring and Safety Protocols: Implement air monitoring during removal activities to ensure asbestos fibers do not pose a risk to workers or nearby residents [source].
4. Revised Work Schedule: Provide an updated project timeline reflecting the asbestos remediation activities [source].

Impact on Project Timeline
We anticipate that the remediation process will cause a delay. However, ensuring the safety of all stakeholders and complying with legal requirements is our top priority. Based on similar projects, it's typical to experience project delays due to environmental issues as the work site must be assessed and cleared before proceeding [source]. A revised project timeline will be communicated once we have more precise information from the asbestos removal experts.

Urgent Meeting Request
Given the serious implications of this discovery, I would like to schedule an urgent meeting to discuss our immediate next steps and ensure all necessary measures are being implemented effectively. Please let me know your availability as soon as possible so we can coordinate this critical discussion [source].

Conclusion
This situation requires our immediate attention to prevent any health risks and potential legal repercussions. We are committed to resolving this issue swiftly and safely, and I appreciate your prompt response to this urgent matter.

Thank you for your understanding and cooperation.

Best regards,

First Name Surname
Contractor
ABC Company
123456789

5. In the development of the questionnaire, a thorough review of relevant literature was conducted to identify key criteria for evaluating written communication. From this review, seven evaluation criteria were selected and included in the questionnaire: clarity, conciseness, completeness, personalisation, courtesy, composition and call to action (Bovee and Thill, 2016) (Guffey and Loewy, 2017). Likert and rating scales were employed (1-5).

6. After responses were gathered from the client representatives, they were requested to review the initial email from the contractor and two additional emails sharing the same context and written by different versions of ChatGPT. It was ensured that participants were never informed that these emails have been generated by ChatGPT. They were then asked to evaluate these three emails using the designed questionnaire.

7. The study began with an initial exchange of messages, where the sender group communicated with receivers. Client reps received the emails and responded. In the next phase, the original senders became secondary receivers. These responses addressed various concerns, including project delays, third-party involvement, and technical inquiries. Unlike the first phase, each email received a tailored AI-generated reply (its prompt outlined in the right column of table 1). With ten initial emails producing two responses each, this phase resulted in 30 unique exchanges.

8. For each contractor in every category, three specific emails were sent, and they were asked to evaluate these emails using the questionnaire designed in step 5.

This research uses central tendency and dispersion measures to analyse participants' perceptions of different email types (human-written, ChatGPT3.5, and ChatGPT4o).

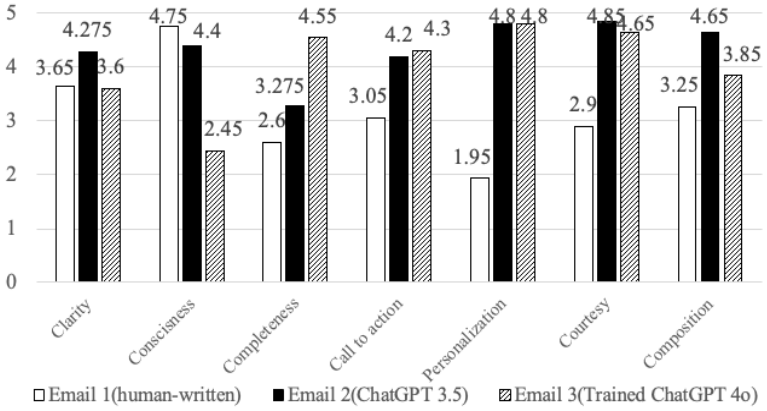
FINDINGS

Throughout this section, "Email 1" refers to the email written by human participants, "Email 2" to the email generated by ChatGPT 3.5, and "Email 3" to the email created by the trained ChatGPT 4o.

Means and Deviations

The questions were based on a Likert scale ranging from 1 to 5. Figure 3 displays the average score for each criterion, while Figure 4 shows the response consistency by illustrating the deviation.

Figure 3: Mean values



Clarity: Evaluations indicate that ChatGPT3.5 excels in clarity and comprehensibility, consistently producing easily understandable content. In contrast, ChatGPT4o, despite its advanced training, shows a decline in these areas, possibly due to the incorporation of more complex language and detailed information. This observation is further supported by consistent deviation, reinforcing the noted differences.

Conciseness: In analysing responses, the human-written Email achieved the highest average conciseness rating of 4.75, with 85% of participants rating it as very concise. However, 65% of participants felt that this brevity led to the omission of essential information. This suggests that, despite its conciseness, the human-written email might not fully meet the communication needs of the audience. Email 2 performed well in terms of conciseness, with an average rating of 4.4 and a standard deviation of 0.75. This indicates that participants generally agreed on the email's effectiveness in being brief (85% rated 4 and 5). Email 3 received the lowest average rating for conciseness, at 2.45, with a high standard deviation of 1.5. This suggests considerable variability in how participants perceived its conciseness. The results show that 55% of participants believed email 3 included unnecessary information (low ratings, 1-2).

Completeness: The comparison highlights the superior performance of ChatGPT4o in delivering complete and effective communication. It is important to note that one question touches on a unique capability of ChatGPT4o, which is trained on a dataset and can provide source references in emails.

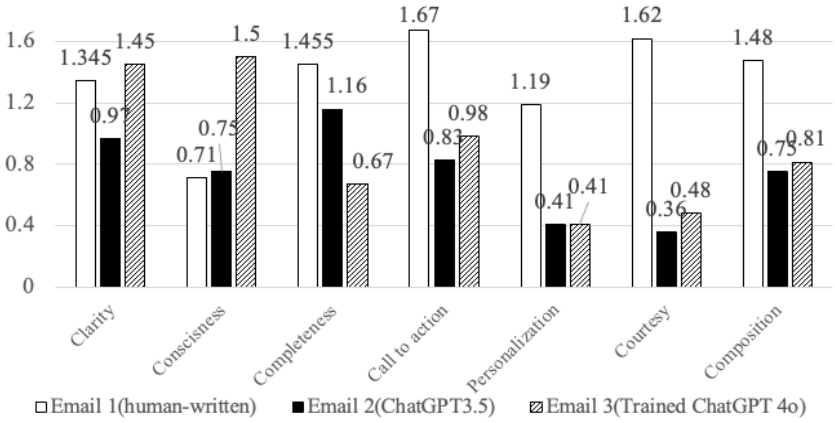


Figure 4: Deviation

Call to action: AI-generated emails excelled in delivering clear and strong calls to action. While both models were effective, Email 2 showed slightly better consistency

with a lower standard deviation of 0.83, compared to ChatGPT4o's 0.98. In the first round, participants were instructed to take whatever actions they felt necessary, but notably, none sought further clarification about the specific next steps.

Courtesy: Most participants rated these AI-generated emails at the highest level of courtesy, reflecting the models' ability to consistently maintain a respectful tone.

Personalisation: Emails 2 and 3 performed well. This impressive performance underscores the potential of AI to deliver highly personalised content, but it's important to note that this effectiveness largely depends on well-crafted prompts. Without such prompts, AI might struggle to achieve the same level of personalisation.

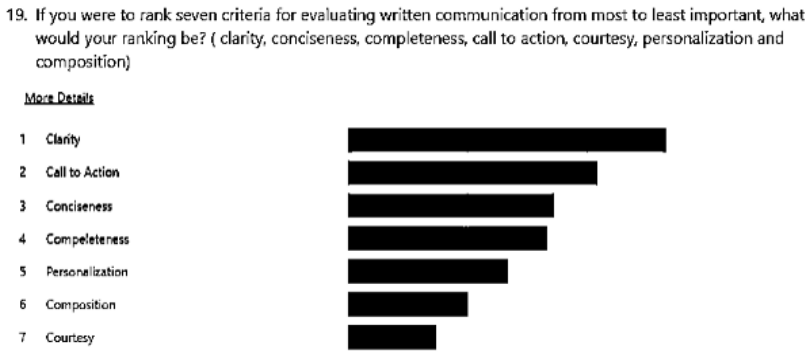
Composition: Email 2 received the highest average rating of 4.65 and exhibited the least variability among responses, as indicated by a standard deviation of 0.75. Interestingly, both Email 1 and Email 3 received relatively similar ratings, though with notable differences in how participants perceived their composition quality. While 35% of participants rated the human-written email poorly, it still managed to achieve acceptable ratings from others, indicating that human-written content can occasionally match or even excel in composition when done well. What is particularly striking is the low deviation of 0.81 in email 3, despite receiving a mix of ratings. This consistency suggests that participants agreed about the composition quality, even if their opinions on its merits varied. The difference in ratings between the two AI-generated emails, despite using the same prompts, may not reflect AI limitations but rather a result of subjective participant perceptions. Factors such as the overwhelming amount of data, different spacing, and the use of bold titles might have led some participants to view the composition as chaotic rather than well-organised.

Regarding Objective Three, participants were asked about their priorities across some criteria. Based on the gathered data, the following ranking reflects their preferences: call to action, personalisation, composition, courtesy and completeness. To refine participants' feedback and improve the reliability of data for assessing the relative importance of the criteria, they were asked to rank them again (Figure 5). This comprehensive question provided a clear overview of their overall preferences and priorities across the seven dimensions, resulting in the following order: clarity, call to action, conciseness, completeness, personalisation, composition, and courtesy. By comparing the two methods for determining the importance of criteria, it is evident that the results are relatively similar, except for the completeness aspect, which requires further investigation.

The prominence of call to action as the second-highest priority underscores the potential impact of ChatGPT’s strength in this area, particularly when compared to the shortcomings observed in human-written emails. However, the effectiveness of this advantage is highly contingent on the quality of the prompts provided. On the other hand, given that conciseness is ranked as the third most important criterion for participants, and training ChatGPT 4o to achieve conciseness seemed to be challenging, and also, it was anticipated that email length could influence clarity (a factor now prioritised by participants), this suggests that the weakness of trained ChatGPT 4o in terms of conciseness requires further attention, underscoring the necessity for careful monitoring when using and training AI.

Participants were asked to rate their overall satisfaction without focusing on any specific criteria. By comparing the average scores across the criteria with responses to the overall satisfaction question, relatively consistent trends were observed.

Figure 5: Ranking of the importance of seven criteria



An unexpected contrast emerged between AI-generated Emails 2 and 3, raising concerns about the effectiveness of AI in communication tasks. The differing performances of these emails highlight the complexities of AI-generated content and suggest that, rather than consistently improving communication, AI may sometimes introduce challenges that hinder desired outcomes. These findings underscore the need for careful oversight in the application of AI to communication tasks.

CONCLUSIONS

This study aimed to examine ChatGPT's ability to enhance written communication in the construction industry, explore the differences in effectiveness between its various versions, and assess the relative importance of key communication criteria to individuals. The study found that AI, especially ChatGPT3.5, generally outperformed human-written emails. However, this superiority was not consistent across all dimensions. AI performed well in terms of clarity, completeness, courtesy, and composition. It also showed good performance in call to action and personalisation, but these two aspects heavily depend on well-crafted prompts. However, AI struggled with conciseness, as many participants felt the emails could have been shorter.

ChatGPT4o underperformed in areas such as clarity, immediate comprehensibility, and conciseness, often falling short compared to human-written emails. Although ChatGPT4o excelled in delivering completeness, particularly by including references that allowed readers to access original sources, this strength did not translate into overall user satisfaction. The excessive length of the emails and related issues adversely affected its performance in courtesy, composition, and clarity, where ChatGPT 3.5 consistently outshined it. ChatGPT4o matched ChatGPT3.5 only in call to action and personalisation, both of which, as previously noted, are highly dependent on the quality of the prompt. Thus, conciseness emerges as the primary weakness of ChatGPT4o. While its ability to provide comprehensive information is commendable, the critical challenge remains: how can an email be both complete and concise?

The research findings reveal that participants' top priorities across the seven dimensions are: clarity, call to action, conciseness, completeness, personalisation, composition, and courtesy. However, the ranking of completeness requires further investigation. These findings highlight the nuanced role of ChatGPT in written communication, where its strengths, such as call to action, can be highly effective with well-structured prompts. However, the challenge of training ChatGPT 4o to achieve conciseness suggests the need for further refinement in this area. This underscores the importance of careful oversight and prompt engineering to maximise AI's effectiveness in professional communication.

LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

While this study provides valuable initial insights into the potential of generative AI tools like ChatGPT to improve written communication in construction settings, certain limitations should be acknowledged. The use of a simulated scenario and a small participant group limit the ability to generalise the findings to all construction contexts. Since only one specific prompt and communication scenario were explored, further research is needed to understand how different scenarios, prompt styles, and project conditions may influence outcomes.

To build on these findings, future research should involve a more diverse range of participant roles, extend to real-world project environments, and incorporate longer communication timelines to provide deeper insights into the performance of AI tools under authentic project conditions.

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AI-POWERED AUTO-SCHEDULING OF CONSTRUCTION PROJECTS FOR IMPROVED EFFICIENCY

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This systematic literature review explores the integration of artificial intelligence (AI) with auto-scheduling in construction projects. (The gap). The study assesses the current practice of AI applications in scheduling, emphasising their potential to enhance decision-making and efficiency. By analysing 31 carefully selected relevant papers, we identify key trends, opportunities, challenges and requirements associated with these technologies. This semi-systematic literature review identified nine key technologies mapped across four primary functions: (1) resource allocation, (2) schedule optimisation, (3) schedule development and (4) decision making. This illustrates AI's effectiveness in scheduling. Our findings indicate that AI can significantly improve scheduling accuracy, reduce project delays, and optimise resource allocation. However, challenges categorised into technical, organisational, financial, security, and skills-related barriers, include issues with data quality, difficulties in system integration, resistance to stakeholder acceptance, financial limitations, and a lack of skilled professionals must be resolved. This is the first paper to map the nine key technologies to enable AI applications in construction scheduling, laying the groundwork for future research and implementation strategies.

Keywords: algorithm; artificial intelligence; auto-scheduling; construction project management; systematic literature review; technology integration

INTRODUCTION

Every construction project, like most observable phenomena, is inherently unique, characterised by a certain degree of risk and uncertainty. The interaction and interconnectedness of project activities contribute to this risk and uncertainty, consequently resulting in project complexity. This dynamic nature, coupled with the high level of risk associated with the construction industry, makes effective planning and scheduling an essential component for project success (Vaghela, 2020; Hamad, Tayeh and Al Aisri, 2021). For the most part, the repetitive nature of construction activities makes auto scheduling a potential contributor to project success (García-Nieves *et al.,* 2019). Extant literature has consistently demonstrated a positive correlation between robust project scheduling and successful project outcomes, further highlighting the importance of effective and efficient planning and scheduling (Derbe

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Chigangacha, S, Henjewele, C, Ibrahim, H A and Bui, N (2025) AI-Powered Auto-Scheduling of Construction Projects for Improved Efficiency, *In:* Thomson, C and Neilson, C J (Eds) *Proceedings of the 41st Annual ARCOM Conference,* 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 89-98.

et al., 2020; Faghihi *et al.,* 2015; García-Nieves *et al.,* 2019). Notably, construction projects are familiar with the lack of dynamic scheduling, inadequate planning, poor project management practices, a deficiency in proactive risk management, and ineffective resource allocation which ultimately lead to delays and budget overruns (Cooke and Williams, 2025; Muhammad *et al.,* 2022). AlMunifi and Almutairi (2021) echoed these findings, attributing many of the challenges in achieving project success to shortcomings in the pre-construction phase, including unrealistic scheduling. The failure to anticipate and address these issues early in the project process often leads to costly delays, quality compromises, and inefficiencies.

The automation of scheduling activities has been a topic for discussion for decades (Chevallier and Russell, 1998; Faghihi *et al.,* 2015). We define automatic scheduling as the application of advanced computing and software to automatically generate, and update construction schedules based on defined data inputs such as task dependencies, durations, and resource data and their availability. Hence, it comes as no surprise when the adoption of AI in scheduling has been identified as an innovative solution for scheduling challenges. Modern project management tools can facilitate more precise planning, dynamic scheduling, and real-time updates, enabling construction project managers to respond proactively to emerging challenges (Cooke and Williams, 2025).

Zwikael (2009) sees the role of planning and scheduling being central to all construction activities and therefore it is considered a critical skill and competence for effective management of projects. The complex interdependence of construction activities signifies that scheduling is an intense task that requires unhindered and upfront access to accurate information, including, task breakdowns, detailed account of hard, soft and monetary resources needed, risks, supply chain and the necessary logistics to get the resources when and where they are needed; to mention a few. This complex interaction of construction processes and activities means that planning and scheduling cannot be an exact science and would require experience to arrive at a justifiable guesswork. The centrality of scheduling regarding its influence on effectiveness of other construction project management systems qualifies it to be a system of systems which can best be explored through the lenses of systems theory (Prieto, 2020).

This study assesses the current practice of AI applications in scheduling, emphasising their potential to optimise scheduling processes, enhance decision-making and efficiency, and in reducing delays. This paper seeks to answer two questions:

- To what extent is AI currently being utilised in the industry for scheduling construction projects?
- How can AI be used to auto-schedule construction projects?

The literature review on auto-scheduling of construction has confirmed that no previous papers have addressed the potential of the AI to automate the development of construction programmes. This paper, therefore, will be the first to offer specific recommendations on applicability of AI for automation and digitalisation in construction by synthesising insights on AI applications in construction scheduling, laying the groundwork for future research and implementation strategies.

METHOD

This paper uses semi-systematic literature review (SSLR) as the key source of data for the analysis. Systematic literature review (SLR) has become a popular data collection

method in management research post-Covid-19 in recognition of its strength to capture the vast data accessible through open access policy (Sánchez-Garrido *et al.,* 2023). While traditional literature review lacks thoroughness and rigor, SLR uses a specific methodological approach to rigorously and reliably collect and synthesize existing knowledge.

Sources of data include research papers published in peer-reviewed journals and conference proceedings in the construction management field. Given the increasing research interest in the application of AI in the field, it was impractical to search through all available databases. As a result, the decision was made to focus on the most used online databases in construction to fulfil the requirements of a systematic review (Snyder, 2019). However, a semi-systematic review approach was ultimately selected as the preferred method for tracking the development of auto-scheduling technologies and their associated barriers over time. Unlike SLR, a semi-systematic literature review allows for purposeful selection of research papers or databases. Various databases were initially searched to identify the most effective one and to define the scope for the search using a combination of keywords. After several attempts, SCOPUS database was selected as the main source as it had more returns from reviewed research papers compared to other databases and it included most of the papers returned from other databases.

To further limit the scope, the search focused on papers that covered both automatic scheduling (also automatic programming) and construction project(s). Other related terms such as planning were too broad and returned papers beyond scheduling or construction scheduling. Prioritisation of papers for analysis was carried out in three steps:

- The first step was the keyword search using various combination of automatic scheduling and construction projects. This stage found 300 matching papers that were published in indexed journals and peer reviewed conferences.
- The second step was to review the abstracts to examine the relevance of these papers, remove duplications, and to check availability of the full text. This process reduced the overall number to 48 papers that met all requirements.
- Step 3 involved scanning through the full papers to confirm consistency and that they contained primary research. This further reduced the number of papers to 31 qualifying papers (as 6 papers were not fully related to auto-scheduling in construction projects and other 11 were literature review papers that do not address the questions raised in the current paper).

The involvement of four reviewers in the selection of the articles further demonstrates a rigorous process that ensures the quality and reliability of the search protocol. The 31 selected papers were then reviewed, and key information such as authors' names, year of publication, paper title, journal title, country of origin, research methods, research topics, etc. was recorded. Figure 1 presents the distribution of papers according to years of publication.

Figure 1 shows a sharp increase in the number of papers discussing auto-scheduling in construction since 2010. While prior to the year 2000, there were only four papers, with the earliest paper published in 1988, in the first quarter of 2025 there were already three papers published. Noteworthy, this research study only utilised papers based on primary research; if literature-based papers were included; the number would be significantly higher. The increasing number of publications demonstrates the

growing desire to investigate innovative solutions to address the longstanding scheduling challenges.

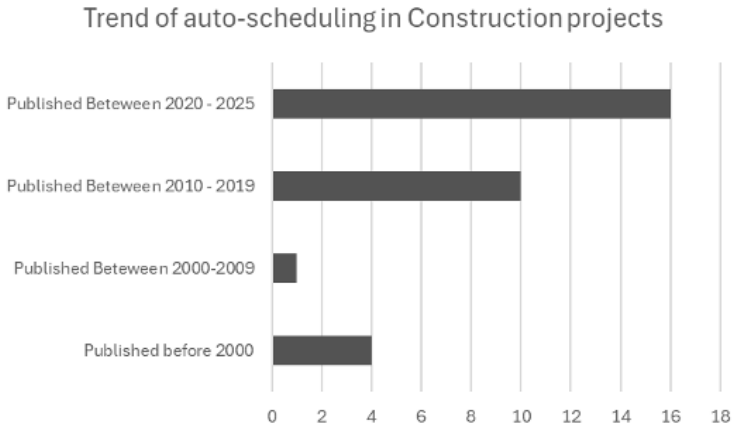


Figure 1: Distribution of papers published between 1988 and 2025

Thereafter, thematic analysis was used to extract data and summarise findings in a table for detailed analysis to answer the questions addressed by this paper.

AI Integration in Construction Scheduling

Evolution of AI in construction scheduling

The literature survey concludes that the construction industry has long struggled with poor planning and scheduling, with traditional methods being time-consuming and dependent on often unavailable data. The analysis has shown that AI is increasingly seen as a solution to these inefficiencies.

To understand this shift, it is essential to trace the evolution of AI applications in construction scheduling. Early knowledge-based systems, such as GHOST (Navinchandra *et al.,* 1988), pioneered rule-based automation for activity sequencing and dependency resolution, embedding construction norms and geometric data interpretation into scheduling logic. Subsequent advancements, like the Finite Element Project Planning (FEPP) method (Sirajuddin and Mawdesley, 1991), introduced dynamic visualisation of Gantt charts and resource usage graphs, enabling planners to analyse ripple effects of delays (Ayman Morad and Beliveau, 1991). These systems laid the groundwork for AI's role in transforming heuristic-driven Critical Path Method (CPM) frameworks into data-driven paradigms.

The 21st century marked a shift toward algorithmic optimisation, with genetic algorithms (GA) (Hui *et al.,* 2013) and fuzzy logic (Tavakolan and Ashuri, 2012; Oz, 2023) emerging as cornerstones for resolving multi-objective constraints. Hybrid models, such as the shuffled frog leaping algorithm (SFLA) integrated with fuzzy logic (Tavakolan and Ashuri, 2012), demonstrated robust handling of uncertainty in activity durations and productivity rates. Concurrently, AI-driven BIM integration automated data extraction for activity synthesis, reducing manual scheduling efforts by 97% in pipe system installations (Singh and Anumba, 2022; Aljebory and QaisIssam, 2019). Innovations like Foresight+AI (Hatami *et al.,* 2021) combined reinforcement learning with discrete-event simulation, enabling iterative refinement of schedules through scenario modelling.

This evolution underscores AI's capacity to address industry-wide inefficiencies while aligning with global priorities like smart infrastructure and digital twins. Emerging frameworks, such as the cloud-based convolutional neural network (CCAS) model

(Dong, 2024), signal a future where AI not only automates scheduling but also empowers adaptive, collaborative project ecosystems. By synthesising historical advancements and contemporary innovations, this paper highlights AI's transformative trajectory and its implications for construction management theory and practice.

Current AI applications in construction scheduling

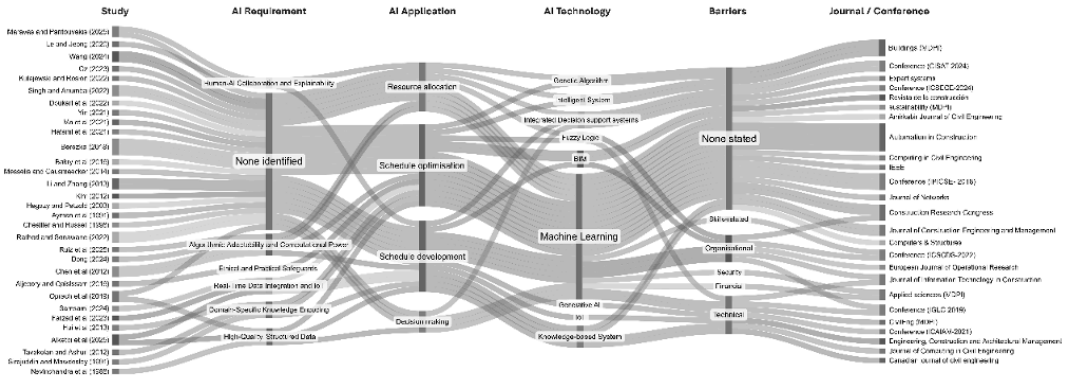


Figure 2: Sankey chart for AI applications in construction scheduling

Figure 2 presents an overview of AI capabilities in construction scheduling, highlighting the application of various technologies, the requirements for its use and the associated implementation barriers. From our thematic analysis, nine AI enabled technologies were identified and mapped against their applications in construction scheduling. These technologies support AI integration across four critical tasks: (1) resource allocation, (2) schedule optimisation, (3) schedule development and (4) decision making.

Table 1: Mapping AI technologies used in scheduling

Type of AI technologies	Decision making	Resource allocation	Developing schedule	Schedule optimisation	Total	%
Machine Learning	3	5	5	10	23	56%
KBS	0	0	4	0	4	10%
BIM - Related	0	0	1	2	3	7%
IDSS	1	1	1	0	3	7%
Fuzzy Logic	0	1	0	1	2	5%
Genetic Algorithm	0	1	0	1	2	5%
Intelligent System	0	1	0	1	2	5%
Generative AI	0	0	1	0	1	2%
IoT	0	0	1	0	1	2%
Total	4	9	13	15	41	
Popularity of use	10%	22%	32%	37%		

Key: IDSS- Integrated Decision support systems; KBS - Knowledge-based System; IoT - Internet of Things

Table 1 shows Machine Learning is the most prevalent AI technology applied for all four tasks, while other technologies were only limited to specific applications. For example, IoT, Generative AI and knowledge-based systems were only limited to generating inputs for schedule development. Nearly 70% of the AI usage was related to schedule development and its optimisation. However, the applications were limited to specific functions such as estimation of activity durations and productivity rates, schedule visualisation and prediction of scheduling issues.

Innovative technologies were adopted when they are believed to offer a solution to the persistent challenges such as inaccuracy of scheduling assumptions, resource allocation inefficiencies, and reactive decision-making

Modern methods have adopted metaheuristic algorithms and scalable infrastructure to address dynamic schedule challenges (Tavakolan and Ashuri, 2012), while cloud-based convolutional networks (CCAS) were used to synchronise real-time resource data for adaptive allocation (Dong, 2024). If these systems are coupled with high-performance computing, they can train deep learning models on datasets to process complex inputs such as resource demand curves to minimise idle time and costs (Chen *et al.,* 2012; Ruiz *et al.,* 2024). Other tools like Prolog-generated Work Breakdown Structures (WBS) can link outputs to inputs, fostering trust in AI logic (Iranmanesh and Madadi, 2008) and dynamic visualisation tools like Schedula Anima animates Gantt charts to prioritise rescheduling based on metrics like duration flexibility and float availability (Maravas and Pantouvakis, 2025).

AI has also demonstrated predictive capabilities such as the LSTM networks achieving 87% accuracy in forecasting delays at the Tehran Metro (Farzad *et al.,* 2023). In UAE, 4D BIM and UAV-tracked data detected spatial conflicts, enabling sustainability-focused resource allocation (Alketbi *et al.,* 2025). Generative AI tools like ChatGPT employed Monte Carlo simulations to revise timelines based on real-time site conditions (Samsami, 2024), highlighting the shift from static plans to responsive ecosystems. Metaheuristic algorithms, such as tabu search (Kulejewski and Rosłon, 2023), optimise ecological and economic objectives, balancing carbon reduction with cost efficiency. Despite these applications, no study has yet demonstrated a fully AI-integrated project schedule.

The requirements and barriers for applying AI into construction scheduling
To achieve the full potential, the effective application of AI in construction scheduling hinges on six critical requirements derived from historical, technical, and contextual advancements in the field. These requirements bridge inputs such as data and domain expertise to outputs like optimised schedules and risk mitigation, as evidenced by the evolution of AI systems across the analysed studies. The requirements are: (1) high-quality, structured data; (2) domain-specific knowledge encoding; (3) algorithmic adaptability and computational power; (4) human-AI collaboration and explainability; (5) real-time data integration and IoT; (6) ethical and practical safeguards.

Even though AI has promising potential, its integration in construction faces several barriers, which can be categorised into technical, organisational, financial, security, and skills-related challenges. These barriers hinder the widespread adoption of AI in construction scheduling. Technical challenges stem from the complexity of AI systems, uncertainties in the construction environment, dependency on AI expertise and varied maturity levels in AI use, unreliable infrastructure, poorly drafted project plan, classification of project type and cultural barriers (Alketbi *et al.,* 2025; Samsami, 2024; Rathod and Sonawane, 2022; Singh and Anumba, 2022; Yin, 2021; Oprach *et al.,* 2019; Bakry *et al.,* 2016; Chevallier and Russell, 1998; Navinchandra *et al.,* 1988).

There are also organisational barriers including poor data management, resistance to change and the lack of support and acceptance of AI technologies, including the fear of job replacement, and poor understanding of AI and algorithm functions (Rathod and Sonawane, 2022; Singh and Anumba, 2022; Oprach *et al.,* 2019; Messelis and Causmaecker, 2014; Tavakolan and Ashuri, 2012 Chevallier and Russell, 1998).

Alketbi *et al. (*2025) and Rathod and Sonawane (2022) identify the high cost of adopting and maintaining AI, shortage of skilled professionals to manage AI systems effectively, and security concerns, such as data leaks and hacking as further hinderances to adoption of AI. However, Figure 2 reveals that over 50% of the publications did not report any barriers, suggesting that AI holds significant potential in construction scheduling, provided the existing challenges are effectively addressed.

CONCLUSION

This study has demonstrated that integrating AI into construction scheduling holds significant promise for optimising workflows, enhancing efficiency, and reducing project delays through real-time data utilisation and automated schedule adjustments. By examining current AI applications, this research identified nine key technologies mapped across four primary functions, illustrating AI's effectiveness in automating resource allocation, timeline management, and progress updates. The integration of advanced algorithms, IoT devices, and real-time data enables dynamic schedule adaptation, resource optimisation, and delay mitigation. To achieve the full potential of AI, the following requirements are critical: (1) high-quality, structured data; (2) domain-specific knowledge encoding; (3) adaptable algorithms supported by robust computational power; (4) effective human-AI collaboration and explainability; (5) seamless real-time data integration and IoT connectivity; and (6) implementation of ethical and practical safeguards. However, the successful adoption of AI in construction scheduling hinges on overcoming challenges related to, inter alia, data quality and interoperability, system integration complexities, stakeholder acceptance, financial limitations, and a shortage of AI-skilled professionals.

Future research should prioritise improving data quality by for example, implementing automated data auditing tools that can detect anomalies and gaps in construction data streams, standardising data formats, and establishing comprehensive data-sharing frameworks to facilitate AI integration. Additionally, developing flexible AI algorithms capable of managing complex project variables and designing educational initiatives to equip construction professionals with AI management competencies are essential. This could be undertaken by partnerships between universities and industry bodies to integrate AI literacy into construction management curricula. Furthermore, advancing secure AI frameworks and data protection protocols will be vital to safeguarding sensitive project information, thereby enabling the broader and responsible adoption of AI in construction scheduling.

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CONSTRUCTION 4.0 ADOPTION IN VIETNAM'S AN PHU PROJECT

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Construction 4.0 (C4.0) adoption in developing countries remains under-researched and facing unique challenges. This study addresses this gap by examining C4.0 enablers and barriers in Vietnam's An Phu Junction Project. Guided by Rogers' Diffusion of Innovations theory, this qualitative case study involved semi-structured interviews with 10 purposively selected stakeholders. Thematic analysis explored how DOI attributes (relative advantage, compatibility, complexity, trialability, observability) shape diffusion. Key findings reveal regulatory mandates and hybrid Building Information Modelling workflows enhanced compatibility, while productivity gains underscored the relative advantage of C4.0. Major barriers included high costs, skill gaps, and institutional fragmentation. The research contributes new empirical evidence on barriers and enablers to C4.0 adaption by contextualising DOI for Vietnam, highlighting specific infrastructural and socio-economic challenges. While the findings are Vietnam specific, the practical implications apply to other developing countries by emphasising the importance of policy adaptation, targeted capacity-building, and strategies to improve C4.0's observability, fostering wider adoption and sustainable project outcomes.

Keywords: Construction 4.0; sustainability; digital technologies; diffusion of innovation; developing countries

INTRODUCTION

Numerous studies have explored construction innovation, with recent emphasis on digital technologies such as Building Information Modelling (BIM), Internet of Things (IoT), robotics, and artificial intelligence, which form the core of Construction 4.0 (C4.0) and offer potential to innovate the sector (Jaiswal *et al.,* 2024; Wang *et al.,* 2022; Balasubramanian *et al.,* 2024). In developing countries, where traditional methods are often acknowledged to hinder progress towards sustainability and efficiency (Balasubramanian *et al.,* 2024), the drive to adopt C4.0 is evident. For instance, in regions like the Mekong Delta of Vietnam, certain aspects of C4.0 have been applied to reduce natural resource consumption and improve critical logistics

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networks (Huynh-Xuan *et al.,* 2024). However, a significant research gap exists, as many studies focus on developed countries, resulting in a lack of comprehensive analysis on C4.0 implementation, particularly in relation to skills development and context-specific strategies relevant to developing countries such as Vietnam (Siriwardhana and Moehler, 2024). This underscores the need to examine the specific enablers and barriers in these unique contexts to ensure that advanced technologies are adopted in ways that are both effective and sustainable, rather than relying on generalised assumptions.

Despite its potential for digital transformation and improved project outcomes (Wang *et al.,* 2022; Ikuabe *et al.,* 2023), the adoption of C4.0 in developing countries faces significant regulatory, resource and skill-related obstacles. These include substantial financial constraints—including high initial costs and limited funding (Dhamak *et al.,* 2025)—along with widespread skill shortages, inadequate technological infrastructure, and complex regulatory and legal environments that often resist change (Jaiswal *et al.,* 2024; Dhamak *et al.,* 2025; Demirkesen and Tezel, 2021). In Vietnam, the construction industry is marked by rapid expansion and a complex value chain, yet it continues to grapple with pervasive corruption that undermines market competition and operational efficiency (Nguyen *et al.,* 2024). While these challenges are also present in other developing countries, the difficulties in adopting technology in the An Phu Junction project may be further compounded because it is among the first major infrastructure projects led entirely by local firms.

While there are a few studies such as Huynh-Xuan *et al. (*2024) that have explored various aspects of C4.0 implementation, context-specific knowledge on barriers and enablers for C4.0 adoption in Vietnam remains unexplored. This study, therefore, addresses the research question (RQ): What are the enablers and barriers to C4.0 implementation in the Vietnamese context? While the broad categories of enablers and barriers to technology adoption are recognised in innovation literature, their specific manifestations, relative importance, and the intricate ways they interact are profoundly shaped by the distinct socio-economic, institutional, and infrastructural realities prevalent in developing nations. Much of the current C4.0 research, despite underscoring its transformative potential in improving sustainability and operational efficiency (Wang *et al.,* 2022; Balasubramanian *et al.,* 2024), originates from developed economies. This focus means that merely transposing findings or assumptions about enablers and barriers from developed to developing countries is insufficient and potentially misleading. Empirical insights into developing countries like Vietnam remain sparse and often lack the granularity needed to understand how unique contextual challenges, such as more pronounced institutional fragmentation, acute workforce readiness issues, and difficulties in aligning global standards with local practices (Demirkesen and Tezel, 2021; Huynh-Xuan *et al.,* 2024), and the pervasive influence of factors like systemic corruption (Nguyen *et al.,* 2024), fundamentally alter C4.0 adoption dynamics. These specific conditions can transform the nature of known barriers or create entirely new ones, while also shaping the effectiveness of potential enablers. Consequently, there is a critical need for empirical investigations that move beyond generalised lists of factors to provide a nuanced, in-situ understanding of these dynamics.

LITERATURE REVIEW

The transformation in the architecture, engineering, and construction (AEC) sector, known as C4.0 (Wang *et al.,* 2022), is fuelled by the introduction of counterpart

Industry 4.0-aligned digital technologies such as artificial intelligence (AI), robotics, and the IoT. Specifically, this innovative approach modernises traditional construction processes through automation and digitisation, aiming to extend the lifecycle of physical resources while also addressing critical challenges related to sustainability, safety, and productivity (Balasubramanian *et al.,* 2024). However, despite its transformative potential (Shafei *et al.,* 2022), stakeholders continue to face challenges including fragmented implementation, high costs, a lack of trained personnel, and resistance to adopting new technology. Therefore, this section provides a C4.0 overview, highlighting key technologies, their respective roles and impacts, as well as the challenges inhibiting their widespread adoption. In addition, this section reviews the state of C4.0 adoption in developing countries.

Key Technologies in Construction 4.0

BIM is a key component of C4.0 adopted in the construction industry. BIM increases decision-making and reduces mistakes by allowing stakeholders to collaborate in real-time (Wang *et al.,* 2022). In addition to BIM, the integration of AI and machine learning has been acknowledged to optimise workflows via automation of processes and predictive analytics (Souza and Debs, 2023), 3D printing has also enabled the creation of intricate structural components tailored to project requirements to reduce construction waste (Balasubramanian *et al.,* 2024). IoT links devices on-site to track factors such as equipment performance and safety risks, and robotics automates dangerous jobs like material handling, increasing accuracy and lowering accidents (Zhang *et al.,* 2025). In addition, through immersive design validation, Virtual Reality (VR) and Augmented Reality (AR) improve stakeholder engagement; however, interoperability issues limit wider adoption (Abbasnejad *et al.,* 2024). These technologies work together to create the foundation of C4.0, increasing productivity throughout project lifecycles.

Construction 4.0 adoption in developing countries

The AEC industry in developing nations is progressively changing by incorporating C4.0 technologies like BIM, IoT, and robotics. IoT allows real-time construction site monitoring to improve safety and resource management, while key technologies like BIM enable digital collaboration and design optimisation (Jaiswal *et al.,* 2024). Although technologies like blockchain and cyber-physical systems are still underutilised because of institutional and infrastructure barriers, advanced tools like 3D printing are becoming essential for reducing material waste (Balasubramanian *et al.,* 2024; Jaiswal *et al.,* 2024).

The adoption of C4.0 has several advantages, including increased safety through IoT-enabled hazard detection and notable productivity gains, such as a 30% decrease in change orders enabled by BIM-driven coordination (Wang *et al.,* 2022). Additionally, the material efficiency of 3D printing and the energy optimisation of BIM contribute to sustainability, while VR/AR enhances stakeholder engagement by visualising designs prior to construction (Balasubramanian *et al.,* 2024; Huynh-Xuan *et al.,* 2024).

However, C4.0 adoption is still fragmented in developing countries, where automation and BIM technologies are mostly used in the design and planning stages, while execution and maintenance phases lag (Ikuabe *et al.,* 2023). This fragmentation is noticeable in developing nations like Vietnam, where Small and Medium-scale enterprises (SMEs) are largely dependent on traditional methods and lack adequate technological readiness (Huynh-Xuan *et al.,* 2024).

Adoption Barriers and Critical Success Factors

Zulfiqar *et al. (*2024) is potent to understand the enablers, barriers, benefits, and application of Industry 4.0 technologies in integration with Lean Six Sigma (LSS) methodologies with a particular focus on the manufacturing sector. While this aligns with the goal of this paper, our focus is specifically on the practical aspects of the construction sector, where lean principles have been adapted to support efficiency and waste reduction. Zulfiqar *et al. (*2024)'s work identified 23 generic factors affecting the integration of Industry 4.0 which were then ranked and compared empirically using data from a survey of 53 respondents from Large Enterprises (LE) and SMEs in developing and developed countries. Their analysis showed that developing countries faced challenges including a poor understanding of Cloud and Big Data analysis, lack of support from top management, and a lack of cultural transformation within organisations concerning the use of Industry 4.0. Müller (2019) interviewed 41 workers in a production plant in Germany to understand barriers that limit the application of Industry 4.0 implementation. Their analysis shows a reluctance among workers to adapt to Industry 4.0 due to fears around job losses, limited knowledge and training, inability to adapt to new technologies at old age and limited competence to develop task-specific software. Both studies reveal a combination of factors that significantly hinder Industry 4.0 adoption. It is evident that these challenges are relevant to both resource-rich and resource-constrained countries alike, therefore validating the specific focus on developing countries like Vietnam.

Diffusion of Innovations Theory in Construction 4.0 adoption

The Diffusion of Innovations (DOI) theory, introduced by Rogers (2003), provides a comprehensive framework for understanding how new technologies, ideas, or practices spread within organisations and industries. It identifies five key attributes—relative advantage, observability, trialability, compatibility, and complexity—that influence the adoption, implementation, and diffusion of technological innovations. These attributes play a crucial role in shaping firms' decision-making processes regarding technology adoption, particularly in industries such as construction, where technological integration presents challenges and opportunities (Lee and Park, 2022). The DOI process unfolds in two main phases: pre-adoption and post-adoption. In the pre-adoption phase, firms evaluate whether an innovation aligns with their needs, while the post-adoption phase involves the actual implementation and diffusion of the technology among users both within and outside the organisation (Geels and Johnson, 2018). Meanwhile, Huynh-Xuan *et al. (*2024) established the motivations and success factors influencing C4.0 adoption in Vietnam. These have been mapped against the five DOI attributes to help guide the development of a comprehensive framework for analysis of the phenomena associated with C4.0 - as summarised in Table 1.

Rogers' (2003) DOI further presents five stages of technology adoption: knowledge, persuasion, decision, implementation, and confirmation. These stages highlight the intricate pathways through which firms navigate technology adoption, shedding light on the factors that either facilitate or hinder the successful integration of innovations. The adoption of C4.0 technologies provides construction firms with opportunities to improve safety, sustainability, efficiency and innovation in developing countries. However, aligning the five attributes of DOI theory with sustainable performance goals across economic, social, and environmental dimensions presents significant challenges, particularly during the post-adoption phase. For instance, sustaining the relative advantage of C4.0 technologies requires ongoing investment, yet financial constraints may limit firms' capacity to sustain long-term technological commitments

(Jiang *et al.,* 2024). Additionally, ensuring compatibility between C4.0 technologies and existing organisational workflows and infrastructure remains a complex task. Construction firms must navigate evolving regulatory frameworks while simultaneously addressing internal resistance to change (Balasubramanian *et al.,* 2024; Huynh-Xuan *et al.,* 2024).

Table 1: Factors that influence Construction 4.0 adoption

DOI Attributes	Identified Motivations (M) and Success Factors (SF)
Relative advantage	M1: Technology-enabled improvement in project performance (e.g., 4D BIM for time predictability)
	M2/M3: Cost savings (short- and long-term)
	M4-M7: Reduced resource use, emissions, and energy consumption
	SF.1: High technology implementation costs
Compatibility	SF.21: Alignment with government policies/frameworks (e.g., BIM standards)
	SF.4: Compatibility with existing tech infrastructure
	SF.24/25: Lack of common standards/methodologies
Complexity	SF.11: Training programs to address skills gaps
	SF.13: Staff knowledge gaps (e.g., digital twins, BIM)
	SF.17: Limited information/awareness of Construction 4.0 tools
Trialability	SF.3: Time allocated for pilot testing (e.g., phased 4D BIM trials)
	SF.20: Professional support for incremental implementation
Observability	M8: Improved reputation from visible sustainability outcomes
	SF.18: Limited knowledge-sharing platforms
	SF.30: Digital databases tracking outcomes (e.g., waste reduction)

Source: Motivation and Succes factors are based on Huynh-Xuan et al. (2024).

METHODOLOGY

This study employs a single-case design to analyse how C4.0 technologies (e.g., BIM, IoT) interact with sociotechnical complexities in Vietnam's An Phu Junction project. This project is a pivotal and highly complex infrastructure project in Ho Chi Minh City, commencing in late 2022. This junction connects vital routes to enhance traffic flow capacity and foster regional economic development, undertaken by domestic contractors and consultants. With a total investment of GBP 100 million (VND 3.4 trillion), the An Phu Junction is expected to complete by 2025, bringing a new dimension to urban transportation infrastructure. The methodology prioritises depth over breadth, aiming to unpack challenges like fragmented governance and localised labour practices (Simons, 2015), offering critical insights for developing economies. The flexibility of the single-case design supports interdisciplinary research and allows for iterative refinement of data collection methods, such as adjusting interview questions to address emerging skill gaps (Mukhija, 2010). To address critiques of generalisability, naturalistic generalisation (Simons, 2015) extrapolates findings to comparable contexts (e.g., BIM adoption in Cambodia), while Mukhija's (2010) "N of one plus some" approach incorporates secondary cases (e.g., Vietnam's National Highway 1A) to identify recurring issues like digital interoperability gaps. Process tracing further strengthens causal analysis of leadership interventions mitigating resistance (Meganck *et al.,* 2022). This approach balances theoretical advancement with actionable strategies for Vietnam's infrastructural challenges.

Data were collected through semi-structured interviews conducted from August to October 2024 with 10 key stakeholders involved in the An Phu Junction project. These informants hold diverse roles and possess extensive experience in civil engineering and project management. The informants include BIM Managers/ Coordinators, Engineers, and Directors from organisations such as V7 Consultancy, IDECO, TEDI SOUTH, BR Consultancy, and the Project Management Board of Transportation Construction Investment Projects. Their expertise is in digital

technology, BIM, GIS, traffic engineering, construction, road infrastructure projects, and project management, with experience ranging from 4 to over 20 years. While the individual experts have experience with related technologies, the An Phu Junction project is the first Grade 1 BIM initiative to be conducted by a fully local project team (contractors and consultants) through a competitive bidding process.

The interview questions were a mix of open-ended and closed-ended questions, developed from the literature review on C4.0 technologies (e.g., BIM, IoT), adoption barriers (costs, skill gaps), and enablers (regulatory mandates, productivity gains) in developing country contexts like Vietnam. This process used Rogers' (2003) five DOI theory attributes to categorise perceptions of challenges, benefits, and adoption dynamics. The interview protocol explored informant backgrounds, their experiences with and demand for C4.0 technologies, and influencing factors, with questions structured around the five DOI attributes. Interviews were then transcribed, coded and analysed thematically using NVivo 14 to align with the DOI attributes. The coding and analysis yielded the core findings, which detailed the specific enablers, barriers, and interactions among DOI attributes observed in the An Phu project, as presented in the subsequent sections. This approach enabled a nuanced, qualitative understanding of the technology adoption process.

FINDINGS

Vietnam's An Phu Junction project is one of the first projects to use BIM in prior to Prime Ministerial Decision 258/QĐ-TTg, dated March 2023 dated Mar 2023 mandating BIM use for all Grade 1 and above projects in the public sector. The project has used digital technologies such as BIM, GIS, and Drones to support the design and construction. Further analysis of the case study evaluates how compatibility, relative advantage, complexity, trialability, and observability shaped the uptake of the technology. The findings are summarised here below.

Compatibility: Regulatory Alignment and Hybrid Workflows

Though the project used BIM prior to the Government mandates, the adoption decision was influenced by the knowledge that they will be required to comply when the Prime Ministerial Decision is enacted for high-priority infrastructure projects. In other words, the adaption was compliance-driven. As Informant 4 emphasized, "BIM adoption is compulsory for special-grade projects". The government had started promoting BIM, even though its own project approval process still requires paper-based submission. The An Phu Junction project had to use a hybrid workflow - maintaining parallel BIM and paper-based 2D drawings for approval. Informant 5 noted, "BIM models must parallel to 2D plans for approval". They also used open formats like IFC to ensure interoperability, reducing reliance on proprietary software. This required the leading BIM consultant (IDECO) to demonstrate a strong leadership to influence cultural shift across the project supply chain.

Relative Advantage - Operational Efficiency and Sustainability

Informants acknowledged several benefits of adopting C4.0. For example, BIM-GIS integration addressed spatial challenges, such as flood-prone areas, by overlaying geospatial data. Informant 1 highlighted, "BIM resolves flood risks through GIS synergy". Automated tools reduced material waste by 20-30%; Informant 3 noted, "Automated quantity extraction improves accuracy". Digital workflows cut paper usage by 50% (Informant 1), while VR simulations enhanced safety training. Long-term lifecycle management justified upfront costs: "Initial BIM costs rise slightly, but long-term savings offset them" (Informant 2).

Trialability - Incremental Adoption via Pilots
This project enabled experimentation and learning. Phased GIS-BIM integration for flood prevention facilitated skill development. Informant 1 explained, "Piloting let us refine workflows without overwhelming systems". Previous public-private partnerships, such as V7's collaboration with the Department of Transportation, provided institutional support. Localised software adaptations addressed compatibility gaps, with Informant 10 stressing, "We developed tools tailored to Vietnam's regulations". However, project deadlines often truncated trials. Informant 6 noted, "Tight schedules forced abbreviated pilots, leaving issues unresolved".

Observability - Visible Outcomes and Fragmented Adoption
Demonstrable outcomes were noted by most informants which enhances credibility of C4.0. BIM's clash detection reduced rework costs, by preventing demolition conflicts at An Phu (Informant 3). Reduction in paper usage raised business reputations for the consultants as sustainability leaders. Informants also admitted to having experienced issues related to fragmentated adoption that obscured the benefits. Informant 8 noted, "Most units used 2D drawings - BIM was limited to complex parts". Centralised data repositories remained underutilised, risking knowledge loss. "Data might not be reused for future projects" (Informant 4).

Complexity - High Costs and Resistance to Change
Despite advantages, high implementation costs and technical complexity were cited to hinder scalability. Advanced tools like 3D laser scanners required significant investment, e.g., "equipment costs are extremely high" (Informant 1). Labour expenses for skilled personnel strained budgets, compounded by fragmented areas of expertise. Informant 4 observed, "BIM specialists lack domain knowledge, causing design clashes". Some resistance remained among senior engineers, as highlighted by Informant 8, who noted that "older staff struggle with BIM". Regulatory misalignment exacerbated issues, as foreign BIM standards (e.g., ISO19650) lacked localisation. Informant 10 criticised, "ISO guidelines ignore Vietnam's road infrastructure needs".

DISCUSSION

This study provides qualitative insights from 10 key stakeholder interviews involved in Vietnam's An Phu Junction project, to address the RQ. Results indicate that compatibility with regulatory frameworks and existing workflows is essential to the adoption of C4.0 technologies, while the relative advantages in efficiency and sustainability justify the investments. Pilot-based trialability and visible outcomes help to reduce resistance to adoption; however, persistent challenges remain due to high costs, skill shortages, and disjointed workflows. Findings reveal context-specific enablers, such as government mandates (e.g., Prime Ministerial Decision 258) that play a critical role in enforcing BIM adoption and integrating with traditional paper-based systems. Conversely, barriers like fragmented system readiness, high implementation costs, and resistance among workers highlight systemic challenges. Table 2 summarises key enablers and barriers to C4.0 adoption in Vietnam.

This study reveals key distinctions between the An Phu case findings and existing literature on C4.0 adoption. While the literature broadly identifies financial constraints and skill gaps as universal barriers (Jaiswal *et al.,* 2024; Demirkesen and Tezel, 2021), and the An Phu project concurs, it further uncovers institutional-localisation gaps—such as foreign BIM standards clashing with Vietnam's specific road infrastructure norms—as critical systemic hurdles, offering a more granular

insight than general discussions of organisational resistance (Demirkesen and Tezel, 2021). Unlike literature that emphasizes collaboration as a primary enabler (Huynh-Xuan *et al.,* 2024), the An Phu project underscores regulatory mandates (e.g., Prime Ministerial Decision 258) as pivotal in driving compliance-oriented BIM adoption. Moreover, its reliance on hybrid workflows to integrate global BIM standards with local paper-based systems highlights context-specific compatibility strategies, diverging from generic collaboration frameworks. Conversely, while the literature points to strategic leadership as a key enabler (Huynh-Xuan *et al.,* 2024; Tayal *et al.,* 2024), the An Phu case presents a paradox of fragmented adoption: significant waste reductions (20-30%) coexisted with uneven BIM uptake across teams, challenging assumptions about the uniform impact of leadership or observability. These findings advance C4.0 understanding by demonstrating how compliance-driven policies and incremental trialability (e.g., phased pilots) uniquely navigate the complex realities, including infrastructural deficits and fragmented expertise, in developing economies—nuances often missing in generalised frameworks.

Table 2: Key enablers and major barriers to Construction 4.0 adoption

Key enablers	Description
Government Policies and Mandates	Mandated BIM adoption, public-private collaborations
Cost Efficiency and Sustainability	Reduces paper use, minimises rework, precise material quantification
Compatibility and Integration	Integrates with AutoCAD, GIS, MS Project, unifies multi-format data
Training and Skill Development	Mentorship, certifications, government-funded programs
Major barriers	
High Costs	Upfront expenses for equipment, software licenses, skilled labour
Knowledge Gaps and Resistance	Limited awareness of advanced tools, generational divides
Fragmented Workflows	Parallel BIM and 2D workflows, mismatched foreign tools
Lack of Standards	Vague execution plans, inconsistent data protocols
Infrastructure Gaps	Cloud storage costs, outdated hardware, limited scalability

Limitations

Despite its contributions, this study has several limitations. First, its single-case design, focused on Vietnam's An Phu Junction Project, limits generalisability to other regions or infrastructural contexts, although naturalistic generalisation was employed to extend insights to comparable developing economies (Simons, 2015). Second, reliance on interviews with 10 stakeholders, while representative of the expertise required, may introduce potential selection bias, as participants were primarily technology advocates or leaders, possibly underrepresenting dissenting perspectives (e.g., workers resistant to change). Third, the qualitative methodology, while rich in contextual detail, precludes quantitative validation of adoption outcomes, such as precise cost-benefit ratios or longitudinal sustainability impacts. Fourth, the case study's focus on the design and construction phases overlooked post-construction technology use, such as digital twins for lifecycle management—a critical gap given C4.0's emphasis on operational efficiencies (Shan *et al.,* 2024). Finally, contextual barriers like Vietnam's institutional fragmentation and infrastructure deficits may disproportionately shape findings, complicating direct comparisons with nations possessing stronger digital readiness.

CONCLUSIONS

This study leverages Rogers' DOI theory to explore the enablers and barriers of C4.0 adoption in An Phu Junction roject. Key findings underscore that compatibility, achieved through regulatory mandates like Decision 258 and hybrid workflows integrating BIM with traditional practices, was pivotal to adoption success. Relative advantages in operational efficiency (20-30% waste reduction) and sustainability

(50% lower paper usage) justified investments, while pilot trials and observable outcomes mitigated resistance. However, complexities like high costs, skill gaps, and fragmented institutional frameworks hindered scalability, particularly in under-resourced contexts. The study advances DOI theory by contextualising its five attributes within infrastructural and socio-economic challenges unique to developing economies, such as workforce readiness and regulatory misalignment. Practically, the study advocates for phased policy interventions harmonising global standards with local adaptations, targeted capacity-building programmes, and centralised data repositories to amplify long-term observability. While the single-case design limits generalisability, the findings offer a roadmap for developing economies seeking to balance innovation with institutional constraints. Future research may explore cross-country comparisons, and lifecycle impacts of C4.0, addressing ethical dimensions like equitable upskilling in the face of automation.

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TRAPPED IN TECHNOCENTRIC THINKING? REVISITING DIGITAL TWINS THROUGH A PRAGMATIC FRAMEWORK

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To conceptualise the requirements and shape of construction digital twins, literature often proposes ideal-types and frameworks involving sensorised, real-time, and highly automated systems. While concepts demand significant resource investments and changes to business processes, their benefits remain debatable. To refocus on the needs of construction practice, we propose an alternative characterisation of construction digital twin systems. This study explores the conceptual diversity of useful systems through a framework comprising latency, fidelity, physical-digital connectivity, and analytic capabilities. It uses an engaged scholarship approach to apply this framework to two cases: A construction control room and an underground utility digital twin. Results show that these cases deviate from techno-centric perceptions, exhibiting variations in latency (low to high), fidelity (low to high realism), physical-digital connectivity (loose to tight), and analytic capabilities (descriptive to predictive). We conclude that construction may defy techno-centric stereotypes. Instead of exploring how organisations must adapt to comprehensive technological twins, future research should prioritise contextual needs to develop useful systems that enhance decision-making practices in the field.

Keywords: digital twin; maturity; context; utilities; site control

INTRODUCTION

Digital Twin (DT) systems integrate a virtual entity in the digital domain with its counterpart in the physical world. Fundamentally, this involves the collection and transfer of sensory data from the physical system to a virtual model, which is then used to provide insights and control the physical system. Many of the presented DTs include fully automatic, real-time data flows between the physical construction assets and detailed virtual models to support autonomous decision-making. However, these "high-tech" ideas are often introduced to practice without critically considering why, and what types of construction-relevant applications these envisioned systems should support. This criticism on techno-centric solutions also exists in BIM literature, where comprehensive technological models, such as 5D and 6D, have emerged. This literature stated that while visions, propositions, and promises are necessary to

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olde Scholtenhuis, L and Soman, R K (2025) Trapped in Technocentric Thinking? Revisiting Digital Twins Through a Pragmatic Framework, *In:* Thomson, C and Neilson, C J (Eds) *Proceedings of the 41st Annual ARCOM Conference,* 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 109-119.

encourage adoption, they should go hand in hand with realistic assessments of implementation scenarios. Also, sociology of technology studies argue that digital systems are highly intertwined with processes and practices, where the change of one aspect is likely to alter the other (Harty, 2005). Building upon this, we argue that the assumption of an all-inclusive, comprehensive Digital Twin may not add value in practice. Construction DTs are more likely to take varied forms; each tailored to specific use cases.

To support this use-case-centric re-characterisation of Construction DTs, we propose a framework that is informed by production systems literature. It incorporates the dimensions of latency, fidelity, physical-virtual connection, and analytic capabilities. To demonstrate its usefulness, we apply the framework to two of our DT-cases. In both cases, the systems support end-user decision-making by integrating data flows between physical and virtual environments; yet they differ significantly in form.

Following the explanation of our research method in the next section, we reflect on the current Digital Twin discourse and our proposed framework. Next, the results illustrate the existence of diverse, functional digital systems, with properties ranging from low to high fidelity and varying levels of automated integration. We finally discussed that our framework could help refocus Digital Twin efforts by addressing the critical "why" question behind their implementation.

METHOD

This study adopts a design-oriented engaged scholarship approach (Van de Ven, 2007), involving the abductive development of a framework through iterative engagement with case data and concepts from Digital Twin literature. Specifically, we reviewed the literature to identify the dominant definitions and evaluative dimensions in DT research and identify key assumptions underpinning current frameworks. Next, we critically reflected on these aspects through our experiences as researchers developing Digital Twin systems. This reflective practice helped us surface tensions between techno-centric DT-frameworks and our observations of real-world constraints and decision needs in construction. Based on the emerging understanding, we synthesized a four-dimensional framework that characterises DT artefacts. We then applied the framework to analyse two of our DT development cases. The first included a retrospective analysis of a completed DT implementation in a construction control setting; the second involved the conceptual co-design of a future DT system for infrastructure managers working on tree-underground infrastructure issues. Finally, our cross-case reflection validated the framework's pragmatic utility.

Characterising the Emerging Digital Twin

Digital Twins utilise integrated sensor data and predictive models for proactive decision-making in building management (Riaz *et al.,* 2014). While sensory data integration is regarded as a foundation marking a paradigm shift from Building Information Modelling (BIM) to DTs (Tuhaise *et al.,* 2023), the "significant similarities in terminology and scope between the two concepts" raise ambiguity about what defines a DT (Chen *et al.,* 2024). Consequently, the literature has been developing optimal versions and technological definitions of the concept (Revolti *et al.,* 2024). These frameworks classify DTs based on the level of interaction between a physical asset and its virtual entity, ranging from static digital models with no interaction to digital shadows with one-way communication, two-way interactive

Digital Twins integrating physical and virtual entities (Tchana *et al.,* 2019), and more autonomous cognitive and federated DTs (Liu *et al.,* 2024).

On such taxonomic ladders, superior Digital Twins are said to offer "more functions and stronger capabilities" while increasing comprehensiveness, automation, and smartness (Calvetti *et al.,* 2025). This implies that the ideal-type DT includes all these functionalities and achieves the highest levels of autonomous decision-making. This techno-optimal view, however, neglects that systems must also be able to support diverse decision-making needs that vary in context, timeliness, urgency, and abstraction. Construction DTs' shapes, therefore, "must be evaluated for each case", so a "one size fits all" blueprint for DTs does not exist (Agrawal *et al.,* 2023). The techno-idealistic fits into what Boyd (2021) describes as a hyperreality. Hyperreality promotes digitalisation "with only a limited amount of critical analysis," based on the belief that computers can emulate complex human thinking processes. It leads to abstract technologies that are presented as straightforward solutions for wicked yet concrete sociotechnical problems.

Framework to Characterise the Construction DT

If the scope and capabilities of DTs are not carefully considered, this may result in overly optimistic yet dysfunctional solutions, which fail to meet stakeholders' needs (Agrawal and Fischer, 2024). We argue that four dimensions from production systems literature on Digital Twins can guide designers in considering these aspects. These are: latency, fidelity, physical-digital connection, and analytic capability.

First, latency specifies the time lag between information that is passed between a physical and virtual entity of the DT. What the right lag time is, is dictated by specific application scenarios for the digital system (Sado *et al.,* 2024). In manufacturing processes or critical infrastructure management, real-time data may be needed for adequate decision-making (c.f., Lu *et al.,* 2020). Conversely, decisions regarding predictive maintenance and long-term planning data may not need to be exchanged instantaneously. Designers, hence, should strike a balance between desired decision outcomes and investment in data management resources (Boschert and Rosen, 2016).

Second, fidelity is the degree of correspondence between the virtual and physical entity. The term stems from computer vision and can also be understood as the level of complexity, level of detail or granularity that is required to represent the physical reality adequately. As such, high-fidelity models are computationally intensive and capture intricate details of the real-world to support precise simulations, such as in vehicle lifecycle prediction and structural health monitoring. Other models, alternatively, are less demanding and may use fewer complex visualisations to support quicker decisions (Kontaxoglou *et al.,* 2021). The appropriateness of model fidelity should ultimately match the speed and type of decision-making of each use case (Bazmohammadi *et al.,* 2022).

Third, physical-digital connection encompasses the connectivity between the physical and virtual realms. Taxonomies progressively model levels of automation of the data integration between physical and virtual systems. Digital models are updated manually by experts; digital shadows automatically capture real-time sensor data; and digital twins even offer bidirectional control loops with the physical system (Revolti *et al.,* 2024). This evolution enables capabilities such as real-time monitoring, predictive maintenance, and autonomous decision-making. However, it depends on the context of use how this integration is shaped. Typically, the built environment remains at the

digital shadow stage, with human oversight ensuring that data integration is both necessary and resource efficient.

Fourth, analytic capability refers to the type of analysis that is desired by users. Descriptive analytics integrates historical data to visualise or analyse patterns within systems (e.g., Gürdür Broo *et al.,* 2022). Diagnostic analytics extends this by utilising data to identify reasons behind past outcomes and identify existing issues with the physical system. Further, in predictive analytics, current data is used within machine learning algorithms to forecast future states or events (Kang and Mo, 2024). Finally, prescriptive analytics also recommend actions to decision-makers (Jeon *et al.,* 2024).

Essentially, Table 1 characterises the techno-centric ideal-type DT along the four dimensions. It also describes design choices besides this ideal type.

Table 1: A characterisation of the techno-centric ideal-type DT along the four dimensions

Dimension	Definition	Technocentric ideal type	Design Choices for Construction DTs
Latency	Data collection and exchange rate between physical and virtual system	Realtime and continuous	From instantaneous data exchange to - aggregated data collected at intervals
Fidelity	Complexity, detail and accuracy desired for adequate decision-making	High-resolution 3D models	From high-resolution graphics to simplified dashboards
Physical-Digital Coupling	Directionality of information communication between system components	Bidirectional	From static model to one-directional connectivity and bidirectional interaction
Analytic Capability	Level of intervention in the human analysis and decision-making processes	Prescriptive	From descriptive to diagnostic, predictive and prescriptive

Framework Application

We apply the framework to an implemented (retrospective) and conceptually designed (future) DT case below.

Retrospective Case: AEC Production Control

This DT system was designed to control construction production by integrating near-real-time data. It enhanced situational awareness and supported look-ahead planning (Soman *et al.,* 2025). Based on the analysis of decision routines, a system was developed that abstracted the physical construction site in digital counterparts, which were presented in a control room (such as 4D progress, weather, workforce presence, delivery schedules, and workplace congestion). Data exchange ensured the DT was updated at relevant frequencies to support real-time planning and decision-making. To achieve this, data flows were standardised, and integration issues were resolved by developing APIs. The resulting DT supported consistent, automated reporting and improved communication of productivity data via real-time dashboards. Based on this, the system could make automatic routine decisions while also flagging non-routine construction events that required human oversight. The streamlined information flow to the control room eventually reduced update meeting times from 45 to 10 minutes per week. This saved the information manager five hours weekly

and reduced the monitoring workload from eight hours of workshop time to a single 45-minute session.

The Production Control DT achieves a moderate level of *fidelity* that captures essential construction details without overcomplicating the model. It aggregates data from multiple sources, including continuous sensor inputs for weather conditions and workforce occupancy, to create a dynamic digital shadow of the construction site. This process leverages data from common data environments and 3D/4D representations.

The physical-digital coupling in this DT is primarily unidirectional, with sensor data flowing from the construction site to the digital model. While this enables real-time monitoring and basic analytics, control remains with human operators, ensuring informed decision-making without automated intervention.

This system is characterised by a differentiated latency strategy. Continuous sensor inputs provide near real-time monitoring of critical parameters such as weather fluctuations and site activity. Further, this "right-time" data is also aggregated to support planning phases. The DT thus supports immediate intervention on issues but also supports longer-term programming. As a result, the DT serves as a live repository that supports routine and non-routine decision-making.

Analytically, the system includes descriptive analytics by displaying the current physical state of the construction site, but also diagnostic analytics by identifying compliance issues—such as verifying if the number of workers adheres to safety regulations and detecting planning constraint violations. Also, basic predictive insights that estimated task confidence levels were provided to assist in foreseeing potential scheduling conflicts and resource bottlenecks. In this case, most critical decisions regarding scheduling and resource allocation were made by human operators. This interplay ensures that the DT functioned as a supportive tool rather than a fully autonomous system.

Future Case: Tree-Underground Utilities Digital Twin

In our latest DT research project, we have been working with eight municipal infrastructure managers to co-define the conceptual requirements for a DT system that they may be developing in future. The purpose of their DT is to support decision-making about relocating cables, pipes, and trees, which are often closely co-located in the same urban underground space. The managers stated the need to track the evolving shapes and sizes of tree root zones to assess potential risks of interference with underground cables. Over time, persistently high groundwater levels could, for example, lead to root zones expanding laterally and becoming shallower, encroaching upon cable beds. Consequently, trees become unstable and fall in strong winds, also damaging cables, pipes, and road infrastructures.

The conceptualised DT system facilitates the diagnosis of vulnerabilities and the simulation of risks by integrating infrastructure data (i.e., road and utility locations) with historical records of groundwater levels and wind conditions. Since the physical phenomenon of root zone growth and cable intrusion occurs gradually, the DT uses monthly intervals to simulate and predict tree growth as a function of groundwater levels and wind conditions. The system alerts engineers when there is a probability that root zones will intercept utilities within the next predicted maintenance period. The professionals then use this information to determine intervention strategies.

When trees or utilities are relocated, updated physical system data is fed into the virtual model.

The *latency* of the DT system for trees and utility management is significantly higher than in techno-centric twins, as data collection occurs at intervals of months. While the system can use real-time data from groundwater and weather databases, these data can be aggregated without compromising on quality for the decision-maker. In other words, since tree relocation and utility reinforcement are planned over months, real-time sensors or high-frequency inspections would only add computation and data management costs to the system, while not improving intervention decisions.

The DT's physical-digital coupling is also less tight and automated than the techno-centric ideal-type. Data on tree root sizes is manually collected using ground radar images and complex seismic interpretation software. Also, intervention decisions are made by managers rather than by the system itself. On the dimension of *fidelity*, the DT employs a detailed and complex physics model for simulating wind loads, root zone movement, and soil stability. This is combined with the seismic data to predict the sizes of root zones and locations of buried utilities. While models are complex, the user interface has a low-detail geospatial resolution only to represent potentially conflicting underground space volumes occupied by both utilities and tree roots. This multi-fidelity approach balances detailed data with users' decision needs.

Finally, the analytic capabilities of the conceptualised system are diagnostic and predictive. On one hand, the simple visual 3D interface presents the current underground conditions to support the diagnosis of the existing clearance space between root zones, cables, and the surface level. On the other hand, the system has the predictive ability to develop scenarios and identify the locations in the municipality where tree growth and water levels become critical. As with the previous case, this DT system uses 'right time' data instead of real-time data. Again, the capabilities of this DT would not benefit from becoming autonomous, as intervention decisions and actual execution of maintenance and reconstruction of underground spaces require more complex human judgment that cannot be emulated by a DT system.

DISCUSSION

The construction production control and underground DT cases perform data integration between physical and virtual systems to enhance the asset's life cycle management. While this is one of the foundational features of DTs (Fang *et al.,* 2025), the functionalities and shape of the DT solutions differed, deviating from the comprehensive and techno-centric DT ideal-type defined in Table 1.

The application of our alternative framework supports the argument that the deployment of construction DTs benefits from the consideration of data latency. This may be real-time, as in the AEC production control case. In this and similar cases, such as occupancy management systems and environmental monitoring, data transfer delays might lead to inefficiencies or safety concerns (Rajan and Li, 2024). Higher latency, where data is collected and analysed at intervals, was evident in the tree-utility case, which, like predictive maintenance, requires less than instantaneous data exchange (Wong *et al.,* 2022). Therefore, it is not real-time but 'right-time' data collection that matters for users' specific project goals.

In terms of fidelity, the cases show the need for application-specific fidelity levels. Both multi-fidelity systems make pragmatic use of computational resources, which

may include high-fidelity physics and coarser representation models in a single use case. Alignment between fidelity and the operational context is key—straightforward tasks may not require the sophistication afforded by high-fidelity models (Sacks *et al.,* 2020, p. 2). This adaptability presents an opportunity for the built environment sector to leverage DT technology in a manner that is both resource-efficient and highly functional (Perno and Hvam, 2020). Both cases remain at the digital shadow stage, where physical and cyber connectivity is limited to one-way data exchange. Direct digital intervention—where the virtual system actively drives changes in the physical world—is still rare, as human oversight remains essential in construction cases reported in the literature.

Essentially, our two cases involve the design of DTs that aim to reduce the cognitive load on engineers rather than replace their expertise. This aligns with the literature. Current applications focus on enhancing situational awareness and predictive capabilities (Deng *et al.,* 2021; Dodt; Pronost *et al.,* 2023). Similarly, a health monitoring DT case in the literature provides insights into infrastructure behaviour and maintenance strategy development but still relies on human judgment to implement these strategies (Parida and Moharana, 2024). As human-computer role divisions in DTs can vary, from analyst, observer, decision-maker, to action-executor, depending on the analytical capabilities required (Agrawal *et al.,* 2023), this underscores the fact that the promise of a fully-fledged automated DT, which prescribes scenarios and makes changes autonomously, remains aspirational.

The findings contribute to the literature by emphasising the earlier claims of Agrawal *et al. (*2023) that DTs do not fit a one-size-fits-all stereotype. Techno-centric frameworks (c.f., Liu *et al.,* 2024; Tchana *et al.,* 2019) currently lean towards such stereotypes, which include real-time, fully integrated, and automated, high-fidelity DTs. Yet, such hyped and optimistic conceptualisations risk rejection (Wright and Davidson, 2020). The characteristics of a much less centralised and controlled industry, with varying site conditions, complicate achieving ambitions that are more commonplace in manufacturing and production environments where the DT concept emerged. The dynamic and iterative relationship between digital capabilities and the scope of the twinned entities in construction, consequently, requires construction managers to invest in DTs to make various trade-offs between the investment in technological capabilities and pragmatic needs from stakeholders (Agrawal and Fischer, 2024).

Agrawal *et al. (*2024) conceptualised the nature of DTs by eliciting their dynamic twinning properties. This study further translates this by focusing on measurable design parameters—fidelity, data frequency, latency, and physical-virtual coupling—to guide the development of digital twin systems in construction. This offers concrete, operational dimensions that directly inform system design and performance in practice, supporting better alignment between construction processes and DT systems during the implementation stage.

Ultimately, we advocate that both technological and managerial studies in CM should steer away from focusing on the ideal-type techno-centric Digital Twin towards a more ambivalent conceptualisation that better fits the context of our industry. This supports the point that a hyperreality may emerge when the construction industry uncritically promotes DTs, resulting in a too great a loss of meaning of reality through abstract digital models, and a loss of control where systems enforce structures that favour only specific stakeholders (Çıdık *et al.,* 2017), and a loss of perspective in

settings where DTs are designed as transferable black boxes but only tested successfully in settings with heavily fixed boundaries (Boyd, 2021). To avoid hyper-real discussions, the technological knowledge domain needs to align better with the practice domain, as design scholars advocate (Hevner, 2007).

Acknowledging context in technology design further means that adoption studies of DTs should focus less on how organisations should change themselves to facilitate the uptake of ideal-type DTs, as happens with established maturity models (Haraguchi *et al.,* 2024; Liu *et al.,* 2024) or the elicitation of DT-adoption factors (Arowoiya *et al.,* 2024). Instead, a more fruitful endeavour would be to explore the rich context and design principles of impactful technologies.

Notably, this research has limitations. By using a pragmatic utilitarian perspective, rather than a techno-centric one, this study proposes four useful labels as dimensions. These dimensions were demonstrated in two cases. It is likely, though, that unexplored dimensions may emerge during extended analyses. By no means do we aim to be exhaustive, and so we encourage the further exploration of dimensions that help guide and describe DTs based on their usefulness. Based on a wider comparison of cases and dimensions, aspects like modularity may also be included. Such a term may describe well how a designed DT may be able to support decision-making in complex use cases, where it becomes part of a larger system of connected DTs. The feasibility and validity of such a dimension would need to be explored in future work through a variation of empirical DT design cases.

CONCLUSION

This study presents a pragmatic and user-centric framework that conceptualises the nature of Construction DTs through dimensions of latency, fidelity, physical-digital connectivity, and analytic capabilities. Using an engaged scholarship approach that iterated between our own fieldwork design experiences and concepts in the literature, we synthesized this framework and illustratively applied it to the DT-cases for AEC production control and tree-underground utility management. The results highlight the diversity of the DT concept and support our claim that debates should move away from techno-centric models, which fail to reflect the realities of construction practice where variability, uncertainty, and human judgment play critical roles. We aim to provide actionable guidance for developing context-sensitive digital systems that are better suited to the dynamic and human-centric nature of construction.

This research holds relevance for the construction management research community as it challenges the prevailing techno-centric paradigm dominating DT discourse. We advocate for a rethinking of digital innovation, not as a linear technological progression but as an iterative, situational design process focused on supporting context-aware decision-making. We encourage CM researchers to prioritise usefulness over technological maturity and move beyond the binary "Is this a digital twin, or not?" debates. This approach could open pathways for theory development around digital technology adoption anchored in construction-specific practices, challenges, and needs. In practice, we hope the proposed framework contributes to digital twin systems that effectively support decision-making, which is a vital step towards bridging gaps between digitalisation studies and practical implementation.

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DIGITAL DISRUPTION AND TRANSFORMATION IN PROJECT COST MANAGEMENT IN DEVELOPING COUNTRIES: A SCOPING REVIEW

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There has been an accelerated push within the built environment toward digital transition in recent years. Developing countries stand to benefit significantly from advancing their levels of digital maturity. The rapid adoption of emerging digital technologies, such as Building Information Modelling (BIM), blockchain technology; and Geographic Information Systems (GIS), has profoundly disrupted traditional practices in project cost management, offering both opportunities and challenges. This study examines the interplay between digitalisation, disruption, and development within the context of project cost management. A four-step methodology was employed to investigate advances in digital transformation within project cost management in the built environment. The review evaluates current methodologies, identifies barriers and explores future trajectories in the digital transformation. The findings reveal several key barriers namely a lack of project team experience, the absence of procurement processes integrated with blockchain technology, modelling complexities, and deficiencies in planning, all of which hinder successful digitalisation. Furthermore, the paper identifies gaps in the literature and proposes directions for future research.

Keywords: blockchain technology; cost; digital transition; project cost management; time

INTRODUCTION

Traditionally, infrastructure projects in the built environment are characterised by discrepancies in cost and time performance compared to initial budgets and to similar projects (Gómez-Cabrera *et al.,* 2024; Dahlin and Pesämaa 2021; Durdyev 2021). These manifest in cost and time overruns. The inability to complete projects within an estimated budget has become a significant concern for infrastructure delivery, especially in the public sector. Scholars have outlined this observed phenomenon within and across projects, locations, and delivery systems as a problem if the current status quo continues (Khabisi *et al.,* 2016; Larsen *et al.,* 2016; Mahmud *et al.,* 2021). Furthermore, Martínez-Peláez et l (2023) articulated that without innovative solutions,

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the risk of inefficient and ineffective project delivery was thus likely to increase and further compromise infrastructure development.

As developing countries strive to keep pace with global advancements, digital transitioning emerges as a pivotal force in addressing project cost management challenges. At its core, digital transitioning represents a gradual paradigm shift (Akanmu *et al.,* 2021). Within the context of project cost and time overruns, transformation and innovation become synonymous with adaptation as the construction sector navigates the complexities of integrating digital tools into traditional operational practices (Tereshko and Rudskaya 2021).

It then becomes critical to understand how digital technologies are leveraged to mitigate variations through enhanced project cost management. Notwithstanding, the phenomenon is not limited to projects in developing countries alone. The issue of project cost and time variability in similar projects and overruns is a global phenomenon. For example, Budayan *et al. (*2020) highlighted the need to understand the variability of time and cost between projects. The authors argued that the construction sector faces numerous challenges in managing projects due to locality-specific problems and conditions, which may lead to variations in the management of similar projects conducted in different jurisdictions. One of the reasons for the problem is due to differing regulatory frameworks, availability of skilled labour, material pricing volatility, and inconsistent historical cost data across regions.

Additionally, information management is compromised because some of the data, like project initiation costs, is not collected and stored in a common data environment (Pedral Sampaio *et al.,* 2023). In project management, the availability of historical data is important for analysing trends and behaviour to decipher underlying issues. It assists in establishing, modelling, and predicting future trends to inform, warn, educate, and prepare society and its communities for what to expect in the future. For small companies, that can either be because the said information is not recorded in the system or is not readily available, meaning that a time-consuming search must be made through piles of hard-copy documents stored in a room.

Literature reveals the rapid adoption of emerging digital technologies, such as Building Information Modelling (BIM), blockchain technology, and Geographic Information Systems (GIS), has profoundly disrupted traditional practices in project cost management, offering both opportunities and challenges Raza *et al.,* 2023; Liu *et al.,* 2021; Zhu *et al.,* 2018). The paper builds on existing literature by examining the interplay between digitalisation, disruption, and development within the context of project cost management. This study is guided by the following research questions:

•What are the main barriers to digital transformation in project cost management in developing countries?

•What digital technologies are currently being applied to improve cost and time management?

•How are these technologies disrupting traditional practices?

METHOD

The study employed a four-step review methodology to examine the advancements in project cost management applications within the construction industry as applied in studies such as (Jiang *et al.,* 2021). The study aimed to investigate the significance, applications, current methodologies, challenges, and future trajectories in computer

vision. The initial step involved defining the review's scope, setting the stage for an in-depth exploration of project cost management's role in construction. Our focus was to provide a comprehensive overview of the field's latest developments, barriers, applications, and prospective directions for future studies. The study sourced academic articles from Web of Science and Scopus Search Engine, comprising journal articles, conference papers, and book chapters (see Figure 1).

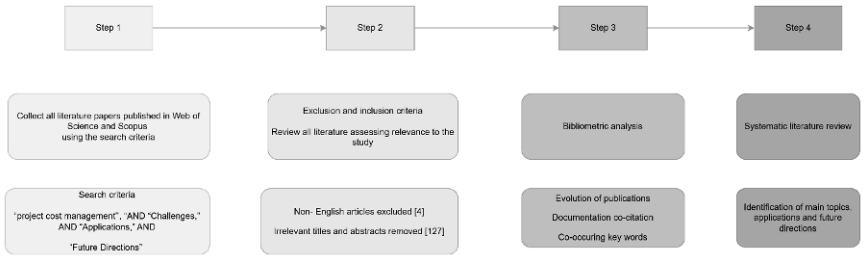


Figure 1: Research approach

Specific keywords such as "project cost management'', "AND "Challenges," AND "Applications," AND "Future Directions" guided our data retrieval process. Following data acquisition, the subsequent steps encompassed data collection and quality assessment, ensuring the inclusion of reliable and pertinent resources. 54 articles were analysed in the bibliometric analysis and 31 in the systematic analysis. Thematic coding was used to identify recurring digital interventions linked to cost/time management strategies. Each identified technology was aligned with a specific project management objective evidenced in the reviewed studies.

FINDINGS AND DISCUSSION

Figure 2 shows the developmental trend in project cost management between 1990 to 2025. In the period from 1990 up to 2002, research was limited and focused on traditional approaches to address project cost and time overruns; the success of the initiatives was inconsistent with limited successful case studies. Post 2002, adopting emerging technologies led to a shift in project management approaches. Between 2002 and 2017, there was a fluctuation due to trial-and-error approaches in technology adoption. Post-2017, there has been a constant increase due to increased digital maturity and improved capacity in organisations. This changed trajectory has led to an increased adoption of BIM and blockchain technology in project management practice.

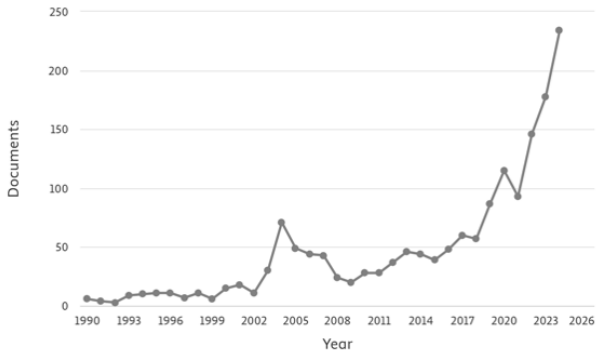


Figure 2: Publication trend on project management

Results showed evidence of emerging key topics and their interconnections in the context of digital technologies, sustainability, and project management over time (see

Figure 3). The colour gradient from blue to yellow indicates the evolution of these topics between 1990 to 2025. The isolated positioning of "business process management" suggests that integrating digital solutions into broader urban and infrastructure projects remains a challenge. While the strong linkage between "construction industry," "project management," and "digital technologies" suggests increasing adoption of BIM, IoT sensors, and AI-driven project planning in construction. Concerning future research direction represented in yellow shows the interconnection between "construction industry," "digitisation," and "design thinking." This alludes to the increasing use of digital technologies for infrastructure planning, predictive maintenance, and sustainability assessments.

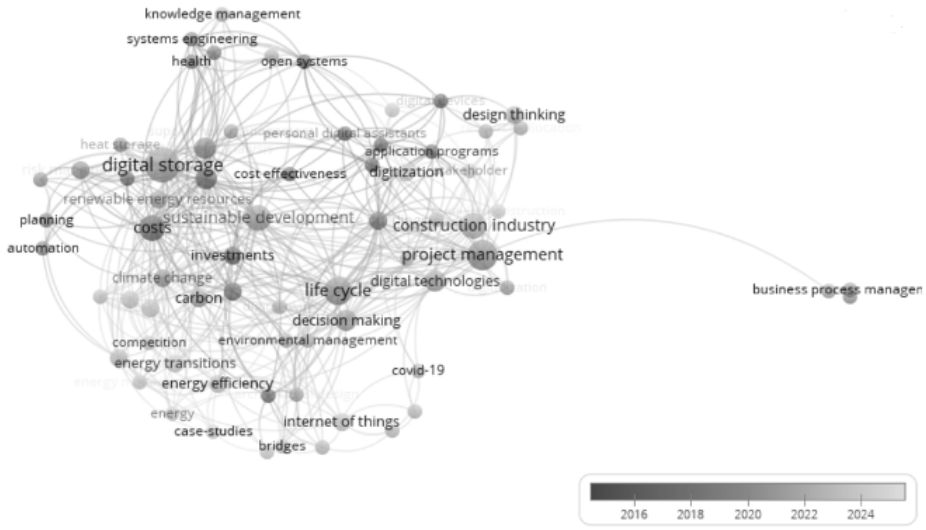


Figure 3: Emerging research trends

Figure 3 highlights how 'project management' increasingly co-occurs with digitisation' and 'BIM', reflecting a growing scholarly interest in digital transformation as a response to cost variability challenges. This trend supports the narrative of evolving digital solutions to cost and time variability by illustrating the growing centrality of digital technology in construction literature.

Emerging Approaches to Address Project Cost and Time Overruns

Time and cost are among major considerations throughout the project management life cycle and can be regarded as important parameters of project success. Despite its proven importance, it is not uncommon to see a construction project fail to achieve its objectives within the specified time and cost. Bubshait and Al-Juwait (2002) conducted a study in Saudi Arabia. It found that the effects of weather, social and cultural impacts, project location, a lack of productivity standards, supplier manipulation, level of competition, economic stability, the nation's insufficient raw material production, and lack of construction cost data were the main causes of cost overruns. A study in Ghana by Famiyeh *et al. (*2017) highlighted crucial elements contributing to project cost performance. Unfavourable weather, high labour costs, fluctuating material prices, bureaucracy in government agencies, poor financial management, and client financial hardship are some contributing factors. Kaming *et al. (*1997) conducted research in Indonesia. The findings showed that project cost overruns were mostly caused by inaccurate material take-off, rising material costs, and cost increases resulting from environmental limitations.

Similarly, Chimwaso (2001) conducted research in Botswana to evaluate the cost-effectiveness of construction projects. The authors found that measurements of provisional works, contractual claims, variations, and changes in the cost of labour and materials were the main causes of cost overruns. In the Nigerian city of Port Harcourt, Olupitan *et al. (*2021) conducted a study to determine the reasons behind cost overruns on public sector construction projects. The findings from these studies showcase that the most significant contributing factors are variation orders, changes to the project's scope, cash flow, and other financial issues contractors confront, delays in decision-making, and improper preparation.

Several reasons are attributed to projects performing differently across types, locations and management. Notable reasons for the varied performance included the project organisation strategy, procurement method and the monitoring and control regime. To address the above-outlined factors, Table 1 outlines emerging preventative measures implemented to address overruns. Notable examples include BIM replacing traditional estimation spreadsheets (Chahrour *et al.,* 2021); Blockchain enabling transparent subcontractor payment verification (Nanayakkara *et al.,* 2021); and AI-driven cost forecasting surpassing manual historical benchmarking (Liu *et al.,* 2021). These strategies employ emerging technologies as key enablers for ensuring the sustainability of built environment projects. The trend toward digital transformation can be seen through the increased use of many emergent technologies across industries, such as BIM, blockchain technology, and digital twin technology (Musonda *et al.,* 2025).

Table 1: Technology based measures

Approach	Technology used	Source
Actively monitoring and addressing delays during the construction process	BIM; Blockchain technology	Chahrour *et al.,* 2021; Radman *et al.,* 2022; Honnappa and Padala 2022; Alnaser *et al.,* 2024
Collaborating closely with subcontractors to reduce the likelihood of time overruns	Blockchain technology	Mohammed *et al.,* 2021; Lee *et al.,* 2021; Nanayakkara *et al.,* 2021; Khalfan *et al.,* 2022; Sarkar *et al.,* 2023
Implementing time management best practices	Internet of Things (sensors), artificial intelligence	Tereshko and Rudskaya, 2021; Oke *et al.,* 2022; Flyvbjery *et al.,* 2022; Furtado *et al.,* 2023; Patil *et al.,* 2023
Regularly assessing and updating project schedules to minimise time overruns.	BIM	Kavuma *et al.,* 2019; Ratajczak *et al.,* 2019; Rao *et al.,* 2022; Sepasgozar *et al.,* 2022; Chamikara *et al.,* 2024
Allocating sufficient resources to project management and scheduling.	AI and machine learning	Liu *et al.,* 2021; Ashtari *et al.,* 2022; Ali *et al.,* 2022; Rathod and Sonawane 2022; Khodabakhshian *et al.,* 2024
Prioritising continuous improvement in time management to minimise time overruns in future projects.	Digital twin	Farsi *et al.,* 2021; Mahmoodian *et al.,* 2022; Omrany *et al.,* 2023; Esmaeili and Simeone 2023; Weerapura *et al.,* 2023; Moshood *et al.,* 2024

In contrast to traditional approaches, through digitalisation construction progress monitoring is supported by a variety of tools and technologies to alarm delays, such as project management tools to monitor progress, track status and delays throughout the project; 4D-BIM which allows for the integration of scheduling tools to collect data, analysis and present them (Mohammed *et al.,* 2021; Liu *et al.,* 2021). Additionally, IoT technologies are emerging useful for optimising resource tracking (Rao *et al.,* 2021). Concerning promising continued improvements, digital twin technologies are

emerging as a sustainable solution (Omrany *et al.,* 2023). The foregoing observed patterns in relation to technology adoption are interesting. However, it should be noted that these apparent patterns must be interpreted considering the digital maturity of organisations and would, therefore, also affect performance levels. Nevertheless, with increased investment in digital capacity, organisations can derive the full benefits of digital transition leading to reduced project cost and time overruns.

CONCLUSION

This study examines the interplay between digitalisation, disruption, and development within the context of project cost management. The findings outlined a lack of project team experience, the absence of procurement processes integrated with blockchain technology, modelling complexities, and deficiencies in planning, scheduling, and monitoring, all of which hinder successful digitalisation. Despite emerging technologies showing promise, empirical validation in developing countries remains sparse. Most reviewed studies focus on conceptual frameworks or high-income contexts. This paper thus recommends context-specific implementation studies to understand the socio-technical complexities of digital transformation in resource-constrained environments.

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DEPLOYING INDUSTRY 4.0 ENABLING TECHNOLOGIES IN CONSTRUCTION PROJECTS: A DANISH APPROACH

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The new EU strategy calls for speeding up technological innovations, sustainability, and social inclusion as the main areas that allow competitiveness to be re-established in a new geopolitical situation. Aligning with this, the Danish construction industry is emphasising leveraging I4.0 technologies to improve efficiency and decrease emissions. However, there is a lack of empirical studies that investigate the deployment of I4.0 technologies in construction. The aim of this investigation, therefore, is to analyse how I4.0 technologies are deployed in real on-site settings. The analysis was carried out using the UTAUT technology acceptance model. The study outlines Performance Expectancy and Effort Expectancy constructs as key predictors for the practical application of I4.0 technologies. Findings suggest that the project-based nature of construction, as well as the high level of variation in physical conditions at the on-site location, may challenge acceptance of new technology in construction. It is suggested to further investigate the "Physical Conditions" as an additional construct in technology acceptance models.

Keywords: construction, Industry 4.0, technology transfer, Denmark

INTRODUCTION

The recent drastic changes in the geopolitical landscape have led the EU to revise its strategic goals in the global tech race. EU countries are responding with new policies and transformation agendas, emphasising three main areas of action for restoring manufacturing potential: technological innovation (1), decarbonisation (2), and preserving social inclusion (3) (European Commission, 2024).

There is a recognised need to strengthen technological innovation by "improving the pipeline from innovation to commercialisation" (European Commission, 2024, p. 17), particularly as the construction sector has long been a cornerstone of socioeconomic development within the European Union (Leontie and Maha, 2022). The Construction Industry (CI) is a major source of greenhouse gas emissions, due to both construction activities and the production of materials such as cement, steel, and concrete (Sáez-de-

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Jørsfeldt, L M, Klitgaard, A Jeppesen, R D, Redmond, C and Justesen, L (2025) Deploying Industry 4.0 Enabling Technologies in Construction Projects: A Danish Approach, *In:* Thomson, C and Neilson, C J (Eds) *Proceedings of the 41st Annual ARCOM Conference,* 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 129-138.

Guinoa *et al.,* 2022; Ruddock, 2008). In response, the EU has prioritised environmentally sustainable construction (Renda *et al.,* 2022).

One of the key strategies for achieving these goals is the integration of advanced technologies under the framework of Industry 4.0 (I4.0) (Xu *et al.,* 2021). Supporting this view, numerous studies highlight how technological advancements can lead to more efficient and sustainable construction methods (Ghobakhloo, 2020; Jin *et al.,* 2017).

While mainstream research presents I4.0 (I4.0) in an optimistic light, some studies challenge this narrative. Marcos Dieste *et al. (*2024), based on a literature review and a Delphi study, identify unintended negative impacts on environmental and social sustainability. These include increased electronic waste, higher raw material consumption, greater equipment obsolescence, reduced privacy and autonomy, poor work-life balance, and rising stress and mental health issues. Stock *et al. (*2018) highlight the risk of resource overconsumption associated with fully automated production. Similarly, Ciriello *et al. (*2021) underscore the loss of employee autonomy due to digital transformation. The study by Al Turk and Weheba (2022) identifies technological unpreparedness, resistance to change, and skill shortages as critical barriers to I4.0 implementation in construction. The slow adoption of I4.0 technologies is particularly evident in off-site construction (Breque *et al.,* 2021; Jørsfeldt *et al.,* 2024). Although some studies have explored technology adoption in the construction sector (e.g., Oesterreich and Teuteberg, 2016), most focus on BIM and other digital design tools. This allows us to conclude that there is a lack of empirical studies investigating the deployment of I4.0 technologies within the CI.

Responding to the call by Statsenko *et al. (*2022) to move beyond literature reviews and theoretical generalisations, our study addresses the lack of empirical research on the on-site adoption of I4.0 technologies in construction. We aim to fill this gap by examining the practical application of I4.0 technologies in on-site contexts, focusing on operational conditions and overall implementation feasibility. In doing so, we contribute to a more grounded and practice-oriented understanding of digital transformation in the construction sector.

Background

This section introduces the main concepts used in the study, with a focus on their relevance to construction.

I4.0 refers to the integration of digital technologies, such as sensors, automation, robots, big data analytics, and additive manufacturing devices, into manufacturing (Xu *et al.,* 2021). Industry 5.0 has emerged with a focus on fostering cooperation between humans and machines to improve both production quality and efficiency (Marinelli, 2023; Maddikunta *et al.,* 2022). Despite its potential, the implementation of advanced technologies in construction faces several barriers, including project complexity, lack of standardisation (Marinelli, 2023), skills shortages, reluctance to invest, security concerns, and restricted access to reliable data (Musarat *et al.,* 2023). This could be explained by construction sites are inherently unstructured and evolve dynamically as building components progress from raw materials to the completed structure. The site serves a dual role, both as a production facility and as the product of the construction process. On-site construction environments are, by nature, temporary, facilitating a limited number of repeatable activities during the construction phase. Once the building is completed, on-site production comes to an end.

A study by Al-Khiami *et al. (*2024) focus on specific technologies but overlook the operational contexts in which they should be applied. Other streams of literature, such as Murguia *et al. (*2024), explore strategic and managerial issues without addressing the practical, day-to-day challenges of technology adoption.

Research on the adoption of technologies in off-site construction (e.g., manufacturing settings) remains limited, as seen in studies like Cai (2022), which focuses on the Chinese construction sector. Research on on-site adoption is even more scarce and is often presented through theoretical proposals rather than field-based investigations, such as Turner *et al. (*2020) in the British construction sector. Literature reviews (e.g., Statsenko, 2024) show that I4.0 and Construction 4.0 technologies are still not widely adopted in construction, especially compared to manufacturing. This may explain the lack of studies critically examining their limitations or questioning the largely positive narrative.

Theoretical considerations

Taking the departure from the outlined research focus and aim, the Unified Theory of Acceptance and Use of Technology (UTAUT) (Figure 1) was chosen. The reason for this choice lies in the fact that it can be used both for explaining the phenomenon under investigation and as a normative theory, allowing us to suggest and predict the successful implementation of technology in construction (Nnaji *et al.,* 2019; Tao *et al.,* 2020).

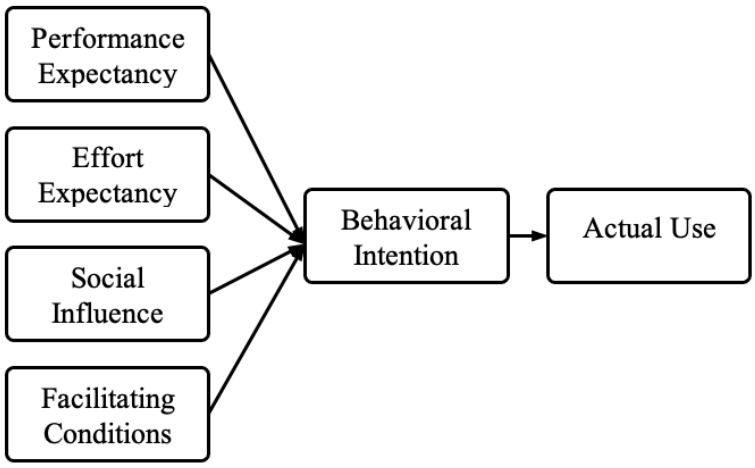


Figure 1: UTAUT model (Nnaji et al., 2019; Tao et al., 2020)

The key constructs of the model are presented in the table (Table 1). Based on the constructs, an ethnographic observation guide was developed. These guides were then used to collect data via writing notes, reflection on data collecting processes and analyses of data collected.

These four key constructs (Table 1) reflect workers' perceptions and attitudes towards adopting new technologies and help explain intentions and actual use of such technologies (Tao *et al.,* 2020; Venkatesh and Zhang, 2010).

METHODOLOGICAL CONSIDERATIONS

In this study, we set out to investigate embedded and potential challenging properties of the construction site that may influence the adoption of I4.0 technologies. Observations allow for a first-hand impression of the complexities in a setting, rather than second-hand knowledge obtained through other methods (Silvermann 2015).

The research setting can be staged by the actors within the setting due to the researchers' presence, so high levels of reflexivity is required by the observing researcher (Klitgaard *et al.,* 2021).

Table 1: Key constructs of the UTAUT-model (Nnaji et al., 2019, Tao et al., 2020; Venkatesh et al., 2003)

Concept	Definition
Performance expectancy	The extent of individual belief regarding how the use of a particular technology will enhance work performance
Effort expectancy	The extent of individual belief regarding how the use of a particular technology would be free of effort
Social influence	Individual perception's perception regarding the extent to which an individual thinks that it is vital that others should utilise the new technology
Facilitating conditions	Environmental factors designed to make an act easy to be carried out.

In addition to structured observation, we engaged in informal, unstructured conversations with site workers and experts during our field visit. These conversations were not formally recorded or transcribed but were captured through detailed field notes. (Swain and King, 2022).

The Construction Sites

This study was conducted at two active construction sites located in Northern Jutland, Denmark. Both sites reflect contemporary Danish residential construction practices and provide relevant contexts for the research.

Site A is part of a broader urban development initiative designed to accommodate approximately 300 residential units, each averaging 99 m², along with a health centre and a community facility. This specific phase comprises 60 residential flats and a 181 m² commercial unit overlooking a public square. The development incorporates 76 parking spaces and 94 dedicated bicycle parking spaces. The projected market value of the project is approximately 150 million DKK. We observed five workers on this site.

Site B constitutes the second phase of an ongoing community housing project. It includes seven semi-detached buildings, providing a total of 14 residential units. Phase 1, completed between 2019 and 2020, delivered 18 similar units. The estimated sales value of Phase 2 is approximately 30 million DKK. The development includes 64 parking spaces, ensuring a minimum of two spaces per home. We observed 6 workers on this site.

The observational data focused on on-site conditions and tool usage, presenting a methodological dilemma, as the UTAUT model centres on actors' perceptions—elements that are not directly observable. However, this approach reduced the risk of impression management and aligned with the study's aim to critically examine the use of technology on construction sites.

Observation and Analysis Approach

The UTAUT model is based on actors' perceptions, which cannot be directly observed. However, the researchers bring extensive construction experience, including backgrounds in carpentry and bricklaying, which informed both the observation phase and subsequent analysis through practical insights.

For the performance expectancy construct, observations focused on the physical environment, the deployment of I4.0 technologies, and contextual factors that may

limit task efficiency, accuracy, or productivity. The analysis also considers the construction site as a production setting, examining how digital tools and site organisation influence overall performance outcomes.

For the effort expectancy construct, observations focused on the perceived ease of learning and using the technologies. On-site contextual factors, such as time pressure and task complexity, were considered for their impact. The analysis addresses how technology is adapted to the specific conditions of the construction site.

For the social influence construct, we observed how workers' use of I4.0 tools was shaped by cultural norms, generational differences, social pressures, and managerial encouragement. Due to limited time and access to only two sites, in-depth observation of social dynamics was constrained. Consequently, the analysis draws on expert insights from the research team and relevant theoretical perspectives.

For the facilitating conditions construct, we examined the extent to which the use of I4.0 technologies was supported by infrastructure, including access to training, technical assistance, and on-site support. However, due to time constraints and limited site access, we were not present during active technology use or training sessions, which may have occurred elsewhere. The analysis is therefore repeat the approach of the previous construct.

Observations from Sites

Physical Conditions on a Construction Site - Empirical Insights
We begin by examining how the physical conditions of the construction site, which we have illustrated through a series of photographs that document typical site conditions. Due to the physical conditions, the construction site has embedded challenges as a production site.



Figure 2: Physical conditions on a construction site

In the above pictures (Figure 2), we can observe how the paths providing access to the production setting are exposed to the weather. In Denmark, these paths are often muddy, which presents challenges for the use of heavy-duty tools. In the second picture, we see how the interior access paths are cramped and used for running cables. In the third picture, we see how the materials to produce a ceiling need to be stored inside the emerging building. In this way, the materials reach a state of equilibrium, preventing expansion or shrinkage during installation. The construction site, as a production site, is thus also a storage site.

This series of pictures demonstrates how construction sites are challenged by access roads exposed to weather, and how these roads serve not only for the movement of workers but also for the delivery of utilities such as electricity. Furthermore, the construction site is also used for the storage of materials.

Our observations indicate that the physical setup of the construction site poses challenges for adopting new technology. Relocating equipment to where it is needed requires time, planning, and coordination. Moreover, the technology is often used for a single task before needing to be moved again. This mirrors challenges seen in production environments, where repeated setups for short-duration activities create inefficiencies and hinder the integration of I4.0 technologies.

Tools - Empirical Insights
In this section we present a second photo series demonstrating how existing tools are adapted to these conditions.

Many tools are lightweight and easily transported, suggesting a strong alignment with the practical requirements of a changing production environment. This mobility is essential for maintaining productivity under spatial and temporal constraints.

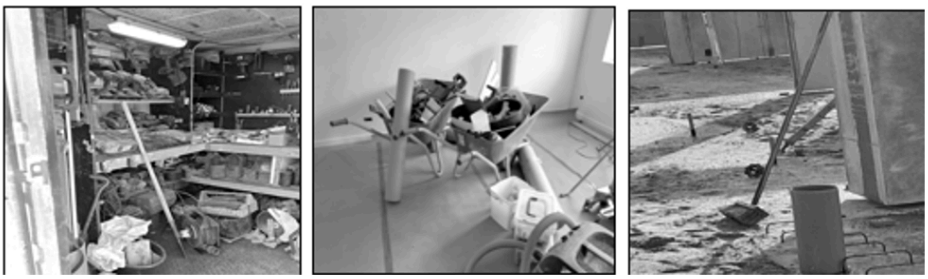


Figure 3: Tools

In the first picture above (Figure 3), we see the inside of a tool shed. Many of the tools are small and easy to move, allowing the workers to easily transport the tools to the location where they are needed. The second picture demonstrates how this can be done using wheelbarrows. The two pictures are from different sites. The movement of tools in a wheelbarrow would be challenged by the conditions of the access roads (see the previous photo series). The last picture shows a broom, which has been moved to the desired location. The broom is an example of a tool that can be easily moved as the building takes shape and the construction site changes.

Many of the existing tools on the construction site are thus characterised by being easily transported to the desired locations as the production site is changed due to the progression of the building. The tools can be easily moved even under the conditions as demonstrated in the first photo series.

DISCUSSION

A potential link between physical conditions and performance expectancy
The first finding highlights the impact of physical conditions on technology use. While digital tools such as BIM systems are easier to implement, physically large or heavy I4.0 tools are significantly constrained by the logistical and spatial limitations of construction sites. Unlike controlled environments in other industries, or even off-site construction settings (Jørsfeldt *et al.,* 2024), the unstable, temporary, and often weather-exposed nature of on-site projects makes the integration of physical tools particularly difficult.

From the UTAUT perspective, these environmental factors directly affect Performance Expectancy: workers may not perceive tangible benefits from new physical tools if those tools are difficult to use or cannot be deployed effectively under site conditions, as pointed out in the analysis. As such, physical constraints reduce the

likelihood of technology adoption, not due to resistance to innovation, but due to contextual incompatibility.

Our findings confirm that the dynamic, unstructured, and temporary nature of construction sites significantly affect the perceived usefulness of I4.0 tools. While the potential for increased productivity is often emphasized (e.g., Turner, 2021), our observations suggest that physical setup issues, logistical barriers, and frequent relocation may limit performance benefits. This supports Marinelli's (2023) conclusion that the complex and changing nature of construction projects poses a challenge to the practical implementation of I4.0.

A potential link between the reference for small tools and effort expectancy
The second observation demonstrates how small, mobile tools are not only preferred but are, in fact, necessary for workers operating in dynamic, space-limited environments. These tools align well with both the physical conditions and the task-related expectations of workers. From the UTAUT lens, this finding strongly relates to Effort Expectancy: smaller tools require less physical effort to use and transport, making them more acceptable and efficient within the changing spatial layout of construction sites.

This result suggests that successful technological innovation in construction may need to prioritise portability, adaptability, and ease of use, rather than simply focusing on technological advancement for its own sake.

The observed preference for portable and intuitive tools illustrates a gap between technological ambition and day-to-day usability. This supports and extends the argument made by Hadi *et al. (*2023) and Breque *et al. (*2021) that technology must adapt to human workflows, rather than the other way around.

A potential link between the embedded nature of the temporality of the construction site and the concept of social influence
A key domain-specific characteristic of the find and replace CI is its project-based nature. The literature reflects ongoing debate about how this temporary structure impacts innovation. Flyvbjerg and Gardner (2023) warn of a uniqueness bias, where each project is viewed as distinct, which can discourage learning and continuity between projects.

These findings relate to Social Influence in the UTAUT model: when workers and managers perceive the current project as unique and time-sensitive, they may be less receptive to external influences encouraging change, whether from management, peers, or industry standards. This leads to a fragmented technological landscape, where tools must repeatedly justify their use on a project-by-project basis. From a project-as-practice perspective (Klitgaard and Gottlieb, 2024), workers' day-to-day practices actively construct and reproduce a social environment in which stability and routine are prioritised over experimentation. As a result, introducing new tools may not only require technical training but also cultural and organisational shifts that challenge established social norms within each project.

"Just One Project" thinking and lack of facilitating conditions.
A key property of the CI is its project-based nature, with construction sites that are temporary and constantly changing. This creates both practical and organisational challenges that make it harder to implement new tools and technologies. The idea that each project is seen as "just one project" emerges as a major barrier to long-term

innovation. This mindset, deeply rooted in the temporal and unique framing of construction work, limits the cumulative learning potential across projects.

In terms of the UTAUT model, this can inhibit Facilitating Conditions by reducing the organisational support structures needed for the sustainable adoption of new tools. This finding highlights the need for further empirical research into how project-based identity and temporal constraints shape technology acceptance, particularly how workers construct a shared social reality that resists technological change. The concept of "just one project" not only limits long-term thinking but also affects the very conditions that would support sustainable technology use. Although recent literature (e.g., Murguia *et al.,* 2024: Jazzar, 2021) has focused on strategic roadmaps and management approaches to digital transformation, our findings suggest that the lack of practical enabling conditions—training, technical infrastructure, and continuity—still presents a major barrier.

CONCLUDING REMARKS

The study responds to the call for empirical, on-site research on I4.0 adoption in construction. While previous studies have proposed strategic and conceptual pathways (e.g., Hadi *et al.,* 2023; Musarat *et al.,* 2023), our findings highlight a clear gap between these visions and the practical realities of construction sites.

This study has demonstrated how the adoption of I4.0 technologies is also influenced by the physical and project-oriented characteristics inherent to construction work. By applying the UTAUT framework, we identified connections between the on-site environment and the constructs of performance expectancy, effort expectancy, social influence, and facilitating conditions. We highlighted how the "just one project" mindset present challenges for I4.0 technology implementation.

While our study provides important insights into the technology adoption in construction, the findings should be interpreted with caution, as it is based only on observation from two construction sites.

We conclude that successful implementation of I 4.0 in construction, the frameworks for adoption of technology must be adapted to reflect the realities of on-site construction operational settings. We therefore propose the inclusion of Physical Conditions as a distinct construct in adoption models such as UTAUT, to enhance their explanatory power in the construction context.

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THE APPLICATION OF BIM FOR CONSTRUCTION CIRCULAR ECONOMY: A SYSTEMATIC LITERATURE REVIEW

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The application of Building Information Modelling (BIM) within the Construction Circular Economy (CCE) represents a transformative approach to enhancing sustainability and resource efficiency in the built environment. Although many studies have explored the feasibility of BIM in meeting the goals of CCE, such as improving energy efficiency and promoting waste recycling, a holistic review of BIM's applications in CCE remains lacking. This study aims to fulfil the knowledge gap through systematically reviewing the relevant literature published from 2009 to 2024 by PRISMA structure and science mapping approach. Keyword co-occurrence and burst detection reveal evolving research from early lifecycle focus to recent themes such as digitalisation and demolition. Four key themes are identified. Despite growing interest, limitations remain in areas such as data interoperability and accurate waste source identification. Future research is included to integrate BIM with IoT to improve material tracking. This review provides practical implications for researchers, practitioners, and policymakers seeking to advance BIM-enabled CCE.

Keywords: building information modelling; digital technology; construction circular economy; systematic literature review; science mapping

INTRODUCTION

In recent years, the integration of Building Information Modelling into Construction Circular Economy (BIM-CCE) has been increasingly prominent, as BIM technology can enhance design optimisation, precision in construction, intelligent operation and maintenance, and sustainable demolition, thereby improving resource efficiency, reducing waste, and promoting zero-waste, low-carbon, and intelligent management in the construction industry (Tomczak *et al.,* 2024).

The circular economy (CE), as an emerging economic paradigm, has gained increasing attention over the past few decades (Benachio, *et al.,* 2020). Unlike the traditional linear economy model—characterised by a one-way flow of "take, make, dispose"—the circular economy emphasizes the continual reuse and recycling of materials within a closed-loop system to achieve a sustainable built environment (Yamoah, 2017). Existing research mostly focuses on specific subfields of this paradigm, such as waste management, material reuse, or life cycle assessment, and introduces the adoption of BIM to improve its efficiency. For instance, in the

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Rong, X, Zou, J and Mohandes, S R (2025) The Application of BIM for Construction Circular Economy: A Systematic Literature Review, *In:* Thomson, C and Neilson, C J (Eds) *Proceedings of the 41st Annual ARCOM Conference,* 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 139-148.

management of construction waste and material resources, BIM has significantly improved the efficiency of tracking, predicting, and classifying building materials (Akanbi *et al.,* 2019; Akinade and Oyedele, 2019; Handayani *et al.,* 2022). Secondly, BIM can simulate component connection methods and disassembly paths during the design phase in material recycling and building lifecycle management, enhancing the reversibility and reusability of the system (AlJaber *et al.,* 2023). At the economic level, BIM not only optimises cost control but also promotes the transformation of circular building business models. Finally, BIM has reduced losses and carbon footprints, improved resource efficiency, and created development space for the local recycled building materials market and green employment in enhancing building sustainability, optimising logistics chains, and fulfilling social responsibilities (Tomczak *et al.,* 2024).

Although research on BIM in the construction circular economy (CCE) has grown, it remains fragmented and limited to specific topics such as waste management or material reuse. Prior reviews, such as Celoza and Alvarez de Neyra (2023), provided a general overview but lacked methodological rigour and thematic structure. To address this gap, this study conducts a systematic literature review of 25 journal papers published between 2009 and 2024, using the PRISMA protocol and science mapping techniques. For further analysis, it also builds a thematic framework (Munaro, Tavares and Bragança, 2020), to identifies four core categories of BIM-CCE research: (1) waste, resources, and materials; (2) reuse, closed-loop systems, and lifecycle; (3) economic feasibility and business models; and (4) sustainability, logistics, and social responsibility.

It aims to systematically review the application of BIM in the circular construction economy and identify key research themes, gaps, and future directions. And fulfill the following four Research Objectives:

RO1: To review and synthesize existing BIM-CCE literature using structured methods.

RO2: To categorise the literature into coherent thematic areas

RO3: To identify gaps in the current research field and provide future direction.

As a result, this research contributes to a clearer understanding of the current state of knowledge. The findings offer valuable insights for both academics and industry practitioners seeking to implement BIM-driven circular strategies and lay a theoretical foundation for advancing sustainable practices in the built environment.

METHOD

This study adopts a systematic literature review (SLR) approach to examine the integration of Building Information Modelling (BIM) within the circular construction economy (CCE). The SLR methodology is a holistic and rigorous method in built environment research, aiming at scrutinising the existing knowledge, identifying gaps, and providing a structured analysis of pertinent research articles (Zhong, *et al.,* 2025). To ensure transparency and replicability, the PRISMA protocol was followed, to guide the screening process, including identification, filtering, and selection of relevant literature (Sarkis-Onofre, *et al.,* 2021). Following a structured search and evaluation process, 25 relevant articles were identified for final analysis, as illustrated in the review framework. Subsequently, a bibliometric analysis based on science mapping was conducted to explore research trends and thematic structures (Pilelienė, Alsharif and Alharbi, 2022). The details of PRISMA are as Figure 1.

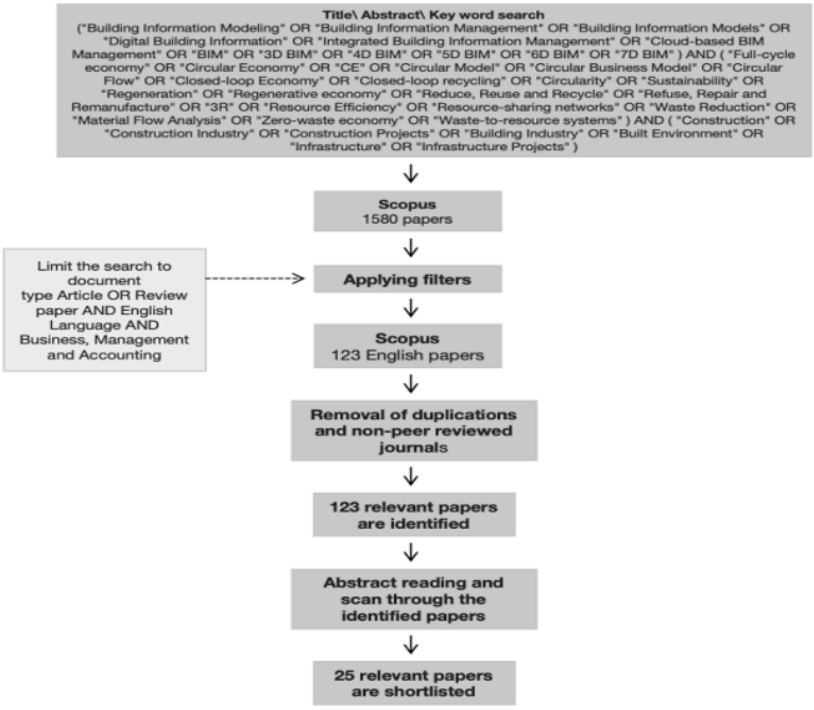


Figure 1: Full PRISMA process flow chart

FINDINGS AND DISCUSSION

This paper explores publication trends, the timeline co-citation map, keyword co-occurrence, strongest citation bursts, and its four key dimensions. The publication trends analysis tracks the growth of research output and emerging focus areas, while the timeline co-citation map reveals the development of influential studies and their interconnections over time. Keyword co-occurrence analysis identifies dominant research themes and their relationships, providing insight into the field' s structure. The strongest citation bursts highlight rapidly gaining research topics, indicating shifts in scholarly attention. Additionally, there is a content analysis, examined through four dimensions: waste reduction, resource efficiency, economic feasibility, and sustainability. Together, these analyses provide a comprehensive understanding of the current research landscape, its key contributions, and future research directions.

Publication Trend

The number of publications in the literature is an indicator of the pace, scope and outcomes of a field and helps researchers identify trends and progress in the field (Ellegaard and Wallin, 2015). Figure 2 shows the trends and progress in the field. The literature shows a growing trend in the applications of BIM in CCE research over 15 years, with 25 papers analysed, indicating that research interest and outputs in this field are sprouting. Initial research from 2009 to 2015, was sparse, focusing primarily on building green rather than construction circular economy (Tulacz, 2009). Between 2016 and 2019, publications increased, reflecting advancements in technology and a push for construction circular economy (Akinade and Oyedele, 2019). Although there is a decrease in 2020, publications recovered from 2021 to 2024, revealing there are more specific strategies to be explored (Tomczak *et al.,* 2024).

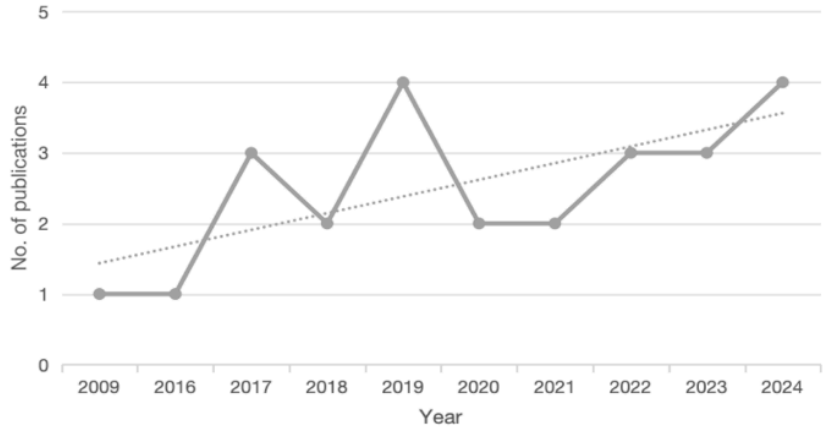


Figure 2: Distribution of published papers (2009-2024)

Co-occurrence Analysis of Keywords

Figure 3 represents a keyword co-occurrence network, visually mapping the relationships between key terms in BIM and Circular Economy (CCE) research. In this network, nodes (circles) represent keywords, where larger nodes indicate higher frequency of occurrence in the dataset, meaning they are core research topics.



Figure 3: Keyword co-occurrence network

The edges (lines) between nodes signify co-occurrence relationships, with thicker lines showing stronger associations between keywords in published studies.

Findings from Figure 3 indicate that "Building Information Modelling (BIM)," "Circular Economy," and "Sustainable Development" are dominant themes, forming the foundation of research in this field. The presence of emerging keywords like "decision making," "construction supply chain," and "energy efficiency" suggests a growing interest in optimising resource use and integrating BIM in sustainable

construction practices. Additionally, the isolated cluster of "end of lives" suggests that BIM's application in managing the end-of-life phase of buildings remains an underexplored research area.

The timeline co-occurrence map (Figure 4) illustrates the evolving trajectory of BIM-related CCE research across three distinct phases. From 2009 to 2015, early studies predominantly focused on lifecycle management and BIM adoption, particularly in supporting the design of net-zero energy buildings (Tulacz, 2009). Between 2015 and 2020, the research emphasis shifted to addressing implementation barriers, strategic planning, and material supply decision-making through BIM (Alireza *et al.,* 2017; Saieg *et al.,* 2018; Vardan and Prasad, 2019). Nonetheless, limitations in BIM user capacity and digital skill gaps persisted as key obstacles (GhaffarianHoseini *et al.,* 2017). Since 2020, the research has increasingly concentrated on demolition planning and material recovery using digital technologies such as IoT and material banks (Balasubramanian *et al.,* 2024). However, challenges remain regarding the accuracy of material data collection and the integration of real-time tracking systems (Manganelli and Tataranna, 2020; Chen, Feng and Garcia de Soto, 2022). Overall, the evolution of BIM-CCE research reflects a gradual shift from lifecycle design to data-driven material recovery.

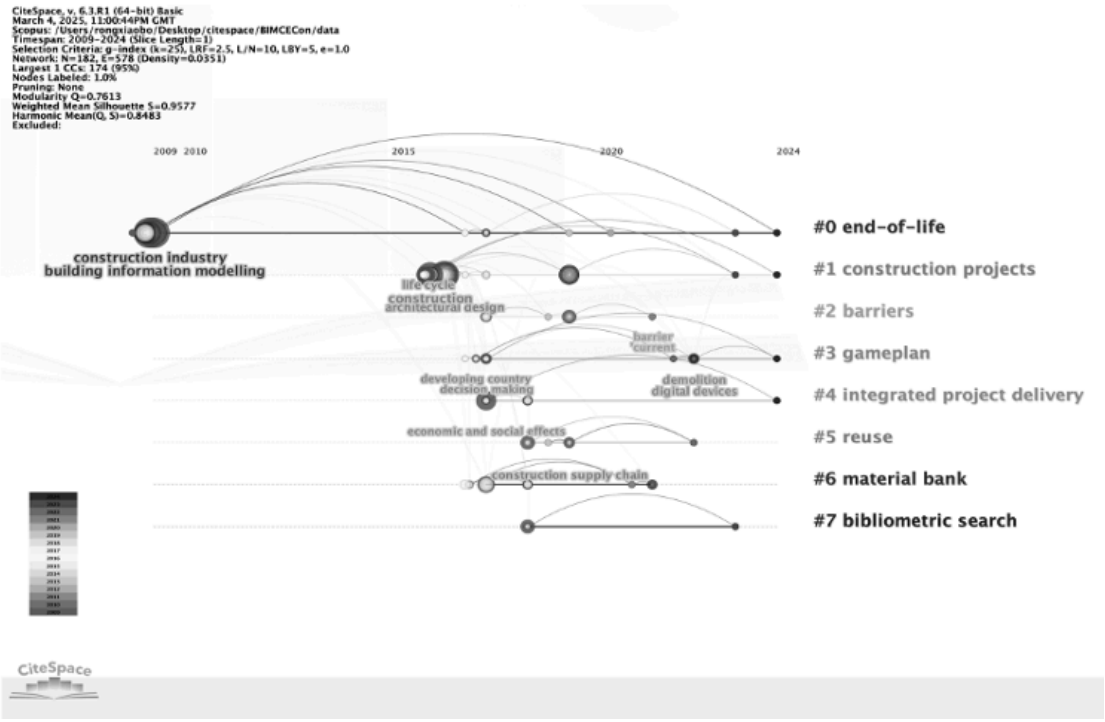


Figure 4: Timeline co-occurrence map of keywords

Keyword Citation Bursts Analysis

The role of burst detection is to identify research frontiers and emerging trends, reveal important topics, and predict future research directions (Zhang *et al.,* 2023). The keywords with the most robust citation bursts, summarised in Figure 5, represent the research trends in BIM in CCE. From 2016 to 2019, studies focused on sustainable building materials, decision-making processes, and the economic and social impacts of construction. Between 2019 and 2021, the emphasis shifted towards end-of-life strategies and circular economy models, highlighting material reuse and recycling within BIM-supported frameworks. More recently, from 2022 to 2024, research has increasingly centred on digital tools, smart technologies, and automated demolition,

aiming to optimise resource recovery and enhance sustainability through BIM integration. This progression reflects a growing synergy between BIM, digitalisation, and circular economy principles in the construction industry.

Figure 5: Top 10 keywords with the strongest citation bursts during the research history of The application of BIM in CCE



Content Analysis

Waste, Resources and Materials

This category centres on the application of BIM in managing construction waste and material flows, which is fundamental to circular construction. Although terms such as building materials are not visually prominent in Figure 4, they are critical in this field. Recent studies have increasingly integrated BIM with IoT to estimate waste generation and develop intelligent systems, such as ANFIS-based analytics, for material classification (Akanbi *et al.,* 2019; Akinade and Oyedele, 2019). Other works focus on identifying recyclable components using BIM-enabled databases (Handayani *et al.,* 2022). Despite these advances, BIM's role in supporting comprehensive waste and resource optimisation remains limited. Future directions include integrating BIM with real-time IoT sensors for material tracking and combining BIM with quantitative tools to improve the estimation of recoverable materials (Akanbi *et al.,* 2019; Akinade and Oyedele, 2019).

Reuse, Closed Loop, and Lifecycle

This category addresses how BIM facilitates material reuse and supports closed-loop systems across the building lifecycle. Studies have explored the integration of BIM and IoT to enable real-time tracking and promote reuse in construction and demolition phases (Heidari, Peyvastehgar and Amanzadegan, 2023) contributing building materials to be recovered, reused, or remanufactured at the end-of-life phase and reintegrated into the supply chain, thus forming a closed-loop system (Feng *et al.,* 2022). Besides, lifecycle assessment (LCA) remains a long-standing research focus (Alireza *et al.,* 2017; Atik, Aparisi and Raslan, 2024), buy a fully integrated framework that bridges BIM, LCA and circular economy principles is still lacking (Akinade and Oyedele, 2019). This highlights the need for systematic approaches to lifecycle-based circular construction.

Diversity, Economic Feasibility and Business Models

This category explores the economic and organisational feasibility of implementing BIM for circular construction. BIM has been applied to create material libraries for

reuse and recycling (Behún and Behúnová, 2022), and to model circular business strategies (Chen, Feng and Garcia de Soto, 2022). However, small- and medium-sized enterprises (SMEs) often face challenges in BIM adoption due to resource constraints (Geoghegan *et al.,* 2023), and the lack of economic incentives remains a barrier to its widespread use (Balasubramanian *et al.,* 2024). These challenges call for new business models and supportive policy frameworks to enhance BIM-driven circular practices.

Sustainability, Logistics Network and Social Responsibility

This category captures how BIM contributes to broader sustainability goals, including environmental performance, logistics coordination, and social impact. BIM integrated with circular economy strategies has been shown to reduce waste and improve recycling rates (Mandičák, Spišáková and Mésároš, 2024). Nevertheless, barriers persist regarding user competency and digital skills, which limit the depth of BIM application (GhaffarianHoseini *et al.,* 2017). In addition, logistics systems for industrial symbiosis and reverse logistics remain underdeveloped (Feng *et al.,* 2022). Further research is needed to enhance BIM-supported coordination across supply networks and stakeholder roles.

Research Gaps and Future Trends

Table 1: Existing Limitations and Future direction

Dimension	Existing gaps	Future direction
Waste, resources and materials	Lack of precise analysis of different sources of waste.	BIM combined with IoT sensors for real-time data tracking.
Reuse, closed loop and lifecycle	Overly theoretical predictions of recyclable materials.	Add quantitative methods to BIM to estimate the quantity of recyclable materials.
Diversity, economic feasibility and business models	Data exchange limitations in BIM through lifecycle.	Improve data interoperability and optimise data sharing mechanisms.
Sustainability, logistics network and social responsibility	Lack of a structured workflow for integrating BIM with LCA and CE principles.	Develop a structured BIM protocol.

This study identifies several existing research gaps across the key dimensions of BIM integration in the circular construction economy, with future directions. These findings serve as a basis for subsequent empirical investigation. Further studies are expected to design and validate a BIM-based framework for circular construction, with a particular focus on material tracking, lifecycle assessment, and cross-platform data integration, thereby making both theoretical contributions and practical impacts in advancing digital circular construction.

CONCLUSIONS

This study systematically evaluates the application of BIM in the CCE, highlighting its role across four key dimensions: waste and material management, reuse and lifecycle, economic feasibility and business models, and sustainability and logistics networks. It also identifies several research gaps, including the lack of IoT integration, quantitative methods for recyclable materials, optimised data-sharing mechanisms, limited BIM adoption, and weak integration with construction supply chains. Key findings include:

There has been a steady increase in the volume of scholarly publications concerning the CCE domain.

The CCE field has formed a knowledge framework centred on "BIM," "sustainable development," and "circular economy", and has expanded in recent years towards "decision making," "construction supply chain," and "energy efficiency" and other directions. At the same time, it also suggests that issues such as "end of lives" still belong to research blind spots and are worth exploring in depth.

The development path of BIM and CCE research from lifecycle management to intelligent deconstruction and recycling indicates that future research will rely more on digital tools to achieve data-driven sustainable transformation of buildings.

The development path of BIM in circular building research, from common concepts in the construction industry to intelligent deconstruction, reflects the gradual concretisation and digitisation trend of BIM in realising circular economy and achieving sustainability.

This study offers meaningful implications for various stakeholders. For academic researchers, the research trends and thematic framework provide a systematic roadmap for future exploration. For practitioners in the construction industry, the identified trends—such as material tracking, deconstruction planning, and resource reuse—can inform the implementation of BIM-based sustainable practices. For policymakers, the highlighted gaps (e.g., end-of-life building management, BIM-IoT integration) can serve as strategic directions for digital transformation and green construction policies. Therefore, this study contributes not only to the theoretical understanding of BIM-CCE integration but also to actionable insights for promoting sustainable and circular practices in the built environment.

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EXPLORING THE ROLE OF DIGITAL TWIN TECHNOLOGY IN ACHIEVING NET ZERO BUILDINGS: A SYSTEMATIC LITERATURE REVIEW

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Digital twin (DT) has emerged as a critical tool in the building sector's transition toward Net Zero. Despite DT makes a significant contribution to sustainable buildings, the role of DT in achieving carbon neutrality remains underexplored. To fill the gap, the study examines the DT implementation in achieving net zero buildings through a systematic review of literature published between 2017 and 2025. Employing PRISMA and bibliometric analysis, 55 publications from Scopus, Web of Science, and Grey Databases are reviewed. The findings reveal a dramatic surge in 2024 when publication numbers quadrupled, due to the demonstrated effectiveness of DT in achieving net zero building performance. Geographic analysis shows European dominance with Italy leading both in productivity and network influence. Keyword co-occurrence analysis identified six research clusters, demonstrating a coherent evolution from theoretical frameworks to technological integration and practical implementation strategies. Beyond mapping the current research status, this study also identifies significant research gaps and future trends, including fragmented lifecycle integration, limited data interoperability, underdeveloped autonomous control mechanisms, geographic research biases, and inadequate incorporation of human-centred approaches.

Keywords: digital twin; net zero buildings; net zero energy buildings; virtual twin; zero carbon buildings

INTRODUCTION

The global imperative to mitigate climate change has propelled the building sector to the forefront of environmental initiatives, as this sector accounts for approximately 40% of total global energy consumption and 36% of carbon emissions worldwide (IEA, 2024). In response to this challenge, the World Green Building Council (2017) has established targets of achieving net zero carbon for all new buildings by 2030 and for all existing buildings by 2050, creating a transformation framework for the built environment. BREEAM (2018) defines "Net Zero Carbon Building (NZCB)" as one that achieves carbon neutrality over its entire life cycle, which provided a holistic scoring system and certification levels.

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The evolution of digital twin technologies, alongside the integration of BIM, IoT, AI and Blockchain, has provided robust technical support for building carbon management. Through continuous monitoring, simulation, and optimisation capabilities, digital twins enable precise management of building systems, integration of renewable energy sources, and implementation of smart control strategies that respond to changing environmental conditions and occupancy patterns (Elghaish *et al.,* 2024). Digital twin technology facilitates the implementation of smart controls in NZCB systems, as demonstrated by Zhang *et al. (*2024) who found that DT-enabled smart control applications in HVAC and lighting systems lead to estimated energy savings of 25 to 42%.

These technologies bridge the performance gap between designed and actual energy usage by accounting for variables traditional models miss, such as occupant behaviour patterns (Agostinelli *et al.,* 2021) and changing environmental conditions (Cui *et al.,* 2024). Digital twins further enable precise integration of distributed energy resources, facilitate predictive rather than reactive building management strategies, and support district-level energy optimisation (Nour El-Din *et al.,* 2024). Despite the significant potential of digital twin technologies in achieving NZCBs, challenges such as data integration between different building systems with varied communication protocols (Liu *et al.,* 2025) and computational demands for processing real-time data remain, alongside data quality issues from environmental factors affecting sensor precision (Zhang *et al.,* 2024), data privacy concerns, and the scarcity of skilled professionals (Falana *et al.,* 2024).

This review addresses research gaps in the adoption of DT to achieve net zero buildings. It identifies key deficiencies, such as fragmented lifecycle integration. The review aims to comprehensively map current research, explore existing gaps and future directions. Finally, it seeks to guide building professionals in developing effective digital twin systems, conducting energy performance assessments, and navigating implementation challenges to enhance sustainability and resource efficiency in net zero built environments.

METHOD

Systematic literature review (SLR) provides rigorous methodologies for comprehensively synthesising existing knowledge within specific domains, following predefined protocols to minimise bias and ensure replicable evidence synthesis (Moher *et al.,* 2009). This paper combines the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) shown in the Figure 1 and bibliometric analysis to produce a SLR of digital twin applications in the net zero buildings. PRISMA guided the systematic literature search, screening, and eligibility assessment across multiple databases (Moher *et al.,* 2009).

Literature Search

The first step was to search in the Scopus, Web of Science, and grey literature databases. After several search trials, the complete search strings used were (TITLE-ABS-KEY (“Digital Twin” OR “Digital Twins” OR “Virtual Twin” OR “Cyber-Physical Systems” OR “Digital Replica”) AND TITLE-ABS-KEY (“Net Zero Buildings” OR “NZB” OR “Net Zero Construction” OR “Net Zero Energy Buildings “ OR “NZEB” OR “Zero Carbon Buildings” OR “Carbon Neutral Buildings” OR “Net Zero Carbon Footprint” OR “Green Building Technologies” OR “Grid-Interactive Efficient Buildings”))

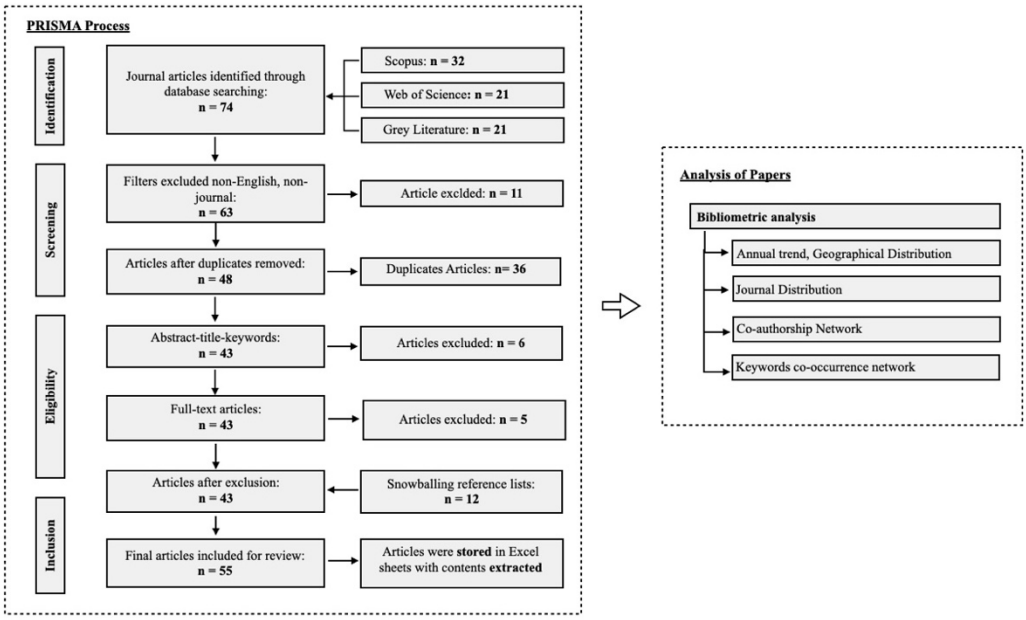


Figure 1: PRISMA process flow chart

Screening

Table 1 presents the screening criteria for systematic literature searching across Scopus, Web of Science, and Grey Literature databases, covering publications from 2017 to 2025 in English. While academic databases focused on peer-reviewed journal articles, grey literature sources targeted reports from key industry organisations to ensure comprehensive coverage.

Table 1: Screening criteria for searching literature (author's own work)

	Scopus	Web of Science	Grey Literature
Year	2017 to 2025	2017 to 2025	2017 to 2025
Document type	Article or Review	Article or Review Article	Reports
Source type	Journal	Web of Science Index: Science Citation Index Expanded (SCI-EXPANDED) or Social Sciences Citation Index (SSCI) or Emerging Sources Citation Index (ESCI)	IEA, UNEP, CIB, WGBC, UKGBC, ISO, McKinsey & Company, PwC, Arup
Publication stage	Final	Published	Published
Language	English	English	English

Bibliometric Analysis

This study employed bibliometric analysis to identify research trends and map knowledge structure of this field (Bota-Avram, 2023). Utilising tools like CiteSpace, the analysis created visual maps of co-authorship, keyword co-occurrences clusters and timeline to identify critical contributors and research hotspots in the DT adoption for net zero carbon buildings.

FINDINGS AND DISCUSSION

This paper examines publication trends, geographical distribution, co-authorship, journal contributions and analysis of keyword co-occurrences.

Publication Trend

As illustrated in Figure 2, the number of publications in the literature is an indicator of the pace, scope, and outcomes of a field and helps researchers identify trends and progress in the field (Ellegaard and Wallin, 2015).

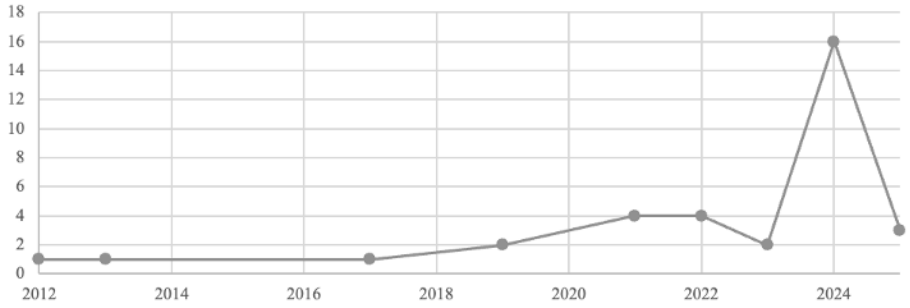


Figure 2: Publication Trend

Figure 3 shows the trend of publications related to digital twin technologies in net zero buildings.



Figure 3: Geographical distribution

From 2012 to 2017, research output remained minimal with approximately one article published per year, indicating this research area was essentially unnoticed in academic circles. Between 2017 and 2023, the field experienced modest growth, gradually climbing to just over four articles per year, suggesting slowly increasing recognition but still limited overall attention. The most striking feature is the explosive growth observed in 2024, when publication numbers suddenly quadrupled to sixteen articles in a single year. This dramatic surge suggests this relatively new topic has abruptly captured significant research interest, potentially due to technological breakthroughs in digital twin implementations or their demonstrated effectiveness in achieving net zero building performance. Although the data for 2025 is incomplete, early indicators suggest this heightened interest may continue, positioning digital twin technologies for net zero buildings as an emerging research hotspot in the sustainable built environment domain.

Geographical Distribution

The hotpots of digital twin and net zero buildings research show a regional imbalance; more researchers in Europe focused on this topic, represented by Italy, Spain, and

England. Italy leads both in productivity (7 publications) and network influence (centrality 0.03), serving as a key connector between research clusters. The United States maintains significant influence (centrality 0.03) despite older publications (2017), highlighting its enduring bridging role. Australia (2022) and Spain (2021), though equally productive (4 publications each), occupy peripheral positions with zero centrality. England's contribution (3 publications, 2019) also shows low network integration with zero centrality, indicating isolated research efforts.

Table 2: Top 9 countries based on frequency

Countries	Frequency	Centrality	Countries	Frequency	Centrality
Italy	7	0.03	Portugal	2	0.00
Australia	4	0.00	China	3	0.00
United States	4	0.03	Austria	2	0.00
Spain	4	0.00	India	1	0.00
England	3	0.00			

Leading Authors

According to Table 3, Kaewunruen has the highest centrality value (0.02) among all authors, followed by Monteleone, Sresakoolchai, Tomazzoli and Welsh (all with 0.01). These authors with higher centrality values likely represent bridge researchers connecting different research clusters or topics within the field. The most frequently cited authors include Agostinelli, Cumo, Guidi, Kaewunruen, and Tomazzoli, respectively with 4 citations, indicating their significant influence in the research domain.

Table 3: Top 10 most cited authors based on frequency

Authors	Frequency	Centrality	Authors	Frequency	Centrality
Kaewunruen, Sakdirat	4	0.02	Monteleone, W	2	0.01
Tomazzoli, Claudio	4	0.01	Sresakoolchai, Jessada	2	0.01
Agostinelli, Sofia	4	0.00	Welsh, Joshua	2	0.01
Cumo, Fabrizio	4	0.00	Bass, Brett	2	0.00
Guidi, Giambattista	4	0.00	Blanco, Teresa	2	0.00

Journal Statistics

Analysis of publication distribution reveals concentrated research presence across sustainability-focused journals. Energies (Switzerland) leads with the highest publication count (7 papers, 16.2%), followed by Sustainable Energy Technologies and Assessments (UK) and Sustainability (Switzerland), each contributing 5 papers (13.5%). Together, these three journals account for nearly half (43.2%) of all publications in the field. While Energy and Buildings (Netherlands) published fewer papers (3 papers, 8.1%), it maintains a strong academic influence with a high h-index of 184.

Most notably, Renewable and Sustainable Energy Reviews, despite containing only 2 papers (5.4%), possesses the highest impact factor (16.3) and h-index (304) among all journals represented, indicating exceptional scholarly significance. Host countries of journals show European dominance in publishing, with journals based primarily in Switzerland, the United Kingdom, and the Netherlands. This publication pattern reflects the field's orientation toward energy sustainability and built environment applications, with research appearing predominantly in specialised sustainability and energy-focused journals rather than general engineering publications.

Table 4: Breakdown of the leading journals

	Host Country	Count	Percentage (%)	Impact factor	h-index
Energies	Switzerland	7	16.2	3.25	93
Sustainable Energy Technologies and Assessments	United Kingdom	5	13.5	5.35	58
Sustainability (Switzerland)	Switzerland	5	13.5	3.889	96
Energy and Buildings	Netherlands	3	8.1	5.879	184
Buildings	Switzerland	2	5.4	3.3	40
Sustainable Cities and Society	Netherlands	2	5.4	7.587	95
Renewable and Sustainable Energy Reviews	United Kingdom	2	5.4	16.3	204

Co-occurrence of Keywords

The keyword co-occurrence network analysis revealed six distinct research clusters, each representing a significant thematic focus within sustainability research during the 2017-2025 period. The earliest research emphasized foundational concepts, with Cluster #0 (Net-zero Energy) establishing the theoretical frameworks and practical approaches to energy neutrality, characterised by densely interconnected nodes indicating a mature research area. Concurrently, Cluster #5 focused on carbon neutrality in building design and business models, forming another cornerstone of early sustainability research. As the field evolved, Cluster #3 emerged as a bridge between conceptual and implementation phases, exploring potential applications and solutions within sustainable frameworks.

The middle period (2021-2023) saw the emergence of Cluster #2, marking the integration of blockchain technology and security considerations into sustainability research, a significant technological advancement in the field. As research continued to mature, Cluster #4 concentrated on development methodologies and implementation frameworks, while the most recent research represented by Cluster #1 (2023-2025) focused on practical approaches to achieving net-zero targets, building upon the decade's accumulated knowledge. This temporal progression demonstrates a coherent evolution from theoretical conceptualisation to practical implementation strategies, with increasing technological sophistication and interdisciplinary integration characterising later research efforts. The clear delineation between clusters, confirmed by high silhouette values, suggests distinct research communities working on complementary aspects of sustainability, though the interconnections between clusters indicate substantial knowledge transfer across these communities.

The temporal bibliometric visualisation from CiteSpace captures a comprehensive analysis of digital sustainability research evolution spanning from 2017 to 2025. Beginning in 2017, foundational work centred on artificial intelligence applications in building systems, energy management, and intelligent automation, which subsequently evolved through multiple phases of specialisation. The visualisation identifies eleven primary research clusters as shown in Table 5, demonstrating how the field has progressively shifted from generalised AI applications toward increasingly specific sustainable building implementations.

The temporal evolution shows three distinct phases: early-stage technological foundations (2017-2020) focusing on artificial intelligence and initial net-zero energy concepts; a consolidation period (2018-2022) emphasising digital twinning, building information modelling, and refined energy efficiency approaches; and a mature application phase (2020-2025) concentrating on carbon-neutral and zero-carbon

building implementations, blockchain security for data management, and comprehensive community-scale solutions.

Figure 4: Keyword co-occurrence network (author's own work)

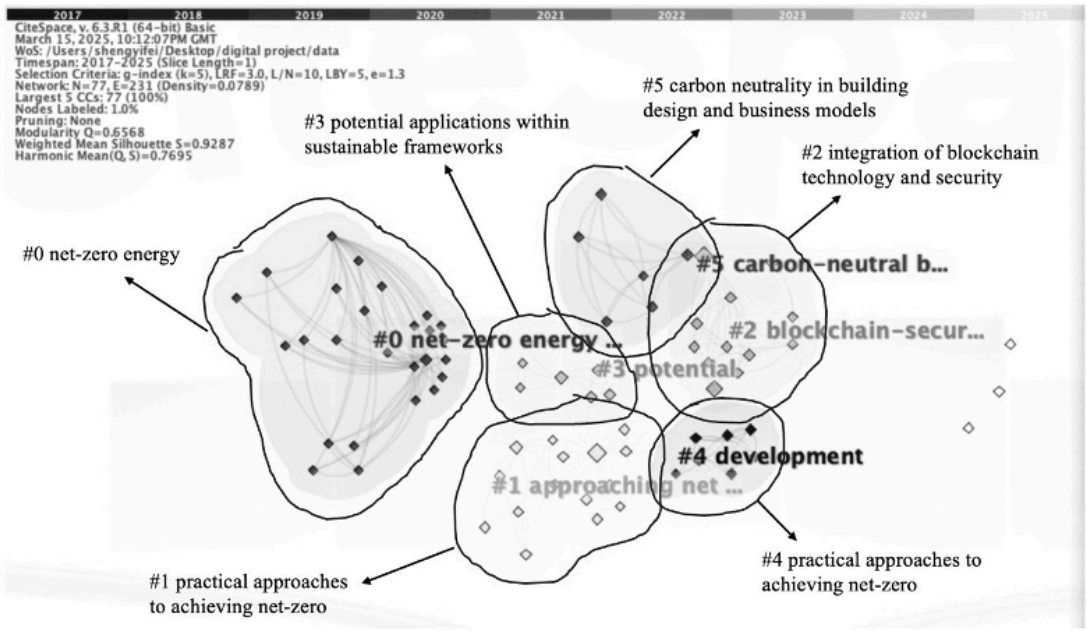


Table 5: Timeline co-occurrence of keywords (author's own work)

Clusters	Research Focus	Keywords	Time Concentration
#0	Artificial Intelligence	artificial intelligence, building systems, energy management, information management, intelligent automation	2017-2020
#1	Net-Zero Energy	net-zero energy, energy efficiency, building performance	2018-2021
#2	Digital Twinning	digital twinning, building information modelling, simulation	2019-2022
#3	Net Zero Energy	net zero energy, renewable energy, energy systems	2020-2023
#4	Carbon-Neutral Building	carbon-neutral building, sustainability, green building	2020-2024
#5	Zero-Carbon Building	zero-carbon building, sustainable design, environmental impact	2021-2024
#6	Blockchain Security	blockchain security, data management, smart contracts	2021-2024
#7	Zero-Carbon Community	zero-carbon community, urban planning, smart city	2022-2025
#8	Monitoring	monitoring, building automation, sensor networks	2022-2025
#9	Potential Energy	potential energy, energy storage, demand management	2023-2025
#10	Approaching Net Zero	approaching net zero, energy transition, policy	2023-2025

Recent developments have expanded toward zero-carbon communities, advanced monitoring systems utilising sensor networks, and sophisticated energy storage and demand management approaches. Network metrics indicate well-defined research communities (Modularity Q=0.7675) with distinct clustering boundaries (Silhouette S=0.9405), suggesting a mature field with specialised sub-domains. The

chronological distribution across the horizontal timeline illustrates how digital technologies have increasingly prioritised practical energy management applications and zero-carbon building solutions as the research domain has matured over these eight years.

Research Gaps and Future Direction

Based on the bibliometric analysis and systematic review, six research gaps have been identified for future research directions, as outlined in Table 6.

Table 6: Existing gaps and future directions

Dimension	Existing gaps	Future direction
Fragmented Lifecycle Integration	Most existing research has dealt with carbon emissions and digital twin applications in individual building stages rather than integrating them throughout the whole building lifecycle process	Develop integrated digital twin frameworks that connect all building lifecycle stages, ensuring seamless data flow from design through operation to end-of-life
Limited Data Integration and Interoperability	There is a lack of data integration frameworks that effectively combine information from diverse building systems, sensors, and stakeholders to support comprehensive digital twins	Create adaptive data architectures that harmonize diverse building systems and sensor networks while providing intuitive visualisation for different stakeholders
Limited Autonomous and Adaptive Building Control	There is insufficient research on autonomous building control systems that adapt to user needs in real-time through digital twin integration, particularly for systems that span multiple zones or buildings	Advance autonomous building control systems that operate across multiple scales, from individual zones to building clusters and communities
Geographic and Climate Context Limitations	A considerable lack of research is observed for African and South American countries, as well as limited ready-to-use applications that cater specifically for hot climates and other specific environmental contexts	Expand digital twin research to diverse geographic and climate contexts, particularly underrepresented regions like Africa and South America
Limited Human-Centred Design and Stakeholder Engagement	There is a lack of human-centred approaches for building optimization and limited focus on the subjective perception of occupants, with few studies systematically identifying key stakeholders in the net-zero carbon building lifecycle	Centre human experience by incorporating occupant perceptions, preferences, and behaviours into digital twin optimization algorithms
Technological Evolution and Integration	Research has evolved from early applications of AI and embedded systems toward specialized approaches (digital twinning, energy efficiency frameworks, carbon-neutral building technologies), but this transition has resulted in fragmented technological development rather than cohesive integration	Develop integrated technological frameworks that synthesize evolved AI capabilities, embedded systems, digital twinning, and energy efficiency technologies into unified platforms for comprehensive building performance optimization

CONCLUSIONS

The SLR examines digital twin technology implementation in net zero buildings by analysing 55 publications from 2017-2025. Using PRISMA and bibliometric analysis, the research identifies research trends, geographic distributions, and key thematic clusters. The main research findings are as follows:

1. Research Evolution: The field has experienced dramatic growth in 2024 with publication numbers quadrupling, indicating a shift from theoretical exploration to practical implementation. This surge coincides with global sustainability initiatives and technological breakthroughs in digital twin capabilities.

2. Geographic Leadership: Italy emerges as both the most productive nation and key connector in research networks. European dominance is further reflected in the publications, hosting the most influential journals. Compared with European, considerable research gaps exist for African and South American countries and limited applications for hot climates in digital twin (DT) applications for net zero buildings.

3. Research Clusters: the keyword co-occurrence analysis identified six distinct thematic clusters that demonstrate a coherent progression from theoretical frameworks (Cluster #0: Net-zero Energy) to technological integration (Cluster #2: Blockchain Security) and finally to practical implementation strategies (Cluster #1: 2023-2025). The high modularity (Q=0.7675) and silhouette values (S=0.9405) confirm well-defined research communities with substantial knowledge transfer between them. Practically, gaps remain in data integration frameworks, autonomous building control systems, and human-centred DT approaches for net zero.

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ARTIFICIAL PROBLEMS WITH ARTIFICIAL SOLUTIONS? EXPLORING THE ROBUSTNESS OF USE CASES WITHIN AI-FOCUSED CONSTRUCTION MANAGEMENT RESEARCH

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Artificial Intelligence (AI) is a rapidly growing focus of construction management research. Various government strategies, research and innovation funders, and industry reports express the tremendous potential that AI is perceived to offer for this domain. While these perceptions may ultimately be proved correct, it is also likely that the current expectations for AI are based largely on technological optimism and deterministic trends that presume value prior to empirical validation. Therefore, this work analyses the body of AI research for construction management, using a purposive sample of the ARCOM abstracts database, with a focus on use case explication. Findings revealed only 56% of the sample papers contained any type of use case, the majority of which were superficial and drew on generalisations of efficiency and accuracy counterpointed with human subjectivity. Some use cases identified lacked contextual justification, which in the case of predictive AI for planning and scheduling diluted the use case arguments made therein. The lack of robust use cases within the body of research was concerning, thus suggestions are made for ways in which researchers can ensure their work is robust and valid rather than simply conforming to the dominant technocratic orthodoxy of our time.

Keywords: artificial intelligence; technology; use case; workers

CONTEXT

Artificial Intelligence (AI) has pushed itself to the forefront of the Industry 4.0 Revolution. With the ability to hold dominion over the nascent technological landscape, AI is able to bring together myriad different applications through the internet of things (IoT), perform human functions with far greater speed, accuracy and efficiency, and indeed take on tasks that humans could simply never achieve due to the sheer volume of data or the numbers of different factors or variables involved (i.e., Big Data). The pace and scope of such technological developments, described as 'exponential' by Brynjolfsson and McAfee (2014), shows few signs of slowing down.

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Sherratt, F, Franz, B, Ayer, S and Sherratt, S (2025) Artificial Problems with Artificial Solutions? Exploring the Robustness of Use Cases within AI-focused Construction Management Research, *In:* Thomson, C and Neilson, C J (Eds) *Proceedings of the 41st Annual ARCOM Conference,* 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 159-168.

With the potential to influence (and, seemingly, always enhance) almost all aspects of human endeavour, it is therefore unsurprising that the construction sector, long criticised for poor performance, a lack of predictability and over-reliance on manual labour (Farmer 2016), has rushed towards technology, and AI, as the solution to all its ills (Sherratt *et al.,* 2020).

However, this sprint towards adoption, loudly cheered on by construction firms, governments, research funders (Green 2022) and, not coincidently, the technology developers and providers themselves, is not without concern. Other factors are at play, not least the inevitable influence of Ellul's (1954) theory of Technique through which our expectations and understandings of what is acceptable and desirable about technologies are shaped. Through Technique, the rapid and unquestioned adoption of technology, in all forms, is positioned as the only appropriate direction for progress, the only logical step to take - if only because we can, with little to no consideration as to whether we should (Sherratt 2022a). Challenges against such technocratic determinism become moot as implementation is surely inevitable because without it, optimum efficiencies could not be achieved. Technology is often ascribed with a neutrality that it arguably does not deserve, and we should be far more wary of its power to influence and shape its own manifestations. How technology, through Ellul's theory of Technique, weaves its twin cloaks of technological optimism and determinism has previously been discussed in depth by Sherratt *et al. (*2020; 2022a; 2024) and so is not repeated here.

However, the consequences of Technique are arguably evident enough, and the body of research surrounding technology within construction management has seemingly become enthralled; technological optimism and determinism abound (Sherratt 2022a). Construction management researchers, like everyone else in the world, are not immune to Technique. For example, considerable hyperbole surrounds the use and benefits of wearable technologies for construction safety: 'It is time construction… strongly embraced these emerging trends in technological development to drastically enhance safety performance.' (Awolusi *et al.,* 2018:104). Yet following a granular analysis of the peer-reviewed body of work on the use of wearable technologies for safety management, the case for implementation, '…could generously be considered 'limited'…. [and is] nowhere near able to make claims of effectiveness in the field…' (Sherratt 2024). Thus, it is based on little to no empirical evidence that we are urged, as an industry to 'strongly embrace' technology to 'drastically enhance' safety on construction sites. This is Technique writ large.

There are however remedies to this situation, and ways to seek to counter the influence of Technique within research of technology. In this paper, we specifically focus on AI and the research of its applications to construction management, because of its pervasive nature. To justify such research (and we use the term 'research' deliberately here to indicate an appropriate testing/validatory step taken prior to implementation) a clear rationale should be provided as to the benefits it is expected to bring. Research usually must justify itself in this way, to not only secure funding but also quite rightly to meet the requirements of ethical approval processes intended to avoid spurious research or wasted time and resources. With regards to AI, such justification can be most readily made through a 'use case'; a description of sequences of events that lead to a system doing something useful (Bittner and Spence 2003). We consider a 'good' use case to not only include consideration of the specific context in which the application of AI is explicitly situated, and thus the reasons and rationale for such application, but to also make clear evaluations of any human involvement,

such as whether the AI is able to perform a task better (defined and explicitly stated whether better is faster, more accurate, or less wasteful, etc.) than a human, or is it something humans do not like to do (e.g., tedious repetitive functions). Any technology will not exist in isolation, they support processes and people, and thus a lack of consideration of human involvement would be incomplete.

Therefore, the aim of this study was to explore the rigor and robustness of use cases within the body of research focused on AI for construction management. We wanted to not only examine the influence of Technique on such research, but more explicitly unpack the rigor of the rationale that lies beneath, in the form of distinct use cases. We ask whether researchers are applying artificial solutions to artificial problems, or whether the body of work is taking a rational and well-justified research approach towards activities and process that are knowingly problematic, and in which AI could potentially have a role to play.

METHOD

The data for this study was drawn from the ARCOM Abstracts Database, which contains abstracts from leading journals in construction management, ARCOM conference proceedings, and PhD dissertations. A combined search on both terms [Artificial Intelligence] AND [Management] undertaken in February 2025 resulted in n=121 outputs. An initial review removed unpublished PhD theses and outputs that did not relate specifically to construction management as out of scope. For example, papers relating to design, facilities management and disaster recovery were not considered. A final screening eliminated one further paper that could not be accessed, resulting in a total of n=59 outputs for detailed analysis. By using the ARCOM database for our search, we were able to limit the sample to a manageable size, as well as draw on a database with specific relevance for this conference. A basic analysis of each paper was undertaken to determine the focus of the AI application and extract the details of any use cases therein. Additionally, a critical discourse analysis (Fairclough and Wodak 1997) was carried out to further unpack any presented use cases, to illuminate the dominant discourses that are shaping the justification and validation of AI within the field of construction management. Due to constraints of space, only the most prominent findings are shared below.

FINDINGS AND DISCUSSION

Research of the application of AI to construction management problems began in the 1980s (Hua 2008) with the creation of Expert Systems in which computers performed decision making using rule-based systems on a par with humans. AI has since developed through machine learning, to generative AI and large language models. Accordingly, the first pass of the sample data revealed papers published between 1985 and 2024. Earlier papers naturally focused more on AI embodiment through Expert Systems and remained tentative in discussing and considering the applications of AI for construction management. Later work is notably more detailed with regards to application to practice and has more recently begun to include evaluations and analysis of the contemporary use of AI by the industry itself. This suggests that academia is now perhaps lagging industry and is certainly behind the innovators of such technologies for commercial use.

Four different types of paper could be categorised within the data: n=5 opinion surveys, n=7 discussion papers, n=14 systematic or state-of-the-art review papers and n=33 technical papers that detailed the development/application of a specific AI for

construction management. Technical papers are those that include details of the development of the AI technology, including explication of its architecture, any networks and models, and thus should also include a use case for the specific application as developed. Among the technical papers, the most prominent uses of AI were for prediction (n=19) including scheduling, planning and resourcing; enhanced decision making (n=8) in a variety of project management applications; and monitoring (n=5) of both the jobsite in terms of progress and productivity and the workers, ostensibly for their own safety.

Making the Argument for AI: Unpacking the Use Cases

33 of the 59 papers were identified through the analysis to contain something that could be deemed a use case. However, these 33 papers did not directly correspond to those identified as technical papers. In fact, n=7 technical papers did not make a use case at all, whilst use cases were identifiable in some of the non-technical papers. These use cases themselves ranged from detailed and focused arguments for the use of AI within that specific context, as found in n=6 papers, to weaker and more superficial evaluations extending to only one or two lines, as found in n=21 papers. Interestingly, several papers made their use case from the point of view of the technology itself (n=6). A total of n=26 papers did not make any type of use case at all. Overall, a use case of any type could only be identified in 56% of the papers of all types. This finding is itself concerning and suggests a field researching AI applications for construction management because it can, not necessarily because it should.

What does a 'Good' Use Case Look Like?

An example of a 'good' use case was identified in the work of Boussabaine (2001), as they sought to apply AI to construction project estimating as a predictive task. Within their use case, Boussabaine argued that AI can make better judgements than experts, is more accurate in application of such judgements, and that contemporary estimating practice was inconsistent due to '… the lack of a binding mechanism that relates the present case to past patterns.' (ibid 2001:105). However, Boussabaine also explicitly considered the human estimator within the process, drawing from the field of human psychology in comparison to the functionality of AI, noting that experts are better than AI at information selection, adding depth to the use case. Indeed, to the reader, this balanced use case suggests areas of human-technology 'co-working' may be necessary to optimise the use of AI for estimating. Interestingly, in this paper Boussabaine also calls for more research to demonstrate the 'benefits of such technology for construction management over traditional methods.' (ibid 2001). This is effectively a call for more evidence-based use cases, which we can only support, and the research is clearly framed as having the potential, as opposed to inevitability, for AI to '…be a valuable tool.' (ibid 2001:105).

A more recent paper also categorised as 'good' with regards to its use case consideration, was that of Cheng *et al. (*2019). They applied AI to construction planning and scheduling, again leveraging its predictive capabilities. Their use case was grounded in the argument that estimating is fundamentally challenging, due to the complex, uncertain and limited nature of relevant information, and thus humans draw on inevitably subjective experiences to supplement the process. This results in poor and inaccurate predictions. Cheng *et al.,* counter this subjectivity, and the limitations of human knowledge with those of AI, which can process greater volumes of data than humans. They use this situation to justify the need for their predictive model. Although they provide a caveat that their AI model is certainly not complete as further data is needed to train it for optimum performance, in practice the model's predicted

project duration only differed by 4 days from the actual completion duration of their case study project. They too position AI as an assistant rather than replacement, noting that an enhanced version could offer '…a valuable tool for project managers, contractors, and clients for facilitating sober and informed decisions related to schedule management and planning.' (Cheng *et al.,* 2019:15).

However, such detailed use case considerations were rare within the data. More common was a generic use case of just one or two sentences. In the 19 papers mobilising AI for predictive purposes, as applied to the scheduling, planning and estimating of future projects, only four contained what was considered a 'good' use case. The others drew on broad arguments and presumptions for their justification, with the influence of Technique notable within the prose. For example, Zhu *et al. (*2021) state that 'Instead of depending on historical records and experts' experience, the scheduling process in time management can be automated by Big Data and AI.' This is undeniably a truth; the scheduling process certainly can be automated, but why this is a better option is less clear and was not well justified in any of the papers addressing this aspect of application.

In general, automation has historically reduced the need for workers and thus also wage bills (Sherratt *et al.,* 2020), so the ability to sack those pesky estimators demanding regular pay checks, sick and holiday pay, and reasonable hours, could certainly be considered a benefit for some. Instead, AI will happily work 24/7 for a one-off payment, or at least until software updates shift to a subscription-only based offering, when perhaps the human wages paid to estimators might start to look more attractive again. Most predictive AI use cases followed this argument; subjective human experiences and their pitiful collections of 'small data' (as opposed to Big Data collected by technology - both of which are inevitably 'historical' of course) summarily devalued and dismissed in the face of potential AI solutions. It seems the fact that we can now collect Big Data means we must, as more is always better, and it must be analysed, otherwise what are we collecting it for? Indeed, as volumes reach levels where decision making becomes impossible for human brains, AI can neatly offer the solution to a problem entirely of its own making. Yet that slightly insidious situation can be readily overlooked given the benefits of AI; in their use case supporting the development of construction labour productivity (CLP) models, Sarihi *et al. (*2023:423) go so far as to label human limitations in modelling such complexity as 'weakness'. However, everything has limitations, and to criticise human limitations whilst ignoring the limitations and weaknesses of AI in such applications is unbalanced at best, disingenuous at worst.

Diagnosing AI Myopia: Why Context Matters!

Indeed, one such limitation of AI emerges as Zhu *et al. (*2021) expand their use case by stating that 'With the applications of smart technologies, the whole process of project cost time management will be more accurate and efficient.' The twin objectives of accuracy and efficiency were often drawn on in the simpler use cases found within the data, the objective nature of AI eliminating the negative influences of subjective human experiences, bias and limited knowledge. Superficially this argument holds, as historically construction estimating is not known for its accuracy and predictability (Farmer 2016), but this is not necessarily the fault of those doing the estimating.

When considering the application of AI for planning and estimating, the internal tender evaluations that such estimates undergo before a formal bid is made to the

client should be explicitly acknowledged. In this process, the schedule initially produced by the human estimator is reviewed by senior leadership, who often then adjust that estimate based on other factors, such as wider market evaluations, existing commitments and capacity, the potential profitability or prestige from the project, and ultimately, whether they actually want to win the work or not (Sherratt 2022b). In fact, it is highly unlikely that the schedule first produced by the estimator is identical to the schedule used to bid for and win the project and, therefore, what is retrospectively used to ascertain delay or cost overruns. Previous research identified other elements that can further influence project estimates, such as 'planning for claims' (Rooke *et al.,* 2004), and the 'planning fallacy' through which delusions (e.g., optimism bias) and deception (e.g., strategic misrepresentation) combine (Love *et al.,* 2022). And that is without noting that construction projects also endemically suffer from '…errors, scope changes, rework, price escalation, inflation, architecture of the project planning organisations, complexity and uncertainty, externalities…' (ibid 2022).

A robust case can therefore be made that we can never actually know whether human estimators are as bad as they seem in retrospect, because the 'tweaks' (e.g., best prices, tighter schedules) made to their outputs are undertaken in commercially sensitive spaces, well-hidden from view. Thus, to build an argument for AI based on a poor estimating track record as evidenced by subsequent project misalignment seems rather unfair. The industry's poor track record in prediction may have nothing to do with the estimators' experience, subjectivity, and reliance on historic data and everything to do with the CFO's annotations. It seems impossible, or at least unwise, for researchers to make blanket claims that this industry generates inaccurate estimates, and equally unwise to indicate that a more accurate number generated through AI will automatically be better. In addition, there is also the question of whether AI's outputs will suffer the same treatment before bids are placed. There is no reason to believe they would not also be tweaked and compressed, should a bid require it. Construction bids are not always aiming for accuracy, and thus, will AI actually be able to do a 'better' job in reality? Time will tell.

Technology is the Problem: It's also the Solution!

An unexpected finding from the analysis was that papers seeking to enhance existing technologies, including older 'versions' of AI, generally made more robust use cases than those seeking to initially apply technology to human processes. For example, Moselhi *et al. (*1991) sought to mobilise more sophisticated neural networks, to '…supplement or a complement…conventional expert systems.' Whilst Lu (2002:438) sought to specifically address merge event bias within PERT through the inclusion of near-critical paths within their model, to improve reliability.

However, the influences of Technique could be seen as proposed solutions to technological problems inevitably necessitated the application of yet more technology. No consideration of a human-centric alternative could be found within the data, even when current technological solutions had been identified as lacking. Although earlier researchers were more aware of the novel difficulties computing would likely introduce to construction management (Rowings 1991), the potential for a non-technical solution is now rendered moot through the influence of Technique.

For example, Fayek (2005) discussed the application of fuzzy logic to existing modelling as a solution to the problems and inaccuracies of existing predictive models. They note that such problems include: the inability to deal with numerous

and simultaneous factors affecting productivity; the inability to allow the subjective evaluation of these factors; the reliance and need for significant-sized data sets for model development and testing; and inflexibility in adapting models to suit different project contexts and different factors. Interestingly, although humans can do many of these tasks - subjective evaluations, consideration of multiple factors at once, adaption of knowledge to different situations - co-working human/technology adaptions are simply not considered.

Indeed, AI seems to be growing ever more envious of what people can do. Son and Khoi (2024) look to metaheuristic algorithms (MA), which they say have '…superior performance, power, and shorter required computation times…' than other algorithms, to enhance time, cost, and quality optimisation. They state that 'MA frequently draws inspiration from real-world phenomena to develop better heuristic solutions to optimisation challenges.' (Son and Khoi 2024). Optimisation trade-offs are not purely numerical, hence the need for real-world phenomena input, yet such input was previously just called experience or expertise, readily found within humans. The presumption that AI can do this 'better' remains firmly entrenched, even though AI is now also having to 'experience' the real world (as humans long have) to be able to deliver the promises made on its behalf.

The most surprising paper found within the data was that of Hong *et al. (*2021) who also focused on predictive AI for construction scheduling and planning. Their focus however was not with how much better the AI is than humans in undertaking this process, but rather that humans are not helping AI due to their inconvenient, whimsical and, well, very human trait of labelling construction activities within construction schedules in ways they want to, rather than in ways AI wants them to. Hong *et al. (*2021) bemoan this thus: 'Activity names are devised to communicate between stakeholders, and therefore often are written using inconsistent terminologies across repetitive activities with omitted contextual information.' This, apparently, cannot stand! AI cannot learn from whimsical data, and we humans really should adapt to serve our new technological master. Activities should apparently not be named in ways easily understood by humans, including those doing said activities, because AI can't follow along. No matter that 'Blk4 RC slab L2 GL/1-3' makes perfect sense to the concrete gang pouring it, we should help AI out and use only standardised tasks and nomenclature so AI can process it. Whether the concrete gang can also then clearly understand it, given they must pour the right bit at the right time in real life, is apparently less important. This is perhaps an artificial problem. If robots were building our projects, then a common scheduling language would be appropriate, but they are not - yet. Instead, humans still build our buildings, and construction may remain a human endeavour for years to come. Thus, if AI wants to interpret schedule data, it should be able to adapt and learn from the humans who created the schedule, not the other way around.

Resistance is Futile: The Inevitability of AI

The influence of Technique in shaping the surrounding discourse was evident throughout the data, with the inevitability of AI particularly prominent. In some cases, this was explicitly acknowledged by the author(s) using precisely that word, for example: 'Big data application in the construction industry is inevitable in the current dispensation of the fourth industry' (Atuahene *et al.,* 2020:353). Apparently, there is no choice to be made. Some are even more vociferous in their arguments: ' [The] likelihood of success without betting on new technologies and labour skills boils down to zero' (Brandín and Abrishami 2021:365): AI is inevitable, and if you do not accept

and adopt it, failure is also inevitable. That AI can influence academics to willingly make such threats on its behalf is quite impressive, if not also slightly terrifying.

Academics are also urged to focus on AI within their own research activities. More is needed: 'Despite the increased number of applications of fuzzy hybrid techniques in construction, research must expand to new areas in order to advance the practicality of these techniques and increase their widespread acceptance and use.' (Fayek 2020). Whether AI should be widely accepted and used when it has not yet been validated in practice seems to be placing the cart-before-horse somewhat, especially when viewed from an academic perspective. That eventual practicality is assumed is also a little worrisome. Indeed, uncritical presumptions that AI will improve things are arguably now firmly entrenched within much of the AI research discourse. As Goh *et al. (*2009) argue: 'In order to improve the quality of risk assessments in the construction industry, it is important to explore the use of artificial intelligence methods to ensure that the process is efficient and at the same time thorough'. Humans can of course be efficient and thorough, but AI is an inevitable improvement.

The inevitability of AI was perhaps best illustrated by Shang *et al. (*2023): 'There is an increasing need for AI to be adopted across industries as we weather the age of technological disruption.' Yet AI, and technological innovation is nothing like the weather. It is not inevitable and could be controlled. But as the theory of Technique dictates, the solution is to adopt more technology to deal with a disruptive situation entirely of our (its) own making.

CONCLUSIONS

In this paper we sought to explore the justifications used to research AI applications within construction management. To do so, we specifically analysed use cases within a purposive sample of research papers, drawn from the ARCOM abstracts database. Drawing on our previous research and experiences, we took an explicitly critical perspective, however our findings were still surprising. Just over half our sample made any kind of use case justification for the use of AI within their work. Only six of those achieved our 'good' evaluation, in which the activity, process and human engagement were all considered in the use case. Most of the remaining use cases were brief and tended to counter human subjectivity and other perceived weaknesses with the hard objectivity, efficiency and accuracy of AI. None of these papers discussed the human within the process explicitly, whether they enjoyed doing the tasks (as the lead author did for many years as a construction planner) or whether AI was taking on work that humans were not good at performing. In addition, there was a lack of wider contextualisation, which in the case of predictive AI for estimating and scheduling, is a considerable oversight that fundamentally undermines any use cases made on the grounds of poor human performance. That research is now reaching into spaces where the construction industry is chastised for not meeting the needs of AI was a startling finding, and one that makes us personally want to cling to the whimsey inherent in human ways of doing things.

The construction industry has plenty of problems that involve people, process and technology. Solutions to such problems are likely to be complex, yet our research found more than a few artificial problems in search of pre-determined artificial solutions mobilising AI. Ironically, despite all the complexity found in AI models, they are a simple solution in that they (at least in our data) often reduce the problem to only an issue of technology, ignoring both people and process issues that are also intertwined. Indeed, given wider societal and environmental concerns around AI,

challenges to its ubiquitous use are sorely lacking amidst the influences of Technique. As are more fundamental challenges to the currently poor justifications and use cases used to underpin such research. We need to be more critical in what we're doing and clearer in how and why we're doing it, to avoid the hype and ensure construction management research of AI applications does not simply become an echo chamber of technocratic optimism and determinism. Use cases matter and should be the first thing looked for in any work advocating for AI application to any aspect of construction management. We all review such papers and can shape this field appropriately. We can and should do better.

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EXPLORATION OF SOCIO-TECHNICAL APPROACH FOR IMPLEMENTATION OF DIGITAL TWINS FOR PREDICTIVE MAINTENANCE IN THE UK

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Digital Twins can provide adaptable comfort models, energy-saving techniques, and optimisation of building comfort for predictive maintenance in residential buildings. Predictive maintenance optimisation research has overlooked the interdependencies among technology, organisation, users, and processes in residential buildings. This study aims to address this gap by exploring a socio-technical approach to implementing DT for predictive maintenance in the UK, supporting technological and sustainable solutions. Thematic analysis was employed to interpret data from twenty-one semi-structured interviews with industry practitioners; the resulting subthemes and themes aligned with the socio-technical pillars: technology, organisation, users, and processes. The research findings indicate that a socio-technical approach aids in analysing the often-neglected challenges associated with predictive DT maintenance in residential buildings within these four pillars: technology (e.g., issues with scalable sensors), organisations (e.g., culture and competence), users (e.g., insufficient technical skills), and processes (e.g., operational inefficiencies); by addressing human interaction and impacts, engagement (stakeholders and supply chains), as well as equality and ethical considerations. This study provides a comprehensive analysis of the socio-technical pillars for implementing DT in predictive maintenance, offering holistic and sustainable cost-saving solutions.

Keywords: digital twin; maintenance; predictive; socio-technical

INTRODUCTION

According to the Committee on Climate Change, 29 million existing homes in the UK will need retrofitting by 2050, as 85% of these homes are expected to remain in use by then (Wentworth and Howlett, 2021). The housing sector is crucial for study due to residents' energy consumption levels and insecurity during the UK's ongoing cost-of-living crisis (Cotton *et al.,* 2024). Crucially, the Fire Safety (England) Regulations 2022 and the Social Housing (Regulation) Act 2023 are significant, particularly considering the Grenfell Tower fire and the death of Awaab Ishak incidents (Gov.UK, 2023a; Gov.UK, 2023b).

In recent years, social housing in the UK has experienced various health issues, such as fire, overcrowding, and energy consumption due to poor maintenance, costs,

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limited resources, and a growing population. In the UK, energy use in residential buildings accounted for 13% of GHG emissions in 2019. Space and water heating accounted for most of these emissions. Consideration should be given to occupant behaviour, liveability, effects on the environment, well-being, and comfort, as well as suitable metrics, standards, and funding for future-proof retrofits (Wentworth and Howlett, 2021).

It has been demonstrated that a step towards implementing a predictive DT can potentially manage these issues and lower lifecycle maintenance costs (Arsiwala *et al.,* 2023; Hosamo *et al.,* 2023; Khajavi *et al.,* 2023). Traditional digital operational and maintenance management in the built environment has not resulted in cost savings or workforce engagement due to repetitive data collection, a lack of defined purposes, and overlooked socio-organisational challenges (Khajavi *et al.,* 2019; Murguia *et al.,* 2024). Likewise, the necessity for predictive maintenance (Arsiwala *et al.,* 2023).

This paper aims to highlight the exploration of a social-technical approach to the potential implementation of DT for predictive maintenance for existing housing in the UK for adaptable comfort models, energy-saving techniques, and building comfort optimisation for residential buildings. The research questions the study answered was: How can the ST approach address the barriers of implementing DT predictive maintenance to optimise energy-saving techniques and building comfort for residential buildings through DT predictive maintenance?

Conceptual Background

The UK construction and built environment sectors increasingly adopt DTs technologies for systems integrations, structural health, lighting and ventilation monitoring and maintenance (Arsiwala *et al.,* 2023; Hosamo *et al.,* 2023) for asset lifecycle management, energy efficiency, and cost reduction. However, a significant gap exists in implementing DTs for predictive maintenance, particularly for existing residential buildings.

These gaps are due to technical barriers to DT Implementation, including interoperability issues, regulatory challenges, and reliance on legacy infrastructure (Cotton *et al.,* 2024). DTs, combining IoT, AI, and data analytics which can resolve these issues. However, face challenges like legacy systems, skills shortages, and regulatory issues (Hosamo *et al.,* 2023). Likewise, undefined data sources and the lack of socio-technical (ST) integration framework to guide (Cotton *et al.,* 2024).

Socio-technical barriers to predictive DT implementation involve a lack of organisational commitment, user resistance and misalignment between technology and workforce training (Jin *et al.,* 2020). A ST approach is needed to align technology with human, organisational, and regulatory factors, including stakeholder engagement (Arsiwala *et al.,* 2023; Cotton *et al.,* 2024; Khajavi *et al.,* 2023).

Socio-Technical Systems (STS) theory, developed in the 1950s, emphasizes the interconnectedness of social and technical subsystems in organisations (Abbas and Michael, 2023). It offers a balanced framework for implementing technology in UK housing, enhancing usability, cost savings, and sustainability (Saurin *et al.,* 2013). However, challenges like stakeholder consensus and complex integrations remain. STS approach contrasts with purely technological implementations, integrating users, processes, and organisations, unlike the Unified Theory of Technology Acceptance (UTTA), which focuses on behavioural intentions (Abrahão *et al.,* 2016). STS theory (Abbass *et al.,* 2021) considers the interdependence of technical and social factors.

Case studies in construction and related industries highlight the importance of ST systems for implementation (Merschbrock *et al.,* 2018), learning engagement and ownership (Atour and Ahmad, 2023); interoperability issues affecting energy efficiency performance and collaboration (Hosamo *et al.,* 2023). The UK can enhance DT implementation for predictive maintenance in residential buildings by addressing technical and social challenges. Other studies highlight the importance of employee orientation in addressing these concerns and promoting monitoring technologies to enhance safety, efficiency, and productivity (Jin *et al.,* 2020).

A holistic socio-technical approach is essential for optimising predictive maintenance DTs, ensuring technological efficiency and organisational effectiveness (Cotton *et al.,* 2024; Murguia *et al.,* 2024). The construction industry has historically overlooked this balance, impacting usability and performance. By integrating DTs with an STS perspective, their implementation can be optimised for both technical efficiency and organisational effectiveness (Jedbäck, 2022; Murguia *et al.,* 2024). While traditional technology implementation models overlook human dynamics, STS theory bridges this gap, fostering innovation, collaboration, and sustainability in the built environment.

METHOD

Qualitative methods for capturing conceptual frameworks support multiple bodies of knowledge (ontological or epistemological role) in various disciplines, like sustainable development (Jabareen, 2009). An iterative and reflective thematic analysis process (data extraction - evaluation) was utilised, an emerging information and integrative concept approach, which involved six steps: data extraction, familiarisation, coding, theme generation, review, and writing up (Braun and Clarke, 2020).

In this case, the purpose of the research study is to inform or provide a solution. The benefits also include a structured approach to handling data and examining the perspectives of different research participants, as well as identifying similarities and differences to produce unexpected insights. However, thematic analysis prevents researchers from making assertions concerning the use of language (Braun and Clarke, 2020). Notably, thematic analysis is essential for researchers to eliminate preconceptions during the identification of key themes (Braun and Clarke, 2020) and the trustworthiness of outcomes to support researchers using data analysis for the research method.

Critically reviewed open-ended semi-structured questions facilitated in-depth exploration of the topic and objectives for better understanding to suit each participant's clarity and to encourage open dialogue between them and the researcher; the process was carried out in line with the ethical guidelines. The focus on the research objectives determines the sample size (Naeem *et al.,* 2024). Hennink and Kaiser (2022) systematic review indicated that 9-17 interviews reached saturation and nothing less than 15 samples were stated for thematic analysis (Brzozowski, 2021). However, 21 interviews conducted to add depth and prevent saturation from losing coherence (comprising strategic BIM, asset, and facilities experts in commercial and residential construction management projects with years in the industry average of 28 years) digitally interviewed to gather their perspectives on the research study. Prior to recording, the interviewees' informed consent forms were collected, presented in writing, and briefly explained at the commencement of each interview. An average of 60 minutes was the length of each interview. The recorded videos were transcribed.

The process of thematic analysis of six steps was followed (Braun and Clarke, 2020) using NVivo 14.0 software.

FINDINGS

The key findings derived from the interviews reveal three central themes: human interaction and impacts, stakeholder and supply chain engagement, and equity and ethical considerations, all of which are critical for facilitating predictive digital twins in residential building maintenance. Each theme was analysed through the lens of the four socio-technical pillars: technology, organisations, users, and processes.

1: Human interaction and impacts

The Human element is vital for comprehensive outcomes. One of the participants stated, “DT can be a powerful tool, with significant benefits. But I suppose it also comes with challenges, in terms of human technology interaction and sustainability.” - P_01.04. The participants report that the O&M and facility managers have been operating the digital technologies provided with a lack of purpose and value. Purpose and value are vital for DT predictive maintenance implementation for existing housing because human interactions impact technology processes. These require ST approach that connect technological systems with humans (society) and organisational factors, leading to sustainable improvements in performance and efficiency under the four socio-technical pillars.

Technology: DTs enable real-time monitoring and predictive maintenance for housing, improving operational efficiency. However, their effectiveness depends on integrating advanced technologies like IoT sensors, AI, and data analytics. Currently, excessive manual data collection and skill shortages hinder implementation in the UK. Participants highlighted the need for seamless interaction between DTs, legacy data, and human operators to enhance accuracy and decision-making. DT technologies implementation remains low, as one participant noted, "We’re still at the bottom of that implementation curve. Achieving full digital integration requires reducing paperwork and increasing API-based automation.” - P_01.05. as commented by another participant.

Organisation: The findings revealed that organisational structures and culture should be adapted to support the integration and operation of DTs for predictive housing maintenance. This includes establishing cross-functional teams that combine technical expertise with operational knowledge, promoting collaboration between IT and maintenance departments, and creating governance frameworks that oversee the ethical use of data. The findings reported that many digital technologies have been adopted for DT implementation but are often redundant in organisations due to attitudes and cultural saboteurs. As one participant expressed, “In terms of making DT safe and secure, the weakest link on any project is going to be a human. It is not going to be the software, to be fair. It is going to be a human. Are they competent to be on the project team?” - P_01.05. The findings suggested that organisations should also consider the implications of DTs on their business models and be prepared to adjust strategies to capture the value generated by predictive maintenance capabilities. One of the participants mentioned: “This is where people come; I mean, it is part of what I call effective digital leadership, which is having people in place who will be able to tell what noise is, what is critical substance to exploit.” - P_01.15.

Users: Human interaction is crucial to the successful deployment of DTs. Operators, maintenance personnel, and decision-makers should be adequately trained to interpret

and act upon the data provided by DTs. Building trust in predictive analytics and fostering a culture that embraces data-driven decision-making is essential. One of the participants attested that "The symbiosis between digital tools optimisation, DT and workers increase productivity and mutual benefits." - P_01.07. The findings acknowledged that engaging stakeholders through skill training and participatory implementation walkthroughs beforehand can enhance user acceptance and commitment, ensuring that the technology meets the practical needs of its users to save operating costs. To affirm this, shared by one of the participants: "There is a huge degree of training that is needed for those using the systems and for all of those involved in the process." - P_01.09.

Processes: The findings emphasize that implementing DTs for predictive maintenance necessitates reengineering existing maintenance workflows for housing in the UK. Predictive maintenance shifts the focus from reactive to proactive strategies, requiring the development of new processes that leverage predictive insights. P_01.03 stated, "Purposeful schedule maintenance in advance with the data and the database focused on improving the operation and maintenance for DT beyond the process or standard." This transition involves redefining task sequences, establishing protocols for data-driven decision-making, and ensuring that maintenance activities are aligned with predictive analytics outputs. One of the participants highlighted, "Absolute interoperability is one of the biggest challenges I face daily, believe it or not. And it primarily has to do with file formats and file types." - P_01.11. The findings stated that clear guidelines and procedures should be established to facilitate the integration of DT insights into daily operations for predictive maintenance outcomes.

By addressing these human-interaction impacts on the technology, organisation, users (people) and processes; organisations can ensure that the implementation of DTs for predictive maintenance for housing in the UK is not only technologically sound but also aligned with human and organisational dynamics, leading to sustainable improvements in performance and efficiency through stakeholder and supply chains engagement.

2: Engagement (stakeholders and supply chains)

The findings articulated that the active involvement of stakeholders (facility managers, maintenance personnel, and supply chain partners) is crucial. Engaging these groups in the design and implementation phases fosters collaboration, user acceptance, and commitment, leading to more effective predictive maintenance strategies and energy and cost savings. One participant stated, "There are naysayers, fearful of new technology; good communication and education will increase uptake." - P_01.07. Although DTs can serve as a unified platform for predictive maintenance of existing housing in the UK, enhancing communication and decision-making across various organisational levels is vital. However, it is still lacking among the O&M senior managers and strategic decision-makers. The communication and language used are too technical for comprehension among the non-technical stakeholders that can influence change or invest in DT implementations. One participant emphasized, "We use lots of jargon terminology, and this does not help a client buy into that or a user buy into. We have to try to keep it as simple as possible." - P_01.01.

The findings also indicated that integrating DTs into the supply chain offers significant benefits for predictive maintenance in the UK housing sector. DT provides real-time visibility into inventory levels, manufacturing rates, and shipment statuses, enabling organisations to promptly monitor and adapt to shifting business

requirements. Supported by P_01.20 “The supply chain needs to be provided with a lot of the data for predictive DT.” Supply chain collaborations with asset information management requirements will allow transparency, standards alignment, and good procurement decision-making.

To reduce the carbon footprint concerning the procurement of materials, the supply chain sector requires an understanding of operations and maintenance activities for cost-saving decisions through implementing DT for predictive maintenance in the UK. A reactive approach generates more costs and carbon footprints in some cases. Therefore, collaborative integration would optimise coordination and quality assurance of the procurement processes. The participants echoed this, with one highlighted: “It has been slow. I would say there are some parts of the industry that are still reluctant. The supply chain is one of them.” - P_01.18.

Supply chain integration improves transparency, proactive maintenance, resource allocation, and operational efficiency. A holistic DT implementation requires addressing four socio-technical (ST) pillars: The technology aspect, deploying advanced DT systems with stakeholders and supply chain collaboration; the Organisation aspect, aligning policies and structures to support DT integration; the User aspect, training supply chain personnel to effectively use DT interfaces and predictive data and the processes aspect, redesigning workflows to utilise predictive insights from DTs. Stakeholder engagement and supply chain integration ensure a balanced approach, enhancing system reliability and performance. However, ethical and equality considerations should also be addressed.

3: Equality and Ethical Considerations

The findings revealed that the equality and ethical considerations approach for implementing DT for predictive maintenance is required for housing in the UK to ensure that the deployment is not only technically sound but also ethically responsible and socially equitable. Highlighted by one of the participants, “Think about wheelchair users, AI usage, emotional and well-being behaviour; there are equality issues and inclusiveness in the building.” - P_01.02

The findings emphasize the importance of involving end-users in designing and implementing systems to ensure they meet their needs and avoid adverse outcomes. It also highlights the need for a clean, secure environment but also acknowledges potential consequences like increased surveillance. The study also emphasizes the need for DT for predictive maintenance and the need to consider the demographics of residents to avoid biased computational solutions. It concludes that a more equitable society in the UK should actively check algorithms and data sources for biases.

DISCUSSION

Human Interaction and Impacts - Realigned human-technology interaction is essential for purposeful and valuable DT implementation (Merschbrock *et al.,* 2018) in existing residential buildings, as a socio-technical system approach that addresses operational challenges, which add to the current understanding through literature (Cotton *et al.,* 2024; Hosamo *et al.,* 2023). Balancing automation with human oversight remains challenging, as AI-driven decision-making enhances efficiency (Wang *et al.,* 2022) and urban planning by enabling data-driven approach in terms of sustainability, compared to traditional paperwork (Wang *et al.,* 2022).

Aligning DT strategies with corporate culture and objectives enhances collaboration and data-driven decision-making at the organisational level (Murguia *et al.,* 2024).

However, gaps in digital literacy and resistance to change impede implementation (Atour and Ahmad, 2023; Dawkins *et al.,* 2018). Continuous training and the promotion of a digital culture are essential; however, they necessitate substantial investment and commitment (Atour and Ahmad, 2023).

User engagement has been evaluated as low based on the findings. Nevertheless, the benefits of intuitive DT implementation have been identified to promote safety and sustainability (Khajavi *et al.,* 2023). However, resistance among those unfamiliar with digital transformation was stated as a challenge (Wang *et al.,* 2022). Interoperability and file format issues highlighted could be improved through socio-technical approach, since DT predictive maintenance enhances efficiency by reducing downtime, and a user-centred, co-creation approach enhances service design and functionality (Arsiwala *et al.,* 2023). ST approach through engagements facilitates effective collaboration.

Engagement (Stakeholders and Supply Chains) - The successful implementation of DTs extends beyond individual users, necessitating engagement with diverse stakeholders, including suppliers, maintenance teams, and organisational leaders. The study emphasizes critical engagement dynamics. At the technology level, successful DT implementation depends on a structured integration of technology, organisational strategies, and user engagement. Communicating the benefits of DTs and providing robust support mechanisms facilitates adaptation, fostering resilience and innovation within supply chains (Murguia *et al.,* 2024). Moreover, effective communication enhances data-sharing practices and decision-making; however, resistance to digital transformation persists as a barrier that must be addressed through transparent engagement (Cotton *et al.,* 2024).

Change management strategies are vital to overcoming stakeholder resistance challenges (Cotton *et al.,* 2024). Skill development is a pivotal requirement from the findings, ensuring all stakeholders, from facility managers to supply chain operators, possess the technical expertise to operate DT systems efficiently (Atour and Ahmad, 2023). While DTs offer potential cost savings and carbon footprint reductions, a lack of engagement can be disruptive to the transition process if not managed carefully in residential buildings (Cotton *et al.,* 2024).

Collaboration in simple language among engineers, data scientists, and decision-makers fosters cross-disciplinary innovation at the user level (Jedbäck, 2022). However, a lack of clearly defined roles and responsibilities in DT implementation can lead to misalignment and inefficiencies (Jedbäck, 2022). At the process level, aligning social interactions with technical dependencies would prevent system integration failures and productivity disruptions (Atour and Ahmad, 2023; Jedbäck, 2022). Adopting ST approach ensures that DT implementation is not merely a technological upgrade but a holistic transformation that optimises efficiency and stakeholder engagement through equality and ethical considerations.

Equality and Ethical Considerations - The study highlights the following critical concerns. Ethical considerations are paramount in DT deployment, particularly regarding data privacy, security, and potential biases (Longo *et al.,* 2020). At the technology level, ensuring data privacy is essential for predictive maintenance applications. Strict data governance policies should be enforced to safeguard individual and organisational data (Murguia *et al.,* 2024). Additionally, designing DT systems with inclusivity in mind prevents disparities in implementation (Longo *et al.,* 2020). Ethical risks such as data misuse and unintended consequences of predictive

algorithms should be proactively addressed to build trust and mitigate harm (Jedbäck, 2022).

Robust data governance frameworks and transparency measures are crucial for ethical DT implementation in support of strategic objectives. Addressing the concerns about AI usage and emotional and well-being behaviours fosters stakeholder confidence, while applying ST approach to big data analytics enhances strategic decision-making (Aseeri and Kang, 2023). Furthermore, integrating ethical principles into DT design and operations ensures that technological advancements align with societal values (Jedbäck, 2022).

Inclusive communication helps address user concerns regarding DT solutions in the built environment. Community engagement and iterative feedback loops enable the refinement of DT interfaces to accommodate diverse user groups, including those with lower digital literacy (Atour and Ahmad, 2023). At the process level, a value-sensitive design approach strikes a balance between technological progress and social expectations. Organisations can foster inclusivity and responsible innovation by engaging communities in discussions about DT deployment (Longo *et al.,* 2020).

A comprehensive approach to exploring ST pillars is essential for successful DT implementation in the UK for predictive maintenance, ensuring an ethical, efficient, and user-centric implementation while optimising energy use, achieving cost savings, and enhancing building conditions. ST approach, which integrates technical solutions with social, cultural, and organisational aspects, is more effective at reducing energy consumption and improving air quality in buildings than traditional digital platforms, promoting collaboration, data management, security, and community engagement.

CONCLUSION

This study provides unique perspectives on implementing predictive DT in maintenance in UK residential buildings, distinguishing itself from previous research. While existing studies primarily focus on technological advancements or commercial buildings, this research highlights the often overlooked human and ethical factors that significantly impact residential energy efficiency and building comfort in the UK. The study identifies critical gaps in predictive maintenance strategies, emphasising the need for more significant consideration of human interaction, impacts, and engagement (stakeholders and supply chains), equality, and ethical considerations.

The researcher found the low implementation of Digital Twins surprising, citing a lack of knowledge and skills, particularly in residential building maintenance. However, reservations regarding AI for ethical reasons were anticipated. Participants emphasized the potential benefits for asset and facility managers in adopting ST approach to implementing DT predictive maintenance, aimed at enhancing energy efficiency, air quality, and reducing maintenance costs. Furthermore, they highlighted its significance for evacuation strategies in high-risk buildings in the UK.

Due to the nuances, the study was limited to residential building maintenance professionals using DT predictive maintenance compared to commercial buildings in the UK. However, the study's strength lies in the qualitative approach with diverse professionals in the public sector's strategic BIM, built asset management industries, and commercial and residential construction management projects, utilising semi-structured interviews with flexible, open-ended questions. Additionally, the credibility of the professional experts interviewed, with an average of 28 years of industry experience, enhances the study’s depth and reliability.

Further research is required to develop a structured framework and real-world case studies on ST approach in residential buildings. These will ensure a holistic, human-centred, and efficient predictive maintenance system that optimises energy savings while maintaining building comfort; by adopting ST approach, asset owners, operations and facilities managers, and policymakers can enhance predictive maintenance, improve energy efficiency, and create sustainable, comfortable residential buildings in the UK.

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CONTRACT MANAGEMENT

FROM ADVERSARIAL TO COLLABORATIVE: LEVERAGING GOOD FAITH TO TRANSFORM UK CONSTRUCTION PRACTICES

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The UK construction industry has long been characterised by adversarial and fragmented practices that hinder collaboration, create inefficiencies, and exacerbate issues such as payment delays and inequitable risk allocation. This research explores the potential of using a statutory duty good faith to address these challenges. Drawing on insights from 12 industry experts, the study explored how statutory good faith could foster collaboration, enhance trust, and ensure fairness within construction contacts while recognising the cultural and operational barriers to implementation, such as resistance from key stakeholders, lack of legal clarity, and entrenched industry practices. The research theorises that codifying a statutory duty of good faith can mitigate the pervasive adversarial culture in construction projects, where delayed payments, disputes, and contractual ambiguities are common. The findings indicate that, subject to a phased introduction, practical guidance, and long-term education initiatives, a statutory duty of good faith could reduce adversarialism. This research contributes to the ongoing discourse on reducing adversarial and fragmented practices in the UK construction industry, offering a practical framework for embedding good faith into UK construction contracts

Keywords: adversarialism; collaboration; construction contract; construction practices; good faith

INTRODUCTION

The construction industry is widely regarded as highly fragmented (O'Connor, 2009; Naoum *et al.,* 2010; Riazi *et al.,* 2020). Conflict and adversarialism within the industry are well-documented in literature (Latham, 1994; Bishop *et al.,* 2009; Arcadis, 2022). These issues have led to significant challenges in productivity, cost, performance, client satisfaction and company liquidity (Latham, 1994; Bishop *et al.,* 2009). One of the key manifestations of adversarialism is the industry's approach to risk allocation and contractual practices, which often prioritise self-protective behaviours over cooperation (Bishop *et al.,* 2009; O'Connor, 2009: National Building Specification (NBS), 2018). An example of such adversarialism is poor payment

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practices in industry which remain a major concern (Constructing Excellence, 2016; Confederation of British Industry ("CBI"), 2020), the roots of adversarialism extend beyond payment to the overall approach to contractual relationships. This paper draws from ongoing PhD research that examines the persistent adversarialism in UK construction contracts (Ng *et al.,* 2002; Bishop *et al.,* 2009). It proposes the incorporation of a statutory duty of good faith as a legal remedy to address these issues (Christies, 2019; Aderibigbe *et al.,* 2023). This research critically examines the barriers to implementing such a duty, including cultural resistance, legal ambiguities, and stakeholder pushback. It explores the extent to which codifying a statutory duty of good faith can mitigate adversarialism and promote collaboration within UK construction contracts.

LITERATURE REVIEW

The UK construction industry has long faced challenges related to adversarialism, particularly in high-stakes and complex projects (Wolstenholme, 2009). A primary concern is the historical prevalence of poor payment practices, with delayed payment and late payment being a constant issue (Constructing Excellence, 2016, CBI 2020). Despite numerous initiatives, such as the introduction of the Reporting on Payment Practices and Performance Regulations 2017, these efforts have not fully resolved the ongoing payment crisis (CBI, 2020). Between 2004 and 2021, 19 separate initiatives aimed at improving payment practices failed to address the root causes of delayed payments (Constructing Excellence, 2016). The government's attempts, such as the introduction of the Prompt Payment Code in 2008 and reforms in 2021, have had limited success (Foreign Commonwealth and Development Office, 2021).

Small businesses, which dominate the industry, suffer disproportionately, with almost half of SMEs within the sector (approximately 45%) reporting that late payments are a major obstacle to their success (Department for Business, Energy and Industrial Strategy ("BEIS"), 2019; CBI, 2020). Compared to the average SME late payment rate of 33% across all other sectors in the UIK (CBI, 2020), 45% is significantly high, reflecting the severity of the problem within the construction industry. These late payments not only cause significant financial strain on businesses but are also linked to rising insolvency rates. For instance, the high-profile collapses of ISG and Carillion in 2024 and 2018 (respectively) as well as others like ROK, Mouchel, and Interserve, demonstrate how poor payment practices and ineffective risk allocation exacerbate adversarialism and industry vulnerabilities (CBI, 2020; The Insolvency Service, 2019).

Despite the government's attempts to address payment issues, the traditional construction business model, which inequitably transfers risk to contractors and subcontractors, remains unchanged (Bishop *et al.,* 2009; O'Connor, 2009). To address this, experts like Latham and Egan have advocated for collaborative working and relational contracting as mechanisms to reduce adversarialism (Latham, 1994; Egan, 1998; Wolstenholme, 2009; Farmer, 2016). However, the impact of collaborative working has been minimal due to industry resistance and deeply entrenched profit incentives which undermine efforts at collaboration (Ng *et al.,* 2002; Bishop *et al.,* 2009).

To elaborate, while collaborative methods like Integrated Project Delivery (IPD) have been proposed as a solution, their practical application is hindered by cultural and structural challenges (Ghassemi and Becerik-Gerber, 2011). IPD aims to create a fully integrated process where all stakeholders share mutual respect, benefit, and

responsibility for project outcomes (Ashcraft, 2010). However, its implementation has encountered barriers related to risk allocation, financial transparency, and joint control (Ghassemi and Becerik-Gerber, 2011; Viana *et al.,* 2020). These limitations suggest that more comprehensive solutions are required to overcome adversarialism and instil genuine collaboration within the industry (Ghassemi and Becerik-Gerber, 2011).

Latham (1994) has also suggested incorporating good-faith-like clauses into standard contracts, which would compel parties to act in a spirit of mutual trust and cooperation. Good faith, as a principle, focuses on mutual trust, honesty, transparency, and fair dealing between parties (Mante, 2018), and it has long been recognised as a foundation for collaborative working (Bresnen and Marshall, 2000). Latham's suggested approach is evident in the New Engineering Contract (NEC), which includes provisions promoting mutual trust and cooperation as central to contract execution (Mante, 2018).

However, despite the presence of such clauses in industry standard forms adversarialism remains entrenched within the industry (Bishop *et al.,* 2009; Christie, 2019). The limited effectiveness of good-faith-like clauses in resolving adversarialism further highlights the necessity to go a step beyond, exploring a statutory based solution. To further explain, the introduction of legislation has proven effective in shifting industry practices, as demonstrated by the success of the environmental regulations within initiatives like the Environmental Permitting Regulations (Constructing Excellence, 2007; Willmott Dixon, 2010; BEIS, 2019). The legal framework surrounding these regulations led to significant changes in the construction industry's approach to sustainability and compliance (Bishop, 2009; Aderibigbe *et al.,* 2023).

Therefore, a similar legislative approach, underpinned by good faith, could be a game changer in addressing adversarialism and promoting healthier, more collaborative project delivery models. Essentially, while collaborative contracts have theoretical appeal, their impact is reduced by industry reluctance to adopt them in practice. Thus, a statutory duty of good faith could compel the industry to adhere to collaboration principles by making compliance mandatory rather than voluntary. However, the application of good faith in contracts remains a subject of debate due to its nebulous nature and the reluctance of UK courts to embrace a broad interpretation of the concept (Santier, 2017). In English law, good faith has not been fully integrated into common law, and courts continue to resist its general application (Leggatt, 2016). Despite this, statutory intervention could provide the clarity and enforceability necessary to foster a culture of trust, cooperation, and transparency across the industry.

METHOD

This study employs a qualitative research design, combining semi-structured interviews and thematic analysis. It follows the Research Onion framework (Saunders *et al.,* 2012), Lin's Literature Research Methodology (2009), and a tailored evaluative framework developed through an inductive approach. A critical methodology approach (Flick, 2009) was also incorporated to examine and critique existing practices within construction contracts while exploring innovative solutions to address adversarial behaviours.

The 12 Participants, selected via the researcher's network, had to meet specific criteria to ensure they possessed relevant experiences and expertise. These included:

- The expert must be a professional working in the construction industry (e.g., architect, engineer, quantity surveyor, project manager, construction lawyer, advisor, etc.).
- The expert must have worked on, advised, or provided services to at least three industry players (i.e., contractors, subcontractors, consultants etc.) who have worked on construction projects valued at no less than £5 million.
- The expert must have at least 5 years of active experience in the UK construction industry.

This diversity of roles was intentionally selected to reflect the multifaceted and fragmented nature of the UK construction industry, where adversarialism manifests across professional, contractual, and operational interfaces. Including a range of perspectives—from engineers and project managers to lawyers and commercial directors—enabled the research to capture how good faith, collaboration, and risk allocation are experienced and interpreted across different parts of the supply chain. This approach supports a more holistic understanding of systemic behaviours and the potential for legislative reform.

Semi-structured interviews were conducted with each participant. This enabled the researcher to probe deeper into their experiences. Participants were not shown an example clause. Instead, they were invited to reflect on whether a statutory duty of good faith should be codified into law, based on their industry experience, the challenges they have encountered, and their views on collaboration and adversarialism. Interviews were conducted in person and/or remotely via video conferencing, lasting between 30 to 45 minutes. Their responses were thematically analysed, guided by the evaluative framework developed through an iterative process for this research. Participants' alignment with the research premise were categorised into four levels:

- Strong Support;
- Moderate Support;
- Conditional Support; and
- No Support/Rejection.

The analysis adhered to Braun and Clarke's (2006) approach for identifying patterns and themes, focusing on emergent themes directly reflecting participants' perspectives. Additionally, a deductive element was incorporated to align the themes with existing legal principles and case law regarding good faith (Bernard, 2011; Saunders *et al.,* 2012). This combined approach facilitated a nuanced understanding of participants' positions, while contextualising their insights within the current legal and practical landscape of the construction industry. The framework ensured systematic evaluation and supported the consistent categorisation of participants' views across the interviews, providing a clear basis for comparison and analysis.

RESULTS AND DISCUSSION

Table 1 presents an analysis of the 12 interviews conducted with the participants, providing insights into the role of good faith in reducing adversarialism in construction contracts. The analysis evaluates the participants' perspectives,

categorised by their level of support for the codification of good faith, as well as key themes and contributions to the research premise. as shown in Table 1.

Table 1: Summary of Concurrence and Alignment with Research Premise

Interviewee	Support Level	Key Themes and Contributions
Interviewee 1: Seasoned BSE Engineer	Strong Support	Advocated for codifying good faith to promote transparency, fairness, and collaboration. Highlighted its role in improving payment practices and reducing disputes, particularly benefiting smaller subcontractors.
Interviewee 2: Legal Director	Conditional Support	Emphasized theoretical benefits of good faith but raised concerns about litigation risks and adjudication complexities. Advocated for phased implementation and complementary cultural reforms.
Interviewee 3: Technical Specialist	Strong Support	Highlighted trust and respect as core components of good faith. Supported phased legislative implementation and emphasized the importance of education to address adversarialism and foster collaboration.
Interviewee 4: Health & Safety Expert	Strong Support	Argued that codifying good faith could improve compliance and reduce adversarial practices. Provided examples of trust's role in health and safety outcomes and suggested integrating good faith into existing compliance frameworks.
Interviewee 5: Commercial Director	Moderate Support	Agreed on the benefits of collaborative principles but raised significant concerns about practical enforcement, stakeholder resistance, and cost implications. Supported NEC contracts as a model for collaboration.
Interviewee 6: Industry Veteran	Conditional Support	Supported codification of good faith with clear legislative frameworks and complementary enforcement measures. Highlighted systemic issues such as payment delays and retention abuse and drew comparisons with UAE good faith principles.
Interviewee 7: Adjudicator	Strong Support	Strongly advocated for legislative action to overcome common law resistance to good faith. Highlighted the potential of good faith to reduce disputes, improve payment practices, and foster collaboration. Suggested complementary measures like training.
Interviewee 8: Seasoned Civil Engineer	Strong Support	Believed good faith was already implied in practice and supported codification to reduce adversarialism. Raised exploratory concerns but ultimately endorsed its potential to foster fairness and collaboration
Interviewee 9: Industry Chief Executive	Strong Support	Emphasised codification's potential to reduce adversarialism and improve collaboration and payment practices. Also highlighted AI's role in enhancing compliance, transparency, and project efficiency, reinforcing good faith principles when integrated with legal frameworks.
Interviewee 10: Independent Arbitrator & Mediator	Moderate Support	Recognised benefits but cautioned against rigidity and noted cultural change is key for effective implementation.
Interviewee 11: The Construction Compliance Geek	Strong Support	Fully supported codification to improve fairness, transparency, payment practices, and SME collaboration.
Interviewee 12: The Independent Construction Mediator	Conditional Support	Supported the principle of codification but raised concerns about enforceability, malicious compliance, industry culture, and implementation challenges. Emphasised the role of training and corporate culture in promoting change.

Analysis of Alignment with Research Question

The interview data reveals strong overall alignment with the research premise. Across the 12 interviews, a clear majority expressed strong or conditional support with only two interviewees offering moderate support, and non-outright rejecting the premise. Participants consistently identified adversarial behaviours, such as payment delays, rigid risk allocation, and contractual opacity, as systemic challenges that the codification of a statutory duty of good faith could help address.

Limitations of the Research

Codifying a duty of good faith presents legal and conceptual challenges. As Xanthaki (2005) notes, goal-based legislation can be difficult to interpret and may introduce uncertainty in enforcement. The Office of the Parliamentary Counsel (2013) also cautions that legislation's effectiveness often depends on user intent and judicial interpretation, which is particularly relevant given the subjectivity associated with good faith (Santier, 2017).

Moreover, common law traditions in the UK have generally resisted overarching duties of good faith due to concerns over certainty and party autonomy (Leggatt, 2016). Even where courts acknowledge relational contracts, a consistent judicial doctrine on good faith remains elusive, complicating the implementation of a statutory obligation.

The primary limitation of this study lies in its sample size. Guest *et al. (*2006) argue that thematic saturation in qualitative research is typically achieved within 12 interviews, particularly where the participant group is relatively homogeneous, and the interviews are semi-structured. This study, which includes 12 such interviews with professionals across diverse roles (e.g., engineers, commercial directors, mediators, adjudicators etc.), meets that threshold and captures a consistent range of insights aligned with the research question. Notably, none of the interviewees rejected the premise of codifying a statutory duty of good faith; the majority expressed strong or conditional support.

While data saturation appears to have been reached, further interviews may help reinforce the findings, validate the emergent evaluative framework, and test the generalisability of the conclusions across a broader cross-section of the UK construction industry. Expanding the dataset would also offer the opportunity to explore whether divergent or minority perspectives emerge outside the current thematic consensus.

CONCLUSIONS

This research reveals strong support for the statutory codification of good faith to promote collaboration, transparency, and fairness in construction contracts. While collaborative working practices and good-faith-like clauses in standard forms offer some benefits, they are widely seen as insufficient to tackle deeply entrenched adversarial behaviours. A statutory duty of good faith is increasingly viewed by industry professionals as essential for enabling cultural and structural reform. Interviewees consistently underscored the need for a legal framework that supports trust-building and discourages opportunistic conduct.

Key challenges—such as definitional ambiguity, enforcement uncertainty, and stakeholder resistance—were also acknowledged. However, these are not insurmountable. The findings suggest that a phased implementation approach,

supported by industry education and contractual guidance, could ease adoption and embed good faith as a functional norm.

In conclusion, this study contributes new empirical evidence to the growing call for reform and lays the groundwork for further exploration into how statutory duties can reshape industry behaviour. Future research should examine potential legislative models, pilot schemes, and the interplay between statutory obligations and existing contract forms.

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DIGITAL AND COLLABORATIVE CONTRACT MANAGEMENT PRACTICES IN THE DANISH CONSTRUCTION INDUSTRY: AN INSTITUTIONAL ANALYSIS OF NEW PRACTICE CREATION

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The transition toward regenerative cities involves the increasing use of digital tools in the construction industry, including management systems and Smart Contracts. These technologies promise enhanced collaboration, productivity, and conflict reduction. However, previous research highlights that Smart Contracts often remain rigid, limiting their transformative potential. This inquiry applies New Institutional Theory to critically examine current contract management and explore how they can evolve from both processual and institutional perspectives. A case study with potential for Smart Contract implementation forms the empirical foundation, supported by interviews with key stakeholders. The analysis scrutinises the interplay between institutional structures, actors, and digital technologies in shaping collaborative contract practices. Findings suggest that the case exemplifies emerging digital and collaborative approaches. Yet, institutional change requires a range of processual elements targeting actors and structures. Theorisation, collective mobilisation, and social recognition are essential for legitimising and embedding new practices across the industry. This research contributes valuable insights into how collaborative contract management can be institutionalised in the construction industry, supporting more regenerative and digital urban development.

Keywords: contract management, institutional theory, digitalisation, collaboration

INTRODUCTION

The Danish construction industry is adapting to various institutional pressures, such as productivity, digitalisation, collaboration, and regenerative demands. As the industry undergoes changes, contract management has emerged as a competency for clients, contractors, and consultants. Traditional contracting practices, often characterised by inefficiency and rigidity, are being challenged by more innovative technologies such as Building Information Modeling (BIM) and Smart Contracts (Szabo, 1997). These technologies offer promising opportunities to revolutionise contract management, making it more collaborative, transparent, and efficient. This alteration is critical for managing the complexities of modern construction projects and can serve as potential tools for developing Regenerative Cities (Eastman, *et al.,* 2018; Najafzadeh, *et al.,*

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2024). Thus, contract management plays a key role in enhancing project management, planning, regulatory compliance, role distribution, and risk management (Ekdahl, *et al.,* 2022). This is important for an industry that still faces challenges like delays, cost overruns, weak cooperation, and contractual ambiguities (Abdelalim, *et al.,* 2024).

While BIM is now integral to many projects, contracts often follow traditional management processes. With the increasing digital demands, such as the use of a Common Data Environment (CDE), contracts have become essential for managing reactive clauses. However, these clauses address issues or actions after they occur, rather than proactively preventing them. The introduction of Blockchain and Smart Contracts (BLOXHUB, 2018) has increased the need for more robust and proactive contract management in practice. Smart Contracts have the possibility to automate and secure contract execution, ensuring transparent and prompt enforcement of terms, thus alleviating legal and logistical challenges (Hupe, 2024). Despite their conceptual potential, the adoption of Smart Contracts remains slow (Lyons, *et al.,* 2019).

The move toward strategic, digital, and collaborative contracting highlights the importance of building value-driven relationships that reduce risk through stronger partnerships and aligned goals, shifting contracting from a reactive to a proactive approach (Ekdahl, *et al.,* 2022). The industry is increasingly adopting collaborative contract models such as Integrated Project Delivery (IPD), strategic partnerships, and contract networks, which share risks and benefits among stakeholders and prioritise joint decision-making and transparency (Cafaggi, 2011). Moreover, regenerative principles are increasingly influencing contract management, with contracts now expected to include provisions for environmental and social governance (Olsen and Lauritzen, 2023). This illustrates a broader shift in the development of contract management practices within the industry, highlighting a gradual move toward more innovative, collaborative, and digitally supported approaches and understandings.

Structure and Questions

Through a lens of neo-institutional theory and socio-technical perceptions, this inquiry aims to understand the important connections between digital technologies, legal frameworks, and actors within contract management processes. This involves a case study and interviews with relevant actors. The inquiry is inspired by Lounsbury and Crumley's (2007) process model for understanding the mechanisms and dynamics of new practice creation in the institutional field of the industry. This inquiry includes an analysis guided by two research questions: RQ1 - How can traditional contract management practices be problematised? and RQ2 - What characterises digital and collaborative contract management practices? The analyses provide the foundation for discussing how new practices can be institutionalised within the industry. This is explored through the dynamic interplay between emerging digital technologies, existing industry structures, and social processes, guided by a third research question: RQ3 - Which institutional processes are essential for transforming industry practices?

Relevance and Limitations

This inquiry is relevant to the industry as it explores the integration of digital tools, including the potential application of Smart Contracts, within a Danish context. It aims to enhance collaborative contract management environments and support the development of more efficient and sustainable models for project collaboration. The findings contribute to both academic knowledge and practical application by offering insights that could improve traditional contract management practices. However, the

study is limited to a single, atypical case within a Danish context and involves a relatively small number of respondents. Consequently, any generalisations should be considered context-dependent rather than universally applicable in the industry.

Theory

Lounsbury and Crumley's (2007) institutional process model offers a framework for understanding the emergence, legitimisation, and restructuring of new practices within institutional fields, such as the construction industry. The model highlights the significance of performativity-driven variations, which are activities that deviate from established institutional norms. Performativity-driven approaches focus on how behaviours, practices, and norms are enacted and reinforced through repeated actions and interactions. These variations occur when actors identify inefficiencies or contradictions within traditional practices, leading to field-level negotiations. Central to the model is the process of problematisation, where institutional actors identify inadequacies in traditional practices. If these problems gain social recognition, they can disrupt the stability of the institutional field, creating opportunities for change. Without such recognition, dominant logics, also called interpretive frameworks, persist, maintaining existing structures in the field (Greenwood, *et al.,* 2017).

Once problematisation occurs, performativity-driven variations become sites of debate, leading to theorisation, where actors construct narratives that justify and legitimise new practices (Suchman, *et al.,* 2020). Legitimisation is critical in this process, requiring collective mobilisation and alignment with broader institutional logics. Lounsbury and Crumley's (2007) model highlights how social validation mechanisms, such as endorsements from influential actors and regulatory adaptations, contribute to institutional acceptance. If new practices achieve legitimacy, they become embedded within the field; if not, resistance may prevent their diffusion, reinforcing the status quo or leading to alternative institutional logics (Scott, 2014). Institutional fields consist of logics that guide and control practices and can be seen as structured arenas where organisations and stakeholders negotiate stability or change. Thus, the inquiry examines the critical interplay between micro-level organisational actions and macro-level institutional dynamics through a processual approach.

METHOD

The inquiry adopts an abductive approach, emphasising a problem-oriented perspective, the use of empirical material, and theories to better understand the underlying issues, mechanisms, and dynamics of the inquiry. Relevant background literature has been utilised to establish the foundational knowledge for scrutinising traditional and untraditional contract management practices, as well as discussing institutional change processes. A Boolean search strategy was employed across databases such as ResearchGate, ScienceDirect, and the Karnov Law Journal for housing and construction law. This approach provided legal documentation, including arbitration awards and contract law articles, essential for understanding Danish construction contracts and general conditions for construction works and supplies, forming a crucial part of the empirical material (Rienecker and Jørgensen, 2017).

Case Study and Interviews

Research on Smart Contracts remains limited and primarily theoretical (Shojaei *et al.,* 2019), with the approach still being conceptual and lacking practical applications. To address this issue within a Danish context, the case study Mini-CO_2 Apartment Building DIGITAL in Fredericia, Denmark (Realdania, 2024) has been selected as a

relevant and atypical case for this inquiry (Flyvbjerg, 2020). The case seeks to tackle industry challenges by examining the effectiveness of digitalisation in contract management, execution optimisation, and time management. Moreover, it incorporates regenerative aspects by adopting various methods for waste and resource reduction. It aims to uncover practical solutions and proposals for addressing legal, technological, and sustainable challenges through digitalisation. By addressing contract management practices, the case offers valuable insights into how digital tools can support more proactive and flexible solutions. This contributes to a deeper understanding of more digital and collaborative contract management practices.

The case study involves four semi-structured interviews, which have been transcribed and interpreted to support arguments in the analysis and discussion. Informed consent was obtained, allowing statements to be used in this inquiry without requiring anonymity (Brinkmann and Tanggaard, 2020). Moreover, an interview guide was developed to explore the challenges and opportunities associated with both traditional and untraditional contract management practices, as highlighted in Figure 1. in the discussion. The respondents include Project Manager Peter F. Poulsen from Realdania, CEO Niels W. Falk from HD Lab, and Project Manager Christian R. Jørgensen from MT Højgaard, who provide valuable insights into the practical aspects of implementing digital solutions in construction processes. Furthermore, external expert Professor Kim Østergaard from Copenhagen Business School's (CBS) Department of Business Humanities and Law participated in an interview.

Analysis

Analysis 1: Problematisation of Contract Management Practices

This analysis section explores what Lounsbury and Crumley (2007) describe as the 'Appropriate Variety' or traditional contract management practices, focusing on how industry actors strive to maintain stability and existing frameworks that often favour reactive aspects over proactive strategies. The industry remains heavily influenced by traditional practices, characterised by 'analogy processes' that make limited use of digital and collaborative methods in contract management. The reactive phenomenon is highlighted by CEO Niels W. Falk from HD Lab, who states, “The contract is only brought out when we have come to blows.” Greenhalgh (2016) similarly emphasizes the reactive nature of the industry, referring to contracts as 'files in the drawer'. Ekdahl *et al. (*2022) moreover emphasize the industry's inertia, pinpointing inefficiencies caused by fragmented operations and a resistance to more collaborative approaches.

Project Manager Christian R. Jørgensen from MT Højgaard states that, despite advancements in BIM, Smart Contracts, and Blockchain, these technologies remain underutilised in contract management practices. This view is supported by respondent CEO Niels W. Falk from HD Lab, who attributes the underutilisation to cultural barriers, noting that reliance on paper-based or static PDF documents prevents dynamic updates and efficient data sharing. According to Ekdahl *et al. (*2022), changing contract management practices requires a new mindset. This mindset should address the tension and differences between reactive contract management, which focuses on independent operations and immediate profit maximisation, and proactive contract management, which promotes collaboration, shared risk, and mutual benefits.

Professor Kim Østergaard from CBS argues that reactive contract management practices foster isolation among industry actors, making transparency and collaboration extremely difficult in practice. This isolation is further reinforced by

substantial arbitration costs, which benefit actors involved in arbitration, meaning the resolution of disputes outside of the court system. Moreover, Buch *et al. (*2020) and Iversen (2016) emphasize that some contractors exploit contractual loopholes to secure additional work, perpetuating industry inertia and reinforcing their control over essential execution aspects. Consequently, Project Manager Christian R. Jørgensen from MT Højgaard argues that more transparent and simple documentation could be a remedy to mitigate loophole exploitation. Thus, dominant actors in the industry have strong incentives to maintain and theorise traditional contract management practices.

There is an industry-wide resistance to change, with dominant actors maintaining the 'appropriate variety' or traditional contract management practices to secure their stable and current position. The lack of awareness among actors regarding the shortcomings of traditional contract management prevents broader societal recognition of the issues, thereby sustaining inertia. As such, dominant actors and current contract terms are reinforcing the boundaries of the current industry. This necessitates contractual reforms and a social recognition that rigid, hierarchical contractual frameworks hinder innovation and intensify conflicts rather than promoting cooperation (Cafaggi, 2011; Komurlu and Yeni, 2019). A theorisation of the advantages of digital tools, such as transparency, real time data access, and automated contract management, is essential.

Niels W. Falk, CEO of HD Lab, notes that Smart Contracts currently appeal mostly to a small group of 'digitalisation enthusiasts'. He indicates that broader acceptance requires both social recognition and contractual reforms. Moreover, he stresses that "There isn't really much about collaboration […] in the Danish contract terms." Professor Kim Østergaard from CBS continues the criticism, stating, "The framework relies on goodwill rather than structured incentives for cooperation, leading to what scholars call 'optimistic behaviour,' where each party assumes best-case scenarios for its interests, often resulting in disputes when reality deviates from expectations."

Reactive and adversarial contract management practices are deeply embedded in the industry, leading to increased costs and conflicts. However, disruptive forces are emerging that focus on more proactive and dynamic approaches. Professor Kim Østergaard from CBS stresses that real transformation of contract management practices requires institutional change. He states, "It demands a fundamental reconfiguration of norms, including revisions of the Danish contract terms, to address the tension between profit-driven isolation and collaborative efficiency."

Analysis 2: Digital and Collaborative Contract Management Practices
This analysis section defines the emergence of digital and collaborative contract management practices. It draws on Lounsbury and Crumley's (2007) concept of 'anomalous variety,' referring to untraditional contract management practices. Together with the previous analysis, it lays the foundation for the following discussion on how institutional processes can lead to industry negotiations and legitimacy processes, steering the industry towards a more digital and collaborative direction.

Niels W. Falk, CEO of HD Lab, emphasizes how collaborative methods replace adversarial dynamics with shared goals and knowledge exchange, "At the heart of the collaborative paradigm is the transformation of clients, consultants, and contractors from adversaries to collaborative partners in a unified team with common objectives, underpinned by the ethos of knowledge exchange." Moreover, Project Manager Christian R. Jørgensen from MT Højgaard emphasizes the role of transparency, "By disclosing our calculations and sharing them with all involved parties, we diminish mistrust and actively cultivate a cooperative atmosphere aligned with unified goals."

These insights reflect a common theme among some respondents, highlighting a shift from confrontational dynamics to mutual trust and advocating for systemic change.

The development of new practices requires support from both dominant actors and pioneers within the institutional environment, fostering deeper social recognition of unconventional practices as critical drivers of innovation and transformation. The case study supports this mindset by fostering development among both dominant, smaller, and emerging actors, encouraging collaborative and digital practices. Among these actors, the project team introduced digital innovations such as real-time BIM updates and a shared project management platform, utilising these tools for more data-driven and collaborative contract management practices. By framing digital solutions as remedies to ongoing issues in the industry, such as cost overruns, conflicts, and communication breakdowns, the case theorised a new narrative from individual profit maximisation to collective transparency, as well as sharing risks and benefits.

The case established a new form of collaborative agreement that overrides traditional contract terms, ensuring that in situations of conflict, the collaborative and digital model takes precedence. This arrangement brought together stakeholders including clients, contractors, and consultants to use a common digital platform that supports real time data sharing and joint problem solving. Project Manager Peter F. Poulsen from Realdania states, "With digital timelines and instantaneous updates to BIM models, we are not merely informed but also nimble, enabling rapid adjustments and the avoidance of expensive errors before they exacerbate." This stresses the value of BIM systems, project management, sensor data, and drones in providing real-time visibility. Early successes, like fewer disputes and more streamlined design processes, helped attract more stakeholders, boosting industry-wide momentum. This can potentially lead to broader social recognition, industry negotiations, and the legitimisation of new practices. A clearer theorisation of digital contract management tools is needed to highlight their role in improving efficiency, transparency, and accountability. Conceptually, these tools centralise workflows, automate key tasks, and support real time communication and compliance. Moreover, mobile access enables on site updates and data capture, linking contracts to actual performance.

This is supported by Goodenough *et al. (*2024), who demonstrate the efficiency gains of computable and Smart Contracts through automated transaction processing and reduced operational costs. Furthermore, Shang *et al. (*2023) highlight blockchain technology's capacity to bolster security and transparency, which is crucial for building trust in collaborative arrangements. Finally, Hafsi (2017) similarly observes that embedding BIM into contractual frameworks creates coordinated project environments through enhanced real-time data access and informed decision-making. Professor Kim Østergaard from CBS argues for an effective interplay between digital technologies and their strategic implications within contractual frameworks. Thus, he emphasizes digitalisation's compatibility with existing contract design and the importance of digital tools in clarifying contractual parameters and minimising disputes regarding quantities or schedules. Moreover, he identifies Smart Contracts' potential for automating contractual elements, such as payment triggers and digital verification, thereby reducing traditional contention and streamlining procedures.

Digital transparency reinforces trust and joint accountability, while collaboration fosters a culture conducive to fully exploiting digital tools. For these innovations to extend beyond isolated projects, institutionalisation through legitimisation processes, such as regulatory and pragmatic legitimisation, is needed. This creates a foundation

for both social recognition and negotiations within the industry. Niels W. Falk, CEO of HD Lab, proposes legally binding digital service obligations as mechanisms to consolidate these practices. Meanwhile, Kadefors *et al. (*2024) argue that relational contracts, characterised by cooperative aims and shared successes, can replace the adversarial frameworks dominant in traditional contract management practices. Thus, the digital and more cooperative orientation diverges from traditional contract management practices, reflecting Lounsbury and Crumley's concept of 'anomalous variety' (or untraditional practices). The theorisation process of these untraditional practices contributes to institutional change and involves a potentially transformative shift in contract management, which will be further discussed in the next section.

DISCUSSION

Historical institutional change processes reveal that implementing new practices within an industry requires more than just introducing new technologies and their contextual potentials. It requires a redefinition of the cultural, professional, and economic norms that shape the industry. This transformation occurs through various processes such as theorisation, social recognition, negotiations, and legitimisation (Lounsbury and Crumley, 2007). Transformation unfolds often on multiple levels and dimensions, involving both dominant and smaller actors, and pioneers of the industry.

Thus, theorising and legitimising new digital tools, which have the potential to automate administrative tasks and enhance real-time coordination among stakeholders, can be needed in the institutional change process. Goodenough *et al. (*2024) argue that Smart Contracts can reduce transaction costs, streamline payment processes, and embed compliance requirements directly into executable code. Hafsi (2017) similarly highlights BIM's capacity to foster transparency by providing a shared and updated information model. Digitalisation encompasses more than just technological capabilities and promising potentials. It also depends on the ability to establish effective collaboration processes and robust governance structures. Furthermore, advancing digital progress within projects can be particularly challenging when collaborating with both dominant and smaller actors across the value chain, especially given their substantial differences in digital maturity, competencies, and technological understanding (Gottlieb and Fredslund, 2022).

Niels W. Falk, CEO of HD Lab, highlights that the use of digital tools remains inconsistent, especially in smaller or less complex projects. He argues that digital requirements should be formalised both legally and practically to ensure effective implementation. Christian R. Jørgensen, Project Manager at MT Højgaard, agrees, noting that while large projects are adopting digital tools, smaller ones are held back by institutional and contractual barriers. Addressing this gap requires not just new technologies but also a shift in legal frameworks and in how clients understand and manage construction projects. Such regulation could also promote fairer market conditions by addressing the costs linked to digitalisation. This is echoed in the case study, where subcontractors showed strong interest in tools like web-based dashboards and real-time contract systems, though financial limitations hinder broader adoption. These perspectives challenge traditional contract management, the Danish Contracts Act , and the legal basis for arbitration in Denmark.

Professor Kim Østergaard from CBS emphasizes the need for institutional change, asserting that transitioning from adversarial relationships to strategic, partnership-based contracting requires a cultural transformation. Additionally, CEO Niels W. Falk from HD Lab argues that contracts must actively incentivise collaboration and

fairly distribute risk, linking payments more closely to milestones that reflect collective achievements rather than individual deliverables. Achieving this goal involves not only restructuring contractual arrangements but also fostering institutional norms that emphasize trust, partnership, and shared objectives across the value chain. These perspectives challenge the reliance on established frameworks in the industry, which are currently institutionalised as the foundation for most construction agreements.

The case study demonstrates that introducing a collaboration agreement within a project is feasible without compromising the underlying construction contract. Project Manager Peter F. Poulsen from Realdania indicates the practical potential of these principles by implementing a comprehensive collaboration agreement alongside traditional contract terms and a shared ICT specification. This additional layer shifted the focus from litigation to dialogue-based problem solving by clarifying roles and communication. Embedding collaboration in contracts could drive wider cultural and institutional change by aligning stakeholders early on digital standards, adjusting incentives to support cooperation, and formalising commitments to new technologies.

Figure 1 illustrates how the respondents' statements subjectively highlight a range of challenges and opportunities related to the adoption of more digital and collaborative contract management practices in a Danish context. Moreover, it also shows the extent to which these aspects are empirically acknowledged by more than one respondent.

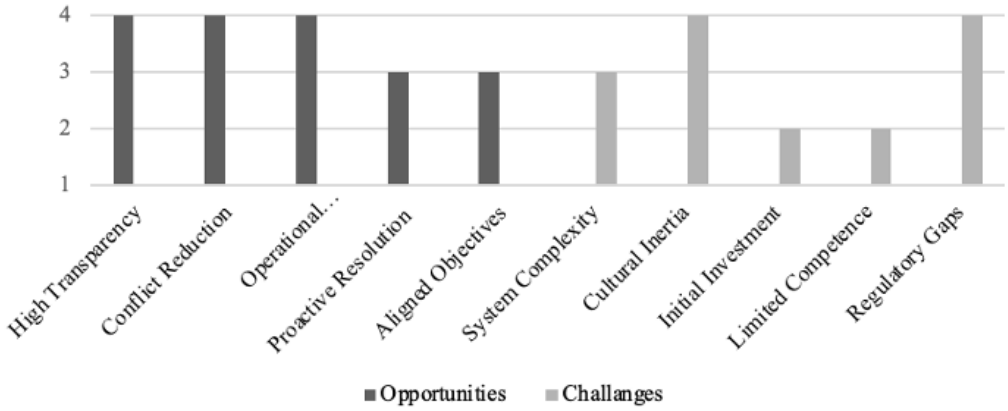


Figure 1: Digital and Collaborative Contract Management Practices

These challenges create space, on the one hand, for re-theorisation, as established actors may seek to preserve their stable environments by marginalising untraditional approaches. On the other hand, the opportunities support the theorisation of new digital contract management practices by addressing persistent issues in the industry. The discussion paves the way for new understandings and developments in contract management, prioritising, for example, transparency, partnerships, and shared objectives over the reactive models of the past. The industry is at a pivotal juncture, driven by demands for efficiency, conflict reduction, innovation, and regenerative impact. Integrating digital and collaborative practices can potentially improve performance, reduce disputes, and foster trust. Yet, this shift requires institutional reform and both regulatory and practical legitimacy to support new contract models. Different actors play a key role in promoting alternative approaches that challenge established norms, which are essential for an effective and regenerative industry future.

CONCLUSION

This inquiry critically analyses traditional and untraditional contract management practices and discusses the processes of institutional change as a foundation for developing more digital and collaborative practices. While the inquiry adopts a more conceptual and theoretical perspective, the case serves as an empirical 'good example' of digital and collaborative contract management in a Danish context. Moreover, the inquiry contributes to additional understandings of both the challenges and opportunities associated with institutional change. Smaller actors, in particular, face difficulties adapting to this shift, where new regulations and collaborative frameworks could serve as potential remedies. Moreover, digital transformation demands not only technological capabilities but also collaborative processes and governance capacities.

Institutional diffusion of new practices, therefore, requires a series of processes, activities, and projects before any meaningful change can alter the current dominant structures. Thus, resistance is expected from actors who benefit from maintaining traditional contract management practices. In this context, theorisation, collective mobilisation, and social recognition form the basis for broader political negotiations and legitimisation processes that can potentially reshape industry practices. The question is whether the current actors recognise the problems with traditional contract management practices or choose to marginalise this development to maintain their stable world. In this case, there is a possibility that a new competing field could emerge, based on more digital and collaborative contract management practices, which implicitly supports regenerative aspects. However, altering the existing field or creating a competing field requires both regulatory and pragmatic legitimacy, which is frequently stated by respondents through empirical formulations and understandings.

Respectfully, generalisations are context dependent and based on a limited empirical foundation. Future research should take a more empirical approach, engaging more cases and actors across the value chain and integrating mechanisms for interventions in the research process. Involving stakeholders with expertise in political negotiation and legitimacy processes could also offer valuable insights into institutional change.

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EXPLORING STAKEHOLDER COLLABORATION IN THE DEVELOPMENT OF BASELINE SCHEDULES

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Effective baseline schedule development is foundational for construction project success, yet its potential is frequently undermined by insufficient stakeholder collaboration, leading to performance inefficiencies and project delays. This research evaluates how stakeholder collaboration influences the process of developing an effective baseline schedule. Specifically, the study seeks to: 1) identify the presence of stakeholder mapping, 2) investigate the extent to which stakeholders are actively engaged, and 3) assess the overall quality of collaboration, and challenges arising, during baseline development. The study includes a literature review and insights from 12 semi-structured interviews conducted with key stakeholders, including project and construction managers, schedulers, clients, and a commercial manager, currently working on Data Centres and Public Works Projects. The findings reveal a lack of formal stakeholder mapping and an unstructured baseline development process with minimal involvement, leading to misaligned schedules, poor onsite coordination, ineffective planning, fragmented client collaboration, and missed milestones, ultimately undermining construction project performance and efficiency. While many studies address stakeholder engagement broadly, this research delves into specific influence on the development process, to advance future collaboration in baseline schedule development.

Keywords: construction planning; organisational culture; productivity; project management; tendering

INTRODUCTION

"The single biggest problem in communication is the illusion that it has taken place." (Moss 2018). Construction is a complex, uncertain, and dynamic industry (Gondia *et al.,* 2020), with project failure rates ranging from 56% (Haass and Guzman 2020) to 85% (Gurgun *et al.,* 2024). While delays are often attributed to factors such as material shortages, labour availability, and weather (Durdyev *et al.,* 2017), poor planning remains a leading cause (González *et al.,* 2014). Alsuliman (2019) argues that insufficient stakeholder collaboration during schedule development significantly affects project performance. Though collaboration is in a project's best interest, stakeholders often fail to integrate effectively, resulting in misaligned schedules and

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coordination issues (Winch 2012). Furthermore, the definition of a stakeholder appears to vary, with Miles (2017) identifying 593 interpretations of the term. While these challenges impact construction broadly, data centre projects face even greater pressures due to their highly compressed timelines and the critical need for rapid delivery to meet increasing global digital infrastructure demands, leaving little room for delays. Similarly, public works projects are experiencing escalating costs and extended delivery timeframes that are garnishing backlash (The Irish Times 2023).

Stakeholders play a significant role in both data centre and public works projects, given the influence the projects play in terms of profitability, social demand and public image. Hence, this research focuses on data centre and building projects under the public works contracts. While previous research has examined project delays and inefficiencies, there remains a gap in understanding the specific mechanisms through which stakeholder collaboration, or the lack thereof, impacts baseline schedule development (Hui Yap *et al.,* 2017). Therefore, this research is a pilot-study as it will look to explore if inconsistencies exist within the available literature (Kistin and Silverstein 2015). Construction typically follows four lifecycle phases: definition, planning, execution, and delivery (Uribe Macías 2017). The baseline schedule, developed during planning, outlines start/finish dates, sequences, and milestones (Vanhoucke 2012), and serves as a benchmark for performance (PMI 2017). Early stakeholder involvement is assumed beneficial, but the extent, structure, and clarity of stakeholder roles remain underexplored (Tampio 2022).

Furthermore, the dynamic and fragmented nature of construction projects introduce further challenges, where multiple stakeholders with varying priorities and risk perceptions must coordinate within constrained timeframes (Mok *et al.,* 2015). As the complexity of projects increase, and the timelines for completion decrease, the focus on a collaborative baseline development is of great significance in the sequencing of activities, determination of resourcing required, and the identification and mitigation of risk through the effective and efficient coordination of a baseline schedule. Understanding the identification and engagement of stakeholders, as well as the degree of collaboration on such projects can provide a first step to enacting strategic practices to improve the process in the construction industry.

To overcome this deficiency, the intricacies of how collaboration occurs on construction projects is explored by the literature review. Secondly, employing a qualitative method, the research employs semi-structured interviews to gain valuable survey data insights from selective industry professionals working in data centre and public works project environments. By integrating insights from the literature review with qualitative interview data, this study explores strategies to foster a more collaborative and stakeholder-driven approach to baseline schedule development. Additionally, an analysis of projects that are compressed in timeline, and of significant social focus, a broader perspective on the diverse challenges and competing priorities within the construction industry is provided. This combined approach enhances the understanding of industry-wide obstacles while emphasising the key factors that influence stakeholder engagement and collaboration, particularly from the perspective of those directly involved in project planning and execution.

Building on these considerations, this study aims to address key research questions regarding how stakeholder collaboration influences baseline schedule development, the extent of stakeholder engagement in the process, and the role of formal stakeholder mapping in improving schedule accuracy and project performance.

Through this investigation, the research contributes to ongoing discussions on enhancing construction planning practices, offering insights that may inform both industry professionals and policymakers seeking to optimise stakeholder involvement in complex project environments.

LITERATURE REVIEW

Stakeholder Identification

Strategic Management (SM) is a concept based on the collective theoretical frameworks of corporate social responsibility theory (Wang 2014), organisational theory (Mainardes *et al.,* 2011), social network theory (Lienert *et al.,* 2013), and fairness theory (Phillips 1997), each of which provides a unique and focused perspective on how stakeholder relationships influence decision-making, governance, and long-term value creation. The theories behind SM, while unique in terms of their focus, have a common approach in that to adequately manage stakeholders on a project, it is necessary to identify, analyse, categorise, and implement a strategic plan to engage and influence stakeholders throughout the project's lifecycle (Missonier and Loufrani-Fedida 2014; PMI 2021; Olatunde and Odeyinka 2021). Freeman (2010) emphasizes the importance of separating SM from merely being a project planning exercise, rather it should be considered as an organisational planning tool that aids companies to identify stakeholders of significance that can provide, or aid in, strategic growth. In complex construction environments, such as data centres and public works, stakeholders include client, contractors, regulatory bodies, suppliers, financiers, and local communities, each with varying levels of influence and decision-making authority (Wood *et al.,* 2021).

In public-private partnership (PPP) projects, failure to properly define stakeholder roles and interests early in the process can result in contractual disputes, scope creep, and budget overruns (Eyiah-Botwe *et al.,* 2020). Similarly, in hospital construction projects, managing multiple stakeholders, such as government regulators, medical professionals, and contractors, requires clear identification frameworks to mitigate governance challenges and prevent delays (Tampio *et al.,* 2022). In infrastructure projects, inadequate stakeholder identification can lead to community resistance, environmental disputes, and legal challenges, all of which contribute to disruptions in baseline scheduling (Yu and Leung 2015). Given these risks, a structured and iterative approach to stakeholder identification is necessary to enhance project efficiency and minimise scheduling uncertainties.

The dynamic and evolving nature of stakeholder influence, and indeed the projects themselves, presents an additional challenge in construction projects. Stakeholders who hold significant power at the initiation phase, such as clients and regulatory authorities, may become less involved during the construction phase, where contractors and subcontractors assume greater influence (Zhu *et al.,* 2024). If these shifts in stakeholder roles and priorities are not anticipated, it can lead to fragmented collaboration, misaligned milestones, and ineffective schedule control. As the baseline schedule is being developed, systematically recognising individuals, groups, or organisations that hold a vested interest in the project's success or failure is an important factor. To avoid a scenario where stakeholders have been overlooked or not included in communications, the development of a stakeholder engagement assessment matrix which utilises a responsible, accountable, consulted, or informed (RACI) is encouraged (PMI 2021). However, while existing literature highlights the importance of stakeholder identification, the client, contractor, and project manager

are generally the only identified stakeholders (Gaur *et al.,* 2023), creating an over-simplistic picture (Tampio 2022).

Stakeholder Mapping

Wood *et al. (*2021) indicates that once stakeholders are identified, mapping is required to provide a structured approach to analysing their influence, interest, and impact on the project outcomes, using a model. Bourne and Kasperczyk (2009) notes that although stakeholder mapping has been in existence for quite some time, adoption within the EU has been slow. Wood *et al. (*2021) developed a stakeholder salience framework, which, after initial identification of stakeholders, categorises stakeholders based on three attributes, namely that of power to influence decisions, legitimacy to their rightful involvement, and urgency to demand immediate action, allowing strategies for specific engagement to monitoring to be developed. Uribe Macías (2017) also suggests a structured approach, however, it assess the influence stakeholders have and the potential dependence the project may have on them in short term, and in the long term as there may be potential for change, enabling the establishment of stakeholder specific actions and strategies. Zhu *et al. (*2024) categorises stakeholders as either "key players", including clients, contractors, government, and designers or "minimal effort" to capture the public and industry organisations, an approach that may not evaluate stakeholders based on project type. Eyiah-Botwe *et al. (*2020) indicates the structured approach may be of little use, should the project fail to produce a clear statement of objectives amongst all stakeholders. The dynamic between decision-making and influence can present a challenge to mapping, as stakeholders such as community groups, environmental agencies, and public institutions may at times lack formal decision-making power, however, still exert substantial influence over project outcomes. Infrastructure and urban development projects often face delays due to public opposition, particularly when community concerns are not considered in early scheduling discussions (Eyiah-Botwe *et al.,* 2020). Gaur *et al. (*2023) notes that mapping should be categorised as either power, durability, or legitimacy to determine stakeholder importance.

Despite the availability of structured mapping techniques to positively influence project outcomes (Uribe Macías 2017), formal stakeholder mapping is often neglected, with 30.65% of private construction projects actively implementing a structured stakeholder management process (Olatunde and Odeyinka 2021). In many cases, stakeholder engagement is limited to regulatory compliance rather than a proactive collaboration approach, leading to inadequate input during scheduling phases and increased project risks (Yu and Leung 2015). This lack of structured mapping is particularly problematic in large-scale infrastructure projects, where stakeholder interests evolve over time, requiring continuous reassessment to prevent misalignment with project goals (Gaur *et al.,* 2023).

METHOD

The existing literature review reveals the availability of tools and techniques capable of the identification and management of relevant stakeholders; however, these are not specific to any specific phase of the project lifecycle, nor are they generally employed (Olatunde and Odeyinka 2021). Therefore, this research is conducted as a pilot study as it involves the investigation of inconsistencies between literature sources (Kistin and Silverstein 2015). A qualitative sampling strategy is adopted, and the two construction sectors selected are data centres and public works projects due to their complex planning environments and heightened scrutiny related to performance and

schedule (George 2016; Osei-Appiah *et al.,* 2024). Wood *et al. (*2021) defines client project management representatives and contractors as fundamental stakeholders in any project. More specifically, PMI (2021) outline the contractor project planner, project manager, construction manager, and commercial manager as the key stakeholder roles in the schedule development and management of a project. Shiyab *et al. (*2023) outlines that low response rates remain a key contributor to bias and the overall quality of results, therefore, a convenience sampling strategy was initially utilised using existing industry connections, with snowball sampling naturally employed. The inclusion criteria for participants were those directly involved in baseline development, or those tasked with recovery should the project fall into delay, have experience in data centre or public works projects, willing to participate in the study voluntarily, employed by an Irish firm to retain consistency among practices, and with titles aligning with the definitions of Wood *et al. (*2021), (George 2016; Osei-Appiah *et al.,* 2024), and PMI (2021).

This resulted in 12 in-depth semi-structured interviews to collect 'thick descriptions' (Bell *et al.,* 2022) of the participants' own interpretations of stakeholder collaboration within their respective firms as outlined in Table 1.

Table 1: Summary of Participants

Stakeholder	Amount	Construction Sector	Years Experience	Organisation Type
Project Managers	2	Data Centres Public Works Contracts	15-20	General Contractor
Construction Managers	4	Data Centres Public Works Contracts	20-25	General Contractor
Project Schedulers	4	Data Centres Public Works Contracts	10-15	General Contractor
Project Manager	1	Data Centres Public Works Contracts	10-20	Client
Commercial Manager	1	Data Centres	15-20	General Contractor

Interview prompts were developed based on key themes in the literature, aligning with the research objectives, and to explore not only whether stakeholders were involved in baseline development, but also how frequently, at what stages, and in what capacity they contributed. The statements evoked in-depth discussions allowing participants to provide insights regarding stakeholder identification, mapping, engagement, also addressing challenges in collaboration, decision-making authority, reporting structures, and strategies for resolving conflicts. The interview questions were presented using Microsoft forms, and the interview was conducted using Microsoft Teams, through the researcher's university account, ensuring secure storage and management of data collection. The questions were tested with members of the training centre prior to distribution. Prior to the interview occurring, participants reviewed and agreed to an informed consent declaration, ensuring participants were aware of the purpose of the research, their rights, and notified all data collected would remain confidential. The interviews were transcribed verbatim, enabling the researcher to familiarise themselves with common themes arising from the data, highlight key points and upload to NVivo 14 before performing coding with an abductive nature, combining both inductive and deductive elements, enabling an iterative and flexible approach as themes aligned or emerged from the analysing process (Page *et al.,* 2024). This approach allowed for open coding of interview transcripts, where categories were not constrained by the initial themes, but rather allowed new insights to emerge during analysis. Inspired by Grounded theory (Glaser and Strauss 1967; Locke 2001) and focusing on the generation of theory from data, the use of open coding was used to group and categorise codes.

FINDINGS AND DISCUSSION

This study presents findings and subsequent discussion derived from in-depth semi-structured interviews conducted with key stakeholders involved in construction project scheduling, each providing insights into their organisations' stakeholder collaboration practices during baseline schedule development. Interviews were analysed thematically to identify common patterns and experiences among participants.

The findings are summarised in Table 2, where interview participants consistently noted the absence of formal stakeholder identification and mapping processes within their organisations. Stakeholders are often identified informally, based on historical project experience rather than structured frameworks, leading to oversight of key stakeholders such as subcontractors, suppliers, and regulatory bodies. Additionally, formal stakeholder mapping tools are rarely employed, causing ambiguity around stakeholder roles and responsibilities. Stakeholder engagement in baseline schedule development predominantly remains minimal and reactive, with limited early-stage involvement from clients, subcontractors, or suppliers.

Table 2: Summary of findings

Theme	Quote	Description & Example
Stakeholder Identification	"Stakeholders identified informally from past familiarity."	Informal identification frequently omits critical stakeholders.
	"Relies heavily on historical contacts."	Assumptions in repeat projects can overlook new stakeholders.
	"Labour unions and inspectors often overlooked."	Overlooked stakeholders cause compliance and schedule disruptions.
Stakeholder Mapping	"Rarely implement formal stakeholder mapping."	Lack of structured methods leads to ambiguity and reactive engagement.
	"No structured classification process."	Unclear stakeholder roles reduce management effectiveness.
	"Clients limited to milestones, minimal detailed input."	Limited client involvement leads to misaligned detailed planning and delays.
Stakeholder Engagement	"Internally developed schedules sent for approval."	Internal-only schedule creation misses stakeholder insights.
	"Subcontractor feedback reactive, after issues arise."	Late subcontractor input results in freque revisions and missed completion dates.
	"Fragmented communication; feedback reactive."	Poor communication results in reactive stakeholder involvement.
Collaboration Challenges	"No regular structured meetings."	Lack of meetings causes misalignment a poor communication.
	"Conflicting priorities unresolved early."	Early-stage conflicts lead to frequent schedule adjustments and delays.

The findings provide valuable perspectives on how stakeholder collaboration is currently practices within industry settings, particularly during the planning and baseline scheduling phases. By incorporating thematic interview prompts and abductive coding to examine recurring themes across participant responses, the discussion highlights underlying issues affection stakeholder collaboration, from which stakeholder identification, mapping, and engagement were identified as the emerging themes.

Stakeholder Identification

All (12) of the participants confirmed their organisation does not have a formal or structured stakeholder identification process, noting the clients and contractor project

managers were generally the assumed stakeholders, with no considerations of subcontractors, suppliers, or external regulatory bodies "Stakeholders are generally identified informally from past familiarity on projects". The failure to systematically identify all influential stakeholders contradicts Wood *et al. (*2021), emphasising the importance of stakeholder identification resulting in construction gaps (Gaur *et al.,* 2023; Tampio 2022).

Stakeholder Mapping

Despite the availability of structured stakeholder mapping (Bourne and Kasperczyk 2009; Olanrewaju and Ogunlana 2021), the project managers (3), construction managers (4), and project schedulers (4) state that these techniques are not adopted in practice, "No structured classification process is utilised". Theoretical models such as the Stakeholder Salience Model (Wood *et al.,* 2021), Power-Interest Matrix (Zhu 2024), and RACI framework (PMI 2017) offer clear methodologies for categorising stakeholders based on power, legitimacy, and urgency, prior and during the planning stages of a project, a sentiment echoed by the project (3) and construction managers (4), however, there was little consensus on who should be responsible for implementing it. Those in scheduling (4) and construction management roles (4) indicated that mapping fell outside their remit, while project managers (3) and the commercial manager (1) assumed that stakeholder identification was a general and informal project function rather than a structured process. Project managers (4) also noted that stakeholder engagement was largely reactive, with certain stakeholders requesting updates or involvement only after project execution had begun, reinforcing that stakeholders are not thoroughly identified, mapped, or engaged, nor do they appear to attempt to engage themselves, facilitating unclear communication channels and undefined responsibilities contributing to misalignment (Tampio 2022; Zhu *et al.,* 2024).

Stakeholder Engagement in Baseline Scheduling

Schedulers (4) indicated that stakeholder engagement in baseline development is often restricted to high-level milestone approval, with little interaction on the sequencing, resourcing, or confirmation of scope alignment, and not an active collaboration between clients, contractors, subcontractors, and other stakeholders (PMI 2021; Zhu *et al.,* 2024). The general contractor project managers (2), construction managers (4), and commercial manager (1) were unsure as to the level of engagement clients were involved, with each noting stakeholder engagement is typically driven by necessity rather than proactive planning. The schedulers (4) noted that the baseline is developed in silo, excluding key stakeholders from early planning discussions, despite the potential to improve scheduling accuracy by collaboratively determining resourcing availability and execution constraints, often resulting in the failure to achieve activity and milestone completion dates (Olatunde and Odeyinka 2021; and Tampio 2022). The absence of early, proactive engagement results in misaligned assumptions, inefficiencies in work execution, and the need for frequent schedule revisions. Several participants did allude to time constraints (schedulers 4), resource limitations (construction managers 4), and concerns over commercially sensitive information (commercial manager 1) being shown to certain stakeholders as some of the reasons to not adopting a structured approach to stakeholder management, however, it was also noted by the schedulers (4), construction managers (4), and commercial manager (1) that they were unsure who should identify the stakeholders. This would indicate there exists systemic issues around stakeholder management rather than simply the

misunderstanding of the approach. Moreover, there is a clear lack of awareness and existence of collaboration mandates and processes within the organisational structure.

Collaboration Challenges

Mok *et al. (*2015) and Zhu *et al. (*2024) state that stakeholders generally interact with the schedule when the project experiences delays, conflicts, or contract enforcement issues arise, with the schedule being built in isolation rather than progressive collaboration, a sentiment echoed by all participants (12). Participants in public works projects, project managers (2), construction managers (2), and schedulers (2), noted that feedback from clients and external stakeholders was primarily focused on verifying milestone dates, rather than contributing to schedule development itself, reducing opportunities for iterative schedule improvements, aligning with the previous studies by Eyiah-Botwe *et al. (*2020) and Olanrewaju and Ogunlana (2021). Without a structured collaboration framework, projects will likely continue to rely on reactive problem-solving rather than proactive stakeholder alignment, reinforcing inefficiencies and leading to frequent schedule adjustments and misaligned priorities.

The findings indicate a persistent gap between theoretical best practices in stakeholder management and their practical application in baseline schedule development. The reliance on repetitive, experience-based identification in familiar project environments may be efficient in the short term but becomes problematic when projects expand into new locations or involve new clients, where compliance and regulatory issues can arise unexpectedly (Yu and Leung 2015). While frameworks and methodologies for stakeholder management exist, they are rarely adopted or adaptable to many live project environments, particularly during baseline scheduling.

CONCLUSION

Construction projects frequently suffer from delays and misaligned schedules due to a lack of structured and adaptable stakeholder collaboration during baseline schedule development. This study explored how stakeholder collaboration influences the creation of baseline schedules, focusing on stakeholder identification, mapping, engagement, and collaboration quality. Using a qualitative approach, the research combined a literature review with 12 semi-structured interviews involving professionals from data centre and public works projects. The findings reveal that stakeholder management is often informal and reactive. Stakeholders are commonly identified through past projects rather than formal mapping, and their engagement is typically limited to milestone review rather than meaningful participation in schedule development. These findings indicate a significant gap between best-practice frameworks and real-world application. There is a need for project teams to adopt more structured and proactive collaboration strategies. Integrating stakeholder engagement frameworks into standard planning procedures could lead to more realistic schedules, stronger alignment, and improved project performance.

As a pilot study, this research provides a foundation for further work. Future studies could explore the implementation and effectiveness of specific stakeholder management tools across diverse project types and delivery environments.

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ADVANCING CONSTRUCTION CONTRACT RISK MANAGEMENT THROUGH NLP: INSIGHTS, CHALLENGES, AND OPPORTUNITIES

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Disputes in the construction industry are increasingly complex, making the need for robust construction contractual risk management (CCRM) more vital to improving project performance in terms of cost, time, and quality. Natural Language Processing (NLP) is found to be a promising solution for creating CCRM system. However, there is very limited research into the application of NLP to CCRM over the last two decades. This study aims at conducting a scientometric analysis by using VOS Viewer for summarising key trends, challenges, and opportunities in NLP applications for CCRM. The results of the study identify gaps in interpreting complex construction legal language, especially nuanced contractual clauses that current NLP is unable to understand correctly; these require well developed methods for NLP studies. Besides that, limited inter-disciplinary research is observed among several knowledge fields: construction, law, management and computer science, leading to shortcomings regarding the elaboration of multipurpose applications for managing the process of risks. The paper concludes that meeting these challenges will utilise NLP's full potential for transformation in the automation and enhancement of CCRM practices yielding better project outcomes.

Keywords: construction contract risk management; contracts; natural language processing; legal text analysis; scientometric analysis

INTRODUCTION

The CCRM is one of the key parameters in the project success. The contractual approach to risk management involves distributing risks among the involved parties within the contracts to facilitate efficient and effective management of these risks throughout the construction process (Zhang *et al.,* 2006). Construction projects, due to their unique characteristics, involve numerous interconnected activities fraught with risks, each capable of affecting costs, timelines, and quality to varying degrees. To ensure project success, a robust risk management system is essential, typically encompassing identification, analysis, and response (Burke, 2013). This enables stakeholders to effectively address risks as they arise. Moreover, manual construction contract risk review is tedious prone to errors and inefficiencies (Lee *et al.,* 2020).

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Rasool, S, Chen, Y, Udeaja, C and Fong, D (2025) Advancing Construction Contract Risk Management Through NLP: Insights, Challenges, and Opportunities, *In:* Thomson, C and Neilson, C J (Eds) *Proceedings of the 41st Annual ARCOM Conference,* 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 210-219.

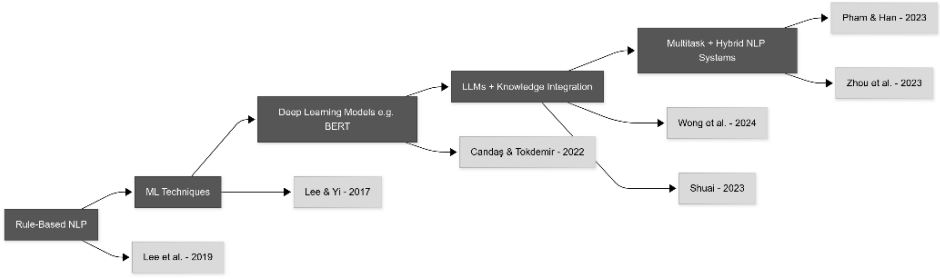
Natural Language Processing (NLP) is a promising solution for enhancing automation, accuracy, and adaptability in CCRM.

In recent times, as NLP has advanced and gained traction within the field of computer science, certain researchers have endeavoured to apply NLP techniques to the construction sector. The expanding use of artificial intelligence (AI), and more especially NLP, in CCRM is a major driving force behind this study. AI is a broad field, while NLP is a subfield focused on understanding and processing human language. Shamshiri *et al. (*2024) conducted a thorough review by aligning the objectives of 205 publications with various domains, areas, tasks, and processes in construction management practices. Through this review, they unveiled numerous facets of the construction sector bolstered by Text Mining (TM) and NLP approaches. Although the review covers certain aspects of risk management, a comprehensive scientometric analysis is warranted to pinpoint research gaps and identify emerging trends in this critical area of construction project management. Therefore, the aim of this study is to use scientometric techniques to examine research trends in NLP-driven contract risk management, emphasising the transition from rule-based systems to Machine Learning (ML), Deep Learning (DL), and Large Language Models (LLMs). The findings aim to inform future research directions that incorporate NLP tools into CCRM processes. It highlights significant developments, seminal publications, and potential paths forward for AI-driven contract analysis.

LITERATURE REVIEW

Scientometric analysis provides valuable insight into publication trends and thematic clusters, it is limited in offering deeper interpretive insights into the literature. To address this, the study includes a targeted review of high-impact articles within the identified clusters, providing a more nuanced understanding of emerging developments and practical challenges in CCRM. From rule-based approaches to sophisticated ML and DL techniques, NLP in contract analysis has advanced, facilitating effective risk identification, automated contract reviews, and decision-making in construction contract management. Although they relied on syntactic/semantic rule matching and lexicon-based NLP, early rule-based models, such as Lee *et al. (*2019), lacked flexibility. With research like Lee and Yi (2017) using classifiers like ANN, SVM, KNN, and NB for contract risk prediction, the rise of ML enhanced automation. As demonstrated by Moon *et al. (*2022a), who used BERT for risk categorisation, and Candaş and Tokdemir (2022), who created a vagueness detection system for FIDIC contracts, DL further improved contract analysis.

Figure 1: Evolution of CCRM using NLP



In recent years, Wong *et al. (*2024) and Shuai (2023) have shown how to link LLMs with domain-specific knowledge bases using knowledge- and rationale-augmented frameworks, which improve explainability and scalability. Further optimising

contract risk management, hybrid approaches like similarity-based clause identification (Zhou *et al.,* 2023) and multitask learning (Pham and Han, 2023) combine rule-based NLP, ML, and DL to improve efficiency, accuracy, and adaptability. The summary and the evolution of these recent studies on NLP in CCRM is presented in Table 1 and Figure 1. The selection of these studies is based on the evolution of NLP in CCRM over the years.

METHOD

To conduct a thorough scientometric evaluation, a tangible technique is essential in which a methodical approach is employed. The present study used a scientific mapping approach to create a bibliometric map of CCRM using natural language processing, based on sources from the Google Scholar and Scopus databases from 2015 to 2025.

Author(s)	Review Type	Review Method	Focus of Study
Lee and Yi (2017)	Empirical	TM and risk prediction	Bidding risk prediction (text and numerical)
Lee *et al.,* (2019)	NLP and Rule-based	Semantic analysis and rule-based extraction	Auto risk clause extraction
Candaş and Tokdemir (2022)	Supervised Learning	ML-based risk classification	Vagueness in FIDIC Silver Book
Shuai (2023)	NLP and AI	Rational-augmented NLP	Unilateral change risk (EPC)
Zhou *et al.,* (2023)	DL and NLP	BERT-based multi-label classification	Missing clause detection
Pham and Han (2023)	Multi-task NLP	Semantic classification	Semantic risk action prediction
Wong *et al.,* (2024)	NLP-Knowledgebase	Large Language Models	Knowledge-based risk ID

Table 1: Recent Studies on CCRM using NLP

A bibliometric search, a scientometric data analysis, and a thorough discussion of the study's findings are among the steps of the review structure and procedures depicted in Figure 2.

Figure 2: Overview of Methodology of Scientometric Review Study

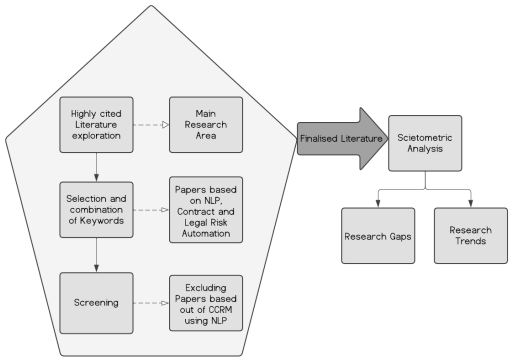


Figure 3: Most Used Keywords



Figure 3 shows the most often used terms and their combinations in the highly cited literature. Relevant papers are extracted using these keyword combinations from

Scopus and Google Scholar (GS). Any document having an academic structure was indexed by GS, which also discovered the highest percentage of citations. However, when two or more online versions of the same journal article are identified, this results in discrepancies and occasionally double citation counts, reporting larger citation counts than the fact (Derbe *et al.,* 2020). These could significantly affect citation metrics, leading to erratic outcomes. For more accurate and consistent results, journals that are indexed by Scopus are used in this study.

The manual evaluation of several research publications is time-consuming and prone to errors and inconsistencies. Therefore, scientometric data analysis is adopted for comprehensive review of bibliometric literatures. Due to its exceptional mining and visualisation capabilities for large amounts of textual data, VOSViewer, a scientometric analysis software program, was used to build and analyse the bibliometric network of science. To find influential researchers, publication papers, and journals, VOSViewer assisted to create, visualise, and analyse bibliometric networks; map and analyse research topic trends using bibliometric networks of words in the CCRM domain using NLP; and analyse 61 journal articles and conference papers with XLSX format file that was downloaded from Scopus (Derbe *et al.,* 2020).

FINDINGS AND DISCUSSION

The author(s) performed a thorough discussion based on scientometric analysis to summarise the main research themes, pinpoint research gaps, and establish a framework for future study. The following subsections provide illustrations of the specific findings and discussion.

A Synopsis of Bibliometric Research

Figure 4 displays the total number of articles published in the field of CCRM employing NLP between 2015 and 2025. This period captures the rise of CCRM as a distinct research area and the growing use of AI and NLP in construction. It reflects key developments in digital risk management and supports forward-looking trend analysis. Since the data was gathered up until March 6, 2025, the number of papers published for 2025 was not comprehensive. The graph, however, demonstrates a notable rise in publications starting in 2018 and peaks in recent years, suggesting a growing interest in the topic among researchers. This surge likely coincides with the wider adoption of AI and NLP technologies in construction.

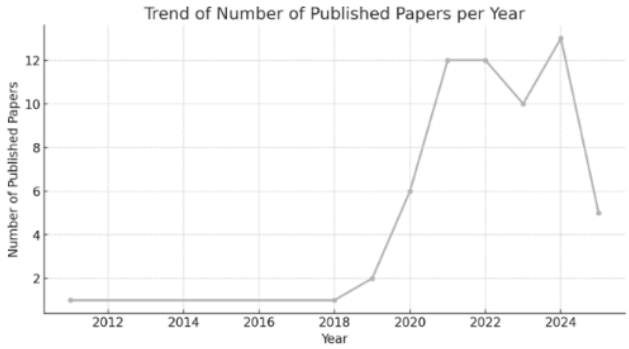


Figure 4: Trend Graph of Published Papers

Key Influential Journals

Figure 5 and Table 2 list the key influential journals in CCRM that use NLP. These prestigious journals were analysed and visualised using VOSViewer's 'citation-

documents' bibliometric network. A minimum of two research papers have been chosen for each journal. The number of publications, total citations, and total link strength, all of which indicate a source's level of connection within the research community are among the important metrics included in each entry.

Automation in Construction is the most influential journal among the sources examined, with eight papers, 222 citations, and the greatest total link strength of 441. This implies that it is a major topic of discussion in scholarly settings concerning construction automation. The Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, with 127 citations, and the Journal of Computing in Civil Engineering, with 136 citations, are two other noteworthy sources. Research on the legal elements of engineering projects and computing in construction is greatly aided by these periodicals.

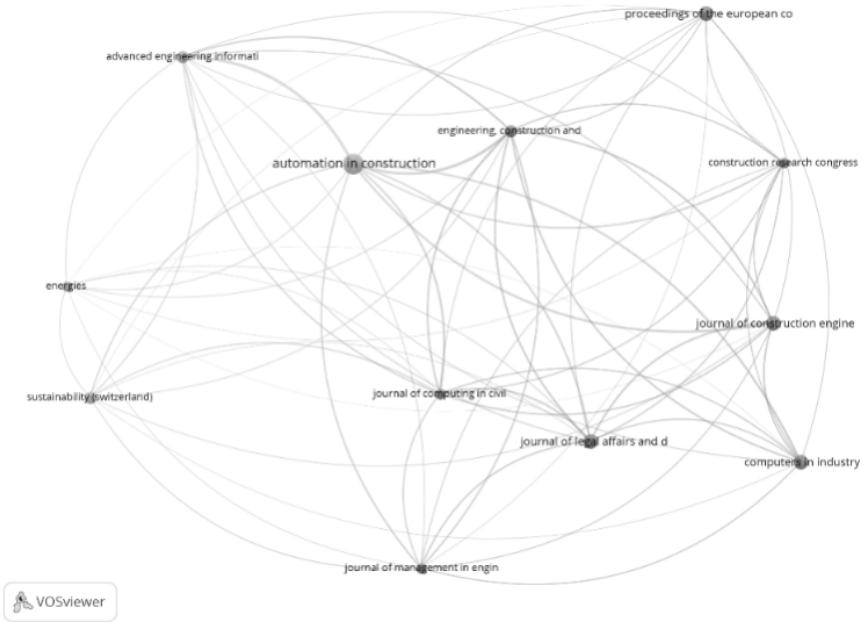


Figure 5: Bibliometric Network of Most Influential Journals

Source	Documents	Citations	Link Strength
Advanced Engineering Informatics	3	95	235
Automation in Construction	8	222	441
Computers in Industry	4	22	204
Construction Research Congress 2022: Project Management and Delivery, Controls, and Design and Materials	2	4	152
Energies	2	49	56
Engineering, Construction and Architectural Management	3	46	328
Journal of Computing in Civil Engineering	2	136	217
Journal of Construction Engineering and Management	4	99	239
Journal of Legal Affairs and Dispute Resolution in Engineering and Construction	4	127	220
Journal of Management in Engineering	2	79	150
Proceedings of the European Conference on Computing in Construction	4	2	90

Table 2: Most Influential Journals

Bibliometric Network of co-occurrence of keywords

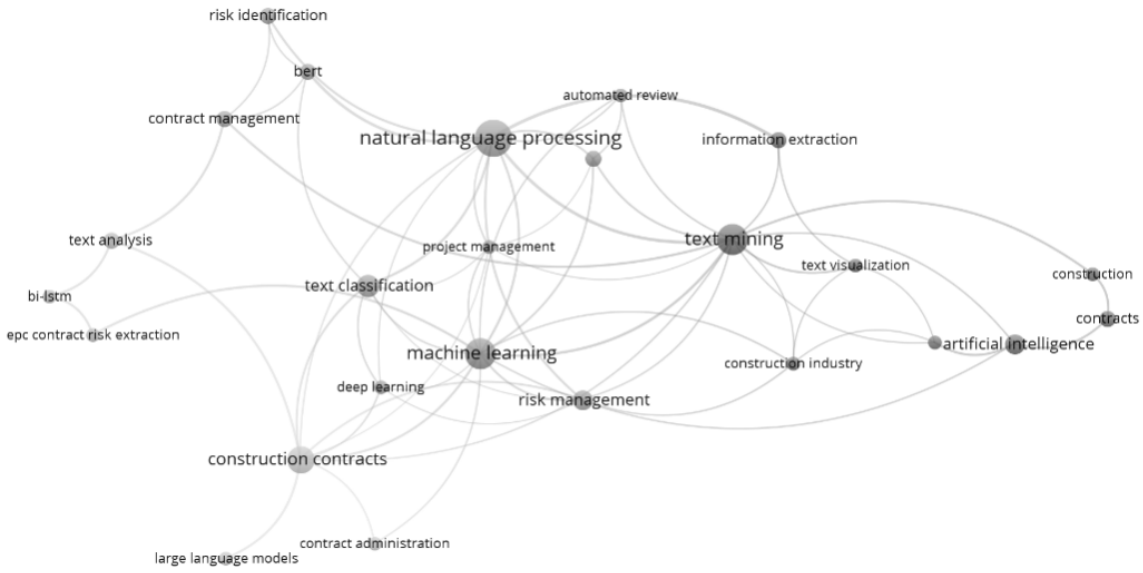
The bibliometric network's keywords show the primary themes of intellectual collaboration and organisations as well as the general boundaries of earlier study. The

following study has adopted bibliometric mapping of co-occurrence of terms using 'fractional counting' and 'author keywords' in VOSViewer to establish a bibliometric network. The major keywords had to appear at least twice. During the initial result, 177 keywords out of 30 keywords satisfied the criterion. Words with the same meaning but multiple differences, like construction contract versus construction contracts, were chosen with a higher occurrence value. Keywords with similar semantic connotations, like artificial intelligence (AI) versus artificial intelligence, and natural language processing (NLP) versus NLP, were disregarded. Twenty-five keywords in all were selected, as indicated in Table 3 and Figure 6. Based on co-occurrence in bibliographic data, link strength in VOSViewer measures the relationship between two elements, such as authors, keywords, or documents. For instance, in keyword co-occurrence analysis, two terms that have a connection strength of five appear together in five publications. These values aid in locating networks and clusters of interest for research.

Table 3: Co-occurrence of Keywords

Keywords	Occurrences	Link Strength	Keywords	Occurrences	Link Strength
Natural Language Processing	14	12.0	Risk Identification	3	2.0
Machine Learning	10	9.0	Text Analysis	3	3.0
Text Mining	10	10.0	Automated Review	2	2.0
Construction Contracts	8	7.0	Bi-LSTM	2	2.0
Text Classification	5	4.0	BIM	2	2.0
Artificial Intelligence	4	3.0	Construction	2	2.0
Risk Management	4	4.0	Construction Industry	2	2.0
BERT	3	3.0	Contract Administration	2	1.0
Construction Specification	3	3.0	Deep Learning	2	2.0
Contract Management	3	3.0	EPC Contract Risk Extraction	2	2.0
Contracts	3	2.0	Large Language Models	2	1.0
Information Extraction	3	3.0	Project Management	2	2.0
			Text Visualisation	2	2.0

Figure 6: Bibliometric Network of Co-occurrence of Keywords



The VOSViewer generated keyword co-occurrence network identifies important study areas at the nexus of TM, ML, AI, and construction contract analysis. NLP and risk identification are at the centre of a significant cluster, with research using models such

as BERT and Bi-LSTM to automate risk assessment and contract review. Scholars like Moon *et al. (*2022a) and Pham and Han (2023) have shown how NLP may be used to identify hazards in FIDIC and general construction contracts at the pre-bid stage. In a similar vein, the ML in Project and Risk Management cluster concentrates on using AI-powered predictive analytics to improve construction project risk reduction. To assist data-driven decision-making for contract compliance and risk monitoring, study by Siu *et al. (*2018) demonstrate how ML models are being used to assess risk registers and textual risk descriptions.

The development of AI-powered solutions for automated risk assessments and legal compliance checks is another noteworthy trend in TM and AI-based construction document analysis. Scholar such as Shuai (2023) have investigated TM methods to monitor contractual deviations and examine legal provisions in EPCs. Study by Candaş and Tokdemir (2022) demonstrate growing interest in blockchain-based smart contracts and AI-enhanced contract administration, which is reflected in the Smart Contracting and Legal Tech in Construction cluster. Finally, works Choi *et al. (*2021a) and Choi *et al. (*2021b) demonstrate ML applications in EPC and ITB contract risk classification, highlighting the critical role that text classification and risk extraction play in AI-driven contract analytics. When taken as a whole, these study clusters show that AI and ML are increasingly being used in contract management to improve risk assessment, compliance, and decision-making in building projects.

Citations of articles

Each of the research papers in the dataset with at least 30 citations is represented by the VOSViewer network visualisation. 13 documents in all satisfied this requirement, showcasing the most important contributions to this field of study, as seen in Table 4. It appears that research in this topic is fragmented, with influential papers being cited in various places rather than establishing a coherent citation network, as evidenced by the high citation counts of several articles despite poor linkages. Some study subfields are more interconnected than others, as evidenced by the existence of small, closely related clusters (e.g., Marzouk (2019) and related works), which may result in future research collaborations that are more robust. The increasing popularity of recent studies (Moon (2022a), Choi (2021b), etc.) suggests that the area is still developing and that new study subjects are appearing. This implies that to examine how these more recent papers fit into the larger body of research, future bibliometric studies must keep tabs on them.

Table 4: Citations of Articles

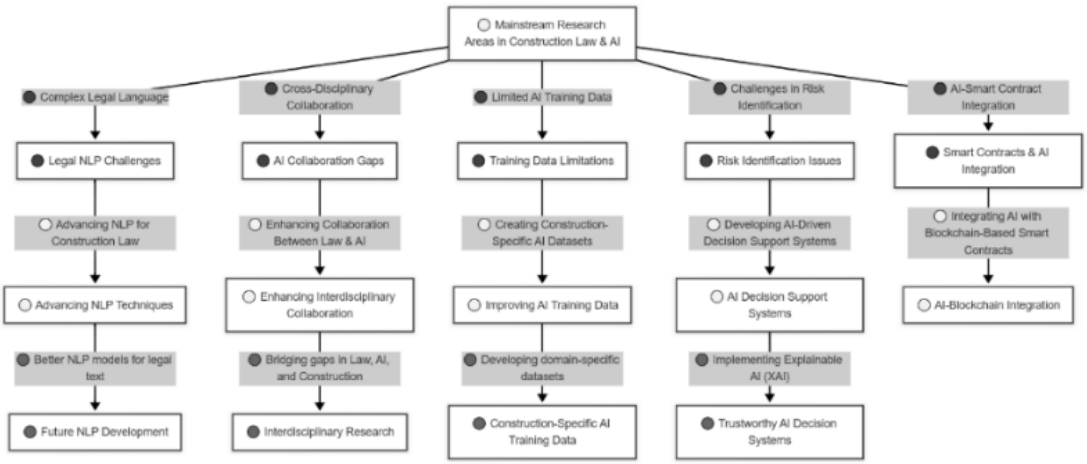
Document	Citations	Links	Document	Citations	Links
Lee (2019)	120	0	Xu (2021)	57	0
Hassan (2020)	96	0	Moon (2022a)	55	0
Marzouk (2019)	71	3	Sun (2020)	44	0
Moon (2021)	68	0	Choi (2021b)	41	0
Lee (2020)	62	1	Gurgun (2022)	39	0
Choi (2021a)	33	1	Moon (2022b)	34	1

DISCUSSION

Beyond identifying frequent keywords and citation patterns, the findings suggest that research in CCRM is increasingly focused on risk prediction models, AI integration,

and collaborative contracting. However, the dominance of citation metrics may obscure less cited but potentially transformative research. For example, while smart contract applications receive fewer citations, they represent a frontier in risk minimisation strategies. A thorough depiction of the primary study areas, gaps, and trends is provided in Figure 7. Given NLP's difficulty understanding complicated contractual agreements and duties, legal language complexity continues to be a significant obstacle. The accuracy of risk categorisation is weakened by a lack of annotated datasets, and customised NLP models are limited by the absence of multidisciplinary cooperation between law, NLP, and construction management. Additionally, unclear contract conditions make it challenging to automate risk identification, and there is still much to learn about integrating NLP with blockchain-based smart contracts for real-time compliance monitoring.

Figure 7: Mainstream Research Areas, Gaps and Trends



Future research should prioritise interdisciplinary methods that integrate data science with legal engineering to address contract ambiguity and automation, upgrading NLP methods with domain-specific LLMs, and enhancing decision support systems using Explainable AI (XAI). AI-driven contract management in construction will advance with the development of extensive construction contract datasets and the integration of AI with blockchain-based smart contracts, which can facilitate automated risk assessment and compliance monitoring. The main research areas in Construction, Law and AI are highlighted with following key enhancements: Main Research Areas (white circles), Gaps (red circles), and Trends (blue circles).

CONCLUSION

This study offers a scientometric assessment of CCRM using natural language processing (NLP), highlighting significant advancements, challenges, and future directions. NLP and ML help with contract analysis and risk assessment but working with legal jargon and integrating AI into contract management still pose challenges. Lack of cross-disciplinary research and annotated datasets limit the utility of artificial intelligence. Closing these gaps requires cooperation between domain-specific AI models and experts in AI, law, and building. Future developments in blockchain-integrated smart contracts, AI-driven decision support systems, and natural language processing could revolutionise contract risk management by reducing disputes.

Data Availability Statement

All data used for the scientometric analysis is available and accessible upon request.

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DESIGN AND TECHNOLOGY

EXPLORING THE POTENTIAL OF VIRTUAL REALITY IN CROSS-BORDER CONSTRUCTION PROJECTS: A CASE STUDY OF QATAR-INDIA COLLABORATION

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The global construction industry is undergoing a profound transformation driven by the rapid integration of advanced technologies. Virtual Reality (VR) technology among the technologies has transformative potential in the construction industry. This research investigates the integration of VR technology in cross-border construction project management, with a specific focus on projects designed in India for Qatar. It addresses the question: How can VR improve cross-border project management, and what are the key challenges and solutions for its integration? While previous research focused on VR's applications in health, safety, and cost management within single-location projects, this study examines VR's role in cross-border contexts. The study revealed that key benefits of VR include improved communication, immersive design visualisation, and enhanced stakeholder interaction. Challenges such as high costs, system compatibility issues, and the need for specialised training were identified. Solutions proposed include targeted training, ensuring system compatibility, and cost-effective leasing models. The study emphasizes robust data security and standardised protocols for VR use in cross-border settings, contributing practical insights for industry professionals and highlighting VR's potential to transform global construction practices.

Keywords: Virtual Reality; VR; technology; cross-border; construction; India; Qatar

INTRODUCTION

The global construction industry is undergoing a profound transformation driven by the rapid integration of advanced technologies. This digital revolution, often referred to as Construction 4.0, encompasses a suite of innovative tools and methodologies that are fundamentally reshaping how construction projects are planned, executed, and managed (Hesselink *et al.,* 2024). Among these emerging technologies, Virtual Reality (VR) stands out for its potential to revolutionise design visualisation,

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Manege, S L, Aravindakshan, A K, Mahmud, A T and Kiwia, N (2025) Exploring the Potential of Virtual Reality in Cross-Border Construction Projects: A Case Study of Qatar-India Collaboration, *In:* Thomson, C and Neilson, C J (Eds) *Proceedings of the 41st Annual ARCOM Conference,* 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 222-231.

collaboration and communication within the construction sector (Watfa and Akili 2023).

However, cross-border construction projects present unique challenges that traditional communication and collaboration methods often struggle to address. These challenges include navigating time zone differences, overcoming cultural and language barriers, and adhering to diverse legal frameworks (Damm 2022). Time zone disparities can lead to delays in communication and decision-making, while cultural and language barriers can result in misunderstandings and conflicts among team members. Additionally, differences in legal and regulatory frameworks can complicate compliance and contractual obligations, leading to potential legal disputes. Logistical challenges, such as the coordination of materials and labour across borders, further exacerbate these issues, often resulting in project delays and cost overruns (Daoud, El Hefnawy and Wefki 2023).

The consequences of these challenges are significant. Project delays and cost overruns can lead to financial losses and strained relationships between stakeholders, including clients, contractors, and investors. Traditional communication methods, such as emails and video conferencing, are often insufficient for addressing these complexities, as they lack the immersive and interactive capabilities needed to effectively convey complex design concepts or facilitate real-time collaboration.

VR technology can be a potential solution, offering a collaborative virtual environment that transcends geographical boundaries. Enabling project teams and stakeholders to engage with project concepts in a truly immersive and interactive manner (Karami *et al.,* 2021). This immersive experience allows geographically dispersed teams to virtually navigate a project under construction, interact with digital twins of building models, and provide real-time feedback. These capabilities hold immense promise for revolutionising design visualisation, collaboration, stakeholder engagement, and overall project delivery within the cross-border construction landscape (Watfa and Akili 2023).

Despite these promising advantages, the application of VR technology in cross-border construction project management remains an under-explored area. While existing research has focused on the use of VR in health and safety (Bao *et al.,* 2024) and cost implications (Mohammadi and Garrido Martins 2024), there is a notable gap in studies examining VR's potential in cross-border construction project management. This research aims to fill this gap by investigating the integration of VR technology in cross-border construction project management, with a specific focus on projects designed in India for Qatar. By highlighting the practical implications of VR, such as improved communication, enhanced collaboration, and more efficient project delivery, this research provides valuable insights for industry professionals and contributes to the growing body of knowledge on VR in construction.

LITERATURE

Qatar-India Collaboration

Qatar's economy, heavily reliant on natural gas exports, has been diversifying through initiatives like the Qatar National Vision (QNV) 2030, which aims to bolster economic and social development. The FIFA 2022 World Cup further accelerated infrastructure development, including stadiums and mega-projects (Jarkas, Kadri and Younes 2012). However, Qatar faces challenges such as high labour costs and a scarcity of skilled professionals, prompting the country to outsource design and

technical services from India, known for its cost-effective and well-trained workforce (Agrawal *et al.,* 2011). Despite the economic advantages, cross-border collaborations between Qatar and India often encounter coordination challenges due to differences in language, work culture, and time zones, leading to miscommunication and project delays (Mahalingam and Levitt 2007).

VR's Role in the Construction Industry

VR technology has gained traction in the construction industry for its ability to enhance design visualisation, collaboration, and stakeholder engagement. During the design phase, VR allows professionals to create and interact with 3D models in a virtual environment, enabling early detection of design flaws and reducing costly rework during construction (Dunston *et al.,* 2011). VR also facilitates real-time collaboration among stakeholders, allowing them to immerse themselves in the project and adjust elements as needed, thereby aligning client expectations with design outcomes (Goulding *et al.,* 2012).

Despite these benefits, VR's adoption in construction faces several barriers, including high implementation costs, the need for significant computational power, and resistance to new technologies (Li *et al.,* 2018). Additionally, the integration of VR with existing workflows, particularly in cross-border projects, presents compatibility challenges that must be addressed to ensure seamless collaboration (Prabhakaran, Mahamadu and Mahdjoubi 2022).

VR In Cross-border Construction Projects

In cross-border construction projects, VR can offer unique advantages by enabling immersive previews of designs, fostering real-time collaboration, and enhancing communication among geographically dispersed teams (Haddud *et al.,* 2017). VR's ability to create a shared virtual environment can allow stakeholders from different locations, such as India and Qatar, to interact with 3D models and provide real-time feedback, reducing misunderstandings and improving decision-making (Wang *et al.,* 2018). Furthermore, VR can be integrated with Building Information Modelling (BIM) to create interactive simulations that enhance project planning and resource allocation (Hesselink *et al.,* 2024).

However, the adoption of VR in cross-border projects is not without challenges. High initial costs, the need for specialised training, and disparities in technology infrastructure across countries can hinder VR integration (Johansson and Roupé 2024). Additionally, while VR can mitigate some communication barriers, it cannot fully address cultural and linguistic differences, which remain critical factors in cross-border collaborations (Nee *et al.,* 2012).

While VR holds significant promise for transforming cross-border construction projects, its adoption is not a remedy for all challenges. The technology's ability to enhance communication and collaboration is well-documented, but its effectiveness depends on the willingness of stakeholders to adopt new practices and the availability of robust technical infrastructure. Moreover, the high costs associated with VR implementation may be prohibitive for smaller firms, particularly in developing countries like India, where budget constraints are a significant concern.

The integration of VR with BIM and other emerging technologies, such as Artificial Intelligence (AI), could further enhance its potential by enabling more accurate simulations and predictive analytics. However, this convergence also raises concerns

about data security and interoperability, particularly in cross-border contexts where sensitive information may be shared across jurisdictions (Delgado *et al.,* 2020).

VR has emerged as a promising tool for addressing the complexities of cross-border construction project management by offering immersive and interactive environments that can bridge geographical, cultural, and logistical divides. While prior research has examined VR's applications in areas such as health and safety (Bao *et al.,* 2024) and cost management (Mohammadi and Martins 2024), there remains a significant gap in understanding its role in enhancing collaboration, communication, and stakeholder engagement in international construction contexts. This study addresses this gap by focusing on the unique challenges of cross-border projects such as time zone differences and cultural barriers with a particular emphasis on Qatar-India collaborations. The findings aim to provide practical insights for industry professionals and contribute to the broader discourse on the transformative potential of VR in global construction project management

METHOD

This study adopts a positivist research paradigm, assuming reality is objective and measurable through systematic observation and quantification (Saunders, Lewis and Thornhill 2019). A quantitative methodology was employed to explore the use of Virtual Reality (VR) in Qatar-India cross-border construction management. This approach facilitated the collection of numerical data from a broad sample of industry professionals, enabling statistical analysis on VR perceptions of its effectiveness, challenges, and remedies.

Key concepts from studies by Nee *et al. (*2012), Li *et al. (*2018), Delgado *et al. (*2020) and Johansson and Roupé (2024) were operationalised to align the literature review with survey questions. VR adoption was measured through questions on usage frequency, specific applications in project phases, and willingness to integrate VR into future projects. Traditional cross-border methods' effectiveness was assessed using a Likert-scale, while VR's perceived benefits and challenges were captured through items focusing on communication, design visualisation, stakeholder engagement, and project efficiency.

A structured online questionnaire was distributed to construction professionals experienced in Qatar-India cross-border projects. It included demographic questions, closed-ended questions, and Likert-scale items to measure perceptions of VR's impact on project management. A combined purposive and snowball sampling approach was used to target a diverse sample of professionals, including project managers, engineers, architects, and quantity surveyors (Trochim and Donnelly 2006; Manege, Kennedy and Aloyce 2024). The questionnaire received 49 responses: 19 from engineers, 11 from project managers, 8 from architects, 4 from quantity surveyors, and 1 from another role.

Data analysis involved reliability testing using Cronbach's Alpha, which yielded a satisfactory score of 0.736, ensuring internal consistency (Tavakol and Dennick 2011). Descriptive statistics summarised participant demographics, VR usage patterns, and perceptions of VR benefits and challenges.

DATA ANALYSIS

Effectiveness of Traditional Cross-border Methods

The effectiveness of traditional design collaboration methods in cross-border projects was assessed using a 5-point Likert-scale (1 = least effective, 5 = most effective). The results (Figure 1) indicate that while a majority (51.2%) of respondents rated these methods as somewhat effective, only 9.3% considered them very effective. Notably, 18.6% of participants found traditional methods to be either neutral or somewhat ineffective, suggesting significant room for improvement in fostering more effective design collaboration in cross-border construction projects.

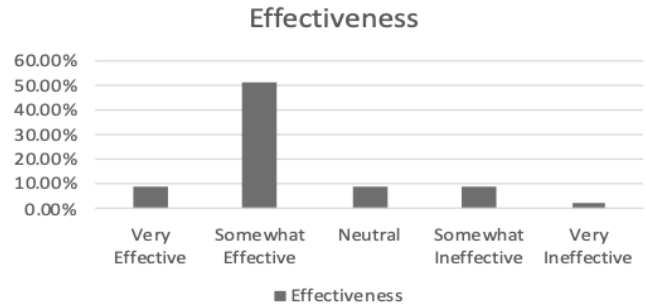


Figure 1: Effectiveness of traditional cross-border method

Effectiveness of VR in Cross-border Projects

Participants were asked to evaluate statements regarding VR's potential in cross-border construction projects (Table 1). The results revealed strong support for VR adoption, with 88% of respondents expressing a willingness to use VR in their projects. Specifically, 42% strongly agreed and 46% agreed with the statement regarding their openness to VR adoption. This positive sentiment reflects a growing recognition of VR's potential to overcome geographical barriers and enhance collaboration.

Additionally, 79% of participants believed VR could significantly improve communication, collaboration, and stakeholder engagement in cross-border projects, with 23% strongly agreeing and 56% agreeing. This indicates that VR is not only seen as a viable technology but also as a tool that can enhance communication channels in cross-border construction projects.

Table 1: Statement Ranking on VR Effectiveness

Statements	Ranks	Frequency	Percentage
You would be open to using VR if introduced in your cross-border construction project.	Strongly disagree	1	2%
	Disagree	2	5%
	Neutral	2	5%
	Agree	20	46%
	Strongly agree	18	42%
VR could improve communication, collaboration and stakeholder engagement in cross-border construction projects.	Strongly disagree	1	2%
	Disagree	1	2%
	Neutral	7	16%
	Agree	24	56%
	Strongly agree	10	23%

Challenges to VR Integration in Cross-border Construction Projects

Participants identified several barriers to VR adoption in cross-border construction projects (Table 2). Compatibility issues with existing systems emerged as the most

significant concern, with 35% of participants selecting it. This aligns with previous research by Li *et al. (*2018) highlighting the challenges of integrating VR into current workflows, especially in geographically dispersed projects where teams may use diverse software and hardware.

Skill development was another key concern, with 35% of participants emphasising the need for training and adapting to new technology. This underscores the importance of targeted training programs to equip stakeholders with the necessary skills to leverage VR effectively. Financial limitations were also noted, with 28% of participants citing high implementation costs as a barrier. This highlights the need for cost-effective solutions, such as leasing models or collaborative procurement strategies.

Notably, 44% of participants identified all presented challenges as obstacles, indicating a multifaceted apprehension toward VR adoption. This suggests that a holistic approach is needed to address technical, financial, and training-related barriers to VR integration in cross-border project management.

Table 2: Barriers to VR adoption in cross-border project management

Barriers	Frequency	Percentage
High implementation cost	12	28%
Compatibility issues with existing systems	15	35%
Training and adapting to new technology	15	35%
All the above	19	44%

Remedies to Overcome the VR Challenges

Participants proposed several solutions to overcome VR adoption challenges (Table 3). Ensuring system compatibility emerged as the most pressing concern, with 58.1% of participants advocating for "ensuring the compatibility and interoperability of VR systems." This aligns with previous research by Li *et al. (*2018) highlighting the importance of seamless data exchange and collaboration in cross-border projects.

Table 3: Remedies for adoption of VR

Remedies for the adoption of VR	Frequency	Percentage
providing comprehensive training and support for VR technology	20	46.5%
ensuring the compatibility and interoperability of VR systems	25	58.1%
Investing in robust data security measures	14	32.6%
Developing standardised protocols for VR use	11	25.6%
Reducing the costs associated with VR implementation and maintenance	12	27.9%
All the above	14	32.6%

Skill development was another key consideration, with 46.5% of participants emphasising the need for "providing comprehensive training and support for VR technology." This underscores the importance of targeted training programs to maximise VR's effectiveness. Data security was also a major concern, with 32.6% of participants advocating for "investing in robust data security measures." This reflects the growing awareness of data security risks associated with VR technology, particularly in cross-border projects.

Additionally, 25.6% of participants supported "developing standardised protocols for VR use," which could help ensure seamless collaboration across geographically

dispersed teams. Financial limitations were addressed by 27.9% of participants who favoured "reducing the costs associated with VR implementation and maintenance," highlighting the need for cost-effective solutions.

DISCUSSION

Integrating VR in Cross-border Collaborations

The findings highlight VR's transformative potential in cross-border construction projects, particularly in Qatar-India collaborations. The data reveals strong industry support for VR, with 88% of participants endorsing its integration. This aligns with literature emphasising VR's ability to bridge geographical divides and enhance communication (Wang *et al.,* 2018). However, challenges such as system compatibility, training needs, and financial constraints must be addressed.

Compatibility issues emerged as the most significant barrier, with 35% of participants citing this concern. This aligns with literature highlighting the difficulties of integrating VR into diverse workflows (Li *et al.,* 2018). Ensuring seamless interoperability, as advocated by 58.1% of participants, is crucial for effective VR adoption. Additionally, 35% of participants emphasized the need for comprehensive training, underscoring the importance of equipping stakeholders with the skills to navigate VR effectively (Johansson and Roupé 2024).

Financial constraints also pose a challenge, with 28% of participants citing high implementation costs. Cost-effective solutions, such as leasing models or collaborative procurement strategies, could mitigate this barrier, as suggested by 27.9% of participants.

VR's Role in Transforming Cross-border Construction Projects

The research builds on the foundational insights of Haddud *et al. (*2017) by demonstrating VR's potential to enrich the design process in cross-border projects. The data reveals that VR enabled immersive previews not only expedite decision-making but could also foster a more inclusive and informed stakeholder environment. This is particularly relevant in the context of Qatar-India collaborations, where stakeholders from diverse locations can actively participate in the design process without the need for physical travel.

One of the most compelling findings is VR's ability to enhance stakeholder engagement. The data indicates that VR could allow stakeholders to not only visualise the finished product but also interact with it, leading to increased emotional investment in the project. This is particularly advantageous for geographically dispersed stakeholders, such as those in India, who can participate in virtual site visits of projects in Qatar. This aligns with the literature, which suggests that VR can foster a deeper understanding of the project's physical context, thereby improving stakeholder engagement (Wang *et al.,* 2018). The data supports this conclusion, with participants highlighting VR's ability to reduce misinterpretations and foster high-quality interactions.

However, the research also reveals that VR's effectiveness is not uniform across all stages of project management. While VR excels in design visualisation and real-time collaboration, the data suggests that traditional methods may still hold value in the early stages of collaboration, particularly when building trust and rapport. This is consistent with the literature, which emphasizes the importance of face-to-face interaction in establishing trust (Hertel, Geister and Konradt 2005). This suggests that

a balanced approach, leveraging the strengths of both VR and traditional methods, may be necessary to ensure successful cross-border collaborations.

Addressing Challenges and Unlocking VR's Full Potential

The research highlights several strategies to overcome the challenges associated with VR adoption. Ensuring system compatibility emerged as the most pressing concern, with 58.1% of participants advocating for seamless integration of VR systems. This aligns with the literature, which emphasizes the importance of interoperability of technologies (Wang *et al.,* 2014). Additionally, 46.5% of participants emphasized the need for comprehensive training programs, underscoring the importance of equipping stakeholders with the skills needed to leverage VR effectively.

Data security also emerged as a significant concern, with 32.6% of participants advocating for robust security measures. This reflects the growing awareness of data security risks associated with VR technology, particularly in cross-border projects where sensitive data may be shared across borders. This suggests that investing in secure VR systems and developing standardised protocols for data sharing could mitigate these risks.

The research underscores the need for cost-effective solutions to facilitate VR adoption. The analysis reveals that 27.9% of participants supported reducing the costs associated with VR implementation, indicating a need for more affordable VR solutions. This could include leasing models, collaborative procurement strategies, or government incentives to encourage VR adoption in the construction industry.

While the findings of this study offer valuable insights into the integration of Virtual Reality in cross-border construction projects, certain limitations must be acknowledged. The sample size of 49 respondents, although sufficient for exploratory analysis, is relatively small and may not fully capture the diversity of perspectives across the broader construction industry. Furthermore, the sample is skewed toward engineers and project managers, which may limit the generalisability of the findings to other professional roles such as architects, quantity surveyors, or clients.

CONCLUSION

This research highlights the transformative potential of Virtual Reality (VR) in enhancing cross-border construction project management, particularly in Qatar-India collaborations. The study identifies significant benefits of VR, including improved communication, enhanced collaboration, and immersive design visualisation, which collectively outweigh the challenges of high implementation costs, compatibility issues, and the need for specialised training.

To address these challenges, industry professionals should focus on targeted training programs, ensuring system compatibility, and developing cost-effective solutions such as leasing models or collaborative procurement strategies. Additionally, investing in robust data security measures and developing standardised protocols for VR use are crucial for mitigating potential risks.

Future research should explore the development of cost-effective VR solutions, standardise protocols for cross-border collaboration, and address the ethical and legal implications of VR use in cross-border projects. By bridging geographical and cultural divides, VR holds the promise of revolutionising cross-border construction projects, fostering a future of seamless collaboration and innovation in the industry. The adoption of VR in the construction industry can lead to more efficient project

delivery, reduced misunderstandings, and increased stakeholder engagement, paving the way for a new era of global construction management.

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FEEDBACK-DRIVEN DESIGN FRAMEWORK TO BRIDGE THE GAP BETWEEN BUILDING DESIGN AND OPERATIONS

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Despite the significance of building design in influencing subsequent lifecycle stages, the disconnect between building design and Operation & Maintenance (O&M) stages remains a persistent challenge in today's building industry. This disconnection creates a critical knowledge gap in the decision-making process, leading to the loss of valuable operational insights for new building designs and limiting the potential to address O&M challenges within modern complexities. While past researchers have examined various building design aspects, a key limitation is the absence of structured frameworks for systematically incorporating building performance feedback into new design decisions. Therefore, this study develops a feedback-driven design framework that ensures the connection between design and O&M, fostering long-term efficiency, adaptability, and continuous learning and improvement. A critical literature review (CLR) was conducted to synthesise existing building design perspectives and identify their limitations. The proposed framework emphasises a key mechanism for integrating operational insights into future design decision-making through interdisciplinary stakeholder collaboration, knowledge integration, and the use of advanced methods and techniques. It positions building design as a dynamic, iterative process shaped by ongoing performance feedback and continuous improvements.

Keywords: building design; design decision-making; design framework; operational feedback

INTRODUCTION

The architecture, engineering, construction and facilities management (AEC/ FM) industry has experienced declining productivity, particularly in building performance. Poor design decisions have become a major contributor to this situation, leading to multiple problems such as difficulty accessing areas for maintenance, safety hazards, budget overruns and inefficient energy usage (Akanmu *et al.,* 2020; Astarini *et al.,* 2024; Guo *et al.,* 2013; Knotten *et al.,* 2015). For example, buildings with poorly coordinated mechanical and architectural designs often face recurring access issues for maintenance, resulting in increased maintenance costs (Akanmu *et al.,* 2020). These

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issues not only hinder efficient building operations but also compromise long-term functionality and maintainability. Therefore, the influence of design decisions extends far beyond the early project stages, ensuring enhanced building performance and sustainability (Akanmu *et al.,* 2020; Astarini *et al.,* 2024).

Building design is a complex, multidisciplinary process (Gray and Hughes, 2000; Hegazy *et al.,* 2001) that has been viewed and conceptualised differently by researchers over time, emphasising various key aspects. However, an essential yet often overlooked aspect of improving building design process is incorporating building performance feedback into new design decisions (Criado-Perez *et al.,* 2019; Hay *et al.,* 2017; Petrova *et al.,* 2018; Wang and Leite, 2016). Building performance data are vital for new design decisions to ensure continuous building performance improvement with modern complexities and demands over time (Goçer *et al.,* 2015; Petrova *et al.,* 2018). Consideration of building performance insights during architectural design has been explored in recent studies through different approaches like Performance-Based Design (PBD), Building Performance Modelling (BPM), Building Information Modelling (BIM), Artificial Intelligence (AI), computational tools (Akanmu *et al.,* 2020; Astarini *et al.,* 2022; Petrova *et al.,* 2018; Tian *et al.,* 2021). However, they are often grounded in data-based assumptions and conceptual ideas rather than real-time operational insights (Breadsell *et al.,* 2020; Yu *et al.,* 2022). While they are valuable for estimating building performance, they rarely reflect actual building operation, leading to discrepancies between predicted and real-world performance. Also, they cannot fully understand the complexity, variability and evolving nature of actual building use. Therefore, a more dynamic and continuous connection between building design and O&M is essential to incorporate real-time building performance data into new building designs to make design decisions more informed and evidence based. However, such connection has not been well-established between building design and O&M, leading to a performance gap, where buildings may be excellent in architecture but underperform in usability, adaptability and operational efficiency (Breadsell *et al.,* 2020; Davoodi *et al.,* 2021).

To address this issue, a systematic feedback-driven approach is crucial to complement conventional design activities across the building value chain, enabling continuous learning and improvement. Since existing literature has not explicitly framed the design process through this lens, and research in building design management is evolving with significant opportunities for further development (Agegn *et al.,* 2024), this study develops a feedback-driven design framework that emphasizes a key mechanism for integrating operational feedback into the design process.

METHOD

This study employs a critical literature review (CLR) following the typologies identified by Grant and Booth (2009) given that it entails to critically assess and synthesize the prevalent literature regarding the research area to produce a ‘conceptual contribution’ to the field (Snyder, 2019). Although CLR does not follow strict, systematic literature selection like systematic literature reviews (SLR), it allows for the inclusion of a wide range of perspectives and theoretical underpinnings from different sources, which is often limited in SLRs (Greenhalgh *et al.,* 2018; Snyder, 2019). As such, adopting CLR is favoured in this study to understand different aspects of building design investigated by various researchers over the past years and develop a new design framework that assists in addressing the limitations in the existing design theories.

The relevant sources were identified through a snowballing search approach, which refers to article identification based on reference lists or citations of a key article/s (Wohlin *et al.,* 2022). This approach enabled the identification of the most appropriate and influential sources in the subject area. This study employed insights from different sources such as journal articles, conference papers, industry reports and documents, books and book chapters. The academic literature search was conducted using Google Scholar, Scopus and Web of Science, which are recognised as main reputable databases that facilitate access to high-quality publications (Ali *et al.,* 2017). To identify the most influential sources, appropriate keywords within the research area were used, such as design process, building design management, design methodology, design strategy, design approach, building performance feedback, and feedback loop. Key seed articles that initiated the snowballing process included (Gero, 1998), (Koskela *et al.,* 2002) and (Bølviken *et al.,* 2010) on different design models, which provided foundational insights into understanding the design process. Ideas generated from reading the resulting sources were then used to develop the new design framework.

Theoretical Background

By the late 19th century, the division between the "hard" (scientific, quantifiable) and "soft" (aesthetic, qualitative) aspects of culture was increasingly questioned, leading to the modern concept of "design" as a bridge between art and science (Flusse, 1995). With that, two dominant viewpoints emerged regarding the value of design as "hard" and "soft". This perspective is deeply embedded in building design where both conceptual thinking and technical implementation need to be effectively reconciled (Bølviken *et al.,* 2010; Knotten *et al.,* 2015). The conceptual aspect involves generating innovative ideas, concepts and assumptions, while the technical aspect focuses on the streamlined and structured execution of those ideas into tangible, meaningful and actionable outputs. Accordingly, Gero (1998) categorised design activities into conceptual and detail designing, further highlighting the interplay between conceptual and structured aspects of design. Conceptual design is often exploratory and problem-defining, where knowledge is incomplete and innovative solutions are required. In contrast, detail designing relies more on structured knowledge to refine established concepts. However, these aspects are not mutually exclusive; conceptual design may also adhere to established patterns, and detail design may require innovative ideas (Gero, 1998). Expanding on this perspective, (Bølviken *et al.,* 2010) defined three main phases of the building design process. Phase one is design creation process which primarily includes conceptual thinking. Phase two is design production process which mainly operates with more defined and structured parameters to execute the concepts. Phase three; the decision-making process connects and guides both phase one and two allowing for iterations. These phases emphasize the dynamic interaction and evolving nature of building design where iteration and feedback play critical roles.

Different perspectives of building design

Over the years, conceptualisations of building design have evolved from structured and linear models to more dynamic, context-sensitive understandings. Early views, such as those by Lawson (1990) described the building design process as a reciprocal process involving analysis, synthesis, and evaluation, suggesting a logical sequence designers follow towards a defined goal. Expanding on this, Knotten *et al. (*2015) highlighted that design problems cannot be documented or stated comprehensively and the design solutions for these problems are unlimited. Therefore, building design

requires a continuous process of analysis, synthesis and evaluation to find the most optimal design solutions. This perspective highlights the iterative nature of the building design process that requires continuous refinement within the design process itself to produce design solutions. Each iteration during this process contributes to adding value to the end product (Aasrum, 2016). While these views acknowledges that design involves iterations and refinements, it still identifies the design process as logical and structured where each step follows from the previous one in a planned way.

Contrasting this viewpoint, Gero (1998)'s different models of design provided a turning point, emphasising that design is not always a problem-solving process with a known goal. The "design as exploration" model embraces the open-endedness of the design process, where neither the problem nor the solution is fully understood at the outset. The possible solutions and pathways to resolve the design problem need to be discovered and defined. More reflective and emergent models like "design as reflection in action" and "design as emergence" started to challenge linear notions of design, emphasising it as an adaptive process where unintended patterns, relationships and opportunities were seen in a design that can lead to new insights or creative solutions. These latter models recognise the importance of intuition, reinterpretation, and continuous learning, aligning more closely with real-world practices where ambiguity and complexity are the norm. However, Gero (1998) argued that these traditional models still do not fully capture the complex, evolving and context-dependent nature of real-world designs. To address this, two new concepts were proposed: situatedness and constructive memory. Situatedness highlights that design decisions are influenced by where and when they are made, while constructive memory identifies that interpreting insights from past experiences shapes future design decisions. This divergence between structured and emergent views of design also surfaces in the three different perspectives: process-driven, flow-driven and value-driven, proposed by Koskela *et al. (*2002). While the process-driven view aligns with older, more deterministic notions of design as a linear transformation of inputs into outputs, the flow-driven view introduces a needed recognition of temporal and collaborative complexity, where the movement and integration of materials, information, and people are central. The value-driven perspective, which is about ensuring that the final design outcomes meet end-user requirements and expectations, is especially critical and aligns with a broader shift towards user-centred and performance-based design.

The managerial lens offered by Emmitt and Ruikar (2013), Knotten *et al. (*2017) and Sinclair (2011) further contributes to the framing of building design as a discipline of management, focusing on planning, organising and controlling the process. People in this context are stakeholders involved in a building project, and information is deliverables among the stakeholders. These different stakeholders possess specific knowledge (which can be explicit or tacit), that they can transform into meaningful data/ information needed by the project.

Together, these perspectives highlight two broad paradigms of the design process.

- Design as a sequential and predictable process that can be planned and managed step by step.
- Design as a dynamic and evolving process, shaped by experience, judgment, and changing situations.

While both paradigms offer valuable perspectives into how building design is approached, it is important to critically examine how they are reflected in current practices and where key limitations persist.

Limitations in the existing building design perspectives

Among the two main paradigms, it is the first paradigm - design as a sequential and predictable process - that has predominantly shaped current building design practices. Jiang (2015) highlighted that since building design practices are based on different design philosophies, assumptions, and theoretical underpinnings at large, often there are buildings with excellent architectural designs but problematic situations in satisfying user experience. In contrast, the second paradigm, which views design as a dynamic and evolving process driven by experience and judgment, remains underexplored in the existing literature and practical applications. Incorporating building performance and Post-Occupancy Evaluation (POE) insights such as energy efficiency, indoor air quality, occupancy comfort and user experience into building design is crucial to ensure continuous building performance improvement within modern complexities and demands (Goçer *et al.,* 2015; Petrova *et al.,* 2018). In the study by (Gero, 1998), the idea of making design process adaptive, flexible and aligned with real-world challenges was emphasized. Similarly, Koskela *et al. (*2002) argued that improvements in building design require a combination of a solid theoretical understanding of the complexities and nuances of the building process and insights from real-world contexts. While existing perspectives acknowledge the iterative nature of design (Gero, 1998; Knotten *et al.,* 2017; Knotten *et al.,* 2015), they primarily emphasize refinement within the design phase itself rather than incorporating insights from the actual building performance or post-construction, leaving a crucial knowledge gap unaddressed.

This gap underscores the missing element in the building process - a structured, long-term feedback loop; a mechanism to integrate building performance data from O&M into future designs. As a result, real-world building performance data are not systematically fed back to inform and drive new designs. While existing viewpoints like process-driven, flow-driven and value-driven perspectives focus on structured information flow, stakeholder engagement, and value-creation (Koskela *et al.,* 2002), they tend to treat O&M as a downstream phase rather than a continuous knowledge source that can continuously inform future design decisions. At the same time, they do not explicitly define how interdisciplinary knowledge from O&M professionals should be structured and how the collaboration of stakeholders should be ensured, although they identified building design as managing people and information (Emmitt and Ruikar, 2013; Knotten *et al.,* 2017). Therefore, the building design process requires a balanced approach that ensures that design decisions are not largely based on initial assumptions, predefined design principles and theoretical models but are continuously refined through real-world building performance feedback. This acknowledges the design process as a dynamic and evolving process rather than a sequential and predictable process, and shaped by past evidence, experience and changing situations.

Towards an Adaptive and Intelligent Building Design Process

Despite the breadth of theoretical perspectives and techniques explored in the literature on understanding building design process, the absence of a structured and continuous feedback mechanism from building operation to design has resulted in a persistent performance gap where design excellence does not necessarily translate into

operational success. The current approaches remain largely predictive and assumption-based with limited grounding in the realities of actual building performance (Petrova *et al.,* 2018; Wang and Leite, 2016; Yu *et al.,* 2022). Also, although a large amount of building performance data is captured through various techniques, the systematic application of these data for future building designs remains incomplete and underutilised due to different challenges (Brown and Arens, 2012; Criado-Perez *et al.,* 2019; Hu *et al.,* 2018; Ostergård *et al.,* 2016; Riley, 2013; Tian *et al.,* 2021). Some of the significant examples of these challenges include limited integration of multi-source data into a centralised, well-designed data models, limited access to the building performance data, lack of building performance data disclosure laws, limited availability of high-quality datasets, financial limitations, interoperability issues between different data management platforms, complexity of analysing a large datasets (Astarini *et al.,* 2022; Fang and Cho, 2019; Tian *et al.,* 2021). Consequently, valuable operational insights are often overlooked, leaving the design process disconnected from real-world outcomes. This disconnection between building design and O&M results a valuable knowledge loss from actual building performance, limited design adaptation based on real-world conditions and siloed decision-making that leads to disjointed workflows and fragmented data utilisation. To address this gap, there is a pressing need to understand the building design process not merely as a sequential process but as a dynamic, feedback driven process that evolves through continuous learning from post-construction performance. This calls for an adaptive and informed design framework (as presented in Figure 1) that actively incorporates operational data in design, facilitates interdisciplinary knowledge exchange, and transforms how design decisions are made in the face of increasing complexity, uncertainty, and performance expectations in the built environment. To that, a structured mechanism that systematically captures, integrates and applies real-world building performance data into new designs is crucial.

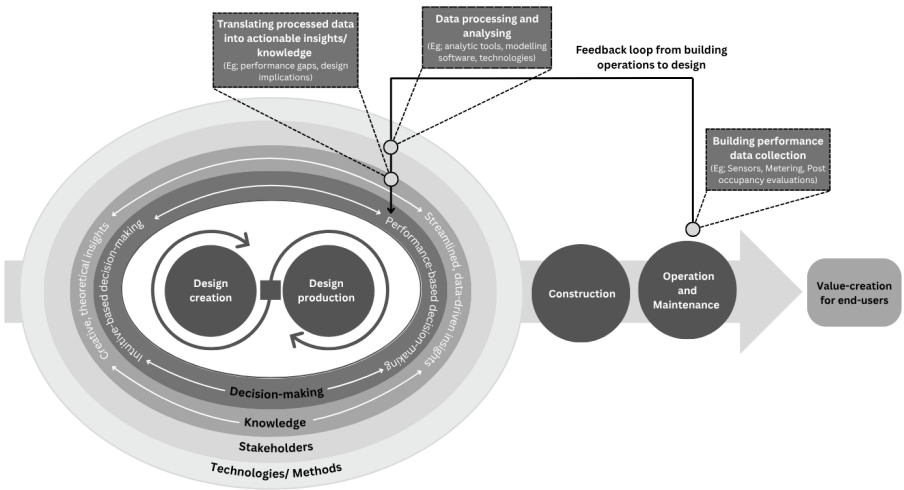


Figure 1: Feedback-driven design framework

The framework operationalises how building performance insights from existing buildings are fed back into the early design process, creating a continuous cycle of learning and improvement in the decision-making process. It positions building design as an iterative and feedback-driven process, rather than a purely sequential.

At its core, the design process comprises design creation and design production, corresponding to conceptual design and detailed design aspects. While the design creation process is primarily driven by innovative, conceptual insights and the design

production process is mostly driven by streamlined, data-driven insights, each phase can inform the other. Surrounding the core design process, multiple layers can be identified that support a structured feedback mechanism.

The decision-making layer constitutes both intuitive-based decision-making (driven by assumptions and conceptual understanding) and performance-based decision-making (informed by building performance data). The framework enables these two modes to co-exist and influence one another. Building performance data are first collected (e.g., sensors, POEs), then processed and analysed (using technologies, modelling tools, analytics), and finally translated into actionable insights (e.g., performance gaps, design implications) that inform early-stage decisions. Early conceptual design ideas can be refined by these analysed building performance insights to make more accurate and informed ideas for execution. The knowledge layer represents the key insights or knowledge areas, either from initial assumptions/ intuition (creative/ theoretical insights) or building performance data like energy use data, temperature data, indoor air quality data, maintenance data etc. (streamlined/ data-driven insights), that lead to actionable decisions. By analysing building performance data, key knowledge aspects like building performance gaps, design implications can be extracted, where these knowledge areas need to be mapped across different design phases to ensure their timely application. The stakeholder layer represents the collaboration between multidisciplinary stakeholders throughout the building value chain who possess multidisciplinary knowledge for decision-making. Building professionals across the entire building lifecycle including architects, engineers, facilities managers, and sustainability consultants contribute different types of knowledge, and the framework promotes structured knowledge transfer among them, especially from operations to design teams. The technologies/ methods layer presents different techniques like BIM, AI, Internet of Things (IoT), digital twins, building performance monitoring, data analytics tools, software etc., that facilitate the transformation of raw building performance data into actionable design decisions in new building projects. These advanced methods enable more effective data-driven decision-making in building design through real-time tracking. Accordingly, this framework presents how to systematically complete the missing link between design and O&M in terms of knowledge management, ensuring that future projects benefit from knowledge accumulated in existing building stock without any knowledge loss. Such feedback-driven design framework transforms more conventional building design process into an adaptive and evolving system, ensuring long-term sustainability and efficiency in building projects within the increased industry demands, changing conditions and complexities.

CONCLUSION

This study proposed a feedback-driven design framework to address the missing link between building design and O&M, ensuring a continuous cycle of learning and improvement. While existing perspectives acknowledge the building design as an iterative process, they have not fully understood the building performance feedback-driven approach in building design that is more adaptable, practical and high performing. In today's industry, building projects often repeat inefficiencies and miss opportunities for continuous improvement due to not having a structured mechanism to incorporate building performance data into the design process. The proposed design framework provides a structured mechanism, making the building process more adaptable and integrated through a continuous cycle of learning and improvement. Further, it highlighted that how multidisciplinary knowledge,

stakeholders, and different methods/ systems can facilitate this feedback-driven approach. Accordingly, the findings of this study offer a novel conceptual perspective that contributes to ongoing efforts to bridge the gap between design and O&M. While preliminary, it lays the groundwork for further research in feedback-driven building design process to make new designs more informed and evidence-based.

Future research could explore the applicability of this approach within the contemporary building industry by exploring how industry practitioners perceive it within the modern world's demands and complexities. This may include investigating its level of acceptance, potential implementation challenges, and the practical implications of such a feedback-driven design process in existing workflows. Further, the role of advanced technologies like AI, BIM and digital twins in automating and optimising this approach can be investigated in future to strengthen its applicability in the real-world context. Accordingly, the proposed framework lays the baseline for a more resilient and data-informed design culture. Also, this will be a crucial step towards proposing a systematic approach for data-driven design decision-making as the main outcome of the first author's Doctoral research.

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INTEGRATING SUSTAINABLE DESIGN AND RESPONSIBLE PROJECT MANAGEMENT: METHODOLOGICAL INSIGHTS FROM A SMART HOSPITAL CASE STUDY

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Smart Hospital Systems (SHS) exemplify Complex Product-Service Systems (CoPSS), derived from the convergence of servitisation, digitalisation, and sustainability transitions. Their design is required to integrate advanced technologies with sustainability goals and diverse stakeholder expectations. However, how such integration is practically coordinated remains underexplored. This study investigates how the strategic approaches of Sustainable Design (SD) and Responsible Project Management (RPM) are embedded in the design of a large-scale SHS project delivered by a global building technology provider. Using the Gioia methodology, data were collected through semi-structured interviews and project documentation. Seven aggregate dimensions of SD-RPM integration were identified: environmental and industry drivers, modular solution strategy, scenario-specific configurations, tailored R&D processes, co-creation mechanisms, coordination practices, and post-implementation performance. These dimensions are synthesized into a conceptual framework that offers a structured, data-grounded view of how SD and RPM interact throughout the design process. The study contributes to CoPSS literature by offering empirical insight and methodological transparency and provides practical guidance for project teams seeking to align design processes with long-term sustainability and responsibility objectives.

Keywords: sustainable design; responsible project management; smart hospital system; complex product-service systems

INTRODUCTION

Smart Hospital Systems (SHS) are emerging as complex infrastructures that integrate engineering subsystems (e.g., HVAC, lighting control, and energy management systems), smart digital platforms (e.g., hospital-wide digital command centres, real-time environmental monitoring systems, and predictive analytics dashboards for energy and occupancy), and service-oriented components (e.g., patient-facing interfaces, remote consultation tools, and tailored environmental controls) to improve

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healthcare efficiency and sustainability (Carvalho and Alves, 2022). Positioned within broader transitions in digitalisation, servitisation, and sustainability, SHS has been sampled as a case of Complex Product-Service Systems (CoPSS). CoPSS are integrated configurations of products, services, and digital platforms that co-create value with stakeholders while addressing long-term sustainability goals in socio-technical-ecological systems (Dehn *et al.,* 2018). Framing SHS through this CoPSS lens highlights the need for sustained collaboration across disciplines, organisations, and professional roles.

The design and development of SHS demand technical advancements alongside nuanced responses to service needs, stakeholder expectations, and long-term sustainability goals (Froufe *et al.,* 2020). This combined complexity is particularly prominent in healthcare settings, where design decisions can directly impact clinical outcomes, operational continuity, and system resilience (Uslu *et al.,* 2020). SHS design faces the dual challenges of achieving energy efficiency and reducing carbon emissions while enabling adaptive, user-centred, and data-driven functionalities to support clinical operations and patient care (Zhang *et al.,* 2021).

Two strategic approaches identified in the literature can provide a foundation for addressing the dual challenge of aligning technical innovation with long-term sustainability goals in SHS design: Sustainable Design (SD) and Responsible Project Management (RPM). SD promotes environmental responsiveness, lifecycle thinking, and long-term adaptability in engineering design (Baldassarre *et al.,* 2020). RPM emphasizes stakeholder engagement, ethical governance, and coordination across interdependent processes in complex projects (Tinoco *et al.,* 2016). Current literature tends to examine SD and RPM in isolation, and few empirical studies have explored how these approaches are integrated in real-world design contexts, particularly in the development of SHS.

Based on interviews with key project actors and company documentation, this study conducted a case study of a Smart Hospital System design project led by a global building technology provider. The research employed a coding strategy to analyse how these approaches interact through the project lifecycle from initiation to design solutions delivery. The study identified seven key dimensions where SD and RPM were concurrent: (1) environmental and industry drivers, (2) modular solution strategy, (3) SHS scenario configuration, (4) tailored R&D strategy, (5) co-creation in design planning, (6) coordination and communication, and (7) post-implementation performance.

The case study has developed a deeper understanding of how SD and RPM can be jointly embedded in SHS design. The grounded framework can be used where integrating digital and physical components is required to meet diverse performance requirements, stakeholder demands, and sustainable goals. The study also offers practical guidance for design and project teams, ensuring alignment between early-stage planning with long-term performance objectives while supporting coordinated decision-making across disciplines and organisational functions.

The remainder of this paper is structured as follows: the next section reviews literature on SHS, SD, and RPM, concluding with a discussion on their integration in SHS design. This is followed by the methodology, including case selection, data sources, and the Gioia-based coding process. The findings are presented across seven aggregate dimensions. A grounded conceptual framework is then developed, followed

by a discussion and conclusion reflecting on the study's theoretical and practical contributions.

LITERATURE REVIEW

Smart Hospital Systems (SHS)

Smart Hospital Systems (SHS) represent a complex integration of digital technologies, medical infrastructure, and service-oriented functions intended to improve operational efficiency, clinical effectiveness, and user experience within healthcare environments. Defined by the convergence of the Internet of Things (IoT), Building Automation Systems (BAS), Artificial Intelligence (AI), and data-driven platforms, SHS enable real-time monitoring, intelligent control, and adaptive management of hospital facilities and services (Froufe *et al.,* 2020; John Clarkson, 2018). Conceptually, SHS can be understood as Complex Product-Service Systems (CoPSS), where technical and service elements are configured to meet contextualised needs. This framing highlights the system-level coordination required to balance digital integration, scenario-driven functionality, and institutional accountability over time (Zhang *et al.,* 2021).

Increasingly, SHS are required to respond to sustainability goals, such as reducing energy consumption, optimising resource use, and lowering the carbon footprint of hospital operations (Zhao *et al.,* 2021). At the same time, they must meet rising expectations for responsibility, including patient safety, ethical data management, equitable service access, and stakeholder accountability throughout the system lifecycle.

Despite growing scholarly attention, much of the existing literature has focused on operational performance, data security, and clinical outcomes (Uslu *et al.,* 2020). Limited studies address SHS as complex design projects that involve multiple stakeholders, evolving use scenarios, and long-term performance goals. Discussions on how SHS design processes can embed sustainability and responsibility beyond technology deployment or system optimisation are particularly limited.

Sustainable Design (SD)

Sustainable Design (SD) is a strategic design approach that promotes environmental performance, resource efficiency, and long-term sustainability across system lifecycles (Baldassarre *et al.,* 2020). Rooted in design and engineering disciplines, SD aims to reduce ecological impact through materials optimisation, energy-efficient operations, and closed-loop production and consumption systems (Vezzoli *et al.,* 2017). Over time, SD has evolved beyond product design and is now applied to broader systems, including service-based and technology-integrated models. It is often linked with terms like Design for Sustainability (DfS) and Sustainability-Oriented Innovation (SOI), which emphasize considering environmental and social factors in design practices (Adams *et al.,* 2016).

In the context of SHS, SD provides the technical foundation for integrating energy-saving technologies, low-carbon materials, and system-level configuration. Recent literature demonstrates that SD ideation methods support the early-stage configuration of complex systems that meet sustainability goals while responding to functional requirements (Iñigo and Albareda, 2016; Zhang *et al.,* 2021). However, a critical limitation remains in translating sustainability ambitions into collaborative design practices, particularly where multiple stakeholders, long-term uncertainties, and institutional goals intersect.

Responsible Project Management (RPM)

Responsible Project Management (RPM) is a management approach that ensures projects are executed with social, environmental, and ethical responsibility (Tinoco *et al.,* 2016). It extends beyond cost-time-scope governance by embedding sustainability, ethics, and inclusivity into project planning and delivery (Laasch, 2021). In the context of CoPSS, RPM provides a values-based orientation that supports stakeholder engagement, cross-functional alignment, and long-term outcomes.

Research has shown that responsible project-based planning and collaborative knowledge practices support sustainable design and sustainability governance (Lehoux *et al.,* 2021). In SHS projects, RPM offers mechanisms for aligning managerial practices with broader system goals, ensuring sustainability through design intent and structured stakeholder-sensitive project delivery.

Integrating SD and RPM in SHS Design

Scholars have recognised the value of SD and RPM to support complex system design. Both approaches emphasize long-term thinking, stakeholder involvement, and systemic planning, making them highly compatible with the development of SHS, where technology, service, and sustainability must be integrated into a single system (Hosseini *et al.,* 2018). While SD and RPM emerge from different disciplinary traditions, design engineering and project management, their integration is a central and essential solution to the strategic complexity of CoPSS design. However, empirical research on their integration remains scarce. This study explores how they are integrated as complementary approaches in the SHS project, contributing to improving sustainability-driven decision-making at technical and managerial levels.

METHOD

This study adopts a qualitative case study methodology (Baxter and Jack, 2008) to investigate how SD and RPM were integrated within an SHS design project. Figure 1 illustrates the roadmap of the overall research methodology. The empirical case is drawn from an SHS design project undertaken by a global building technology provider. The project aimed to develop scenario-specific SHS system solutions to support the needs of operational and energy efficiency.

Data collected included five in-depth interviews with key participants in the SHS project, including the research director, solution sales engineer, solution architect/project manager, software engineer, and cloud software developer. They were selected because they were highly, deeply, and personally involved in the project and provided various professional perspectives. While the number of interviewees is limited, this case forms part of a broader empirical study encompassing four projects. Secondary sources were collected, such as internal reports and webpages related to design documents. These archival data complemented interview data and enhanced contextual understanding. Table 1 lists the details of the data collected and their use in data analysis.

This study adopted the Gioia methodology to conduct inductive analysis, as it offers a structured and transparent approach to developing context-rich conceptual frameworks from qualitative data (Gioia, 2021).

Table 1: Sources of data collected

Data Source	Type of Data	Data Collected	Use in analysis
In-depth interviews	Interview transcripts	5 interviews, each lasting about 1 hour.	Understanding the participants' perceptions and experiences of the design process.
Archival data	Design reports and webpages	2 design reports. 11 webpages.	Used to support and complement the interview data.

As shown in Figure 1, coding proceeded through three levels: first-order concepts derived from participants' language, second-order themes reflecting interpretive insights, and aggregate dimensions representing theoretical integration. Rather than constructing a formal theory, this study aimed to produce a transparent, data-grounded conceptual framework to describe and interpret patterns of SD-RPM integration in the design of a smart hospital system.

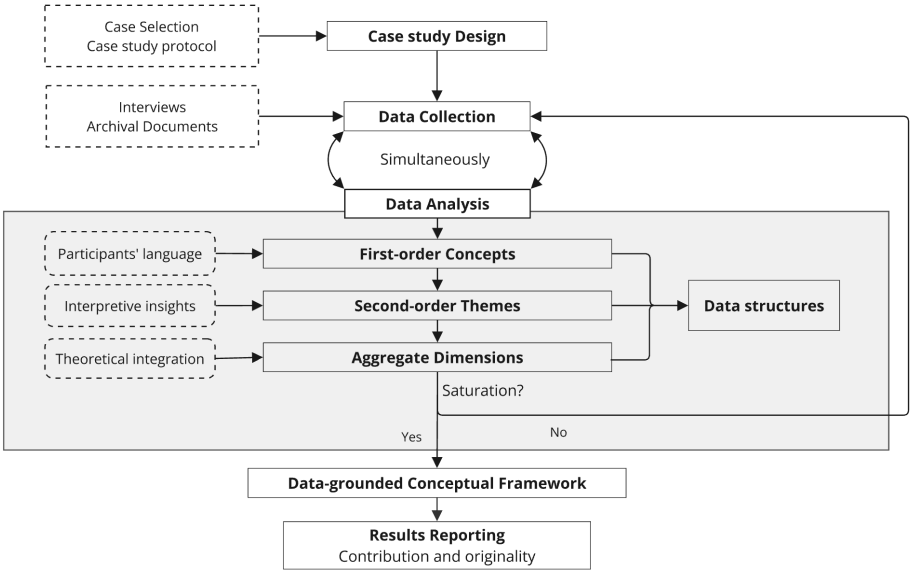


Figure 1: Research Methodology

FINDINGS

Drawing on structured data analysis, first-order concepts extracted from empirical data were organised into second-order themes and further synthesized into seven aggregate dimensions. Figure 2 presents the data structure. These dimensions reveal how Sustainable Design (SD) and Responsible Project Management (RPM) were integrated through the SHS design project.

Environmental and Industry Drivers

The first dimension captures external conditions influencing SHS design, including regulatory pressures, policy drivers, and institutional expectations. Participants described how national policy targets, economic return expectations, and evolving customer demands shaped strategic project directions. As one respondent emphasized,

> "Customers also want to pursue green hospital certificates, such as China Green Hospital Building Label and LEED (Leadership in Energy and Environmental Design) Green Building Certification."

Scenario-specific functional requirements for technological innovation emerged as key motivators, reflecting SD's focus on functionality. The formalisation of smart hospital standards promoted professional alignment and encouraged knowledge

sharing, aligning with RPM's emphasis on coordination and knowledge management. In this dimension, SD themes emphasized environmental performance and technological innovation, while RPM focused on institutional policy alignment and customer accountability. Their integration ensured the design met both sustainability expectations and organisational responsibilities, supporting a more coherent and credible project direction.

Modular Solution Strategy

This dimension presents the use of modular design strategies identified through the data analysis. The findings indicate that SD emphasized standardisation, adaptability, and lifecycle performance through reusable and customisable components. RPM, on the other hand, focused on structuring these reusable modules to improve stakeholder coordination, ensure delivery consistency, and reduce risk in project management. Participants described how functional similarities across hospital scenarios enabled component reuse while tailored software interfaces supported user-specific requirements. As one interviewee put it,

> "If we wait for one project to start products development, it's inefficient, especially with multiple projects happening at once. To handle this, we developed in-house products that can be adapted to different projects through modular breakdown and reassembly."

Integrating SD and RPM allowed the project to balance the need for system efficiency with contextual flexibility. Their interaction enabled scalable and responsive solutions that promoted both sustainability goals and project delivery reliability.

SHS Scenario Configuration

This dimension draws on scenario-specific insights from empirical data, explaining how the SHS system was configured for hospital operations. The findings indicate that SD focused on enhancing long-term performance through user-centred functionality and adaptable system configuration. While RPM emphasized aligning system architecture with the broader operational context, coordinating spatial-functional needs, and supporting institutional requirements. Data highlighted that solutions were tailored to reflect real-world constraints such as diagnostic and treatment capabilities, medical quality expectations, and human-centred experience goals in the hospital scenario. According to a design report,

> "To ensure system stability during IoT integration, clear requirements were established for protocol standards. A testing platform was built to conduct application tests on various subsystems' compatibility, functionality, interfaces, and services."

The integration of SD and RPM at this dimension ensured technically optimised and operationally accountable design outcomes, allowing the design to respond flexibly to scenario needs while maintaining functional efficiency and stakeholder relevance.

Tailored R&D Strategies

This dimension focuses on how strategic R&D practices support project execution and value creation. Participants highlighted that R&D efforts were not only directed at technical improvement but also served to differentiate the organisation's strategic positioning in a competitive market. Initiatives focused on leveraging hardware strengths and seizing business opportunities through structured investment. In parallel, the findings show that capability building was achieved through iterative experience accumulation, recruitment of skilled professionals, and formal documentation processes. One participant remarked,

> "Business recognition is crucial, and each scenario offers unique user experiences. Companies rely on specialised talent and existing knowledge rather than starting from scratch during research."

These practices ensured that R&D activities remained aligned with business goals and delivery standards. While RPM primarily drove this dimension, the outcome supported SD indirectly by enabling the development of solutions that were not only technically feasible but also strategically relevant and deliverable. This highlights the importance of aligning business logic and long-term planning within design processes in complex system design projects like SHS.

Co-Creation in Design Planning

This dimension gathered themes related to accounts of co-creation practices. SD was reflected in the iterative development of user-centric design ideas and responsiveness to functional demands. RPM emphasized structured facilitation, role clarity, and distributed decision-making. Findings indicated that co-creation workshops involving stakeholders were central to managing system complexity by bringing together diverse perspectives early in the design process. According to one interviewee,

> "It's often about engaging frontline workers one-on-one, but brainstorming sessions can be more effective as they spark new ideas and lead to better results."

They supported the convergence of technical ideas while clarifying roles and aligning responsibilities across organisational teams. The integration of SD and RPM resulted in a design process that was both inclusive and technically robust, showing how co-creation served as a bridge between system needs and project governance.

Coordination and Communication

This dimension presents insights into the project's coordination mechanisms. SD contributed to ensuring design coherence across systems, while RPM focused on the structured flow of information, role coordination, and documentation practices. Participants noted the seamless integration of external systems and continuous improvement based on real-time feedback. As one participant observed,

> "On-site issues, bugs, or unexpected service shutdowns can disrupt the system, leading users to encounter errors and seek our help to resolve them. While regular debugging ensures that our systems remain responsive and efficient."

The integration of SD and RPM supported a project environment that was agile, transparent, and accountable project environment, enabling effective complexity management across functional and managerial layers.

Post-Implementation Performance

This dimension reflects the performance expectations considered during the design process, which were aimed to be maintained and enhanced after the SHS handover. Participants emphasized that post-implementation processes were critical to realising the intended value of the SHS, showing how design and management responsibilities extended into the operational phase. As one participant stated,

> "The solution must be thoroughly tested and experienced internally before being presented to the client. This ensures that it meets the client's needs and functions as intended."

SD focused on post-delivery efforts to promote energy efficiency, system usability, and continuous improvement. RPM emphasized ensuring operational impact and long-term engagement with users. Integration of both approaches ensured that the system remained adaptive, functional, and responsive.

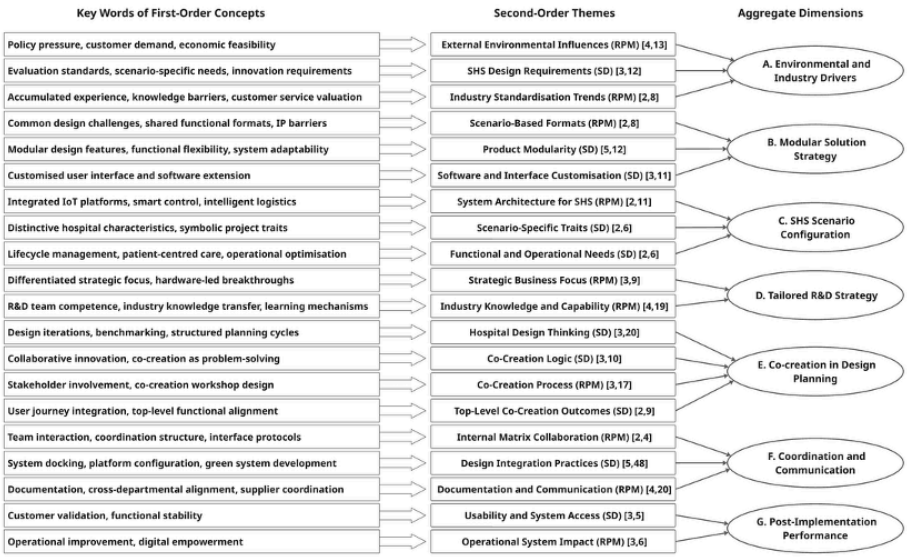


Figure 2: Data Structure

Note: The numbers in brackets [X, Y] indicate the support for each theme. The first number represents the number of distinct references that validate the theme, while the second number represents the total number of pieces of evidence drawn from these references.

GROUNDED CONCEPTUAL FRAMEWORK

Based on the seven aggregate dimensions, this study develops a grounded conceptual framework that illustrates how Sustainable Design (SD) and Responsible Project Management (RPM) can be integrated into the design of a smart hospital system.

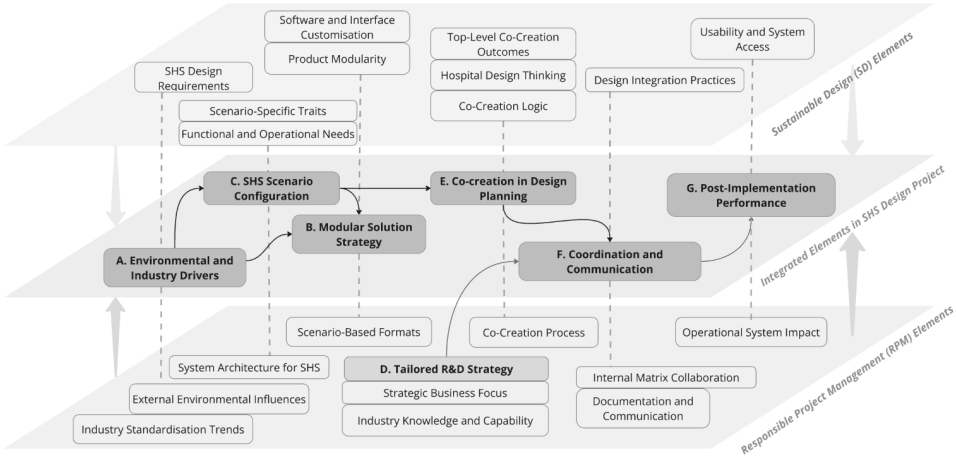


Figure 3: Data-Grounded Conceptual Framework

As shown in Figure 3, the framework is organised into three interrelated layers. The upper layer captures SD-related elements and highlights how the project proactively addressed energy and operational performance through context-sensitive, modular, and adaptable system design. The bottom layer comprises RPM-related elements that reflect the role of responsible planning, stakeholder engagement, cross-functional communication, and coordinated delivery in managing design practices. Between these two layers is the interaction space where the seven aggregate dimensions operate to reflect the integration of SD and RPM.

The framework is also designed to apply across different roles within SHS development, making it theoretically valuable and practically usable. The upper layer is relevant to design engineers and system architects, and the bottom layer is for project managers and business strategists. The middle layer is essential for system directors, sustainability officers, and senior decision-makers who oversee holistic sustainability strategies. Therefore, this framework is applicable across roles and organisational boundaries, enabling CoPSS practitioners to align technical, managerial, and contextual strategies during the design process to support sustainability and responsibility goals. It demonstrates how SD and RPM approaches can be implemented through context-specific coordination mechanisms. The framework supports a shared language for CoPSS stakeholders to understand and integrate sustainability and responsibility imperatives into design planning.

This framework enhances the practical integration of sustainability in SHS development by providing a structured, multi-layered approach aligned with different professional roles. The actor-oriented adaptability makes the framework a practical tool for advancing sustainability-driven SHS design.

DISCUSSION AND CONCLUSION

This study explored how Sustainable Design (SD) and Responsible Project Management (RPM) were integrated into the design of a smart hospital system (SHS). Through a grounded analysis of empirical data collected from interviews and design documents, it identified seven aggregated dimensions and proposed a three-layer framework that elucidates the integration of SD and RPM.

Theoretically, the findings contribute to the literature by moving beyond parallel discussions of SD and RPM to show how their integration occurs in practice through coordinated design and project management. While previous studies have examined SD and RPM in isolation, this research demonstrates how these strategic approaches intersect and synergise through collaborative design practices and cross-functional coordination, advancing understanding of complex system design in sustainability-driven contexts. In addition, the SHS case enriches the emerging CoPSS literature by offering both conceptual clarity and empirical grounding. It illustrates how sustainability and responsibility considerations are embedded in cross-functional design processes, offering contextualised insight into CoPSS development.

Practically, the research provides actionable insights for project teams and system designers involved in SHS projects to balance technological innovation with social responsibility and environmental sustainability. The proposed framework serves as a roadmap for integrating SD and RPM from the early stages of the design process, ensuring alignment with stakeholder needs and long-term sustainability goals.

While this study offers novel empirical insight into SD-RPM integration in SHS design, it is based on a single case, which may limit generalisability to other building scenarios or cultural contexts. The analysis primarily draws on internal interviews and documents and does not use long-term operational data. Future research could build on this framework through multi-case comparisons, cross-sectoral studies, or longitudinal evaluations to examine how integrated SD and RPM approaches evolve over time and influence system performance in varied smart building contexts.

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DISASTER MANAGEMENT AND RESILIENCE

BUILDING ORGANISATIONAL RESILIENCE: A STRATEGY-AS-PRACTICE PERSPECTIVE ON LARGE CONSTRUCTION FIRMS IN SOUTH AFRICA

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Organisational resilience is increasingly critical in South Africa's construction sector, where firms are routinely exposed to systemic uncertainty and volatility. While extant research has explored resilience through structural or performance-oriented lenses, limited attention has been paid to how resilience is enacted through the everyday strategic practices of organisational actors. This study adopts a strategy-as-practice (SAP) perspective to investigate how resilience is performed within large construction firms through the social, symbolic, and material practices of key practitioners. Three large South African contractors were purposively selected as case studies. Data were collected through eighteen semi-structured interviews with strategic actors, supported by documentary analysis. The findings reveal that resilience emerges through iterative and adaptive strategising practices enabled by practitioners who contextualise and translate strategic goals into situated responses. These individuals play a central role in shaping how resilience is understood, narrated, and enacted. This study contributes to SAP scholarship by illuminating the micro-level practices through which organisational resilience is constructed, highlighting the role of human agency, narrative infrastructure, and identity work in navigating chronic disruption and uncertainty.

Keywords: contracting; narrative; organisational resilience; South Africa; strategy-as-practice

INTRODUCTION

Long plagued by structural inefficiencies, policy fragmentation, and stagnating performance, the South African construction industry contrasts sharply with the global construction industry's celebrated role as a catalyst for employment, national output and broader socio-economic development. Instead of driving inclusive growth, the sector in South Africa has experienced sustained contraction, institutional dysfunction, and persistent underperformance since 2017 (Statistics South Africa, 2024). A convergence of challenges including economic volatility, endemic corruption, insufficient public infrastructure investment, and violent disruptions by organised criminal groups or networks that illegally disrupt construction projects has severely undermined the sector's stability and growth potential (Nyangiwe, *et al.,* 2023; Soni and Smallwood, 2024). These pressures are further compounded by fragmented

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regulatory oversight, socio-political unrest, and the residual impacts of the COVID-19 pandemic (Aigbavboa, *et al.,* 2022), creating a volatile and high-risk environment for construction firms. In this context, organisational resilience has emerged as a strategic imperative, enabling firms to survive, adapt, and respond effectively to persistent disruption.

While traditional strategy perspectives such as Porter's (1985) strategic positioning view, Barney's (1991) resource-based view, and Teece et al.'s (1997) dynamic capabilities view provide valuable insights into how firms respond to disruption, they privilege macro-level analyses and normative models (Zungu, *et al.,* 2024). These approaches provide limited insight into how resilience is enacted in practice, particularly within complex, project-based settings like construction (Seriki and Murphy, 2024). In contrast, Whittington's (1996) strategy-as-practice (SAP) perspective challenges these perspectives, offering a practice-oriented lens that centres on the micro-level routines, discourses, and interactions through which strategy is performed. By attending to what organisational actors do in their daily work, SAP is uniquely positioned to capture resilience as a socially embedded and continuously evolving process.

Despite its relevance, there remains a notable lack of research on how organisational resilience is enacted in practice, particularly within the construction industry (Zungu *et al.,* 2025). To address this gap, this study adopts the SAP perspective to explore how resilience is constructed and sustained within South African construction firms. The specific objectives are to: (1) identify the everyday strategising practices through which organisational resilience is enacted; (2) examine the narrative structures that shape and maintain resilience over time; and (3) explore how organisational actors interpret disruption and mobilise social, symbolic, and material resources in response. Organisational resilience is conceptualised here as a strategic narrative that is continuously co-constructed by practitioners through their everyday actions, interpretations, and interactions (Zungu, *et al.,* 2024).

LITERATURE REVIEW

Organisational resilience is increasingly conceptualised not as a fixed capacity to recover from disruption, but as a dynamic process of anticipating, adapting, and learning in response to adversity (Williams *et al.,* 2017). Duchek's (2020) influential processual model re-conceptualises resilience as a multi-stage capability, comprising anticipation, coping, and adaptation. This framing highlights the importance of forward-looking preparedness and post-shock transformation, positioning resilience as a composite of behavioural and cognitive mechanisms. Similarly, Shepherd and Williams (2023) argue that resilient organisations exhibit the ability to learn from disruption, transform routines, and reconfigure internal resources in real time. These perspectives, while helpful, assume that such capabilities exist in relatively stable organisational conditions and remain under-theorised in relation to the lived complexity of practice.

This limitation becomes even more visible when contextualised within the construction industry, where project-based, temporary, and inter-organisational modes of organising prevail (Riazi *et al.,* 2020). Romo *et al. (*2023) identify factors such as leadership, culture, inter-firm networks, and supply chain stability as critical enablers of resilience, but the mechanisms through which these are translated into action remain largely unknown. Conz and Magnani (2020) advocate for a move away from abstract typologies of resilience capabilities toward frameworks that reveal how

resilience is enacted through situated, often improvised action. Their work emphasizes that resilience is as much a product of social interpretation and interaction as it is of planning or resources. This argument resonates particularly in construction, where Duman and Green (2025) note a tendency to treat strategy as a linear, top-down process, detached from the fluid realities of site-level decision-making. In fragmented and uncertain project environments, resilience must be continuously co-produced through sensemaking, negotiation, and situated judgement. Such a perspective requires a shift in analytical lens, from assessing what resilient organisations possess, to how resilience is done in practice.

The SAP perspective facilitates this shift by centring on the everyday actions, routines, and discourses through which strategy is performed (Whittington, 2006; Jarzabkowski *et al.,* 2007). Rather than treating strategy as a formal output or organisational attribute, SAP views it as a socially embedded activity shaped by practitioners navigating local conditions. Vaara and Whittington (2012) extend this view by incorporating discursive dimensions, positioning strategy as something constructed through language, meaning, and interaction. In the construction sector, this offers a particularly useful lens for examining how resilience emerges within temporary, multidisciplinary, and geographically dispersed teams, where practitioners must continually interpret disruption, coordinate across boundaries, and adapt in real time. Nevertheless, SAP remains underutilised in construction resilience research. Existing studies in strategy research disproportionately focus on senior management or high-status professional service firms, leaving the strategic practices of contractors and middle managers underexplored (Duman and Green, 2018). Yet, these actors are frequently responsible for translating strategic intent into day-to-day action, managing ambiguity, and mediating between internal and external stakeholders.

Recent SAP literature has begun to address this by drawing on narrative theory. Fenton and Langley (2011) demonstrate how narratives serve as vehicles through which practitioners make sense of disruption and construct coherence in uncertainty. Barry and Elms (2017) similarly explore how narrative alignment facilitates coordination across shifting organisational contexts. Deuten and Rip's (2000) concept of narrative infrastructure further highlights how stories become embedded within organisations through repetition, symbolic framing, and institutional reinforcement. From this perspective, resilience is not only enacted through practices but also authored through strategic storytelling, a view especially pertinent in industries marked by turbulence.

This narrative dimension is critical in the South African construction sector, where firms operate within conditions of economic instability, political volatility, and social contestation. In such contexts, practices like agile project management and digital innovation become more than technical routines, they are narrative acts, embedded in broader efforts to legitimise and coordinate action (Fonseca *et al.,* 2024; Ma *et al.,* 2024). Middle managers play a central role in this regard, acting as narrators, translators, and brokers of meaning across organisational levels and actor networks (Nauman *et al.,* 2023; Luo *et al.,* 2023).

Despite these insights, empirical research on resilience in emerging market construction sectors remains limited in both scope and conceptual depth (Zungu and Laryea, 2024). Many studies continue to prioritise formal systems, performance indicators, and prescriptive strategies, leaving the emotional, symbolic, and improvisational dimensions of resilience underexamined (Zungu *et al.,* 2024; Seriki

and Murphy, 2024). As a result, we still know relatively little about how resilience is constructed, narrated, and sustained by practitioners embedded in volatile, project-based environments.

RESEARCH DESIGN AND RESEARCH METHODS

This study is grounded in an interpretivist research paradigm, which holds that organisational realities are socially constructed, contextually situated, and mediated through the lived experiences of actors (Pervin and Mokhtar, 2022). Rather than seeking universal laws or deterministic relationships, this paradigm privileges depth, meaning, and understanding. The research adopts an inductive approach to theory building, allowing patterns, concepts, and theoretical insights to emerge from empirical engagement with participants, rather than being imposed through pre-existing hypotheses (Denzin and Lincoln, 2018). This epistemological orientation aligns with the study's aim of uncovering how organisational resilience is enacted through the everyday strategising practices of construction professionals operating in a high-risk, dynamic environment. A qualitative, multi-case study design was employed to explore how organisational resilience is enacted in large South African construction firms. Given its socially constructed, practice-based nature (shaped by multiple actors, dynamic contexts, and organisational age), a multi-case approach is appropriate for capturing embedded processes and enabling cross-case comparison (Yin, 2018). This design provided the flexibility to investigate both organisational-level dynamics and individual-level interpretations. Cases were selected using purposive sampling based on theoretical relevance. Inclusion criteria required that selected firms be operationally independent (i.e., not subsidiaries of larger parent companies), operate primarily in the South African construction industry, hold a Grade 9 Construction Industry Development Board registration (indicating capacity to deliver large-scale projects), and possess a trading history of at least ten years. These criteria ensured that selected organisations had the strategic maturity, institutional autonomy, and operational experience necessary to generate rich insights into resilience practices. Three firms (aged 11, 41, and 51 years) as presented in Table 1, were selected to enable theoretical replication and pattern variation, providing the minimum needed for meaningful cross-case comparison while retaining depth (Farquhar, 2012).

Table 1: Description of Selected Case Study Organisations

	Case Organisation 1	Case Organisation 2	Case Organisation 3
Contractor Type	Infrastructure Contractor	Building, Civil, Mechanical Contractor	Civil Contractor
Project Typology	Civil, Roads and Bulk Earthworks, Renewable Energy, Telecommunications and Asbestos	Bulk water infrastructure, mechanical and civil works, mining sector developments, heavy industrial projects, marine construction, renewable energy systems, petrochemical infrastructure, and power and industrial facilities	Civil, Dust Suppression, Mining, Energy
Age	51 Years	41 Years	11 Years
Supporting Data Sources	Company Profile, Company Website, Annual Reports	Company Profile, Anniversary Speeches, Company Website, Annual Reports	Company Profile, Company Website, Annual Reports, Project Reports
Number of Interviewees	6	6	6

Data Collection

Following ethical clearance, the selected firms were invited to participate in the study. Human resources departments facilitated initial access, and participants were recruited through voluntary response to circulated invitations. Semi-structured interviews were conducted with 18 managers across the three firms. Interviews were held virtually to accommodate participants' schedules and ensure anonymity. Participants were purposively selected based on their tenure, strategic responsibilities, and professional diversity. Their years of service ranged from 2 to 41 years. Professional backgrounds included quantity surveying, civil engineering, finance, human resources, information technology, and construction management, as indicated in Table 2. This heterogeneity enriched the dataset, enabling the analysis of resilience from multiple vantage points within each organisation.

Table 2: Participant Demographics

Case 1	Role	Tenure	Case 2	Role	Tenure	Case 3	Role	Tenure
P1	Executive Director	8 Years	P7	Board Chairman	41 Years	P13	CEO	11 Years
P2	Commercial Director	12 Years	P8	Commercial Director	13 Years	P14	COO	11 Years
P3	QS Manager	7 Years	P9	HR Director	4 Years	P15	Projects Director	5 Years
P4	Estimating Manager	15 Years	P10	Financial Director	7 Years	P16	Project Manager	6 Years
P5	Business Development Manager	20 Years	P11	Renewable Energy Manager	2 Years	P17	Quality Manager	3 Years
P6	Projects Director	5 Years	P12	IT Manager	4 Years	P18	Commercial Manager	4 Years

The interview schedule was designed to elicit narratives about how participants conceptualise, experience, and enact organisational resilience. Questions focused on responses to disruption, perceptions of resilience, and the strategies used to adapt and maintain continuity. Emphasis was placed on the micro-level practices through which disruptions were sensed, interpreted, and managed. Participants were encouraged to share stories that illustrated strategic shifts, unexpected challenges, and lessons learned from adversity. These accounts were analysed as situated narratives rather than treated as objective descriptions (Qin and Green, 2022). To triangulate and contextualise the interviews, secondary data were collected from internal and public sources. These included company profiles, annual reports, project documentation, and speeches. This material enabled cross-verification of participant accounts and facilitated richer contextual analysis of firms' strategic trajectories and operating environments.

Data Analysis

Data analysis followed an iterative thematic process informed by Braun and Clarke's (2006) framework, combined with sensitising concepts from the strategy-as-practice and narrative literatures (Jarzabkowski *et al.,* 2007 Interview transcripts and documentary sources were read repeatedly to ensure familiarity and identify emergent patterns. Initial codes were developed inductively, capturing recurring practices, interpretations, and responses to disruption. Axial coding was used to link codes thematically, attending to temporality, causality, and symbolic framing. Consistent with narrative inquiry, particular focus was placed on plotlines, character roles, and temporal sequencing to examine how stories of resilience were constructed and deployed (Duman and Green, 2018).

Themes were refined through constant comparison across the three firms, allowing for the identification of both common patterns and context-specific nuances. This approach facilitated a grounded interpretation of resilience as a socially constructed, practice-based process. Credibility was strengthened through triangulation across roles and data types, while construct validity was enhanced via an audit trail and the cross-verification of interview claims with internal documents (Yin, 2018). A case study database and consistent coding protocols supported analytic reliability. The goal was not mere categorisation, but to surface the strategic and narrative structures through which resilience is enacted in everyday organisational life.

FINDINGS AND DISCUSSION

This section presents the findings from the multi-case study. Four inductively derived themes structure the analysis: (1) Resilience in a Context of Chronic Disruption, (2) Performing Resilience through Improvisation and Strategic Flexibility, (3) Narrating Resilience as Sensemaking and Identity Work, and (4) Managing Informal Power and Community Legitimacy. These reflect shared patterns and context-specific nuances across the three cases.

Resilience in a Context of Chronic Disruption

Across all three cases, disruption was not experienced as a singular or exceptional event, but as an ongoing condition of practice. While the COVID-19 pandemic was mentioned, it was consistently framed as less impactful than the structural uncertainties embedded in the South African construction industry, such as delayed payments, community resistance, and state dysfunction. This aligns with Zungu *et al. (*2024), who argue that resilience in emerging market construction contexts must be understood not through a crisis lens, but as an everyday organisational requirement. As one director explained, “Covid didn’t knock us, that came and went. But the daily stress is different: Waiting three months for payment, watching a community forum shut your site down overnight. That’s what you plan for” (Case 3, P14). These experiences extend Duchek’s (2020) dynamic view of resilience by demonstrating that, in volatile contexts, the anticipation of disruption becomes embedded in routine planning, costing, and tendering strategies. The SAP lens helps clarifies how practitioners do not merely respond to environmental conditions but co-construct resilience through situated actions (Jarzabkowski *et al.,* 2007; Löwstedt, 2015).

Performing Resilience: Improvisation, Routines, and Strategic Flexibility

Resilience was performed not through formalised frameworks but through practitioners’ capacity for improvisation and adaptive judgement. Middle managers played a central role, managing daily tensions between delivery imperatives and shifting external conditions. Their practices ranged from informal problem-solving to scenario-based adjustments, highlighting the praxis dimension of strategising (Jarzabkowski and Spee, 2009). One manager reflected, “We plan for a perfect project, but we never get one. So, you learn to adjust — to tweak programmes, shift crews, negotiate time extensions — every week” (Case 3, P16). Another recalled, “During one protest, we hired a security firm just to escort workers in. That wasn’t in the budget, but not acting would’ve cost more. You’re constantly deciding what risk you can carry” (Case 2, P7). These practices reflect strategic improvisation, supported by Conz and Magnani (2020) and SAP scholars who emphasize the role of micro-practices in enabling resilience. All three firms have developed internal tools, such as project screening matrices or disruption cost trackers that facilitated structured

flexibility. This illustrates a broader understanding of resilience as rooted in dynamic, situated actions undertaken by those closest to operational realities.

Narrating Resilience: Sensemaking, Identity, and Strategic Memory

Resilience was also constructed through narrative. Practitioners frequently referred to past disruptions to justify current actions, embed organisational learning, and shape expectations. These narratives functioned as sensemaking devices, helping practitioners interpret events, assign meaning, and shape collective understanding of what it means to be a "resilient" construction firm (Fenton and Langley, 2011). As one participant shared, "We always talk about the Malelane job. That's when we realised we need to check the client's financials upfront. Now it's standard practice" (Case 3, P18). Another noted, "When things go wrong, we remind each other what happened before — who stood firm, who buckled. That becomes part of how we work now" (Case 2, P9). These narratives functioned as sensemaking tools, aligning individual experiences with collective meaning. They also served as informal scripts that legitimised behaviour and preserved continuity. This aligns with Deuten and Rip's (2000) concept of narrative infrastructure, where shared stories stabilise meaning and support organisational coherence.

Narratives further operated as mechanisms of identity work (Duman and Green, 2018). Through storytelling, practitioners presented themselves and their firms as competent, principled, and resilient. As one director stated, "We've been through worse, we know how to survive — that's just how we're built. It's in our DNA now" (Case 3, P14). These accounts helped reaffirm values and roles, especially in contexts where formal systems were unreliable.

Strategy-as-practice literature increasingly recognises the symbolic and discursive nature of strategy work (Vaara and Whittington, 2012). In this study, narrative emerged as both a sensemaking process and a political tool, a way of managing ambiguity, coordinating meaning, and reinforcing legitimacy, particularly when formal strategy artefacts fall short. Importantly, these narratives circulated outside formal spaces, through informal check-ins, cross-site calls, and mentorship conversations, rather than strategy workshops or reports. This highlights the distributed nature of strategising in these firms; it is not the exclusive domain of executives, but something co-constructed across roles and time, through the stories practitioners tell about what resilience looks like, and who they are becoming as they practice it.

Managing Informal Power: Politics, Community, and Moral Legitimacy

The final theme, and arguably the most contextually distinctive, was the role of sociopolitical negotiation in sustaining organisational resilience. In contrast to many global studies that treat resilience as an internal organisational process, participants in this study described a complex interplay between firm-level strategy and community-level politics. Particularly in public infrastructure projects, firms were required to manage relationships with politically connected actors, local gatekeepers, and informal power structures.

One participant recounted, "We've had sites shut down by groups demanding work. No letter, no formal channel. Just a group with weapons and demands. You have to manage that before you can build" (Case 1, P3). In response, firms developed adaptive strategies that included appointing local liaison officers, engaging traditional authorities, and providing informal support to community initiatives. These practices

were often framed not as compliance measures but as strategic investments in legitimacy and continuity.

One manager explained, “Our Project Liaison Officer is not just a translator; he’s an insider. He knows who needs to be heard. If you ignore that, you lose the site” (Case 1, P6). These actions resonate with the notion of micro-political strategising, in which practitioners draw on emotional intelligence, social capital, and contextual awareness to navigate contested environments (Golsorkhi *et al.,* 2015).

Furthermore, these practices involved considerable moral and emotional labour. Participants spoke of the need to make ethical judgements in morally ambiguous situations, such as whether to acquiesce to local demands that lacked formal legitimacy but were necessary for project continuity. These dilemmas underscore the moral complexity of strategy work in contexts characterised by institutional fragility. This theme extends the SAP literature by highlighting the political, relational, and moral dimensions of resilience, which are often overlooked in more technical or abstract models. It also reinforces the importance of studying strategy-in-practice within specific socio-political contexts

CONCLUSIONS

This study examined how organisational resilience is enacted within construction firms in South Africa. The findings address the study’s objectives by showing that resilience is not solely embedded in formal systems or predefined capabilities. Rather, it is constructed through the adaptive practices, judgments, and narratives of practitioners who operate across organisational levels. Resilience was found to emerge in response to chronic disruption, through both routine and improvised actions, particularly by middle managers navigating volatile project environments. These actors engaged in situated strategising, combining formal tools with flexible responses, while continuously drawing on organisational memory and shared narratives to make sense of uncertainty. Storytelling was central to this process, serving as a form of strategic sensemaking and identity construction that reinforced shared understandings of resilience. The study contributes to the strategy-as-practice literature by elaborating existing theoretical understandings of resilience through in-depth, contextualised insight into how it is performed in high-risk construction settings. It shows how narrative infrastructure and moral agency underpin resilience in ways not fully captured by existing models. This aligns with the logic of theory elaboration (Ketokivi, 2014), where case-based inquiry deepens and refines general theory considering complex, real-world practice. For practitioners, the findings suggest that resilience can be enhanced through reflective routines, relationship-based strategising, and attention to narrative coherence. Rather than relying solely on formal planning, organisations should support the strategic work of those at the interface of planning and implementation, particularly in contexts marked by persistent instability.

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EQUALITY, DIVERSITY AND INCLUSION

BREAKING THE CONCRETE CEILING: WHY THE UK CONSTRUCTION IS STILL WAITING FOR DIVERSITY TO 'BUILD' ITSELF

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The UK construction industry continues to lag other sectors in achieving diversity particularly in promoting women from ethnic backgrounds into leadership roles. Only 20% of the 3.1 million construction workforce in the UK are women. Black, Asian, and Minority Ethnic (BAME) Representation in the industry is 6%. No statistics is available to reflect Female BAME leaders. Despite national initiatives and corporate commitments to equity, diversity, and inclusion (EDI), the sector remains structurally exclusionary with systemic barriers such as cultural stereotypes, unconscious bias, and exclusive workplace practices. This paper investigates the barriers that hinder the progression of ethnic minority women into leadership roles in the UK construction industry. Using a qualitative semi-structured interview approach grounded in Critical Race Theory (CRT), the study explores challenges of systemic bias, workplace exclusion, and the limited impact of current EDI initiatives. Findings highlight persistent discriminatory practices, lack of representation and role models, and ineffective diversity strategies. The study proposes actionable strategies and recommendations for industry reform including mentoring initiatives, leadership development programmes, and fostering inclusive cultures.

Keywords: construction industry; ethnic females; diversity and inclusion; leadership; critical race theory

INTRODUCTION

Despite its role as a driver of economic growth, the UK construction industry remains one of the least diverse sectors. According to the Office for National Statistics (ONS, 2023), only 20% of the 3.1 million construction workforce are women, and just 6% identify as BAME (CIOB, 2024). The construction industry remains predominantly white and male-dominated, presenting significant challenges in attracting and retaining females from underrepresented ethnic groups due to lack of visible, relatable role models and mentors (Strachan *et al.,* 2020). These challenges are even more pronounced at the leadership level, where there is an almost total absence of women from ethnic backgrounds. This study investigates the systemic barriers impeding the progression of BAME women into leadership positions in construction. It aims to explore the lived realities behind exclusionary practices and the nature of barriers hindering ethnic women's progression to leadership roles.

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Employment in the UK Construction Industry

Estimates of the UK construction workforce varies depending on the source. The Office of National Statistics (ONS, 2025) Records an employment figure of 2.14 million workers in 2024, while the Construction Industry Training Board (CITB, 2024) Reports 2.67 million. Of these, approximately 270,850 employees within the construction sector are in leadership positions, including roles as directors, executives, and senior managers, yet women, and particularly ethnic women, remain underrepresented. Projections by CITB indicate that to accommodate industry growth between 2024 and 2028, the sector will require an average Annual Recruitment Requirement (ARR) Of 2580 professionals within this occupational category. By 2028, the total number of individuals in these leadership roles is expected to increase to 277,060. Additionally, data from the ONS (2025) Estimates that the total number of job vacancies across all occupational categories within the construction industry will reach 38,000 between December 2024 and February 2025. This figure represents an annual increase of 6.7% compared to the same period in the previous year.

Despite the significant workforce demand projected within the UK construction industry, the progression of women from ethnic backgrounds into leadership positions remains severely limited. While CITB (2024) Anticipates thousands of leadership vacancies annually, and ONS (2025) Reports steady job growth, there is little evidence to suggest that these opportunities are equitably accessible to ethnic women. Deep-rooted structural barriers, including institutional biases, exclusionary workplace cultures, and limited access to mentorship and sponsorship, continue to restrict their career advancement (Suresh et. al., 2025). Without targeted interventions, the industry risks perpetuating a leadership landscape that fails to reflect its diverse workforce. This study seeks to critically examine the systemic obstacles that hinder ethnic women's progression into leadership roles, offering insights into the structural reforms necessary for fostering inclusive leadership pathways in the UK construction sector.

Women in Leadership: FTSE Overview

This section reviews latest statistic on women in leadership in the UK construction industry. It draws secondary data from several recent reports (FTSE, 2025), construction companies' annual reports for 2024, and CITB (2024). The section reviews and discusses data on representation of women in leadership in the Financial Times Stock Exchange Group (FTSE) Listed construction companies trading on the London Stock Exchange.

Female Leaders in FTSE Companies: Construction compared to other Sectors
The FTSE Women Leaders Report (2025) Distinguishes between 'Women on Boards' and 'Women in Leadership' with the latter comprising of women in Executive Committees and Direct Reporting to those committees hence focusing on the pipeline of female talent already in leadership positions. The FTSE Women Leaders group is an independent, business-led framework supported by the UK Government to encourage on a voluntarily basis the percentage of women on boards and in leadership. It has set two targets: A minimum threshold of 33% of women on boards; and a 40% representation of women in leadership to be achieved by the end of 2025. The following analysis of female leaders in the construction industry is based on the above definitions and figures set by FTSE Women Leaders.

As can be deduced from Figure 1, the 'Construction and Materials' sector is underperforming in its female representation at leadership level with the sector ranked

5th from the bottom in comparison to other sectors. Moreover, the sector is underperforming in relation to the target of 40% to be achieved by the end of 2025.

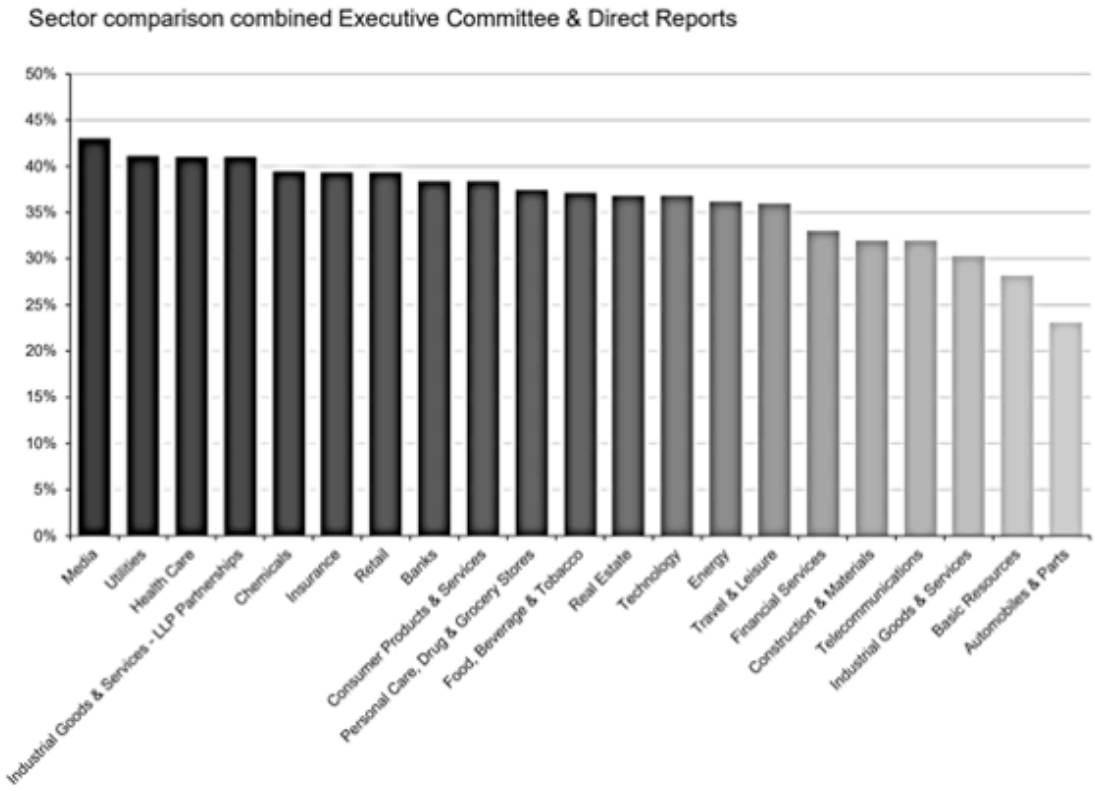


Figure 1: Women in Leadership. Source: FTSE Women Leaders Report (2025)

It comes as no surprise that the total number of women in leadership positions in construction is low. This should be set against the backdrop of the percentage of women in the industry irrespective of their career position. Figure 2 reflects these statistics obtained from latest figures published by the Office of National Statistics (2025). These provide an overview of the percentage of women in full time and part time roles in the industry. The figure shows that in December 2024, the percentage of women in full-time employment in the sector remains stubbornly below 10%, a growth of just over 2% from December 2015. For the past 9 years, the percentage of women in part time jobs in the industry remains close to the 6% boundary. It can be argued that the low number of women in leadership positions in construction is attributed to the low level of entry and middle management pool from which leadership talent could be drawn.

As this research primarily focuses on women in leadership in construction, the following sections present statistics obtained from the UK FTSE Women Leadership organisation which monitors data obtained voluntarily from FTSE 'construction and materials' companies listed in the London Stock Exchange. Two listings are consulted in this paper: Private 50 and FTSE250.

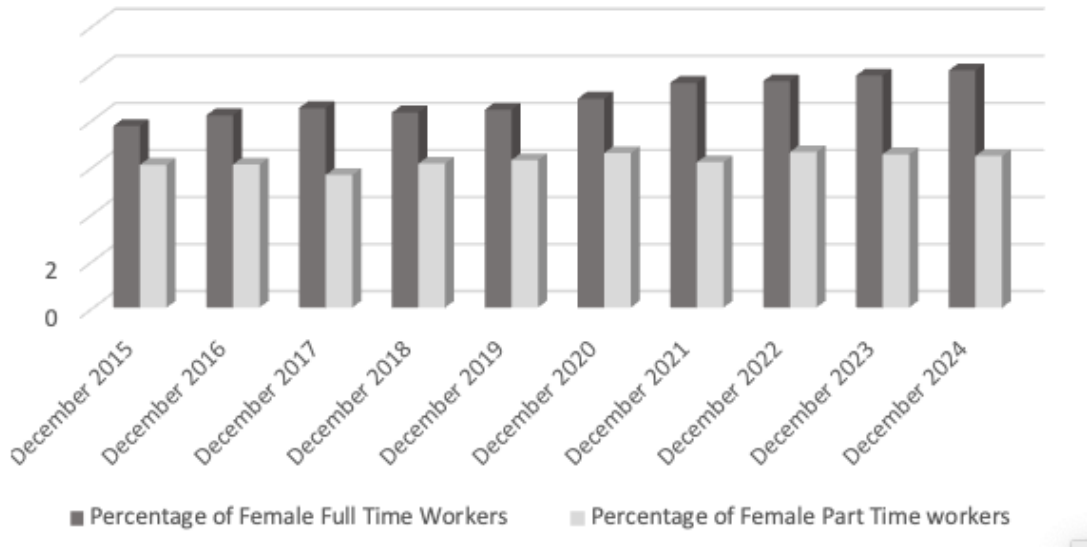


Figure 2: Percentage of Female Workers in Construction. Source ONS (2025)

Female Leaders in Private 50 Construction and Materials Sector

The Private 50 companies are those top 50 FTSE-listed private companies. Under the category of 'Construction and Materials', there are 5 companies in this group which represent top construction and consultancy firms in the industry. According to FTSE Women Leaders Report (2025), these 5 firms are ranked 13, 16, 20, 35, and 36 in terms of the percentage of women in leadership roles. As previously mentioned, there are two statistics of relevance set by and for UK business which is supported by UK government: the achievement of a minimum threshold of 33% women representation at leadership level and a target of 40% representation to be achieved by the end of 2025. The top performing construction company, ranked 13th in the Top Private 50 FTSE-list, leads the way with a 37.3% women representation in leadership. Whilst this company has met the threshold for Women in Board (44.4%), it is yet to hit the 40% target expected by the end of 2025 for Women in Leadership (37.3%). The second-best performing company is ranked 16th with 36.4% women in leadership positions. The third company is ranked 20th in the group and 3rd from the construction and materials sector perspective. This company reported a 55.6% women representation in its board but a mere 35.2% in leadership positions. All three construction companies have 0% of ethnic women of construction-related qualifications in their Boards/Executive Committees according to published details of their leadership teams. The remaining two construction and materials companies in Top Private 50 have one ethnic woman each in Corporate Functional positions.

Female Leaders in FTSE250 Construction and Materials Sector

Data from 9 construction companies listed on the FTSE250 is analysed in relation to the percentage of women and ethnic women in leadership roles. The data indicate that only one construction company achieved an above target percentage of women in leadership of 43.8% (FTSE, 2025). The company is ranked 23rd within the wider group. However, a detailed analysis of its annual report shows that there are 3 women in a 9-member combined executive committee (33%). These women do not have construction-related qualifications. They occupy Corporate functional roles including Corporate Development Director, Chief People Officer, and Corporate Affairs Director. Whilst these are significant positions, they do not reflect core construction professions. None of the women are of ethnic backgrounds. Of the remaining 8 companies with leadership composition datasets in the FTSE250, one company,

ranked 56, achieved the threshold of 33% female representation in leadership and is expected to be on track for meeting the voluntary 40% target in 2025. However, none of the women are from underrepresented ethnic groups. Five companies ranked 98, 107, 109, 114, and 117 have neither met the threshold nor are deemed on track to meet the target. Of interest, the percentage of ethnic women in leadership occupations are 0%, 6%, 11%, 0%, and 11% respectively. The numbers are very low - one ethnic women in each case in Corporate Functional roles. The remaining two companies listed ranked 136 and 146 on the FTSE250's Women in Leadership dataset. They are classified as 'below 25%, adrift from peers and with a significant shortfall to address' Data shows that one ethnic woman occupies a Corporate Functional position in each of the two companies.

Theoretical Underpinning: Critical Race Theory

critical race theory (CRT) is adopted as a theoretical framework for this study. Three constructs are mobilised: Intersectionality of Race and Gender, Lived Experiences, and Narrative Sharing. The theory emerged in the USA in early 1970s as a scholarly movement through the writings of Derrick Bell, the first African American academic at Harvard Law School (Morgan, 2024; Delgado and Stefancic, 1989). According to Delgado and Stefancic (1989, p.467), Bell's early works focused on 'interest convergence' as a 'means of understanding Western race history and the conflict of interest in civil rights litigation'. By early 1990s, scholarly work by prominent Critical research shaped the tenets of CRT leading to the birth of a theory with well-defined themes grounded in 'how racism was connected to the law' (Morgan, 2024). Morgan (2024) Stipulates that despite differing opinions, CRT theorists agree on the main principles of the theory, namely that: A. interest convergence is prevalent where 'white elites and large segments of society' are only interested in addressing racism if it serves their interest, b. racism is normal and common hence difficult to recognise and deal with, c. Intersectionality across multiple social identities overlap to shape discrimination.

CRT has seen a growing interest by UK-based researchers exploring female BAME underrepresentation in leadership in various industries including UK Higher Education (Heslop-Martin et. al., 2024, Omhand, 2023), Football (Godhania, 2024), Finance (Babafemi, 2022), and Arts (Marsh, 2020). A thorough search for scholarly research mobilising CRT in exploring female BAME underrepresentation in leadership in the UK construction industry yielded no return. The author believes that this study may be the first of its kind given the focus and context of the research. There is, nevertheless, considerable studies on Gender, EDI, BAME, and Female underrepresentation in the UK construction industry. Examples include the works of Suresh et. al., 2025; Missa, 2013; Clarke and Gribling, 2008; and Steele and Sodhi, 2006. Neither of these studies are grounded in CRT nor focused on female BAME in leadership in construction; hence the originality of the study presented in this paper. The near total absence of research into this social category indicates the urgency in the need to understand and support women from underrepresented backgrounds on their journey to leadership.

METHOD

This study adopts a qualitative research design using semi-structured interviews with three women from underrepresented ethnic groups in senior leadership roles within the UK construction industry. The selection was purposive, focusing on participants who matched the FTSE Women Leaders' defining of leadership: executive roles or

those reporting directly to executive committees. Interviews were conducted virtually, each lasting between 45 to 60 minutes. The participants were anonymised and assigned identifiers: Interviewee 1 (Senior Project Manager); Interviewee 2 (Architect/Partner); Interviewee 3 (Civil Engineer/Divisional Technical Director).

FINDINGS AND THEMATIC ANALYSIS

Thematic analysis was conducted manually, following Braun and Clarke's (2006) Six-step approach. Four main themes emerged: (1) Systemic Barriers and Intersectionality; (2) Discrimination and Exclusion; (3) Representation and Role Models; (4) EDI Initiatives and Tokenism.

Systemic barriers and Intersectionality

Interviewees emphasized the profound adverse impact of systemic barriers and gender/race intersections in their career journeys to leadership. These were cited as daily challenges. Participants described needing to work significantly harder than peers and often being overlooked or underestimated. Discrimination was frequently subtle, embedded in organisational culture, promotion practices, and industry norms such as after-work networking in public houses (pubs). The following extracts depict their experiences:

> "… just trying to get yourself heard in meetings… that has been one of the biggest challenges in terms of being able to put your thoughts and your views among many white men in the industry... I do have a very different accent compared to the people in the UK industry, so it does get ignored frequently." Interviewee 1

"I am first generation born in the UK in the late 60s and grew up in an all-white environment… Since young, I saw myself as a white person… As an architect, I needed to totally assimilate and regard myself as one of the lads" Interviewee 2

> "It irritates some individuals that I am outspoken, that I speak my mind… my biggest challenge was that certain men did not stomach that I was speeding ahead with my career and tried to halt my progression." Interviewee 3

The intersectionality of gender and race posing significant barriers is reflected in the lived experiences of all three interviewees. It is interesting to note how each woman developed different coping mechanisms. What distinguishes interviewee 2 is that she is UK-born whereas the others came to the UK having completed their undergraduate studies and gained construction experience in their home countries prior to settling in the UK. For them, the pride in their own rich culture, their sense of professional competence, and aspiration for success meant that they had to self-promote and challenge discriminatory boundaries. In other words, they had to break down concrete ceilings to progress to leadership roles whilst maintaining their authentic self.

Discrimination and Exclusion

Both direct and indirect discrimination were encountered by the interviewees. Some very overt; others quite subtle. Findings can be viewed from CRT's principle that racism is normal and common and is manifested in direct and indirect discrimination. It can be difficult to recognise and deal with when it is subtle. Some of these experiences are evident in the following quotes:

> "I'll be honest. It's nothing direct ever… it's very subtle. For me, it's a list of small things which sort of add up" Interviewee 1

> "I've been discriminated against on countless occasions. I worked for a company after Part 1 qualification. I was made redundant as an architectural technologist but was

> offered a part-time job as an administrator in the same company! I was young and they took advantage!" Interviewee 2
>
> "I was 3 years overdue for promotion to Divisional Technical Director… following amazing reviews by a major Client I was working with, after several tries, I finally put my case in front of my line manager; he said "Oh (name), when I look at you, you don't look like a divisional director to me"!" Interviewee 3

Representation and Role Models

The absence of ethnic role models amplified the sense of isolation and slowed career progression. Although informal mentorships were helpful, participants noted that formal structures were lacking. The three interviewees reinforce the challenges relating to underrepresentation and how this had delayed their own career journeys into leadership:

> "I've been to events; I've been to talks; I probably will see one other female from ethnic background that is if the organising committees have actually made an effort to look for them and extend an invitation" Interviewee 1
>
> "I am the only women - Director - on our Board and it happens that I am from an ethnic background… the rest are 9 white men… and this is typical of the total lack of role models I experienced in my career journey" Interviewee 2
>
> "How many CEOs are from ethnic minorities in this country? They don't even get you on the executive boards. I'm on the non-executive board of [name] but there are next to no ethnic females on executive boards in construction" Interviewee 3

EDI Initiatives and Tokenism

Regarding EDI initiatives, all participants were sceptical. They perceived them as 'tick-box' activities driven more by compliance than conviction. No concrete implementation checks were in place, and unconscious bias training was viewed as insufficient. Interestingly, one of the interviewees suggested that EDI initiatives are not making real impact or difference for ethnic females in the industry. She suggested that initiatives and policies are often mobilised by firms to win work however, no due diligence takes place to ascertain whether they are implemented effectively.

"There are people pushing policies wherein projects are awarded to companies who have diversity and inclusion initiatives, but there's nobody actually checking whether they are actually being implemented or not." Interviewee 1

> Interviewee 2 agreed that some of these initiatives are a "tick-box exercise and genuine efforts are desperately needed to make them effective".

An example was given by Interviewee 3 who went further and suggested that "conscious bias" training should replace "unconscious bias" training by construction companies. She explains:

> "I think companies need to start training people for conscious bias. Unconscious, much easier to deal with than conscious bias where people wilfully do things which are wrong." Interviewee 3

DISCUSSION

Findings confirm previous literature suggesting that women from ethnic minorities face several barriers preventing them from reaching leadership positions. Using CRT, this study highlights how race and gender intersectionality operate structurally, often invisibly, within workplace practices. Ethnic women must work much harder to prove they have merit and can succeed in the industry. This finding corroborates with Suresh et. al. (2025) And Otaye-Ebede and Shaffakat (2024) Who explored lived

experiences of BAME women in construction and psychology professions respectively. Furthermore, direct and indirect discrimination experienced by the interviewees can be explained from a CRT perspective that racism is normal and common, yet it can be difficult to recognise and deal with when it is subtle.

Underrepresentation of female leaders from ethnically diverse backgrounds is an undisputed phenomenon across industries (Heslop-Martin et. al., 2024; Godhania, 2024; Babafemi, 2022 Marsh, 2020). Data analysis of the Top Private 50 and FTSE250 construction companies provides sufficient evidence for the total absence of profession-related ethnic female leader. The three interviewees reinforce the challenges relating to underrepresentation and how this had delayed their own career journeys into leadership. The complexity of underrepresentation goes deeper than just lack of role models and raises questions around male-focused career pathways, structures, and policies that disadvantage women (Babafemi, 2022). Intentional exclusion of ethnic groups is highlighted in a study on USA construction industry regarding male BAME in trade and the profession in which the researcher stresses that "exclusion remains the ordinary business of the USA construction industry, with routines, practices, and institutions that perpetuate minoritising and sub-ordinating non-whites" (Piatt, 2023:93). Experiences of the interviewees with promotion suggests that some parts of the UK construction industry exhibit exclusion practices.

The cultural practices of the industry often act as reinforcement of concrete structures hindering career progression for ethnic females. The long working hours and prevalent drinking culture are indicative of a male-orientated model of success and serve as significant barriers to ethnic female career progression. Cultural issues continue to undermine EDI efforts which resonates with CRT's interest convergence discourse that changing racially discriminatory systems is a slow process and requires interest convergence (Piatt, 2023:92). Interestingly, one of the interviewees suggested that EDI initiatives are not making real impact or difference for ethnic females in the industry. She suggested that initiatives and policies are often mobilised by firms to win work however, no due diligence takes place to ascertain whether they are implemented effectively.

Otaye-Ebede and Shaffakat (2024) Findings corroborate with the interviewees' opinions and suggest that BAME women are still severely underrepresented in top leadership positions despite increased interest in EDI initiatives and policies which have been put in place to reduce discrimination and improve access to leadership. Findings are further supported by Babafemi (2022) Who believes such policies may not be effectively implemented due to the unwritten norms that persist within the workplace such as after work networking.

Interviewees stipulated that EDI initiatives should not be about increasing numbers or be seen as favouring ethnic women (tokensim) For promotion and career progression but should be grounded on merit. These sentiments feature strongly in the findings of Suresh et. al. (2025) And Godhania (2024) Where recognition of merit and accomplishment are strongly argued for in promotion of women and ethnic females into leadership positions. However, one interviewee questioned calls for EDI initiatives to be applied on merit suggesting that such language is problematic indicating that 'BAME women are not meritorious' hence creating exclusively mutual tick boxes 'BAME' and 'MERIT'.

RECOMMENDATIONS

Based on the findings from this study, the following actions are recommended for implementation by UK construction industry plc:

- Establish accountability mechanisms for EDI policy implementation.

- Promote conscious (not just unconscious) Bias training.

- Create structured mentoring and sponsorship programs targeting ethnic women.

- Embed inclusive leadership pathways in professional development.

- Ensure executive recruitment panels are diverse.

Accountability, transparency, ethical practices and professionalism are strongly advocated to ensure better outcomes for ethnic women aspiring to take their rightful place in leadership roles within the UK construction industry.

CONCLUSIONS

This paper has revealed how ethnic women in UK construction industry face systemic, cultural, and institutional barriers in their pursuit of leadership. Despite the presence of EDI policies and initiatives, practical implementation is ineffective, and accountability is minimal. Furthermore, the scarcity and invisibility of females from underrepresented ethnic backgrounds in leadership positions raises serious questions about the industry's engagement, efforts, and effectiveness of these initiatives in addressing equity, diversity, and inclusion concerns. The use of CRT has provided a powerful lens to understand how exclusion persists, and how targeted, systemic change is needed to transform the leadership landscape of the industry. The study makes recommendations which may help deliver change in the industry.

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AN EXPLORATORY STUDY ON GENDER-BALANCE INFLUENCE ON HIRING AND PROMOTION IN CONSTRUCTION COMPANIES

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The focus of this study was to investigate the level of impact that equality, diversity and inclusion (EDI) legislation focused on gender has on creating an equal opportunity regarding hiring and promotion processes in companies operating in the construction industry. Qualitative data was gathered through semi-structured interviews with managers from two Project Management firms: one in Ireland and one in the United States (US). Findings indicated that in Ireland, there is positive discrimination towards females seeking employment and promotion in the construction industry whereas US participants reported a focus on race / ethnicity but not on gender. The companies involved, appear to have a focus on satisfying external requirements from clients and legislation compliance rather than developing a sustainable EDI approach regarding gender balance that could positively impact on company performance.

Keywords: EDI; gender balance; construction industry; positive discrimination

INTRODUCTION

The construction industry is actively developing Equality, Diversity, and Inclusion (EDI) policies to ensure fair treatment and opportunities for all, regardless of gender, civil status, family status, sexual orientation, religion, age, disability, or race (Equality (Miscellaneous Provisions) Act, 2015). While EDI covers many areas, this study focuses on gender, recognising the sensitivity of this issue in a male-dominated field where gender imbalance persists.

For clarity, it might be useful to take a moment to consider and define what the terminology used in the EDI construct means. Even though they are sometimes used interchangeably since both terms have their root in the Latin 'aequus' meaning fair and even, the words equality and equity have different meanings and therefore implications when looking at EDI policies. Equality projects a sense of ‘evenness and a lack of difference’ while equity implies ‘fairness’ (Loefler,2006). Regarding diversity - the inclusion of people from different genders, abilities, races and ethnicities should be an easy thing to do but it is blocked, especially in the construction industry, by issues such as poor training, working conditions and

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Harrison, A, O'Connell, K, Spillane, J P and Bradley, J G (2025) An Exploratory Study on Gender-Balance Influence on Hiring and Promotion in Construction Companies, *In:* Thomson, C and Neilson, C J (Eds) *Proceedings of the 41st Annual ARCOM Conference,* 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 277-286.

employment conditions that contribute to make construction 'exclusive'. This lowers the diversity of the workforce with the status quo maintained by 'adherence to traditional practices' such as apprenticeship, the itinerant nature of the industry and intensive use of labour (Clarke and Gribling 2008).

This study examines two project management firms-one in Ireland and one in the US, to assess how EDI influences hiring and promotion policies focusing on gender. It also considers whether gender-focused policies are the most effective way to address the gender gap in the construction industry.

The work included completion of a literature review to identify and summarise current knowledge and resources in the Irish and US jurisdictions. It used semi-structured interviews with managers from both companies to gather in-depth perspectives on the influence of EDI policies, practices and decision making on creating gender balance within the companies. While the limited sample size restricts the generalisability of the findings, the approach allows for a detailed exploration of attitudes and experiences regarding EDI initiatives pertaining to gender in the construction companies examined.

Given the ongoing lack of diversity in the sector, this study examines how EDI policies focused on addressing the gender imbalance help, or inadvertently hinder, the creation of a more diverse, inclusive and successful workplace

LITERATURE REVIEW

The construction industry has traditionally been viewed as low-status, with challenging working conditions and poor work-life balance, reinforcing the stereotype of men as the ideal professionals (Krings *et al.,* 2011; Caplan *et al.,* 2009). Despite some progress, significant inequalities persist across gender, race, ethnicity, and disability (Choi *et al.,* 2022), creating challenges in hiring and retaining skilled workers (Caplan *et al.,* 2009).

Research indicates that greater diversity in the workforce improves company performance, increases profits, and helps address skill shortages, especially when women hold leadership roles (Rohwerder 2022; Lammers and Gast 2017). However, some studies warn that overemphasising female leadership or mandating gender equality in leadership can inadvertently increase gender inequality or reduce firm value (Adams and Ferreira 2008).

The legislation governing EDI focused on gender balance varies by country. The UK and Australia require gender pay-gap reporting and compliance reports, while Ireland mandates annual gender pay-gap reports only for large companies (Equality Act 2010; Workplace Gender Equality Agency n.d.; Gender Pay Gap Information Act 2021). Ireland's Employment Equality Acts 1998-2015 protect nine demographic groups and require reasonable accommodations, aligning with EU directives (Employment Equality Act 1998; Council Directives 1989/391/EEC, 2000/78/EEC 2006/54/EEC). The EU's anti-discrimination directives provide a progressive foundation, with research showing positive impacts on gender equality in Belgium and the UK (Lemeire and Zanoni 2022; Fagan and Rubery 2018). In contrast, the US Equal Employment Opportunity Act applies only to companies with 15 or more employees and protects slightly different aspects, such as genetic information and political beliefs, while excluding civil or marital status. US enforcement is more robust, especially in federal contracts, and some states, like California, require women on

company boards, with penalties for non-compliance (US Equal Employment Opportunity Commission n.d.; OFCCP n.d.; Vosko *et al.,* 2016; Blyton *et al.,* 2011).

Automated hiring systems (AHS) are widely used in large companies outside of construction to promote fairness, but evidence shows they can reinforce bias if not carefully managed, as seen in Amazon's case where AHS favoured men (Sánchez-Monedero *et al.,* 2020; Nugent *et al.,* 2022; Ajunwa 2020). Within construction, AHS are used to recruit professionals as companies find themselves in tough competition for talent in the market. The reasons for construction companies using AHS are cited as cost effectiveness, ease of use for candidates, access to a larger pool of potential candidates, faster hiring process need for less HR (Afolabi *et al.,* 2018).

Some organisations have adopted 50:50 gender targets e.g., Wilmott Dixon in the UK set out in 2018 to achieve this by 2030. Actions such as increasing the percentage of female trainees up to 50% in 2019 were cited as first steps (Construction News, 2018): while these can help close gender gaps, the current workforce has 32% women up from 2018 when the level was 24% (Willmott-Dixon, 2024), they may also lead to perceptions of positive discrimination and concerns about fairness for men (Kewley 2021; Rafnsdóttir *et al.,* 2018; Ly-Le 2022; De Kretser 2020).

Government-led diversity efforts in the US appear limited in impact, with few construction companies aware of available resources. Some studies find that diversity policies benefit both minorities and non-minorities (Roberts 2019; Karakhan *et al.,* 2020), while others report no clear link between formal EDI initiatives and gender balance in management, and in some cases, equality policies have led to more men in supervisory roles (Baker *et al.,* 2021; French and Strachan 2021; Roberts 2019).

The Chartered Institute of Building in 2024 (CIOB, 2024) set out its charter for Diversity and Inclusion In Construction and outlined a business case for increasing diversity and inclusion to ensure future availability of replacements for a workforce that is currently aging, with 32.5% aged over 50 and imminent retirement looming for another 15% This makes moving towards a more diverse and inclusive workforce an essential action for the continued survival of the industry, which will be impossible if adherence to the current demographic showing 87.7% male with women making up just 12.3% of the UK construction workforce.

Increased gender diversity in leadership is reportedly associated with improved financial performance, corporate responsibility, and sustainability (Baker *et al.,* 2021; Glass and Cook 2018; Boulouta 2012; Gul *et al.,* 2011; Ben-Amar *et al.,* 2017). The positive image created by such diversity can provide a competitive advantage, help win public contracts and attract a broader applicant pool. For example, after the Women into Construction project at the London Olympic Park, employers reported that increased female representation directly contributed to business success and contract opportunities (Shrestha 2020; Wright 2014).

METHOD

The literature review summarised current research on diversity in construction and the impact of EDI on hiring and promotion. The research approach was designed according to the Saunders's Research Onion (Saunders *et al.,* 2007) entailing an interpretivism philosophy, with an inductive approach that involved using a mini-case study (Yin, 2012) taking a cross-sectional sample of relevant personnel from the participating companies for interview.

Primary data was collected through semi-structured interviews with 13 questions, based on 3 main themes outlined below that emerged from the Literature Review -

(1) Hiring and promotion policies in place. (2) EDI initiatives pushing a specific demographic i.e., focused on gender balance and (3) Impact of EDI initiatives on construction company - in terms of productivity / efficiency, attractiveness to candidates and clients,

The semi-structured interview format allowed for flexibility and in-depth exploration of participants' perspectives (Doody *et al.,* 2013; Adams 2015). Ethical approval was secured before the study began, and all interview questions were pre-approved.

Interviewees were chosen based on the following criteria: holding a management or hiring position in the organisation, at least two years' experience in construction, current employment based in Ireland or the USA. The companies involved were of a similar size and had been trading in the construction sector for more than 10 years and were drawn from two very different jurisdictions for comparison.

Potential participants were identified and provided with an Information Pack including a detailed information sheet that briefed them on the study's purpose, their rights and responsibilities, and highlighted that both company and individual identities remain anonymous. An Informed Consent Form was also included in the pack. Participation was entirely voluntary and if participants wished to be involved, they signed and returned the Informed Consent Form. In all 10 potential participants were identified in each company, however there was a disparity in the participation rate with only 3 people from the US based company consenting to participate. Participants were then contacted to arrange the interview schedule.

Interviews were conducted via MS Teams, each lasting 35-55 minutes. To encourage open contribution on sensitive topics, responses were recorded in writing only, as interviewees are often more open without audio or video recording (Adams 2015). All notes were anonymised within 1 day of the interview and securely stored in a password protected system.

Data was organised using thematic cluster analysis to identify key issues and relationships, enabling comparison of similarities and differences between the two jurisdictions. The findings were then analysed and are presented in the next section

RESULTS

Interviews for this case study were conducted with six managers (five male, one female) from an Irish construction consultancy and three managers (two male, one female) from a US electrical contractor in Northeast America. The Irish firm's overall workforce is 60% male and 40% female, though the project management team is 98% male. The US company is 98% male across all departments, with a similar ratio among job applicants.

All interviewees agreed EDI regarding gender balance is important in construction. The Irish firm has formal EDI hiring policies, particularly focused on meeting gender-based targets. All Irish interviewees cited "box ticking" as a driver for diverse hiring and promotion, to meet corporate expectations and workforce gender balance 'optics'. Irish views were divided on whether gender-based hiring is used to satisfy client requirements, while all agreed gender is the focus in EDI initiatives and that recently there has been an increase regarding attention to LGBTQIA+ inclusion.

The US firm lacks formal EDI policies, but public contracts sometimes require disclosure and attainment of diversity goals, such as targets for female, local, or minority hires. All US interviewees identified race/ethnicity, particularly African American employment, as the primary focus in their EDI efforts, followed by initiatives for hiring residents, women, and low-income individuals. All US interviewees said client requirements do not influence their hiring or promotions in relation to gender balance.

Five of the six Irish interviewees felt there was a gender influence leading to positive discrimination for females in hiring and promotion with a tendency to promote women faster in response to social and corporate pressures. However, interviewees did state that this was only the case when candidates were equally qualified, emphasising that women must still meet the relevant skill requirements. Two interviewees admitted reluctance to hire women of childbearing age due to concerns about maternity leave and workflow disruption.

In contrast, all US interviewees said gender demographics do not affect hiring and unanimously reported equivalent experience among male and female applicants, while noting that more female applicants were received for entry-level roles than for senior positions. One noted physical disabilities could be a barrier in their company for fieldwork positions, but not for office roles. All three interviewees did state that belonging to a qualified minority could be advantageous for both hiring and promotion.

Most Irish interviewees believed women are promoted faster due to gender, with some suggesting that this perception may stem from male insecurities. All US interviewees denied any gender-based advantage in promotions, noting only one woman was in a senior role in their company. When asked about current gender bias, five of six Irish interviewees felt there is now a positive bias toward promoting women, while two of three US interviewees saw no such bias in their organisation though they acknowledged it occurs elsewhere in the US.

None of the Irish interviewees observed improved efficiency or skillsets from increased gender-based diversity; one even suggested it could decrease efficiency. In contrast, two US interviewees noted positive effects, such as broader perspectives, improved workplace atmosphere, better client communication, and technical problem-solving by women, though they did acknowledge the consideration of female physical limitations when it came to suitability for physical site work.

DISCUSSION

A key difference between the Irish and American companies lies in their external motivators for EDI activities such as policy development but particularly in how they influence hiring and promotion. All US interviewees highlighted that federal contracts require compliance with the EEO Act of 1972, and companies often advertise locally to meet 'local resident goals.' This 'soft' enforcement through public contracts has positively influenced hiring diversity, aligning with Vosko *et al. (*2016) and Blyton *et al. (*2011). However, US contracts where diversity levels are a pre-requisite or award criterion focus primarily on race, not gender from a diversity perspective. Notably, no Irish interviewee mentioned government-led EDI initiatives as a motivator, but an Irish participant observed that HR had a bias toward hiring female candidates, provided they were qualified. It was also evident that hiring practices tend to reflect the similarity-attraction paradigm (Roberson, 2019; Bryne,

1971), with one American interviewee specifically noting that hiring often mirrors existing staff demographics, thereby perpetuating the male majority in construction companies.

Five Irish interviewees and one American believed women are promoted faster, provided that their qualifications and skills are equal. One Irish participant noted that a woman with less experience could be promoted over a more experienced man, supporting De Kretser (2020) on the potential for positive discrimination favouring female candidates for hiring or promotion. Both Irish and US interviewees acknowledged that women often perceive the need to work harder to earn respect in construction which is still a primarily male dominated workplace.

Despite positive discrimination in promotion and hiring decisions, being of childbearing age or having perceived physical limitations can negatively impact women's hiring prospects. While Irish and EU laws protect against such bias, two Irish interviewees admitted reluctance to hire women of childbearing age due to potential workflow disruption. Similarly, two Irish and one US participant believed women are less capable on-site, and the lack of female welfare facilities was cited as a barrier.

Demographic priorities differ: All US interviewees prioritised race (especially African Americans), local hires, and low-income candidates, while Irish interviewees focused mainly on gender, with some mention of LGBTQIA+ inclusion.

Although literature suggests diversity improves financial performance (De Villiers *et al.,* 2016; De Klerk *et al.,* 2015), no interviewees from either company reported increased profits that could be directly attributed to any EDI initiatives. Only two US interviewees noted efficiency or skillset improvements. However, benefits such as a wider applicant pool, public contract opportunities where EDI constitutes a pre-requisite or contract award criterion, and competitive advantage (Wright, 2014) were mentioned by both Irish and American participants.

Interviewees distinguished between diversity's benefits in the office versus on-site. Having a female 'perspective' involved in a team was seen as valuable in office-based and project management roles, while a third of Irish and US interviewees believed women's physical capability on-site was generally less than men's thereby limiting what the females could do in terms of physical labour on site.

It should be noted that the researchers did note that the sensitivity of the topic led to some reluctance from interviewees, which may have limited the findings and perhaps even the willingness to participate noted in the US-based company.

CONCLUSION

The two jurisdictions had different focus in terms of which element of EDI was considered as important. In Ireland, being female positively influences promotion, whereas no significant bias was observed for other demographics. In the US, the focus is on racial diversity, though employers claim race does not affect final decisions. It wasn't clear whether these differences were due to limited resources, the structure and intention of legislative instruments or the strength and activity of specific lobby groups to influence practice and policy.

The findings from this study and the literature review make it clear that gender equality remains lacking in the construction sectors of both the US and Ireland. While EDI was stated as a priority for both companies, hiring and promotion should be based

on ability rather than gender or minority status to avoid both positive and negative discrimination. EDI policies and initiatives should reflect the actual availability of women in the workforce and address ongoing negative discrimination. It is apparent that the gender ratio needs to be reflective of many industry-specific factors such as the nature of construction work and the number of females involved in studying construction-related professions and trades that make achieving a 50:50 gender ratio unrealistic in this male-dominated construction industry.

It is recommended that legislators introduce more comprehensive EDI legislation across all sectors, including construction, and that both governments and companies implement such initiatives sustainably. But there also needs to be more effort made to make the construction industry more attractive to females so that they can see a way to build a career through promotion of opportunities in school and removal of any negative impact (real or imaginary) of childbearing and child-rearing activities traditionally attributed to females. Despite some progress, Loeflers ideals of equality - evenness and a lack of difference, and equity -fairness (Loefler,2006). still remain far away in the construction industry of today.

Future research should consider anonymous surveys and larger sample sizes to gain deeper insights into EDI focused on gender-balance issues in Ireland and the USA.

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A JUST GREEN TRANSITION: ATTITUDES OF SCHOOL PUPILS TO CONSTRUCTION CAREERS

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Construction has a long-term skills crisis, an ageing workforce, and a tendency to recruit from within. Family connections are a common entry mechanism resulting in a homogenised male workforce with females constituting 14% of technical roles and a negligible proportion of trade roles. A challenge facing the industry is to develop green skills. Females are more sympathetic towards green issues than males and given the need for the industry to make a green transition, encouraging females represents an opportunity for the industry. It also offers potential for enhanced earnings for females in 'decent' green roles. A longitudinal project in East Anglia, UK, is giving year 9 school pupils exposure to the construction industry through taster days and work experience. The authors collected data via questionnaires from the pupils regarding their attitudes to the construction industry. Findings from the survey reveal females have a more mixed view of the industry than males and are less likely to believe 'it is for them'. The project has much work to do to promote revised perceptions.

Keywords: education; gender; green transition; skills shortage

INTRODUCTION

The UK built environment creates approximately 25% of the nation's greenhouse gases which highlights the significance of the potential contribution which the industry could make to reduce total carbon emissions (House of Commons 2022). Developing green skills and using green technologies are important for the construction industry's role in the transition to net zero. Yet while trying to deal with issues of sustainability, the industry also experiences several other challenges associated with its workforce — a skills shortage, an ageing demographic, and a tendency to recruit from within. One response to this is employing more females. This is an often-stated goal of the industry, but one which is not nearly realised as much of the industry remains male dominated (Norberg and Johansson 2020). There are projects seeking to understand how to secure long-lasting changes to gender-based employment patterns in the construction industry, and this research is borne out of one of those projects.

Recruitment to the construction industry is often framed around issues of technical skills, competencies, and STEM (science, technology, engineering and mathematics)

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subjects. Despite many efforts for over 20 years to increase the number of females in construction, as recently as 2019, little progress had been made in this area (Naoum, *et al.,* 2019). However, considering a sociological approach to address behaviours around climate crisis (Kwauk and Casey 2022) then opens the debate to new perspectives and alternative approaches helping tackle such important issues. This approach offers value in terms of encouraging females to enter the industry and a challenge in overcoming the status quo in the context of construction. At the same time, there is understanding that children's career choices are often gendered (Scholes and McDonald 2022).

This paper has its roots in a funded industry-based longitudinal project with an emphasis on equal opportunity seeking to encourage children to regard construction as a potential career choice and subsequently to gain employment in the industry. The project begins with school children aged 13 to 14, offering taster days, activities, and industry work experience opportunities. These children will be tracked over a period of five years to establish whether the project, with its provision of information and experience, is effective in encouraging young people to join the industry. Schools participating in the scheme must provide a 50:50 male to female split in the students they nominate. Here we focus on the role the project could play in broadening the participation of females in the construction industry. If successful, the project could be mutually beneficial as it may both contribute positively to females' earnings while benefitting the green transition of the industry as females are better disposed towards 'green' approaches. This first phase of the project explores the gendered nature of school children's perceptions of the construction industry. As the study progresses, their perceptions of the industry will continue to be monitored, evaluating the efficacy of the actions taken. It is hoped that the project will facilitate development of resources to continue promoting career choices which are less gendered than at present.

This paper examines these children's perceptions of the construction industry at the outset of the project. This will also allow for subsequent examination of how their perceptions evolve as the project unfolds. First is a discussion of the influences on career choice, perceptions of the construction industry, and 'green' construction skills. Following this are the method and findings of the project as it has thus far progressed.

The Gender Imbalance

The Learning and Work Institute Report (2022) suggests young people's awareness and knowledge of green skills is low, with 63% reporting that they had never heard of green skills and do not know what they are. 24% had heard of green skills yet did not know what they are. Only 11% knew what green skills are. Compounding this, there is a significant gender gap in young people's knowledge and understanding of green skills. Females are less likely than males to be aware of green skills, which may in part follow from their lower participation in STEM disciplines (Stojanov and Bremner 2024).

Earnings for operatives skilled in the use of green technologies are higher than for those without such skills, suggesting that developing these skills can lead to well-paid work, including for females. Additionally, there is evidence suggesting that in respect of consumption, 'green' issues and femininity are cognitively linked (Brough, *et al.,* 2016), and which may be an indicator of wider issues at play. Combined, these factors suggest there is scope to encourage women to engage with development of their own green skills. Individuals possessing such skills can earn more than

otherwise, highlighting how the industry would benefit from more females who are likely to be sympathetic to these issues. However, currently females are less interested in training in green skills (NESTA, 2023) and remain reluctant to enter the construction industry; progress addressing this problem has had limited success.

Approximately 300,000 women work in construction, a figure little changed over the past 25 years (Office for National Statistics 2025). Women comprise only 1.3% of operatives in manual trades and 16% in professional construction roles, illustrating gender segregation by occupation within the construction industry (Wright 2015). Women are more likely to work in areas such as architecture rather than being site-based. There may a tendency to regard construction as 'dirty and messy', and females could deem such attributes negatively for themselves.

Influences on Career Choices

Family and environment influences

Diverse and inter-related factors influence the career path chosen by an individual including family influence, psychology of the individual, and social environmental factors such as the influence of friends (Lan Oo, *et al.,* 2019). However, given that there is pressure to conform or at least adhere to social norms, so the degree of 'free' choice for females to join the industry may be more limited than might have been supposed. Therefore, this suggests the necessity for a long-term drive to support and encourage changes in these social norms and influences.

That family and environment, including peer pressure, exerts influence over approach to education and choice - or lack of choice - of career has been acknowledged for some time (Willis 1977). Other aspects of influence include jobs which may be secured through informal social networks and connections (Merlino 2019) and thus the individual's network of relatives, friends and acquaintances may represent directions of opportunity. Equally, the absence of types of network or connections represents a vacuum of information, 'persuasion' and opportunity for children. Given that social connections may include a gendered dimension, this represents part of a pattern of social and subsequently employment reproduction. Lack of suitable informal networks and role models which could have encouraged or inspired females to join the construction industry are likely to be weak or absent.

Gender influences

Gendered roots of career choice have their foundations as early as primary school (Scholes and McDonald 2022). Career choices are influenced by stereotypes and professions which could be deemed 'feminine' often reap less financial reward (Jaoul-Grammare 2024). However, the picture is more complex than this; females tend to select more altruistic careers, and gender-based aspirations along with their role in child-rearing play some part in this situation (Chevalier 2007).

Many occupations could be considered as being 'gendered', for example childcare (Haralambos and Holborn 2008) where the 2021 UK census data show 97% of early years education practitioners and childcare employees were female. By contrast, and of interest to us, in construction, most manual trades operatives were male, for example 99% of bricklayers were male (Office for National Statistics 2023).

Reasons for this tendency to occupational gender segregation include stereotyping, poor and outdated careers information, business culture problems, downgrading largely female jobs, and that females often need part-time and flexible working (House of Commons 2005) to accommodate child-care commitments. Gender

segregation has resulted in women tending to be in occupations which are low paying (Giddens and Sutton 2017). Nonetheless, the effect of being 'post-parenthood' on women's wages is recognised here (Francis-Devine 2024). Women often undertake fewer hours of formal employment (Norman 2019) allowing them to spend time in the home. Parenthood then impinges on career progression if females seek flexibility to accommodate their childcare commitments, reinforcing differentials in earnings.

Influence of schools and stereotypes

Careers in STEM subjects are often underpinned by proficiency in mathematics. However, school children often perceive mathematics as 'not very exciting'. Worse, frequently they hold misconceptions around STEM careers, for example car mechanic being conflated with engineer (Prieto and Dugar 2017). This suggests that females would also need support to help overcome antipathy towards mathematics as well as support to develop their interest in STEM subjects and knowledge of STEM careers.

Schools have long been regarded as agents of social reproduction (Apple 1990) and their influence - witting or not - on the choice of construction as a career may be one area where this is especially visible. Counter-stereotypical role models, although useful for females, need to be relatable to counteract pre-existing social stereotypes and the practical considerations of childcare which still exert influence over both female and male children (Olsson and Martiny 2018).

Research has found it possible to address problems around gender bias and stereotyping for women in STEM fields (Moss-Racusin, *et al.,* 2018). However, the reality is that training in these areas remains limited, and in schools there are constraints of delivering the national curriculum within school timetabled hours and budget. That sexual harassment and violence continue in schools today (House of Commons 2023) suggests there are deep-seated challenges to address. The end does not yet perhaps seem to be in sight. Worse, schools have in the last few years experienced regressive challenges with misogyny promoted and normalised by popular social media influencers promoting "hegemonic masculinity" (Haslop, *et al.,* 2024) for boys' social status and identity. This suggests the challenges are indeed considerable to address gender bias and gender-based employment patterns.

Brown and green skills and technologies

'Green' and 'brown' sectors refer to industries based on their environmental impact. Green skills are often associated with the green sector or the environmental goods and services sector (EGSS) i.e., those industries involved in the provision of goods and services for environmental protection and resource management including pollution prevention, resource efficiency and clean technologies. Both sectors require green skills to support the green transition (Strachan, *et al.,* 2023), recognising the role of all sectors in terms of environmental activity and minimising carbon emissions. Inspired by the International Labour Organisation's (ILO's) four categories of green employment effects, the Eco-Transformation of Industries Matrix (Kapetaniou and McIvor 2020) analyses industries in the UK based on their current level of environmental friendliness. The matrix currently recognises the construction industry as a follower with high carbon emissions and high level of environmental activity. It remains highly polluting but is also the agent of change for a better built environment. To make this move will require green skills, to which females potentially have an affinity, but these skills are also conflated with STEM, to which females are under-recruited. The impasse is clear: the industry needs green skills, green skills pay well,

women are entitled to well paid ‘decent jobs’, but they are under-represented in the construction industry which offers those jobs.

METHOD

The project from which our data derives was initiated by a Tier 1 contractor and a county council with support from industry contractors and consultants. Its goal over a five-year period is to provide a group of school children with early and ongoing exposure to the construction industry. It begins with children in year 9 and will track them through to the end of year 13. Activities provided include taster days, work experience and site visits. Schools were invited to participate and asked to provide approximately thirty pupils each, split evenly between males and females. This is the first year of the project.

The project is a longitudinal study, initially from 2024 to 2029. To evaluate the efficacy of the programme, the authors were invited to conduct a survey. Ethics approval was secured via the university's protocols for this research. This paper begins at the starting point, examining the base line of children's perceptions.

The children were invited to participate in the project and thus were self-selecting. However, it is not known whether there were any school, parental, or peer-based influences regarding an individual child's decision as to whether they would participate. The number of participants at this stage was 99, and 94 gave consent to have their data included. There is an assumption that as the project unfolds the number participating will decline as some lose interest.

Participants and their parents were informed the data from the survey would be provided to the university for analysis. Consent to undertake the survey was requested in the first question. The data of those who declined is excluded from this research. The children's identities were not known to the researchers, who were not involved with the provision of the project's activities and did not visit the schools. The children participated in the various activities of the project, regardless of whether they consented to take part in the survey.

On the morning of the first taster day the children were asked by the project facilitators to complete an anonymous online survey. The object of this was to establish their perceptions of the construction industry before they had received any experiences or activities of the project. A survey was an appropriate means to gather data as it was important to gather data from all the children involved in the study and to be able to analyse relationships between gender and perceptions (Gray 2014). It was also considered that a questionnaire was the most effective and consistent way to gather the data given the different locations involved (Matthews and Ross 2010).

This survey was composed of 26 checkbox questions and one free-text question. Designed by the project team in consultation with the researchers, the questions asked for views of the construction industry and what working in it might be like. Children were also asked whether they had any relatives in the industry and to identify their gender. Once the survey was conducted, the researchers were provided with an excel file containing the raw data.

The design of the questionnaire enabled the researchers to explore if there were differences in sentiment between girls and boys where gender is the independent variable. This enables the development of the null hypothesis: there is no difference in perception of the construction industry between boys and girls. A Chi Square test and a Mann-Whitney U-test were used with two questions: 'Is the construction

industry for someone like me?' And, 'how attractive is the industry?', respectively. An independent T-test was used with the combined means of seven Likert questions. In each case, differences in responses between boys and girls was tested.

FINDINGS AND DISCUSSION

Analysis focuses on whether there is a difference between male and female pupils' attitudes to the construction industry. It is important to emphasize the survey was carried out on the first morning of the first activity of the project. Thus, this is a measure of perception before the pupils had been exposed to any positive messaging about the industry. This paper reports part of those results: whether there is a gender-based differing perception of the construction industry and a construction career.

Is the construction industry for someone like me?
The pupils were asked the following: 'to what extent do you agree that the construction industry is for someone like you?'A Chi-Square Test of Independence was performed with the Likert responses collapsed into 'agree', 'disagree' or 'don't know'. The observed frequencies revealed that among female pupils, 10 believe the construction industry is for them, 12 believe it is not and 24 don't know. Among male pupils, 36 believe the construction industry is for them, 1 believes it is not and 11 don't know. The relationship between these variables was significant, $X^2(2, N = 94) = 28.802$, $p<.001$. Female pupils were less likely than male pupils to believe the construction industry was for someone like them. Many more females were unsure compared with males.

Is there a positive view of the construction industry?
Seven Likert-type questions on a four-point scale, with a fifth 'don't know' option were asked of the pupils to indicate a positive or negative view of the construction industry. The topics were: how dangerous construction is; if the work is varied; how dirty and messy construction might be; whether construction is a well-paid career, if it makes a positive impact on people's lives, if it changes the world in which we live, and, if construction is a creative career.

Taken in isolation, the questions reveal differences in opinions between males and females about the working conditions of the industry. Girls viewed construction as dirtier than boys (61% compared with 48%) and more dangerous (46% compared with 30%).

In terms of construction being a well-paid career, making a positive impact, being creative, the results are much closer. Both males and females had a positive view of pay in the construction industry (males = 78%; females 77%). Both males and females agreed that a construction career can be creative (males = 88%; females = 87%). Similarly, there was agreement that construction changes lives (males = 80%; females = 78%).

Across the seven Likert questions, females were more likely to answer 'don't know'. From the sample, 79.2% of males had a relative working in the construction industry while only 56.5% of females had a relative working in the industry. It could, therefore, be possible that more of the boys were better informed, through this contact, about the construction industry but it doesn't necessarily follow that this familiarity will be positive. Furthermore, it isn't obvious why school age males would have more relatives working in the industry than females.

The means of the seven Likert scale questions were used for an independent T-test to see if there was a difference across the seven Likert questions. Male pupils (n=48)

reported a more positive view of the construction industry (mean = 3.05, SD = .347) than girls (n=45) (M = 2.96, SD = .424). The difference between the genders is not significant. Both male and female pupils had a moderately positive view of the industry.

How attractive is a career in the construction industry?
At the end of the survey the pupils were asked 'based on what you know at the moment, how attractive to you is a career in the construction industry?'. Responses were given on a 10-point Likert scale where 1 is not attractive and 10 is very attractive.

A Mann-Whitney U-test showed that there was a significant difference (U= 399.5, p = <.001) between the responses of male and female pupils when asked how attractive a career in construction is. The mode rank for boys (n = 48) is 7 and 8 (12 responses each) and for girls (n = 46) the mode was 6 (10 responses). Boys view of a career in the construction industry is more positive than girls' view.

DISCUSSION

The survey analysis shows female pupils at the age of 13 or 14 hold the view that the construction industry is less suitable for them when compared with male pupils. This shows gendered ideas about suitable job roles take place early. For projects such as this, it also shows children are starting not with a blank canvas, but with preconceptions to manage and overcome. Whether these preconceptions come from home, education or elsewhere cannot be explored here and these may manifest in informal networks and connections that influence careers (Gabler 2021). But the data does show a difference between girls and boys in the way they perceive the construction industry before they know very much about it. Given that boys have a more positive disposition towards the construction industry at this age, they are more likely to take an interest in construction career opportunities. The mandated 50:50 ratio of boys and girls was anticipatory of these gender-based perceptions, as left to their own devices the schools and pupils were deemed more likely to have formed a male dominated cohort.

Overall, females tended to regard the construction industry as 'not for someone like them'. Boys were much more likely to consider construction as an attractive career prospect than were girls. Interestingly, the prospect of well-paid work was not enough to tempt the girls to consider construction as a realistic career choice, although they are comparable to boys in their view of the industry making a positive difference. Other larger surveys have shown that, for females, earning potential was one of the construction sector's appealing factors (Redrow 2024). Construction has the smallest gender pay gap (ONS 2024) and communicating that fact to females should be a goal of the project.

The positive impact of diversity on business productivity and profitability is well known. The business case for gender diversity on executive teams has more than doubled over the past decade Companies in the top quartile for both gender and ethnic diversity in executive teams are on average 9 percent more likely to outperform their peers (McKinsey 2022). However, it is not just a case of numbers and representation, it requires a corporate mind shift to truly realise any benefits. The 'add women and stir' approaches of early gender and development efforts failed to consider the influence of gendered relations of power and gender norms on the achievement of gender equality (Datzberger and Le Mat 2018). Our analysis shows females already

feel differently about the industry, long before they could join it. Diversifying the senior leadership of the construction industry is different and somewhat remote from gender equality for those entering the industry at the bottom.

Gendered occupational segregation amplifies the risk that women will lose the most from the climate transition. Male-dominated sectors, such as electricity, construction and manufacturing, are likely to see the biggest increases in jobs over the next 10 years. Climate transitions will increase labour market disparities and gendered inequalities in the long term based on the current trajectory. Historically, in economic and societal transitions, gender justice has often been overlooked leading to the marginalisation of women and the exacerbation of existing inequalities. Therefore, in the green transition there is recognition that greater equality and inclusion are key to social justice and just transition, as gender diversity also contributes to more innovative and inclusive solutions (Mininni and Hiteva 2023). Our analysis shows females do believe the construction industry can make a positive impact, but they are less sure, compared to males, about whether they themselves will be a part of this impact.

CONCLUSIONS

The real value of the project which has been the basis of this study will be revealed over time and is not yet known. The initial survey reveals that, even at a young age, male and female pupils have different views on the construction industry as a career. That females find it less attractive is not surprising given what we know, but the baseline for the project has now been set empirically. Our small sample size and geographic clustering are limitations on generalisation, and we have not ascertained where current attitudes have come from. Future funding may allow this to happen, and to expand the reach of the programme and our accompanying research.

The ability to access relatively young people, years before they will commit to a career, and to ask about how they perceive the construction industry has provided a view that might not be surprising: males and females have different views. Construction performs very poorly for female representation. These findings function as a cautionary tale to the construction industry. The promise of green skills remains high, and women have the skill set to thrive and earn well in “decent jobs” (ILO 2012), but their view of the industry already formed at such an early age is a barrier to address. That it should clearly be exhibited in this 2025 study is indicative of how much work remains to be done.

It will be interesting to see whether, and to what extent, the project is able to encourage the children to modify these gender-based perceptions. This would encourage girls to consider more widely their choices for their post-school employment than they may otherwise have done.

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ASSESSING THE ROLES OF EMERGING TECHNOLOGIES ON DISABILITY INCLUSIVITY IN THE CONSTRUCTION INDUSTRY

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The construction industry is witnessing a transformative shift with the advent of emerging technologies (ETs), profoundly impacting disability inclusivity. This research assesses the roles technologies have in enhancing inclusivity for individuals with disabilities within the industry. The analysis explores the effects of ETs on disability inclusivity in the construction industry. Based on quantitative research method, purposive and convenience sampling techniques 190 valid responses were collected, and a one-sample t-test was conducted. The findings indicated that reducing physical strain and fatigue, participating remotely in project management and decision-making and reducing the need for manual labour were the most ranked roles of ETs on disability inclusivity in the construction industry. The study offers critical insights for policymakers and industry stakeholders to realise the full potential of ETs in promoting disability inclusivity.

Keywords: emerging technologies; disability inclusivity; construction

INTRODUCTION

According to the World Health Organisation (WHO) (2011), about 15% of the world's population lives with some form of disability. In January 2025, this had increased to 16% - approximately 1.3 billion people as reported by WHO. That is for every six people you find in the world; you will find a person who is disabled. Some of the reasons behind the rising number are ageing of the population and the rapid spread of non-communicable or chronic diseases as well as the improvement in the methodologies used to measure disability (Sable *et al.,* 2019). The inclusion of this population in the social-labour environment has been discussed and encouraged in many countries through various laws, for example from quotas set for the employment of people with disabilities. For instance, Article 27 of the UN Convention for the Rights of Persons with Disabilities obligates member states to promote employment for people with disabilities, often through legislative measures like quotas. The EU Directive 2000/78/EC supports positive actions to prevent disadvantages linked to

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disability. China has established a formal quota system over the past three decades, though implementation inconsistencies remain (Liao, 2020).

However, persons with disabilities experience an Internet of Things (IoT) of barriers to inclusion which makes them live in deplorable conditions as a result of their physio-biological and psychosocial incapacitations of which the construction industry is not an exception (Bailey *et al.,* 2022; McKinney and Swartz, 2021). The construction industry has traditionally been characterised by physically demanding tasks, hazardous environments, and limited accessibility, making it challenging for individuals with disabilities to participate fully in the workforce. Despite global efforts to promote disability inclusivity through policies and regulations, the industry continues to face barriers in creating an equitable work environment for persons with disabilities. However, the construction industry worldwide is facing significant challenges due to a lack of skilled labour, which impacts productivity and project timelines. This issue is prevalent across various regions, affecting both developed and developing countries (Manoharan *et al.,* 2023). Given these labour shortages, there is a growing need to explore alternative workforce solutions, including the inclusion of individuals with disabilities, who remain an underutilised segment of the labor market. ETs have the potential to bridge this gap by enabling PWDs to perform construction tasks in addressing labour shortages and inclusivity concerns. Workers with disabilities typically work in offices rather than construction sites, in most construction companies (Guimarães *et al.,* 2018). The advent of ETs presents new opportunities to enhance accessibility, safety, and productivity for individuals with disabilities in construction. The integration of ETs in the workplace has the potential to significantly enhance the inclusion of individuals with disabilities (Jetha *et al.,* 2023). This involves not only providing assistive technologies but also transforming work environments to be more inclusive and accessible. ETs have been described as facilitators for social inclusion because it allows for the delivery of real-time services that can enable individuals to learn, work, travel, socialise, shop, and interact with the community without being subject to physical barriers (Manzoor and Vimarlund, 2018).

While these technologies have been widely recognised for improving efficiency and innovation in construction processes, their roles in fostering disability inclusivity remain underexplored. There is limited empirical evidence on how ETs can mitigate workplace challenges for persons with disability workers in the construction industry. This research aims to identify the roles of emerging technologies on disability inclusivity in the construction industry.

LITERATURE REVIEW

Disability

Defining disability is complicated as it is complex, dynamic, multidimensional and contested (WHO and World Bank, 2011). It is an evolving concept that results from the interaction between persons with impairments and attitudinal and environmental barriers that may hinder their full and effective participation in society on an equal basis with others (UNCRPD, 2019). Disability is a multifaceted and dynamic concept that can be understood through various lenses, each contributing to a more holistic understanding of its meaning and implications. From medical, social, biopsychosocial, legal, cultural, human rights, economic, identity, functional, and critical perspectives, disability can be described as a natural part of human diversity that arises from the interaction between an individual's physical, sensory, cognitive, or

mental health impairments and the societal, environmental, and attitudinal barriers that restrict their full participation in life (WHO, 2001). It encompasses both the intrinsic limitations of impairment (as highlighted by the medical model (WHO, 1980)) and the external obstacles created by inaccessible environments, discriminatory practices, and cultural norms (Shakespeare, 2006). Disability is not merely a personal or medical issue, but a social construct shaped by historical, cultural, and political contexts, as well as a lived experience that intersects with other aspects of identity such as race, gender, class, and sexuality (Goodley, 2011).

Emerging Technology (ET)

ETs are those technologies that are in the infancy stages of creation and implementation and can transform industries and society**.** ETs are typically character**ise**d by radical novelty, fast growth, high uncertainty, coherence, and big impact (Rotolo ***et*** *al.,* 2015)**.** Unlike established technologies, ETs are in the development stages, and their full implications, both positive and negative are not yet determined**.** According to Halaweh (2013) ETs are characterised by high uncertainty, network effects, unseen social and ethical implications, cost, unobvious impacts, limited availability, and limited research.

Role of Emerging Technologies on Disability Inclusivity in the Construction Industry

Technologies are essential for strengthening construction ventures, yet still, the point of embracing technology in the construction sector has been low compared to other industries (Bashir and Kivrak, 2020). ETs have to be proven helpful in the Construction industry due to their varied benefits to project stakeholders, such as enhanced visualisation, better data sharing, reduction in building waste, increased productivity, sustainable performance and safety improvement. (Manzoor *et al.,* 2021). ETs can contribute significantly to disability inclusivity in the construction industry through enhanced accessibility, safety, and productivity for individuals with disabilities. One of the significant contributions of these technologies is that they assist in enhancing physical capabilities and reduce strain. Exoskeletons and wearable technologies, for instance, assist construction workers with mobility disabilities by minim*ising* physical exertion and fatigue, enabling their inclusion in physically demanding activities (Rahman *et al.,* 2023). This is particularly helpful in an industry where manual labour is common and can serve as a point of exclusion. The integration of assistive and individual*ise*d tools facilitated through augmented reality (AR) and virtual reality (VR), has also assisted in introducing greater inclusivity. These technologies allow individuals with disabilities to interact with virtual construction environments, improving their ability to understand designs and perform tasks efficiently (Almeida *et al.,* 2021). The Walkin VR application, for example, provides virtual movement and rotation functions for individuals with mobility impairments, enabling their ability to engage with construction processes (Lagos Rodríguez *et al.,* 2022).

Besides, ETs have improved communication and coordination in construction projects. AI-driven communication systems and AR support collaboration by providing real-time visual presentations and interactive systems that help workers with disabilities communicate effectively with other workers (Almeida *et al.,* 2021). This ensures that persons living with disabilities are effectively integrated into construction teams rather than being marginalised by communication barriers. With technologies like IoT and AI, individuals with disabilities can participate in project management

and supervision without being physically present at the site (Louis and Dunston, 2018). Using AI-powered project monitoring and cloud-hosted collaboration tools, disabled construction professionals can effectively contribute to decision-making, overcoming physical accessibility limitations (Almufareh *et al.,* 2024). These among other effects are summarised in Table 1.

Table 1: Role of emerging technologies on disability inclusivity in the construction industry

SN	Role Emerging Technologies on Disability Inclusion	References
1.	Improving muscular fitness, cardiorespiratory fitness, balance, and speed and agility in individuals with intellectual disabilities e.g., VR-based exercise can	Li *et al.,* (2023)
2.	Developing customised assistive tools for the disabled (e.g., AR)	Almedia *et al.,* (2021)
3.	Helping in remote monitoring and oversight without being physically present.	Halder *et al.,* (2023)
4.	Providing support systems for day-to-day activities (e.g., Internet of Things (IoT))	Heyn, (2020)
5.	Providing assistance and security for visually impaired persons (e.g., IoT)	Haouel *et al.,* (2016)
6.	Enhancing effective communication between employees especially PWDs	Almeida *et al.,* (2021)
7.	Reducing physical strain and fatigue	Rahman *et al.,* (2023)
8.	Assisting in remote site inspection (e.g., VR)	Zhou *et al.* (2017)
9.	Enhancing safety for workers (e.g., Wearable technology)	Dobrucali *et al.,* (2024)
10.	Delivering real-time alerts for emergencies.	Cheung *et al.,* (2018);
11.	Reducing physical strain and fatigue	Almufareh *et al.,* (2024); Rahman *et al. (*2023)
12.	Participating remotely in Project Management and Decision-Making	Almufareh *et al. (*2024); Shaw and Vinsen, (2023)
13.	Providing greater independence in navigation and mobility	Almufareh *et al.,* (2024)
14.	Providing ergonomic adjustments.	Rahman *et al.,* (2023)

Source: Authors' construct (2024)

METHOD

This study adopted a quantitative research method to assess the role of emerging technologies on disability inclusivity in the construction industry. Quantitative research allows for systematic investigation of relationships between variables, ensuring objectivity and replicability (Creswell, 2017). Contextually, this study primarily focused on physical and sensory disabilities, as these are most relevant to participation and safety in a construction environment (Owusu *et al.,* 2024).

Primary data was collected using a closed-ended questionnaire, which was divided into two sections that are demographic information of respondents and the roles of ETs on disability inclusivity. The questionnaire utilised a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree) to measure respondents' perceptions and experiences. Purposive and convenience sampling techniques were used ensure that individuals with relevant experience in construction technology and disability inclusion participated in the study. Although the study did not explicitly target individuals with disabilities, the insights reflect the perspectives of those involved in implementing or observing inclusive practices. The combination of purposive and convenience methods ensured that the study focused on informed respondents while maintaining a practical approach to data collection. Prior to the administration of the questionnaire, content validity was done, by incorporating expert opinions from

researchers and professionals in the construction and academia through a pilot survey involving 15 respondents, whose feedback helped refine the questionnaire for clarity and effectiveness. Ethical approval for the study was sought to ensure adherence to research ethics. The study complied with ethical guidelines for research involving human subjects, ensuring voluntary participation and data protection. Following this, a total of 215 questionnaires were distributed to professionals in Ghanaian construction industry. Out of these, 190 completed responses were retrieved, yielding an 88.4% response rate, which is considered adequate. The Statistical Package for the Social Sciences (SPSS) software version 23.0 was used for data processing and analysis. Descriptive statistics were employed to summarise the demographic profile of respondents. One-sample t-test was conducted to determine the significance of the mean scores relative to a test value of 3.5 (Mireku *et al.,* 2025), providing insights into the perceived importance of the variables. A one-sample t-test was appropriate to determine whether the sample means for each variable differed significantly from the neutral test value of 3.5, which served as the benchmark for evaluating perceived effectiveness of the roles.

DATA ANALYSIS

Prior to the main analysis, to ensure reliability of the data set, the Cronbach's Alpha test was conducted, which yielded a value 0.959 which is above 0.7 as generally considered acceptable for reliability (Tavakol and Dennick, 2011).

The respondents represented various professions within the construction industry. Quantity surveyors comprised the largest group, accounting for 27.4% (52 respondents), followed by construction managers at 26.3% (50 respondents). Project managers represented 15.8% (30 respondents), while architects accounted for 13.7% (26 respondents). Civil engineers made up 10.5% (20 respondents), and geomatic engineers represented 6.3% (12 respondents). The educational background of respondents indicates a high level of academic qualification, which contributes to informed perspectives on the research topic. Most respondents held a first degree (49.5%, 94 respondents), followed by those with a master's degree (38.9%, 74 respondents). A smaller proportion had a PhD (4.2%, 8 respondents), while 7.4% (14 respondents) possessed a diploma or technician qualification. These figures highlight that most participants had advanced academic qualifications, ensuring their ability to comprehend and provide insightful responses to the questionnaire. The study also captured the work experience of respondents, as this factor influences their familiarity with ETs and their application in construction. The largest group had up to 5 years of experience (37.9%, 72 respondents), followed by those with 6 to 10 years (27.9%, 53 respondents). Additionally, 25.8% (49 respondents) had 11 to 15 years of experience, while 8.4% (16 respondents) had been in the industry for more than 16 years. These statistics indicate that the sample included both early-career professionals and seasoned experts, ensuring a balanced range of perspectives in evaluating the effects of ETs on disability inclusivity.

To examine the statistical significance of these effects, a one-sample t-test was conducted, comparing the mean difference for each variable against a test value of 3.5 (neutral midpoint). Using a 95% confidence level, Table 2 presents the results, showing that all effects were statistically significant ($p < 0.05$), indicating a strong positive impact of ETs on disability inclusivity. The mean score ranking method was used to assess the perceived role of ETs on disability inclusivity in the construction industry. Table 2 presents the 14 response variables, ranked from highest to lowest

based on their mean scores. All the variables were above the tested mean of 3.5 and all were also significant.

DISCUSSION

With a mean score of 4.22, the highest-ranked benefit of ETs is their ability to reduce physical strain and fatigue for workers with disabilities. Automation and robotics, for instance, perform physically demanding tasks, reducing the need for manual labor. Exoskeletons and wearable technology provide physical support, enhancing workers' strength and endurance. This technological assistance allows workers with disabilities to perform tasks that would otherwise be physically challenging. This agrees with Rahman *et al. (*2023) when they highlighted that exoskeletons and robotics significantly reduce physical strain and injury risks, thereby promoting a more inclusive workplace for individuals with physical limitations.

Table 2: Mean Score and One-sample t-test of Identified Effects

SN	Roles	Mean	SD	t	Sig. (1-tailed)	Rank
1.	Reducing physical strain and fatigue	4.22	0.830	11.358	< .001	1st
2.	Participating remotely in Project Management and Decision-Making	4.22	0.875	11.890	< .001	2nd
3.	Minimising the need for manual labour, which is beneficial for workers with physical disabilities	4.18	0.862	10.936	< .001	3rd
4.	Helping in remote monitoring and oversight without being physically present	4.17	0.808	11.498	< .001	4th
5.	Delivering real-time alerts for emergencies	4.17	0.846	10.977	< .001	5th
6.	Providing greater independence in navigation and mobility	4.16	0.833	10.882	< .001	6th
7.	Enhancing Collaborative Work Environments for Persons with Disabilities	4.13	0.854	10.199	< .001	7th
8.	Assisting in remote site inspection	4.11	0.857	9.824	< .001	8th
9.	Providing of assistance and security for visually impaired persons (e.g., IoT systems)	4.09	0.855	9.584	< .001	9th
10.	Enhancing safety for workers	4.09	0.889	9.137	< .001	10th
11.	Providing support systems for day-to-day activities (e.g., Internet of Things)	4.08	0.790	10.108	< .001	11th
12.	Providing customised assistive tools for the disabled (e.g., AR)	4.03	0.806	8.998	< .001	12th
13.	Providing ergonomic adjustments	4.02	0.914	7.857	< .001	13th
14.	Improving muscular fitness, cardiorespiratory fitness, balance, and speed and agility in individuals with intellectual disabilities.	3.89	0.786	6.833	< .001	14th

Source: Field Survey (2024)

VR and AR tools provide immersive experiences that allow workers to visualise and interact with construction sites remotely. These technologies ensure that individuals with mobility challenges can actively participate in project reviews, site inspections, and decision-making processes. According to Almufareh *et al. (*2024), and Shaw and Vinsen (2023), the use of VR/AR in construction enhances remote collaboration and allows for greater inclusivity in project management. The adoption of automation and advanced machinery significantly reduces the need for human intervention in repetitive and physically demanding tasks. This shift increases efficiency and creates a safer and more inclusive work environment for individuals with disabilities. This agrees with Almufareh *et al. (*2024) and Rahman *et al. (*2023), who highlight that automated material handling and robotic assistance minimise the reliance on manual

labor, thereby enhancing accessibility for disabled workers in construction. Technologies such as drones, IoT sensors, and AI-driven monitoring platforms allow for real-time oversight of construction sites. According to Halder *et al. (*2023), remote monitoring enables individuals with mobility impairments to participate actively in site management and supervision, eliminating the need for physical presence. According to the respondents, digital collaboration tools, such as Building Information Modeling (BIM) and project management software, enable seamless communication and coordination among team members. This inclusivity ensures that workers with disabilities can actively participate in team activities and contribute effectively to the project. According to Oke *et al. (*2021), the use of digital tools in construction enhances team collaboration and streamlines workflow processes, making the industry more inclusive for individuals with disabilities.

The ability of ETs to deliver real-time alerts for emergencies was ranked fifth. IoT-connected wearable devices can detect hazards such as gas leaks, structural failures, or fires and instantly notify workers. Cheung *et al. (*2018) emphasize that these alert systems improve safety measures for all employees, particularly those with auditory or visual impairments. Technologies like exoskeletons, robots, and AI-powered mobility aids enable individuals with physical disabilities to navigate construction sites more independently. Almufareh *et al. (*2024) highlight that these advancements not only enhance the independence of disabled workers but also integrate them into the workforce, promoting a more inclusive and diverse work environment. AR and AI-driven communication tools improve workplace interactions by providing real-time visual aids, speech recognition, and adaptive interfaces. Almeida *et al. (*2021) confirm that these technologies help individuals with disabilities, particularly those with speech or hearing impairments, to communicate effectively with colleagues. VR and simulation-based training provide immersive learning experiences, allowing individuals with disabilities to acquire construction-related skills in a controlled and risk-free environment. In agreement with existing studies, Zhou *et al. (*2017) highlight that VR enhances site inspections by improving the interpretation of results and increasing accessibility to critical areas.

In the views of the respondents, ETs can enhance safety for people living with disability in the construction industry. Wearable devices, such as smart helmets and vests, provide real-time monitoring of workers' vital signs and environmental conditions, ensuring a safer workplace. Studies confirm that wearable technology significantly improves safety measures in high-risk environments, particularly for workers with disabilities (Dobrucali *et al.,* 2024; Rahman *et al.,* 2023).

CONCLUSIONS

The findings indicate that ETs play a significant role in promoting disability inclusivity in the construction industry. From enhancing teamwork and reducing physical strain to enabling remote participation and improving safety, these technologies help integrate individuals with disabilities into the workforce. The statistical significance of all effects supports the need for construction firms to prioritise technological adoption to create a more inclusive industry. Future research could explore implementation challenges and strategies to optimise the use of ETs for disability inclusivity.

This study has some limitations that should be acknowledged. First, the research relied on self-reported data, which may introduce response bias. Second, the study focused on a specific geographic region herein Ghana, limiting the generalisability of

findings to other construction industries worldwide. To enhance disability inclusivity in construction, it is recommended that industry stakeholders invest in advanced technological solutions, including AI-driven safety systems, AR/VR-based training, and wearable assistive devices. Policymakers should develop regulations that promote the adoption of these technologies while ensuring accessibility and affordability. The study adopted a univariate analysis due to the specific objective of assessing the role of technologies relative to a baseline. Future research may employ multivariate techniques to explore inter-variable relationships and causality.

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HEALTH, SAFETY AND WELLBEING

BRIDGING THE GAP: INTEGRATING INFORMAL AND FORMAL SAFETY TRAINING IN INDIA'S CONSTRUCTION INDUSTRY

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The construction industry in India, employing 51 million workers and contributing 9% to the GDP, faces significant safety challenges, particularly for unskilled labourers who often lack formal health and safety training. This research explores the informal training practices prevalent in the sector, shaped by cultural, economic, and practical realities. Despite the existence of formal safety programmes, many workers depend on informal, peer-led learning acquired through on-the-job experiences. While this method allows for immediate knowledge transfer and fosters communication and camaraderie, it lacks structure, leading to inconsistent safety standards. Based on 10 semi-structured interviews with labourers and supervisors, the study found that safety knowledge is often passed down by experienced workers, some of whom lack formal training themselves. Informal practices help some workers gain clarity, yet others feel uncomfortable raising concerns, highlighting a key risk. Additionally, many projects neglect safety due to the prioritisation of meeting deadlines. The study calls for integrating structured training with existing informal practices to develop a more robust safety culture, reduce workplace accidents, and promote healthier working environments in India's construction sector.

Keywords: informal training; safety culture; unskilled labourers; India

INTRODUCTION

India's construction industry is one of the largest employers in the country, with over 51 million workers and a 9% contribution to national GDP (Rani, 2021). Despite its economic significance, the sector continues to struggle with critical health and safety (H&S) issues, particularly among its vast unskilled labour force (Gupta, 2021). Globally, formal H&S training remains limited in accessibility and effectiveness, while informal, experience-based training passed from peer to peer dominates on-site learning (Aboagye-Nimo *et al.,* 2015). This informal model is often rooted in cultural norms, economic constraints, and practical site realities (ibid). However, as these informal practices are not recorded, there is the possibility of a lack consistency, structure, and alignment with modern H&S standards. Through ten semi-structured interviews with unskilled labourers and supervisors, this study will critically explore the lived experiences and perceptions in relation to H&S training on Indian construction sites. The research's geographic context is Mumbai. This paper argues

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Aboagye-Nimo, E, Jain, M and Chiponde, D B (2025) Bridging the Gap: Integrating Informal and Formal Safety Training in India's Construction Industry, *In:* Thomson, C and Neilson, C J (Eds) *Proceedings of the 41st Annual ARCOM Conference,* 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 309-318.

that instead of disregarding informal methods, H&S policies and practices should embrace and integrate them into structured frameworks. By bridging the gap between formal programmes and informal learning, India's construction industry can adopt proactive measures which will lead to a more inclusive and sustainable safety culture, thereby enhancing wellbeing and reducing occupational hazards for its most vulnerable workers.

LITERATURE REVIEW

This literature review critically examines three interconnected themes: the challenges of health and safety (H&S) in the Indian construction sector, the role and limitations of informal training, and emerging discourse on integrating informal and formal H&S training. This structure allows for a comprehensive understanding of the contextual, theoretical, and practical dynamics shaping current practices.

It is imperative that some terminologies are clarified to help offer a better understanding of the research context. In the Indian construction sector, unskilled labourers typically refer to individuals engaged in physically intensive, non-specialised tasks such as carrying materials, site cleaning, or digging, often without formal education or vocational certification (Panneer *et al.,* 2019). While they are formally classified as "unskilled," many of these workers acquire knowledge through informal, peer-led experiences on site. This distinction is essential because, although they lack accredited training, they may still develop job-specific competence informally. This form of informally acquired competence/skill is crucial to building a positive safety culture on site (Aboagye-Nimo and Raidén, 2019). Understanding the position of unskilled labourers in relation to both formal and informal training approaches is key to exploring how H&S knowledge is transmitted and applied in real site conditions. The relevant literature themes are discussed next.

H&S Challenges in the Construction Sector

The construction industry is one of the most hazardous sectors globally, with a high rate of workplace accidents. Studies indicate that inadequate training significantly contributes to accidents (Fang and Wu, 2020). Unskilled workers in particular face elevated risks due to their limited exposure to structured H&S education.

The construction sector is globally recognised as one of the most hazardous industries, with high rates of accidents, injuries, and fatalities. In India, these challenges are compounded by a rapidly expanding workforce, a large proportion of which is unskilled and migratory. Workers often operate in dynamic environments with poor infrastructure, inadequate supervision, and limited access to personal protective equipment (PPE) (Boakye *et al.,* 2022). This creates an environment where H&S protocols are either weakly enforced or altogether absent.

The informal nature of employment further exacerbates the issue, as many workers are not covered by formal contracts or H&S regulations. Site-specific challenges, such as time pressures, harsh weather conditions, and multilingual workforces, also contribute to safety lapses. Moreover, regulatory frameworks such as the Building and Other Construction Workers (Regulation of Employment and Conditions of Service) Act, while well-intentioned, are inconsistently implemented (Sharma and Mohanpuria, 1996).

Cultural norms play a role as well, where risk-taking behaviour and fatalistic attitudes towards accidents are normalised (Teye-Kwadjo, 2019). Combined, these factors make it difficult to build a unified safety culture. Addressing H&S challenges in this

sector requires not only improved formal training and enforcement, but also recognition of informal practices that shape worker behaviour and decision-making on site (Aboagye-Nimo and Raidén, 2019).

The Role of Informal Training

Informal training, often peer-driven and experience-based, is a common means of transferring safety knowledge in construction (Hofmann and Stetzer, 2016). While this method helps create a strong sense of teamwork, it is inconsistent and varies widely depending on the knowledge of more experienced workers.

Informal training plays a critical yet often under-recognised role in the construction industry, particularly in low- and middle-income countries like India (Panneer *et al.,* 2019). It refers to unstructured, experience-based knowledge transfer that occurs outside formal educational settings, typically on-site, peer-led, and learned through observation, imitation, and practice (Aboagye-Nimo and Raidén, 2019). In contexts where formal H&S training is scarce or inaccessible, informal methods become the default mode of learning for unskilled workers.

Informal training has been widely known to facilitate quick adaptation to tasks and also improves camaraderie among workers (see Acheampong *et al.,* 2024). It often aligns more closely with the practical realities of the construction site, enabling immediate application. However, its informal nature also leads to inconsistent H&S practices and knowledge gaps, as workers may learn from peers who themselves lack formal training or up-to-date knowledge of H&S protocols.

While informal training can enhance teamwork and shared responsibility, it often fails to instil a deeper understanding of risk, legislation, or long-term safety implications (Lingard and Holmes, 2001). As such, reliance on informal methods without integration with formal training can perpetuate unsafe practices (ibid). Bridging these systems could help enhance safety outcomes by combining contextual relevance with structured guidance.

Bridging Informal and Formal Training Approaches

There is growing recognition in the literature that a rigid divide between informal and formal H&S training can limit overall effectiveness, especially in complex, high-risk sectors like construction. Researchers (Billett, 2002; Eraut, 2004) argue for a more integrated model that leverages the strengths of both approaches. They further argue that informal training is valued for its immediacy, contextual relevance, and accessibility, particularly for unskilled and low-literacy workers. In contrast, formal training offers standardised knowledge, regulatory compliance, and a platform for structured learning. However, without integration, formal training often fails to resonate with site realities, while informal training lacks the rigour needed to prevent unsafe practices.

In India's construction sector, where informal learning dominates, bridging the gap requires aligning formal programmes with workers' everyday experiences. Studies (such as Panneer *et al.,* 2020) advocate for hybrid models that include hands-on demonstrations, storytelling, mentorship, and visual aids. The above methods mirror informal learning but are embedded within formal frameworks. This also creates teams that are resilient and adaptable during uncertainty. The blended strategies can develop deeper engagement, better retention, and a more inclusive safety culture. By recognising and validating the role of informal learning while providing structure and

reinforcement through formal means, the industry can promote more consistent and effective H&S practices across the workforce.

Adaptability and implications on H&S practices

Working teams and their adaptability are crucial to the safety of workers and their surroundings (Aboagye-Nimo and Raidén, 2019). There are three types of team competencies required for success: knowledge (cognition), attitude (feelings), and skills (behaviours) (Salas *et al.,* 2008). The above traits will inform the empirical phase of this study to help in give the research project a better understanding of how workers stay safe and more importantly, how H&S knowledge is passed on informally. Considering that construction work environments are dynamic work; it is imperative that workers possess the quality of adaptability for success in H&S and a successful project overall.

Considering the high-workload and time-pressured situations, adaptability becomes the key trait that can help workers create and maintain a positive safety culture (Burke *et al.,* 2006). Successful adaptation requires anticipation and recognition, all of which require several factors both internal to the individual and external (Malakis *et al.,* 2010). Due to the informal nature of the training and H&S practices (due to organisational structures, financial constraints etc.), workers must be able to anticipate risks in a dynamic setting to appropriately manage them.

The Heurestic Framework of team adaptation by Stagl *et al. (*2006) offers a lens to explore the individual aspects of team practices by acknowledging the plethora of factors that lead to overall success i.e., developing and maintaining a positive safety culture. Figure 1 shows that individuals, teams and job characteristics shape the emergent cognitive and affective states of the projects. Since a lot of training offered to individuals is done on the site by their respective teams and is also, determined by job characteristics, this model fits the research context sufficiently. In this instance, the team situational awareness and mental models will be beyond the scope of the study although some aspects may be coincidentally revealed in the empirical phase of the work. The adaptation as a process is iterative thereby feeding into each other and thus workers learning from each situation or encounter (see Figure 1).

Using Figure 1 as a tool for exploring the Indian construction sector, it is evident that several factors play a role in shaping an individual's personality, in this case knowledge, traits, attitudes and cognitive ability. The knowledge that the workers mainly acquire in this context is informal. However, their attitude towards learning and their cognitive abilities will play a key role in in the shaping of their overall H&S knowledge. Furthermore, as the team learns and adapts, there is a cyclical loop that feeds back to start the cycle again. In a formal setting, the lessons learnt would have been documented or recorded but, in this situation, most practices are presumed to be done informally and thus losing the opportunity to explicitly capture the learning and training. While the unit of analysis for this research is for the individual (thus not the team), findings will explore how the individuals perceive their personal training and knowledge in the context of individual and team adaptability as well as overall H&S.

After the critical consideration of the conceptual components of informal training and its impact on site practices as well as the overall adaptability of individuals and teams, the next section presents the methodological approach adopted for the empirical phase of the research.

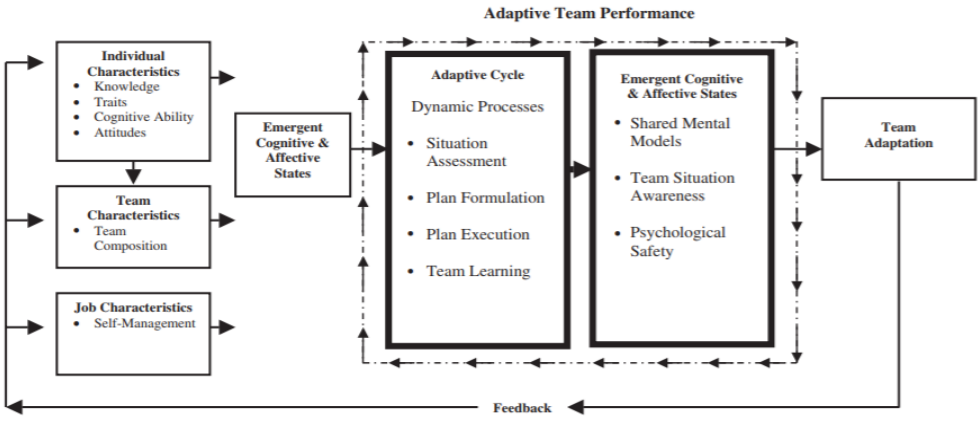


Figure 1: Heuristic Framework of Team Adaptation (Stagl et al., 2006)

METHOD

This study adopted a qualitative research design to explore how unskilled construction workers in India acquire and perceive H&S training, with particular attention to informal practices. A qualitative approach was appropriate given the need to understand worker's lived experiences, beliefs, and behaviours within the context of their socio-cultural and economic environments.

Data collection was undertaken through semi-structured interviews conducted with ten participants, comprising eight unskilled labourers and two site supervisors, across various construction sites in Mumbai, India. Participants were selected using purposive sampling to ensure representation of individuals with practical, on-site experience and differing levels of exposure to both formal and informal H&S training. The interviews were conducted in Hindi and later translated into English for analysis. An independent native speaker reviewed the transcriptions, and interview notes to ensure the meaning of the responses were not lost through the translation process. Each interview lasted between 30 to 45 minutes and followed a flexible guide that allowed participants to elaborate on their training experiences, perceptions of safety, and sources of knowledge.

The unit of analysis for this study was the individual worker, not the team or the broader construction site. This focus was critical for capturing the nuanced and personal experiences of unskilled labourers whose H&S learning often occurs informally through peer interaction, observation, and trial-and-error. By centring on individuals, the study aimed to uncover the personal coping strategies and informal learning mechanisms that may be overlooked in site-level or policy-driven H&S assessments.

Thematic analysis was employed to interpret the qualitative data. Transcripts were coded using NVivo using an inductive approach to identify recurring patterns and themes related to training practices, risk perception, and communication dynamics. Codes were refined through iterative readings, and themes were developed based on frequency, significance, and relevance to the research objectives.

Informed consent was obtained from all participants, and anonymity was ensured by using pseudonyms (see Table 1). Participants were briefed about the purpose of the study, and interviews were conducted in locations and at times convenient to them. Cultural sensitivity and respect for local norms were maintained throughout the research process.

FINDINGS AND DISCUSSION

There was a wide range of participants, and the general roles and Table 1 covers pseudonyms and roles of the participants who were interviewed.

Table 1: Overview of the interviewees

Name	Pseudonym	Role in industry	Years of experience	Formal training
Labourer 1	L1	General Labour	9	No
Labourer 2	L2	General Labour	15	Yes
Labourer 3	L3	Demolition	10	No
Labourer 4	L4	General Labour	8	Yes
Labourer 5	L5	Interior Design	8	No
Labourer 6	L6	Joiner	12	Yes
Labourer 7	L7	Grounds Work	14	No
Labourer 8	L8	Masonry	6	No
Site Supervisor 1	SS1	Supervisory	20	Yes
Site Supervisor 2	SS2	Supervisory	16	Yes

Prevalence of Informal Training

Interviews reveal that most workers acquire H&S knowledge through direct observation and peer instruction. Experienced workers take on a mentorship role, but their knowledge is not always based on formal guidelines, leading to gaps in H&S protocols. When interviewees were asked about their training and backgrounds in their roles, some of them were quotes as follows:

> "I have never been formally health and safety trained, and the only safety instructions[training] I get are informal." L1

L1 had 9 years of industry experience but all the instructions he had received were informal. In his general labourer role, he had never any formal training. However, he clarified that he had received informal instructions. In a related context, L3 added that supervisors remind them of H&S practices but indicated it was not effective as it was often unstructured thereby making the ad-hoc nature reduce its effectiveness. He was quoted as follows:

> "Although supervisors occasionally remind us about basic safety practices, the information is rarely structured." L3

L2 had had formal training but he believed he required some form of refresher training considering the dynamic nature of the industry and, site practices. He stated: *"The initial training was good. Unfortunately, frequently I am of the belief that due to a very changing interior environment constantly, additional training would be helpful.".* Although he values the training he had received, he believes additional training is very important. Knowing he needs periodic training considering changing site and project conditions indicates his appreciation for the training process. Panneer *et al. (*2019) extensively documented the prevalence of informal training practices in India and offered insights on how this can be improved and how other emerging economies could learn from such approaches.

One observation from the data showed that formal training often came with provision of appropriate PPE as some training practices are centred on the appropriate use of the equipment. L2 stated that due to financial/resource constraints, there are instances where there is PPE shortage. He stated: *"Sometimes there is a shortage of equipment at work, and that places us in higher danger of being injured*."

When probed further, he stated that having a formal training gave him the ability to identify the right PPE and appropriate way to use it.

Strengths and Weaknesses of Informal Learning

Workers expressed appreciation for informal learning due to its immediacy and relatability. However, supervisors highlighted concerns about its inconsistency and the potential reinforcement of unsafe practices.

One supervisor SS1 recalled his own practices: "*While I remember the key points from my initial training, I often find myself wishing for refresher courses or more in-depth sessions."*

With some responses, it was evident that some workers without formal training often blurred the lines when it came to the use of PPE. L7 casually stated that PPE use is sometimes dependent of availability and not necessarily based on the task at hand.

> "We use PPE only when it is available." L7

In an ideal situation, he should refrain from undertaking a specific task if it required PPE that was not available. Although it can be argued that financial constraints have led to such decisions, it is important to acknowledge that if he knew the implications of certain hazards, he would not consider using PPE only when available as stated. The lack of proper use and unavailability of PPE has been highlighted by previous studies (Boakye *et al.,* 2022) and this finding confirms how widespread an issue this is.

With informal H&S learning and training comes lack of formal communication channels. L4 who had received formal H&S training stated that he was not always comfortable raising some concerns. He believed it created more potential problems than solutions. He stated that he was hesitant to raise such issues due to potential issues that would be dragged up.

> "I always hesitate to bring up the safety issues because maybe they will create some conflict." L4

L3 shared a similar concern: *"I am hesitant more often than I would like to speak up and initiate conflict or offense."*

For others who had managed to raise concerns on some occasions such as L6, he believed there was not always a positive response to the issues.

> "The management does not always act on our concerns promptly." L6

While there were several negative views on how informal H&S practices play out on sites, there were some good aspects about it. L8 believed the situation of informal training created a space for him to continuously ask about matters he was not sure of. He stated that it helped him continuously ask questions:

> "I like the informal sharing of knowledge on site because it gives me a chance to ask and clarify some things that I am unsure about." L8

This informal opportunity allows for experienced workers to teach less experienced workers without having to formalise their arrangements. This approach is crucial to having workers learn continuously. Workers expressing greater reliance on peer-led instruction and on-the-job demonstrations, which they found more relatable and practical. The value of this practice was also identified by Aboagye-Nimo *et al. (*2015).

Potential for Integration

Supervisors and workers acknowledged the benefits of combining formal and informal training. They suggested that structured H&S workshops could be incorporated into daily site activities, using experienced workers as facilitators to ensure relevance and engagement. SS1 stated that he felt fortunate that he received formal training. He stated: *"I consider myself fortunate to learn from my experienced co-workers."*

From the above, it is evident that SS1 greatly values the knowledge acquired from peers (often informal); a practice encouraged by Aboagye-Nimo *et al. (*2015) in promoting the use of tacit knowledge in accident prevention on site. Before SS1 became gained his supervisory role, he believed he learnt a lot from experienced workers. He appreciated the formal training he received, and the subsequent informal training acquired from his colleagues.

SS2 added that he believed combing the two regularly was the most effective approach especially in the situation where culture and resource scarcity were very influential in shaping project H&S. He stated that:

> *"The most effective way to change our working conditions would be to set up a regular schedule of safety meetings and training sessions." SS2*

L2 who had a very extensive experience in the industry and had also received formal training pointed out some of the issues with the refresher training practices. He believed that they were generic and were not context specific enough.

> "While we have health and safety training every year compulsorily, the content is usually very general and superficial in nature." L2

He had previously indicated how additional training was a necessity. By adding the above, he clarifies that the training must be effective and must also consider the working conditions. Without tailoring methods to workers' socio-cultural contexts and integrating informal practices, formal training alone is unlikely to create the robust safety culture required on construction sites (Billett, 2002). L5, who had had no formal training, explained that he had learnt of risks and hazards through observation of more experienced workers.

> "I am somewhat aware of major risks, like falls or tool-related injuries, my understanding is thus acquired through observation and experience than education." L5

He indicated that he was somewhat aware of the major risks, thus indicating a limited level of confidence in his learning approach. Understandably, confidence comes with years of experience and continuous practice thereby leading to continuous improvement. In an alternate response, L8 stated that he was comfortable using informal means to communicate his concerns unlike L4 and L3 who felt intimidated to do so. He stated that:

> "I feel somewhat at ease raising my concerns if I find unsafe practices, especially if others are doing it, too." L8

L2 added that productivity often took precedence over good practices. He stated that resources for formal training resources were limited and, other project pressures are often prioritised over H&S. He was quoted as follows: *"Resources for good training are at a minimum and often considerations of productivity override safety."*

With his years of experience, he had noticed that project completion was often the priority. SS2 added that safety cultures get disrupted when workers move across

projects especially when they have different training backgrounds e.g., no formal training versus formal training. He stated that:

> "I see my colleagues switch to different projects very often, disrupting our continuity in training." SS2

Using Stagl *et al. (*2006) Heuristic Framework of Team Adaptation, teams that have workers with different attitudes and differing goals will reduce the team's adaptability thereby reducing overall team and project H&S.

While situations force some teams to adopt informal practices and training, it is important to note that there are some limitations. This confirms revelations presented in the literature review (Panneer *et al.,* 2019).

CONCLUSION AND RECOMMENDATIONS

In this paper, the often-overlooked role of informal training practices within the Indian construction sector was explored, with a focus on how these mechanisms sustain knowledge transmission and skill development among labourers. Despite the sector's heavy reliance on informal labour, there is a distinct lack of formal training pathways, making informal systems like on-the-job learning, imitation, and peer-to-peer guidance vital for workforce productivity and H&S.

The findings of the study suggest that these informal practices are not merely coping mechanisms but rather culturally embedded, dynamic systems that respond flexibly to the industry's needs. However, their unstructured nature also raises concerns about consistency, quality assurance, and the long-term professional development of workers. The research highlights the urgent need for policy interventions that recognise, support, and potentially formalise aspects of this informal learning, without erasing the organic knowledge-sharing networks that have evolved over time.

This research contributes to the broader conversation on construction labour, skills, and education in the Global South, advocating for a more nuanced understanding of how training unfolds in practice and the need to bridge the gap between formal frameworks and the lived realities of construction workers.

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INFLUENCE OF SAFETY CLIMATE ON SAFETY BEHAVIOUR: EVIDENCE FROM CONSTRUCTION INDUSTRY OF A DEVELOPING COUNTRY

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Occupational Health and Safety (H&S) problems remain prevalent in the construction industry in most developing countries, despite considerable efforts to ensure safer operations. Research posits that both human and climatic factors contribute to accidents on construction sites. The human factors which are seen in unsafe practices account for a greater percentage of occupational H&S incidents. This study therefore sought to empirically examine how safety climate factors influence worker behaviour on construction projects in Kumasi, Ghana. Using a quantitative research design, purposive sampling was employed to select construction companies, with 210 valid responses collected from 250 distributed questionnaires. Data analysis involved descriptive statistics, mean score ranking, and partial least square-structural equation modelling. Findings revealed a significant positive relationship between safety climate and safety behaviour in the construction sector. The research provides valuable guidance for H&S professionals and construction managers, including enhancing H&S programs for workers, implementing effective H&S management systems, and addressing worker H&S concerns promptly. This study provides insights into improving H&S performance in construction industry of developing countries.

Keywords: safety climate; safety behaviour; partial least squares; structural equation modelling, construction industry

INTRODUCTION

The construction industry is not only identified as a significant contributor to a nation's GDP but also a major contributor to occupational H&S challenges due to its activities (Oni *et al.,* 2023). Workers face serious injuries, which can lead to hospitalisation, loss of work time, disability, and even death (Ahmad *et al.,* 2016). Improving H&S on construction sites is crucial as accidents not only result in pain and discomfort but also affect productivity, quality, time, and the environment, ultimately increasing project costs (Osei-Asibey *et al.,* 2023). Construction site accidents are mainly caused by careless or unsafe behaviour (Adinyira *et al.,* 2020). According to the World Bank's GNI categorisation system, a developing country is one that is classified as low-income or lower-middle-income based on its gross national income

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(GNI) per capita. This classification reflects a country's level of economic development and is revised annually. A construction industry of a developing country is one that struggles with inefficiencies and systemic challenges that hinder its growth and performance. It is characterised by bureaucratic impediments in project planning and management, ineffective enforcement of existing regulations and outdated statutes and codes, leading to cost overruns, delays, and low-quality construction (Rwelamila and Ogunlana, 2015). The work safety climate of an organisation is explained by some writers as the views people have regarding how important H&S is as compared to other work ethics like work speed (Griffin and Curcuruto *et al.,* 2016; Zohar, 2014). Lestari *et al. (*2020) added that work climate states the rules and best H&S practices needed to achieve safety on the construction site. Encouraging and emphasising the importance of managing H&S in the workplace is one way to turn systems and procedures into reality. However, little attention has been given to the importance of climate safety in ensuring best H&S practices by workers on the construction site. This research seeks to build an in-depth knowledge of the influence of safety climate on safety behaviour in construction industry of a developing country. This paper explores the relationship between safety climate and safety behaviour in the construction industry. It aims to uncover insights into how safety climate influences worker behaviour and provide practical implications for improving H&S outcomes on construction sites. Through empirical research and analysis, factors contributing to safety climate and their impact on safety behaviour will be examined, offering valuable insights for industry stakeholders.

Safety Climate

Safety Climate (SC) is a framework that guides workers on adopting proper safety behaviour in the workplace (Griffin and Curcuruto *et al.,* 2016). According to Arzahan *et al. (*2022) safety climate is different from safety culture, which is an organisation's core belief. This is because safety climate is seen as the knowledge and the understanding workers have in H&S within a specific time frame. Restuputri *et al. (*2021) argue that, to ensure an effective H&S, more attention must be paid to various mechanisms that will help improve a positive safety culture. The safety climate will be the tool that will be used to measure whether there has been an improvement in the safety culture or not. This is to say that, the safety climate is used to assess the state of safety culture in an organisation. Research has been conducted on SC in various industries, including construction, manufacturing, road administration, airport ground handling, and wood processing (Griffin and Curcuruto *et al.,* 2016; Oah and Moon, 2018; Keffane, 2020; Cabrera *et al.,* 2020; Novie and Ahmad, 2018). Studies conducted by Jiang *et al. (*2019) revealed that SC factors have no universal set that is to be strictly followed although some of the factors by different scholars appear to be similar. Therefore, the factors that affect SC within one industry may not be valid in another, which suggests that no common set of SC factors exist (Jiang *et al.,* 2019). The SC which was considered for the study was adopted from Flin *et al. (*2000), Mohamed (2002), Fang *et al. (*2006) and Choudhry *et al. (*2009). Research has shown a positive relationship between safety climate and occupational H&S performance, with negative attitudes directly linked to accident rates (Kalteh *et al.,* 2019).

Safety Behaviour

In recent times, safety behaviour (SB) has been conceptualised to include the specific behaviour performance of workers on site. The performance has been categorised into contextual and task performance, which serve as the bases for differentiating safety

behaviour at the workplace (Meyer *et al.,* 2019). Task performance involves adhering to H&S rules like wearing protective gear, directly contributing to H&S, whilst contextual performance, involves activities that enhance H&S, such as attending H&S meetings or volunteering to take part in H&S activities. These activities contribute to a safer environment. The concept of SB has been adopted in various studies, such as those by Zid *et al. (*2018) and Osman *et al. (*2019). Safety behaviour is the best practices that workers should adopt to ensure occupational H&S and avoid workplace accidents. Many H&S practitioners believe that worker behaviour is a major contributor to accidents, with H.W. Heinrich's dominos theory suggesting that 80% of all accidents stem from unsafe actions (Busch, 2021). Studies have found a positive correlation between risk-taking behaviour and H&S outcomes, and a meta-analytic path model for workplace H&S focusing on personal and situational factors has established a causal link between safe behaviour and H&S outcomes (Lyu *et al.,* 2018; Panuwatwanich, 2017).

Conceptual Framework and Hypotheses

Figure 1 shows the conceptual framework and hypotheses developed for the study through relevant literature from safety climate factors and safety behaviour.

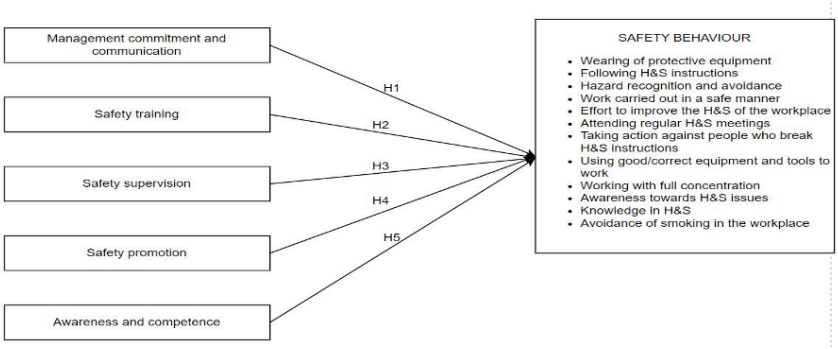


Figure 1: Conceptual framework of safety climate factors on safety behaviour

Hypotheses

H1: 'Management commitment and communication' positively influences safety behaviour.

H2: 'Safety training' positively influences safety behaviour.

H3: 'Safety supervision' positively influences safety behaviour

H4: 'Safety promotion' positively influences safety behaviour.

H5: 'Awareness and competence' positively influences safety behaviour.

To this end, five safety climate factors were identified after reviewing several models. The factors have various indicators that form each construct of the safety climate factor. The safety behaviour also identified is geared towards the best H&S practices that need to be employed by workers to ensure H&S on site. Therefore, various indicators also inform the safety behaviour construct. Table 1 details the definition of the various indicators under the constructs of the latent variables.

Table 1: Definition of safety climate factors and safety behaviour

Factors	Variables	References
Safety climate factors	**Exogenous variables**	
Management commitment and communication (MCC)	1. Management acts quickly to correct H&S problems 2. Management and supervisors listen and discuss H&S issues 3. Management encourages feedback and H&S participation from site workers on safety issues 4. Management offers enough H&S information 5. Management believes H&S is of the same importance as production	
Safety Training (ST)	1. Training in PPE usage 2. Regular and useful H&S training	
Safety Supervision (SS)	1. Production level should be frequently checked by supervisors 2. Workers attention should be drawn to the production level 3. No- smoking rules in the workplace should be strictly enforced by supervisors 4. Supervisors should make emphasis on H&S in each day of work 5. Supervisors should make sure that workers wear PPE	Cabrera et al., 2020; Oah and Moon, 2018; Griffin and Curcuruto et al., 2016; Choudhry et al., 2009; Fang et al., 2006; Flin et al., 2000; Mohamed 2002
Safety Promotion (SP)	1. H&S bulletin boards 2. H&S signs and posters 3. Recognition and reward for good H&S performance by individuals	
Awareness and Competence (AC)	1. Workers are clear about responsibilities for workplace H&S 2. Workers understand the H&S rules in my job 3. Workers deal with H&S problems in my workplace 4. Workers comply with the H&S rules all the time	
Safety Behaviour	**Endogenous variables**	
	1. Wearing of protective equipment 2. Following H&S instructions 3. Hazard recognition and avoidance 4. Work carried out in a safe manner 5. Effort to improve the H&S of the workplace 6. Attending regular H&S meetings 7. Taking action against people who break H&S instructions 9. Using good/correct equipment and tools to work 10. Working with full concentration 11. Awareness towards H&S issues 12. Knowledge in H&S	Meyer et al., 2019; Zid et al., 2018; Osman et al. 2019; Lyu et al., 2018; Panuwatwanich, 2017

METHOD

Questionnaire Survey

For this study, a quantitative approach comprising both desktop and field studies, as outlined by Adinyira *et al. (*2020), was adopted to confirm and test the research hypotheses. The questions were structured into four sections starting from sections A, B, C, and D. Section A collected demographic information to analyse its potential impact on experience and expertise ratings. Section B asked respondents to rank safety climate variables on construction sites on a Likert scale of 1=Insignificant; 2=Less significant; 3=Moderately significant; 4= Significant; 5=Very Significant, while Section C assessed inappropriate behaviour frequency on a Likert scale 1=Not frequent; 2=Less frequent; 3=Moderately frequent; 4= Frequently; 5=Very frequently. Finally, Section D explored the influence of safety climate on safety behaviour on a Likert scale 1=Very low; 2=Low; 3=Medium; 4=High; 5=Very high. Pilot questionnaires were distributed to industry professionals and academics for feedback on clarity, ambiguity, and completion time, ensuring relevance and suitability for the study. The researcher administered the questionnaires in person to building contractors and their operatives over a period of two weeks.

Participants

Key respondents were class D1 construction contractors and their operatives in Kumasi, identified using purposive sampling, a non-probability sample method. A Class D1 construction contractor in Ghana is the highest-grade contractor certified to undertake general building works of any size or value. The study's sampling size was based on two criteria: Construction sites visited should have H&S policies and be working, and operatives selected to answer the questionnaire should have completed

several projects and gained enough experience. A total of 250 questionnaires were distributed.

Data Analysis

The data collected was sorted and coded and subjected to analysis using descriptive statistics, mean ranking and partial least square (structural equation modelling). Mean scores and standard deviations were obtained to determine the significant safety climate factors and the frequently occurring unsafe behaviours on the sites visited. This was shown via frequency tables. The relationship between safety climate and unsafe behaviour was examined using Partial Least Squares (PLS) - Structural Equation Modelling (SEM).

RESULTS

A total of 250 questionnaires were administered, out of which 210 were retrieved. Thus, a response rate of 87.5% was achieved from all the 12 construction sites employed for the study. As shown in Table 2, 90.5% of the respondents were males while 9.5% represented females with most of the respondents falling between the ages of 18 to 40 years.

Table 2: Respondents characteristics

Information Background	Characteristics	Frequency	Percentage (%)
Gender	Male	190	90.5
	Female	20	9.5
Age (years)	18-30	105	50.0
	31-40	63	30.0
	41-49	29	13.8
	50 years and above	13	6.20
Role of respondents in their firms	Construction manager	7	3.3
	Construction supervisors	24	11.4
	Operator	9	4.3
	Safety officer	10	4.8
	Carpenters	29	13.8
	Electricians	20	9.5
	Tiller	18	8.6
	Steel fixers	12	5.7
	Masons	33	15.7
	Labourers	48	22.9
Working experience (years)	1-4	20	9.5
	5-10	108	51.4
	11-15	52	24.8
	16 and above	30	14.3
Educational background	MPhil/MSc	20	9.5
	BSc	42	20.0
	High National Diploma	52	24.8
	Technician (CTC1,2,3)/ SHS/JHS	96	45.7

Safety Climate Factors in the Construction Industry

The study analysed safety climate factors in the construction industry. The top three significant factors, as presented in Table 3, were 'management believes H&S is of the same importance as production', 'regular and useful H&S training', and 'H&S signs and posters'. However, 'workers are clear about responsibilities for workplace H&S', 'No-smoking rules in the workplace should be strictly enforced by the supervisors', and 'workers deal with H&S problems in my workplace' were considered insignificant. The study highlights the importance of addressing safety climate factors in the construction industry.

Table 3: Safety climate factors

Safety climate factors	Mean	Standard deviation	Ranking
Management Commitment and Communication (MCC)	**3.19**	**1.302**	
1. Management acts quickly to correct H&S problems	3.60	1.090	**5th**
2. Management and supervisors listen and discuss H&S issues	2.43	1.570	**14th**
3.Management encourages feedback and H&S participation from site workers on H&S issues	2.40	1.461	**15th**
4. Management offers enough H&S information	3.06	1.278	**10th**
5. Management believes H&S is of the same importance as production	4.44	1.111	**1st**
Safety Training (ST)	**3.86**	**1.255**	
1. Training in PPE usage	3.67	1.254	**4th**
2. Regular and useful H&S training	4.05	1.256	**2nd**
Safety Supervision (SS)	**2.76**	**1.221**	
1. Production level should be frequently checked by supervisors	2.31	1.468	**16th**
2. Workers attention should be drawn to the production level	2.25	1.371	**18th**
3. No- smoking rules in the workplace should be strictly enforced by supervisors	3.27	1.071	**8th**
4. Supervisors should make emphasis on H&S in each day of work	2.66	1.083	**13th**
5. Supervisors should make sure that workers wear PPE	3.29	1.114	**7th**
Safety Promotion (SP)	**3.45**	**1.126**	
1. H&S bulletin boards	3.17	0.996	**9th**
2. H&S signs and posters	3.72	1.352	**3rd**
3. Recognition and reward for good H&S performance by individuals	3.46	1.031	**6th**
Awareness and Competence (AC)	**2.52**	**1.274**	
1. Workers are clear about responsibilities for workplace H&S	2.04	1.332	**19th**
2. Workers understand the H&S rules in my job	3.02	1.119	**11th**
3. Workers deal with H&S problems in my workplace	2.26	1.346	**17th**
4. Workers comply with the H&S rules all the time	3.00	1.298	**12th**

Unsafe Behaviour Occurring on Construction Projects

The study examined common unsafe behaviours on construction projects in Ghana; results in Table 4 revealed that 'disregarding the wear of PPE (Personal Protective Equipment)', 'Not paying much attention to the instruction on manuals before using new machines', and 'Placing materials and objects in dangerous positions and locations' were the most frequently observed unsafe behaviours. Conversely, 'Smoking at the workplace', and ' Doing work under the influence of drug or alcohol' were reported as infrequent occurrences. This underscores the necessity of addressing H&S practices in the construction sector.

Table 4: Level of occurrence of unsafe behaviours

Unsafe Behaviours (variables)	Mean	Standard deviation	Ranking
1. Disregarding the wear of PPE (Personal Protective Equipment)	4.40	1.317	**1st**
2. Not paying much attention to the instruction on manuals before using new machines	4.35	1.161	**2nd**
3. Placing materials and objects in dangerous positions and locations	4.21	1.051	**3rd**
4. Using faulty tools and equipment to work	3.87	1.107	**4th**
5. Not switching of power source and not reporting to supervisors when machines become abnormal during work	3.59	1.096	**5th**
6. Leaving the work benches dirty after work	3.45	0.988	**6th**
7. Removing H&S guards from the workplace or equipment	3.43	1.066	**7th**
8. Working with lack of concentration	3.30	0.960	**8th**
9. Failing to caution members or failing to rescue workers out of danger	3.06	1.098	**9th**
10. Working above the expected speed limit	3.03	1.030	**10th**
11. Doing work under the influence of drug or alcohol	2.24	0.924	**11th**
12. Smoking at workplace	2.08	0.901	**12th**

Composite Reliability and Convergent Validity

Internal consistency reliability was assessed using composite reliability and Cronbach's alpha, yielding satisfactory values as shown in Table 5 for both measures

(composite reliability ranging from 0.750 to 0.980 and Cronbach's alpha ranging from 0.744 to 0.976). Convergent validity was confirmed with all constructs exhibiting average variance extracted (AVE) values above 0.5, indicating a robust relationship between the latent variables and their indicators.

Table 5: Composite reliability and convergent validity

Constructs	Cronbach's Alpha	Composite Reliability	AVE
Management commitment and communication	0.943	0.949	0.898
Safety Training	0.744	0.750	0.795
Safety supervision	0.773	0.775	0.815
Awareness and Competence	0.976	0.980	0.977
Safety promotion	0.778	0.785	0.698
Safety behaviour	0.973	0.974	0.776

T Statistics and P Values

Table 6 presents path model relationships with t-values using a two-tail distribution and an alpha value of 0.05. Only four constructs—Management commitment and communication, Safety training, Safety supervision, and Safety promotion—showed significant relationships with Safety behaviour, surpassing the critical t-score of 1.96 for df = 98, while Awareness and competence did not reach significance.

Table 6: T statistics and P values

Relation	Original sample	Sample mean	Standard deviation	T statistics	P values
Management commitment and communication > Safety behaviour	0.195	0191	0.099	1.974	0.049
Safety training > Safety behaviour	0.186	0.170	0.148	1.254	0.021
Safety supervision > Safety behaviour	0.450	0.484	0.178	2.534	0.012
Awareness and competence > behaviour	-0.115	-0.128	0.113	1.024	0.306
Safety promotion > Safety behaviour	0.341	0.331	0.141	2.426	0.016

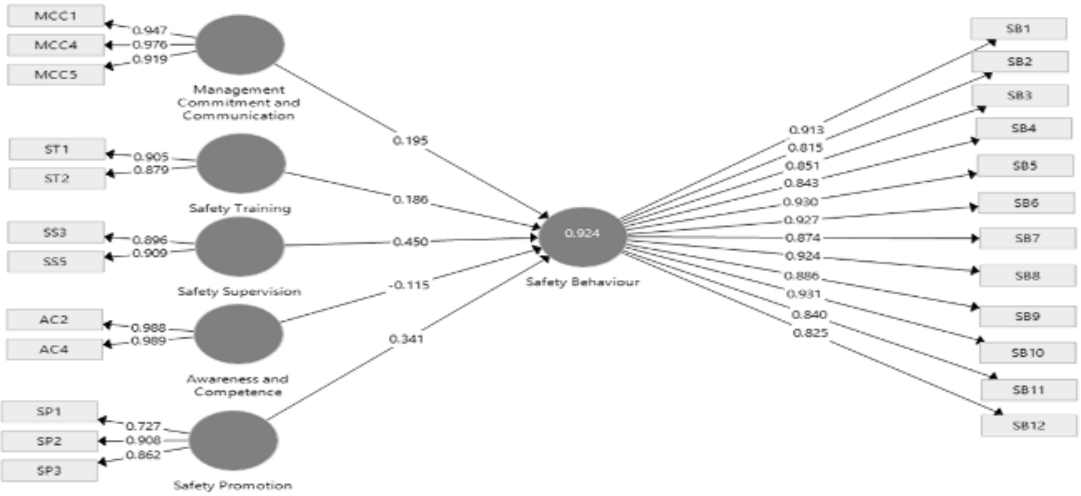


Figure 1: Path algorithm of constructs

DISCUSSION

The analysis of safety climate and behaviour in Ghana's construction industry reveals a significant correlation, despite certain indicators not aligning perfectly with the PLS-SEM model. Management Commitment and Communication (MCC) emerged as a crucial factor, indicating management's role in fostering a positive safety climate, in line with previous research emphasising its importance (Mohamed 2002; Fang *et al.,*

2006). Safety Supervision (SS) also played a pivotal role, particularly in enforcing the consistent use of Personal Protective Equipment (PPE), supported by previous studies such as (Oah and Moon, 2018; Cabrera *et al.,* 2020) showcasing the effectiveness of supervisor interventions in enhancing H&S communication. Specific indicators within SS, such as reminders for PPE usage, were particularly influential. Safety Training (ST) was identified as crucial for risk prevention, with informal methods like on-the-job training proving effective in enhancing safety behaviour. Targeted training, especially in PPE usage, was deemed significant in bolstering H&S compliance among workers. Safety Promotion (SP) initiatives, including displaying H&S precautions prominently and recognising good H&S practices, were also vital in fostering a robust safety climate within construction environments. However, the study highlighted areas for improvement, particularly in Awareness and Competence (AC). The lack of significance in this indicator suggests a gap in employees' understanding of H&S issues and their ability to consistently comply with H&S rules. Addressing this gap through targeted training and communication efforts could be crucial in enhancing overall H&S performance within the construction industry. In conclusion, while certain safety climate indicators may not align perfectly with the model, they offer valuable insights into safety behaviour dynamics within the construction industry. By focusing on key areas such as management commitment and communication, safety supervision, safety training, and safety promotion, stakeholders can work towards creating a safer and more productive work environment for all employees, ultimately enhancing H&S outcomes in Ghana's construction sector and similar developing contexts.

CONCLUSION

The study investigated the impact of safety climate on safety behaviour in construction industry of a developing country, identifying key factors like management commitment and communication, safety training, safety supervision, and safety promotion. Data from 250 construction workers on 12 sites revealed significant indicators such as 'management's belief in H&S is of the same importance as production', 'regular and useful H&S training', and 'H&S signs and posters'. Unsafe behaviours were ranked, with 'disregarding the wear of PPE' being the most frequent. Positive correlations were found between safety behaviour and climate factors, except for awareness and competence. Safety behaviour was examined holistically, but the impact of safety climate on its two key dimensions was not explicitly analysed. This limitation highlights an area for future research. The study recommends strengthening management and supervisory roles, formalising training, and promoting H&S to improve worker competence. The findings also guide policymakers toward mandating focused training and integrating H&S promotion into national regulations, while encouraging future research to explore weak indicators and long-term impacts.

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AN EXPLORATION OF CONDOM USE AMONG MALE CONSTRUCTION WORKER CLIENTS OF FEMALE SEX WORKERS IN THE WESTERN CAPE

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This study investigated condom use among male construction workers who engage with female sex workers in the Western Cape, South Africa. It used three self-reported measures of condom use with a sex worker: condom use at last sex, frequency of condom use in the past 3 months, and intention to use a condom at next sex. Cross-sectional data were collected from 227 participants across 18 sites representing 7 firms. Multiple linear regression identified several determinants of condom use frequency, including risky sexual behaviour, HIV/AIDS knowledge, and control over condom use. The likelihood of using a condom at next encounter was influenced by drug consumption, HIV/AIDS knowledge, control over condom use, and a positive attitude toward condom use. Binomial logistic regression showed that workers with higher levels of risky sexual behaviour were 1.08 times more likely to have used a condom at last sex, with no other variables being significant. The study emphasizes the complex factors influencing condom use and the value of methodological triangulation in cross-sectional survey design, enhancing the precision of assessment of condom use.

Keywords: male construction workers; male clients of female sex workers; condom use; HIV/AIDS

INTRODUCTION

Approximately 10% of sexually active men in sub-Saharan Africa report paying for sex, and those who do so are 50% more likely to be living with HIV (Hodgins *et al.,* 2022). While female sex workers (FSWs) are often central to HIV intervention programs, modelling studies suggest that male clients may be responsible for up to 42% of new heterosexual HIV infections, with only 5% being directly attributable to FSWs (Stone *et al.,* 2021). Factors that hinder consistent condom use include client preferences, financial incentives for unprotected sex, substance use, and a low perceived risk of STIs (George *et al.,* 2019). Additionally, fear of violence from clients limits FSW's ability to negotiate condom use (Gore *et al.,* 2020), with 43% of FSW in Soweto, South Africa (SA), reporting physical or sexual violence in 2016, and 14% reporting rape by a client (Coetzee *et al.,* 2017). Despite their central role in the transmission chain, male clients of sex workers (MCSW) are frequently excluded

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from HIV research and programming due to stigma, legal risks, and recruitment challenges (Morse-Karzen, 2020). Consequently, some scholars have highlighted a need for more targeted interventions addressing gender norms, violence, and HIV prevention among MCSW in SA (Huschke and Coetzee, 2020).

LITERATURE REVIEW

Despite a growing recognition of the link between male-dominated, mobile occupations, elevated HIV risk and transactional sex, MCSW remain significantly under-researched. Much of the existing literature focuses on the vulnerabilities of FSWs or on phenomena such as age-disparate relationships (e.g., "blessers") (Stoner *et al.,* 2021). Moreover, studies rarely differentiate among occupational subgroups or examine the unique psychosocial and structural vulnerabilities associated with specific forms of work. Research on miners (Campbell, 2000), truck drivers (Delany-Moretlwe *et al.,* 2014), and military personnel (Mankayi, 2006) in SA has documented patterns of transactional sex, limited access to healthcare, and low condom use. The construction industry shares many of the same risk-enhancing characteristics - a predominantly male workforce, spatial mobility, job insecurity, and informal employment arrangements. In SA, Meintjes *et al. (*2007) found that construction workers face structural vulnerabilities that increase their risk of HIV. Relatedly, Bowen *et al. (*2017) identified age, gender, and education as indirect determinants of condom use. Notably, their findings suggest that lower levels of HIV/AIDS-related knowledge were paradoxically associated with better condom use, implying that knowledge alone may not predict safe sexual behaviour in this population. Compounding this, adherence to non-scientific beliefs about disease (Govender *et al.,* 2017) and normative expectations of masculinity (Stern and Buikema, 2013) further constrain the ability and willingness of male construction workers to engage in protective behaviours or health-seeking practices.

Despite these findings, the specific pathways through which occupational stressors and behavioural norms shape condom use among MCSW in the construction industry remain poorly understood. Existing studies tend to treat MCSW as a homogeneous group, often ignoring differences in employment status, work culture, and educational background. This limits the effectiveness of public health interventions, which require nuanced, context-specific approaches grounded in the lived realities. While previous research has highlighted the structural risks associated with construction work, few studies have examined the psychosocial mechanisms underlying condom use—especially in the context of MCSW. A recent study by Yakubu *et al. (*2025) addressed this gap by examining the psychological factors influencing condom use intentions among MCSW in Western Cape, SA. Utilising a cross-sectional survey, the study assessed how past condom use relates to condom use intentions. The findings revealed that both self-efficacy and positive attitudes toward condom use significantly mediated the relationship between past condom use and intention to use condoms, while perceived norms did not show a significant mediating effect. This research underscores the importance of targeting psychological constructs, particularly self-efficacy and attitudes toward condom use, in interventions aimed at promoting consistent condom use within this population.

A limitation in the work of Yakubu *et al. (*2025) is that condom use is primarily assessed at a single point in time (e.g., condom use at last sex), which may obscure important temporal variations in both behaviour and intention. While such a measure is commonly used in public health research for its simplicity, it does not account for

fluctuations in individual motivation, risk perception, or contextual factors that influence condom use over time. Specifically, it fails to capture the dynamic and situational impact of psychosocial determinants such as attitudes toward condoms, perceived social norms, self-efficacy, and substance use, all of which can vary across sexual encounters. There is increasing support for triangulating self-reported condom use measures - combining point-specific, retrospective, and prospective indicators - to provide a more comprehensive understanding of sexual risk behaviour (Fenton *et al.,* 2001). However, studies applying such approaches among MCSW are rare. Equally underutilised is the application of behavioural theory in designing interventions (Glanz and Bishop, 2010).

This study addresses several critical gaps in the literature:

- Occupational specificity: It identifies construction workers as a distinct at-risk group, rather than aggregating them with other mobile or informal workers.

- Gendered analysis: It interrogates how constructions of masculinity intersect with occupational contexts to influence sexual behaviour.

- Theory application: It applies behavioural science frameworks to assess condom use.

- Measurement innovation: It triangulates behavioural data to capture point-specific, retrospective, and prospective condom use indicators.

Policy relevance: It aligns with global calls for inclusive, gender-responsive, and occupation-specific HIV interventions.

By foregrounding these dimensions, the construction workplace emerges as a critical site where behavioural science, occupational health, and HIV prevention efforts can converge to drive meaningful change. Moreover, the present study deepens our understanding of HIV vulnerability among MCSW in construction and highlights the need for targeted, context-sensitive interventions.

Theoretical Framework

Several health behaviorur theories have been used to explain condom use and HIV-related decision-making, particularly among high-risk populations. Two prominent models underpin this study: the Health Belief Model (HBM) (Abraham and Sheeran, 2015) and the Reasoned Action Approach (RAA) (Fishbein and Ajzen, 2010). The HBM posits that behaviorur is influenced by perceived susceptibility to a health threat, perceived severity of that threat, perceived benefits and barriers to action, and cues to action (Abraham and Sheeran, 2015). In the context of HIV prevention, these constructs can help explain why individuals may or may not engage in condom use. For instance, knowing someone who died from AIDS can increase perceived severity and susceptibility, thereby influencing safer sexual behaviorur. The RAA builds on the theory of planned behaviorur, emphasizing attitudes, perceived norms, and perceived behavioral control as predictors of condom use intention, which in turn predicts behaviorur (Fishbein and Ajzen, 2010). Prior research supports the predictive utility of these two models across various populations (Buldeo and Gilbert, 2015; Kabikira, 2010). However, there is limited application of these theories among MCSW in SA. This gap underscores the value of theory-driven, survey-based research like the present study.

METHOD

Participants and Setting

A convenience sampling method was used to select construction companies and workers for data collection. The sample included all male employees on-site during scheduled field visits across 18 construction sites from 7 companies in the Western Cape, SA. Participants ranged from unskilled workers to skilled tradesmen, site clerks, and technicians. Questionnaires were available in English, Afrikaans, and IsiXhosa, the region's most spoken languages. Participants were informed the survey was voluntary, confidential, and anonymous. Completion time varied based on education and literacy, but analysis showed good question comprehension. Data collection occurred from mid-March to June 2019, with ethical approval granted by the researchers' university (8th March 2019).

Measures of Condom Use

Accurately measuring sexual behaviour is inherently challenging due to participation bias, recall issues, and respondents' willingness to accurately report on their sexual activities (Fenton *et al.,* 2001). This paper employs three distinct approaches to measure condom use with a FSW - condom use at last sex, frequency of condom use in the past 3 months, and intention to use a condom at next sex - each addressing different aspects of usage, thereby enhancing the robustness of our findings.

Condom use at last sex (HCU): This approach assesses whether the respondent used a condom during the most recent sexual encounter with a FSW ('yes' or 'no'). It provides immediate and specific insight at a particular point, but it does not capture patterns or trends over time.

Frequency of condom use in the last 3 months (PCU): This approach evaluates how often condoms were used, independent of intercourse frequency. A 5-point Likert scale from 'never' to 'always' was employed.

Intention to use a condom at next sex (FCU): This approach involved asking respondents how likely they are to use a condom at the next sexual encounter with a FSW ('never' to 'always'). Comparing the determinants of the three measures of condom use allows for nuanced insights that are critical for developing targeted interventions and understanding complex behaviours within the population of MCSW.

Determinants of Condom Use

The dependent variables comprised the three measures of condom use described above. Based on the HBM and the RAA, demographic, experiential, behavioural, and cognitive variables were explored as determinants of condom use in the regression analysis (see Table 1).

Demographic variables (D) include age, education, relationship status, employment status, and province of domicile. Experiential variables (E) include knowing an HIV-positive person, knowing someone who died from HIV/AIDS, knowing where to obtain ARVs, knowing someone on ARVs, and having previously had an STI.

The experiential variables align closely with the HBM, particularly its constructs of perceived susceptibility and perceived severity. These personal experiences may heighten an individual's perception of HIV risk or the seriousness of the disease, thereby increasing the likelihood of engaging in preventive behaviour. In addition,

knowing where to access ARV medication may serve as a cue to action, one of the core constructs in the HBM that triggers health-related behaviour.

Behavioural variables (B) include risky sexual behaviour, sex-related substance use, alcohol and drug abuse. Such variables can be interpreted through the lens of both models. In the HBM, such behaviours may reflect perceived barriers to condom use - for instance, if substance use reduces an individual's capacity to use condoms consistently. In the RAA, these behaviours function as background factors that influence key proximal determinants such as perceived behavioural control and behavioural intention. Substance use, for example, may diminish the perceived or actual ability to negotiate or use condoms during sexual encounters, thereby weakening intention and follow-through. Cognitive variables (C) include control over condom use, positive attitude toward condom use, perceived norm, perceived threat of HIV infection, HIV/AIDS knowledge, and depressive symptoms. Cognitive variables map most directly onto the core constructs of both models. For example, HIV/AIDS knowledge reflects a foundational understanding that informs both perceived threat (HBM) and attitudes toward the behaviour (RAA). Perceived control over condom use represents self-efficacy in the HBM and perceived behavioural control in the RAA - both crucial predictors of behaviour and intention. Similarly, positive attitudes toward condom use and perceived social norms are central to the RAA, influencing intention through affective and normative beliefs. Higher scale scores indicated greater levels of each construct. The dimensionality, validity, and reliability of these scales have been well established (Yakubu *et al.,* 2025).

ANALYSIS AND RESULTS

Analysis

First, the full dataset was examined for anomalies. Multiple linear regression examined demographic, experiential, behavioural, and cognitive factors predicting condom use frequency and future intentions, with models compared for variance explained and predictor differences across measures. Binomial logistic regression then evaluated predictors' impact on condom use at last sex with a female sex worker, considering all variables while addressing correlations.

Results

No outliers were found, but 24 participants (9.56%) had missing dependent variable data. Using listwise deletion, the sample size was reduced from 251 to 227.

Participants were males aged 18-60 (M=35; Md=33). Seventy-four percent were Black African, and 45% were married or in long-term relationships. Nearly 22% had primary education or less, while 72% had at least some secondary education. Fifty-eight percent were casual/contract workers, and 47% lived in the Western Cape.

Forty-five percent knew someone with HIV, 54% knew someone who died from HIV/AIDS, 63% knew where to obtain ARVs, and 39% knew someone on ARVs. Fifteen percent had a prior STI diagnosis.

Regression analysis of condom use with a FSW in terms of frequency of condom use over the last 3 months and intentions of condom use at next sex with a FSW (Models 1 and 2)

Preliminary analyses found no violations of normality, linearity, multicollinearity, or heteroscedasticity. Model 1 examined factors influencing condom use frequency with a sex worker in the past 3 months (see Table 1).

Table 1: Multiple linear regression of frequency of condom use over the last 3 months and intention to use a condom at next sex with FSWs on characteristics of construction MCSWs (n=227)

Variables	Model 1 Frequency of condom use with FSWs over last 3 months	Model 2 Condom use intention at next sex with FSW
Demographic:		
Relationship status (D1)	.210	.114
Age (D2)	.003	.014
Education (D3)	-.180	-.043
Work status (D4)	-.029	-.160
Province domiciled (D5)	-.092	-.048
Experiential:		
Know someone with HIV (E1)	-.003	.076
Know someone who died from HIV/AIDS (E2)	.277	.265
Know where you can get ARV medication (E3)	-.209	-.265
Know someone on ARV medication (E4)	.207	.101
Previously had an STI (E5)	-.063	-.150
Behavioural:		
Risk sexual behaviour (sexual encounters) (B1)	.050*	.038
Risk sexual behaviour (substance use during sex) (B2)	.009	.022
Alcohol consumption (AUDIT) (B3)	-.019	-006
Drug consumption (DUDIT) (B4)	.062	.106**
Cognitive:		
Presence of depressive symptoms (C1)	-.017	-.020
HIV/AIDS knowledge (C2)	.184*	.298***
Control over condom use (C3)	.104***	.122***
Perceived threat of HIV infection (C4)	.036	.001
Positive attitude toward condom use (C5)	.049	.069*
Perceived norm (C6)	.002	-.009
Constant	-.387	-1.123
R2	.289	.393
Δ R2	.289	.393
F	4.046***	6.431***
Δ F	4.046***	6.431***

The model was significant, $F(20, 199) = 4.046$, $p < 0.001$, explaining 28.9% of the variance. Significant predictors included risky sexual behaviour ($\beta = .050$, $p < 0.05$), HIV/AIDS knowledge ($\beta = .184$, $p < 0.05$), and control over condom use ($\beta = .104$, $p < 0.001$). Model 2 assessed determinants of intention to use a condom at next sex

with a sex worker (see Table 1). The model was significant, $F(20, 199) = 6.431$, $p < 0.001$, explaining 39.3% of the variance. Significant predictors included drug consumption ($\beta = .106$, $p < 0.010$), HIV/AIDS knowledge ($\beta = .298$, $p < 0.001$), control over condom use ($\beta = .122$, $p < 0.001$), and a positive attitude toward condoms ($\beta = .069$, $p < 0.05$).

Binomial logistic regression analysis of the relationship between use of a condom at last sex with a FSW and the demographic, experiential, behavioural, and cognitive variables (Model 3)

The Likelihood Ratio Test evaluates the overall relationship between an independent variable and the dependent variable, providing an indication of the unique contribution of each independent variable to the prediction of condom use at last sex with a sex worker. In Model 3 (not depicted here), a statistically significant unique contribution was made by risky sexual behaviour (sexual encounters) ($\chi 2 = 4.339$, $p<0.05$ with $df = 1$). Notably, none of the other variables made significantly unique contributions. The odds ratio (OR=1.081; 95% CI=1.003, 1.165) indicates that workers engaging in higher levels of risky sexual behaviour (sexual encounters) are 1.08 times more likely than their counterparts to have used a condom at last sex with an FSW. All three condom use models were statistically significant (*p< .05; **p< .01; ***p< .001).

DISCUSSION

The assessment of condom use among MCSW in the construction industry enhances our understanding of condom use by demonstrating the efficacy of using three distinct, but related measures - HCU, PCU, and FCU. It is important to note that risky sex behaviour was the only variable determined to be statistically significant across all three measures. Consequently, our findings complement the HBM, which implicitly includes risk as part of its framework through the constructs of perceived susceptibility and perceived severity (Carpenter, 2010). Perceived susceptibility refers to an individual's belief about the likelihood of experiencing a health issue or condition. In the context of condom use, this would translate to the person's assessment of their risk of contracting STIs including HIV.

Relatedly, perceived severity considers how serious an individual believes a health condition or its consequences to be. For condom use, it involves understanding the potential severity of contracting these infections and the impact they could have on one's life, health, and well-being. A study conducted in SA among young adults demonstrated that higher levels of HIV knowledge were directly linked to increased condom use. This was particularly evident when comparing different regions, suggesting that effective HIV education could counteract geographical and socio-demographic disparities in health behaviours (Shamu *et al.,* 2020). The predictive relationship between HIV/AIDS knowledge and increased condom use found in our study aligns with prior research suggesting that increased HIV knowledge can lead to more protective behaviours (Faust and Yaya, 2018). Our findings also lend empirical support to the RAA, which posits that attitudes toward a behaviour and perceived control over a behaviour significantly influences behavioural intentions. The fact that control over condom use and positive attitudes towards condoms were significant predictors of FCU aligns with this theoretical framework, highlighting the role of cognitive and experiential factors in shaping health behaviours.

Cross-sectional surveys, like the one conducted in this study, are essential tools in behavioural research as they describe data and inform longitudinal and experimental designs. However, they typically lack temporal depth and control over confounding

variables, making them less effective for causal inference. To address these limitations and enhance the robustness of our findings, this study employed three distinct self-reported measures of condom use, each serving to capture different facets of the behaviour. Using these three measures collectively addresses the critical gap left by the inherent limitations of cross-sectional designs. It allows for comprehensive data collection, enhancing the depth and breadth of understanding condom use behaviours. The multiple measures enable cross-verification and validation of the data, where consistencies strengthen the reliability of the findings, and discrepancies provide a basis for further inquiry. This approach also reduces measurement bias by diluting the impact of biases specific to any single measurement method.

Furthermore, the diversity in measures increases analytical flexibility, allowing for complex statistical analyses that explore correlations and predict behaviours based on a variety of inputs. This multiplicity not only supports different research questions within the same study framework but also improves the external validity of the findings. The results are thus potentially more generalisable and can inform more effective health promotion strategies.

CONCLUSIONS AND RECOMMENDATIONS

Importantly, the results align with core constructs of the HBM and the RAA: HIV/AIDS knowledge, perceived control over condom use, and positive attitudes toward condoms were consistent predictors of both actual condom use and behavioural intention. These findings underscore the role of perceived threat, self-efficacy, and motivational factors in shaping sexual health behaviour and affirm the relevance of theory-informed public health interventions. Future research can usefully test these associations in larger, more representative samples to enhance generalisability and support the development of targeted prevention strategies.

In terms of actionable insights for public health practitioners designing workplace-based or mobile interventions, the following recommendations are offered:

a) Incorporate prospective behavioural measures into intervention planning: Programs should go beyond assessing past behaviour and integrate indicators such as intention to use condoms to better predict future risk and tailor interventions accordingly. This is particularly relevant in the context of informal employment and high internal mobility that characterise the construction industry.

b) Design behaviour change content that targets key psychosocial drivers: Given the strong predictive value of condom use self-efficacy, positive attitudes toward condoms, and HIV/AIDS knowledge, interventions should include components that build confidence, challenge misconceptions, and reshape norms around condom use through culturally resonant and gender-sensitive strategies.

c) Leverage risk awareness in communication strategies: The observed association between higher levels of risky sexual behaviour and more frequent condom use may indicate that some men are responding to risk with protective behaviours. Messaging should acknowledge and reinforce this adaptive response; framing condom use as an act of responsibility and self-protection rather than simply a risk-avoidance measure.

These recommendations highlight the importance of aligning intervention strategies with both the lived realities of MCSW and the theoretical frameworks that best explain their behaviour, thus enhancing both program design and implementation impact.

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REPORTING OF WORK-RELATED STRESS: DISCLOSURE HESITANCY AMONG A SAMPLE OF CONSTRUCTION MANAGERS IN IRELAND

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Workplace stress in the construction sector is reported to have negative implications for employees and work practices. Although much literature exists on workplace stress, one relatively unexplored area within the field is the reporting of stress-related concerns. This study investigated the hesitancy to report workplace stress from a sample of construction managers in Ireland. Using semi-structured interviews and interpretative phenomenological analysis, 25 construction managers were interviewed about their reluctance to report workplace stress to their employers. Participants noted an inability to report workplace stress due to fear, stigma, and possible repercussions. The main causes of this workplace stress reported by participants were interpersonal conflict, bullying, deadlines, workload, penalty clauses, shortages, costs, communication, quality issues, and delays. A reluctance to report these stressors was also found to exacerbate stress as well as contribute to a sense of mistrust. Employee hesitancy to report psychosocial stressors represents an important barrier to improving workplace safety in construction. Therefore, further research into pragmatic stress risk management interventions is required to ensure the health, safety, and well-being of Irish construction managers.

Keywords: workplace stress; reporting hesitancy; construction manager

INTRODUCTION

Employment in the construction sector in Ireland reflects its importance, with 167,300 employees reported in the second quarter of 2022. This represented six percent of total employment in the Irish economy, with over 90 percent of Ireland's construction workforce being men (Government of Ireland, 2022). Construction professionals bear significant responsibilities for project success and have long experienced numerous workplace stressors in this demanding industry (Liang *et al.,* 2021). Although workplace stress is one of the most heavily studied topics in occupational health psychology, one relatively unexplored area within the field of organisational stress is the reporting of stress-related problems in the workplace. The apparent paucity of research on reporting workplace stress among construction managers in Irish construction settings led the authors to ascertain the causes, effects, and prevalence of reporting workplace stress in a sample of 25 construction managers in Ireland.

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Interpretative phenomenological analysis was used to obtain data from these construction managers to analyse their lived experiences of reporting workplace stress.

LITERATURE REVIEW

Construction has been described as a high-stress profession where professionals are subjected to a plethora of occupational demands that can hurt their psychological well-being and mental health (Love *et al.,* 2010). Many construction managers experience excessive levels of workplace stress, which can lead to psychological, physiological, and sociological effects on employees (Leung *et al.,* 2011). The literature notes that workplace stress and burnout experienced by construction managers have costs to the individual, the organisation, and the community (Bowers *et al.,* 2018). Although workplace stress is one of the most heavily studied topics in occupational health psychology, one relatively unexplored area within the field of organisational stress is the reporting of stress-related problems in the workplace (Britt *et al.,* 2016). A study by Nixon *et al. (*2011) noted that to respond to stress-related concerns, organisations need information on their nature and impact, however, employees often hesitate to discuss their occupational health concerns with their employer.

The literature also demonstrates that employees' hesitancy to report workplace stressors represents an important barrier to improving stress-related occupational health (Klinefelter *et al.,* 2020). Further studies have noted that victims of stress and bullying may lodge a formal complaint with their human resources personnel about inappropriate workplace behaviour and stress; however, complaining is an unusual occurrence and subject to several uncommon facilitative conditions being met (Harlos, 2010). Studies have also shown that up to 80 percent of occupational injuries go unreported in certain settings (Probst *et al.,* 2008). Similarly, research on workplace violence has shown that a large proportion of incidents go unreported at work and that underreporting has long been recognised as a barrier to the improvement of psychosocial issues in the workplace (Chappell and Di Martino, 2006; Pransky *et al.,* 1999). A study by Morse *et al. (*2000) found that workers who report health problems or workplace stressors to supervisors may risk disciplinary action, denial of overtime or promotion opportunities, stigmatisation, drug testing, harassment, or job loss. Their study noted that some safety incentive systems reward workers who do not report health and safety incidents or injuries with money, material goods, or recognition, thereby contributing to these issues being underreported.

While positive working relationships and the ability to confide in work colleagues can act as a buffer to workplace stress, evidence suggests that these avenues of support are often not available for construction workers (Bowers *et al.,* 2018; Geldart *et al.,* 2018). It is also well-established in the literature that men are less likely to discuss workplace stress and mental health issues than women (Schofield *et al.,* 2000). Furthermore, the strong prevalence of traditional masculine norms in construction has been linked to negative and discriminatory attitudes toward mental illness and perceptions of unsupportive working relationships, which may further erode opportunities for open communication (Battams *et al.,* 2014). Xiao-Hua *et al. (*2024) note that social support, supportive supervision, and employment assistance programmes in construction settings can assist in reducing mental health stigma.

The literature frequently identifies fear as a characteristic emotion in subverting attempts to seek help or redress in work-related issues (Mannix, McNamara *et al.,* 2018). The literature also shows that workplace stress and stress reporting stigma

experienced by workers have costs to the individual, the organisation, and society (Vogel *et al.,* 2006). In addition, the perceived stigma of negative treatment from co-workers and supervisors for admitting stress-related concerns is expected to be related to the experience of bullying within the organisation (Wright *et al.,* 2014). The findings on the reluctance to report workplace stress are also supported in a study on workplace stress and mental health by Britt and McFadden (2012), which found that employees in high-risk occupations may experience a heightened stigma associated with admitting stress-related problems and seeking treatment for these difficulties.

The perceived stigma of negative treatment from co-workers and supervisors for admitting stress-related concerns is also correlated with the experience of bullying within organisations (Klinefelter *et al.,* 2020). This study also found that if individuals are in an organisation where stress-related concerns are stigmatised, then it is likely that they would be subjected to behaviours representing a lack of care for employees, such as bullying and harassment. Manapragada and Bruk-Lee, (2016) have detailed several motives for this safety silence. Their study noted that a poor safety climate is not conducive to reporting workplace stress. They also found that perceptions of negative relationships with colleagues, characteristics of the job, and the individual's assessment of the safety concerns were all barriers to reporting. It has also been noted that employees avoid reporting workplace violence due to the characteristics or the nature of their employment (Chappell and Di Martino, 2006).

Psychosocial stressors such as workplace stress have some key distinctions from other workplace safety concerns. Psychosocial stressors are likely to be far more subjective than other workplace safety concerns and are less observable than many physical workplace hazards (Haslem *et al.,* 2005). Their study also notes that many employees assume that workplace stress is a typical job-related experience and therefore that it may be counter-normative to discuss stress-related issues at work. Studies also note that the psychosocial safety climate within an organisation is a noteworthy factor surrounding the reporting of stress-related concerns (Dollard and Bakker, 2010). Psychosocial safety climate refers to the extent to which an organisation places an emphasis on the psychological health and well-being of employees rather than an emphasis on productivity.

Considering the findings in the literature cited above, the authors set out to engage in an initial scoping study to explore the prevalence of workplace stress and the stigma associated with reporting it among a group of 25 construction managers in construction projects in Ireland. The research question derived from the data was “Is there a reluctance to report work-related stress among a self-selected sample of Irish construction managers?”

METHOD

After ethical approval was granted by TU Dublin, approval number (REC 20-247), 25 construction managers from the construction sector in Ireland were recruited and interviewed individually using semi-structured interviews. The interview questions were formulated and finalised through a pilot study conducted with two participants before the study commenced. The initial participants were recruited through the authors’ contacts in the construction sector, and after that, snowball sampling was used to obtain further participants for this study. The interviews were conducted between September 2022 and March 2024. Each face-to-face interview was conducted in the Leinster region of Ireland and lasted approximately 30 minutes. The interviews were recorded by a handheld device, which assisted in transcribing the

interviews verbatim for further analysis. The participants recruited were all experienced professionals, with the mean length of years working being 16.80 years. All participants had worked as construction managers in Ireland for a minimum of two years. In addition, eight of the participants did not have a trade background of any kind but had worked as general operatives before becoming construction managers.

Semi-structured interviews were chosen as an effective way of gathering data for small-scale research (Rapley, 2001). This type of interview is also commonly used in qualitative research and is characterised by a dialogue between the researcher and participant (DiCicco and Bloom, 2006). A snowball strategy can be the best way to locate subjects with certain attributes or characteristics necessary in a study. Snowball sampling techniques offer real benefits for research that requires access to difficult-to-reach or hidden populations. Snowball samples are particularly popular among studies interested in studying various classes of deviance, sensitive topics, or difficult-to-reach populations (Bryman, 2016). These are often obscured from the view of social studies and policymakers who are keen to obtain evidence of the experiences of some of the more marginal excluded groups (Atkinson and Flint, 2001).

Interpretative phenomenological analysis was the research methodology chosen to evaluate construction manager's own stress experiences. This methodological approach theorises that different people perceive the world differently depending on their personalities, prior life experiences, and motivations (Smith and Osborn, 2008). Therefore, it was considered an appropriate methodology to evidence the causes and effects of the hesitancy to report workplace stress by Irish construction managers. Participant's answers were recorded and transcribed verbatim and entered into NVivo version 12 software. Smith and Osborn, (2008) provide an eight-step cycle of analysis for interpretative phenomenological analysis, which was followed in this study.

FINDINGS

The two main findings of this study were the reluctance of participants to report workplace stress and the absence of appropriate employer initiatives in terms of managing workplace stress. Collectively, these overarching themes had caused participants to reduce their productivity and resulted in absences from work. In addition, the reluctance to report workplace stress also caused mistrust among participants. All 25 participants stated that they had experienced a high level of workplace stress and would not declare workplace stress to their senior manager, Human Resources, or employer due to perceived negative reactions. These participants believed that the fear of reporting workplace stress would make many workplace stressors worse and contribute to a lack of trust in the organisation. Thomas, a construction manager, explained, “Reporting workplace stress would not be done on any job that I know. I believe that could be a career-ending move; you would not be trusted ever again on the job. It would never be forgotten”. Another participant, Michael, noted, “I would not report workplace stress, I have heard in the industry of people reporting workplace stress, and it has not gone well for them, in every case that I have heard workplace stress reported, the individual who reported it was not there 12 months later.”

The fear of reporting workplace stress resulted in mistrust and further exacerbated the negative effects of workplace stress. All participants believed that there was a stigma associated with reporting workplace stress and that this would have negative implications for them in their future within their companies. The participants described a highly masculine, hierarchical environment where difficulties are

discussed in a direct and sometimes aggressive way or not discussed at all. The reluctance of construction managers to broach or express their difficulties meant that issues were rarely discussed at all in the workplace and only a small number of participants were willing to discuss their difficulties with family or friends.

Participants had different reasons for their reluctance to report workplace stress. Ten of the 25 participants associated the reporting of workplace stress with negative outcomes for career development and promotion. Twelve of the 25 participants were aware of other construction managers who had reported workplace stress, and this reporting had negatively impacted their careers. This can be exemplified by William, who noted, "I am aware of other construction employees who brought up workplace stress when interacting with the Human Resources and senior management, and it was not warmly received. It may be a complete coincidence, but I don't think so, hearing stuff like this on the grapevine does not fill you with confidence, you would be very reluctant to bring up the subject".

Eight of the participants identified mistrust as a barrier to reporting workplace stress. These participants believed they would not be treated the same way again if they declared workplace stress, and that the company would mistrust them in future interactions. These participants believed that reporting workplace stress would be viewed as suspicious by the company and, in some cases, colleagues, and there was therefore a reluctance to do so. One of the participants, Noel, noted: Many years ago, I reported workplace stress, and I have been bypassed for promotion ever since. My career has been at a standstill; younger and less experienced managers have been promoted over me. In retrospect, it was a really bad idea to report stress at work.

All participants noted that the fear of reporting workplace stress was justified because of their belief that their confidentiality could be compromised if workplace stress was reported. These participants believed that their concerns would not be handled discreetly by Human Resources or senior management and that their privacy would be compromised. There was therefore a reluctance to report. One participant, James, noted, "If I reported workplace stress, it would somehow get out and the whole company would know about it, this would have negative consequences for me, I would be known as a snitch, or a whistleblower, and it would not end well."

DISCUSSION

The extent to which the Irish construction sector is being affected by the reluctance to report workplace stress remains unclear due to a lack of relevant research. However, the findings that all participants would fear reporting workplace stress would be a cause for concern in this regard and suggest this issue may be commonplace. Nevertheless, a larger study on the underreporting of work-related stress concerns in the Irish construction industry is appropriate to investigate and empirically evidence this issue with sufficient sample power.

An inability to report safety issues at work, such as workplace stress, has been described in the literature as safety silence. Tucker and Turner (2011) describe safety silence as the act of withholding safety concerns during hazardous scenarios. Although few studies have focused directly on safety silence, it has been implicit in research on communication and safety (Noort *et al.,* 2019a). Due to its importance for safety management, safety silence is integral to measures of organisational safety (Griffin and Neal, 2000). The reluctance of all participants to report workplace stress

in this study indicates a proclivity amongst construction managers to engage in safety silence, which could have negative implications on safety management practices.

Zohar (2002) notes that the non-reporting of workplace stress in organisations correlates with higher rates of accidents and injuries. Accidents and injuries have noteworthy cost and time implications for organisations, including damage to their reputations. Participants in this study strongly associated the reluctance to report workplace stress as an additional workplace stressor. Workplace stress is strongly related to low productivity, high absenteeism, presenteeism, and poor job performance (McShane and Von Glinow, 2005). Additionally, safety silence or the underreporting of safety concerns such as workplace stress may cause leaders or teams to miss important information and thus fail to detect errors or correct recurring problems, resulting in mistakes and poorer performance (Morrison and Milliken, 2000).

Employees who believe that they will not be able to affect organisational outcomes will most likely choose to remain silent about safety concerns, potentially causing difficulties for organisations (Kerrissey *et al.,* 2022). Previous organisational studies have shown that employees' decision to stay silent about workplace stress is strongly related to workplace burnout (Milliken *et al.,* 2015; Sherf *et al.,* 2021). Repeated decisions to remain silent about workplace stress could increase burnout due to the strain of holding back emotional expressions of distress or feelings associated with ideas being dismissed by colleagues or management. Lastovkova *et al. (*2018) note that for organisations, burnout can have serious consequences, leading to high replacement costs due to turnover, sickness absence, work incapacitation, and poor business outcomes regarding job performance, occupational safety, service quality, and productivity.

Stress-reporting stigma is defined as the perceived real or imagined negative outcomes of experiencing and reporting a stress-related concern at work, including those concerns originating from others (Klinefelter *et al.,* 2020). A study by Wright *et al. (*2014) noted that employees who report high levels of stigma for admitting stress-related problems are likely to experience discomfort and social exclusion associated with the experience, resulting in an exacerbation of mental health symptoms and increased levels of bullying. Reducing stigma in the workplace may involve creating a culture of acceptance, understanding, and support. This could be aided by educating and training employees on the different forms of stigma, promoting open communication, and normalising mental health conversations.

What is also clear from this study is the negative effects on participants from the inability to report workplace stress. All participants were mistrustful of senior management and Human Resources' possible responses to their declaration of workplace stress. This caused deep frustration and increased stress for these participants. Bamberger (2009) notes that employees' decisions to report or not report stress-related concerns may be influenced by the overall safety climate of the organisation as it pertains to psychological health and well-being. It is plausible that a poor safety climate may be the cause of the reluctance of the participants in this study to report workplace stress. Organisational safety climate refers to employee perceptions about various policies, procedures, and practices in a workplace (Jex and Britt, 2014). Forehand and Von Haller (1964) note that safety climate is also regarded as a set of characteristics that represent the workplace atmosphere and influence employee behaviour. Improving organisational climate may be achieved by creating a work environment that fosters collaboration, engagement, and well-being through

leadership commitment, recognition, appreciation of employees, flexible policies, and employee involvement in decision-making (Sparer *et al.,* 2016).

While the further quantification of the reluctance to report workplace stress in the construction industry is important, it can be considered secondary to the need for pragmatic solutions. In this regard, strategies such as improving the psychosocial safety climate seem important as it can attenuate the relationship between work-related stressors and employee outcomes (Garrick *et al.,* 2014). Studies by Probst *et al. (*2008) show high amounts of underreporting of occupational injuries, while Chappell and Di Martino (2006) found similar findings of underreporting of workplace violence. These studies suggest the possibility of a comparable degree of underreporting of more minor workplace stressors as found in this study.

The literature notes that a positive safety climate may diminish employees' reluctance to report work-related stress. However, Black *et al. (*2019) noted that while pressure to work safely in an organisation may increase perceptions of safety climate, the pressure may also create a stigma that discourages individuals from reporting safety concerns or incidents and is associated with negative psychological outcomes. Addressing the reluctance to report workplace stress may require a multifaceted approach. Promoting a positive work environment, such as fostering a workplace climate that values open communication, empathy, and support, can help break down barriers (Laschinger *et al.,* 2014) and may assist in reporting workplace stress.

Destigmatising mental health by actively emphasising that seeking help is a sign of strength and resilience (Amanullah, 2010) should set an example by openly discussing the importance of mental health and demonstrating a commitment to employee well-being. A possible solution for underreporting workplace stress could also be specific training for construction managers on the importance of reporting workplace stress and building trust in organisations. The use of confidential employee assistance programmes that employees could contact when experiencing workplace stress may also assist. Finally, a larger study to investigate the relationship between safety climate and the reporting of workplace stress in construction settings would seem appropriate.

CONCLUSION

This literature notes a paucity of studies on the reluctance to report workplace stress in construction settings. What this study adds to the literature is further evidence of the very real reluctance of construction managers to report workplace stress, thereby answering the research question. What also became clear from this study is the urgent need for the development and trials of pragmatic and effective interventions to assist construction managers in reporting workplace stress. In this regard, the authors are currently engaging with Irish companies to develop and trial interventions specifically for improving the reporting of workplace stress for construction workers. Without such interventions, the negative effects of the reluctance to report workplace stress will likely continue to affect workers in the Irish construction industry negatively.

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HOW DO ORGANISATIONS RESPOND TO MAJOR REGULATORY CHANGE? INSIGHTS FROM THE UK BUILDING SAFETY ACT 2022

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As regulatory frameworks evolve across industries in response to global issues such as safety, sustainability, and ethical governance, the construction sector is also under increasing pressure to reform. Yet, the organisational response to regulation (how firms interpret, internalise, and act on major legislative changes) remains underexplored. This paper addresses this gap by asking: How do organisations in the construction sector respond to major regulatory change, and what shapes their adaptive responses? Using the Building Safety Act 2022 as an empirical case, we draw on qualitative interviews with professionals across the construction industry to examine how The Act is perceived and implemented in practice. We use Satir's Model of Change as an interpretative framework to trace how individuals perceive and navigate change processes. Rather than compliance being automatic or uniform, our study highlights the interpretive and contextual nature of regulatory response. The paper contributes to a more nuanced understanding of regulatory change in construction and offers practical insights for policymakers and industry leaders seeking to improve the effectiveness and uptake of regulatory frameworks in complex, fragmented sectors.

Keywords: regulatory adaption; organisational change; leadership

INTRODUCTION

Regulatory reforms in the construction industry, such as the new Building Safety Act 2022 (UK Government, 2022), increasingly target transformational outcomes, extending beyond mere compliance towards comprehensive shifts in culture, accountability, and operational practices. Thus, they have become a defining force disrupting construction practice worldwide. As Alsharef *et al. (*2019) show, major legislative interventions such as safety, environmental, product and labour regulations, exert wide-ranging influence over project delivery, organisational behaviour, and industry structures. Yet, despite its significant implications, we have limited insights

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into how construction organisations practically respond to such complex regulatory demands, especially in the early phases of implementation.

Traditionally, research on regulatory response within construction has focused on compliance. Within this broad focus, one strand has examined how compliance is shaped by organisational context, culture, and capacity, highlighting its nuanced, strategic, and often partial nature (Loosemore and Andonakis, 2007). A second strand has proposed planning-oriented approaches, offering structured frameworks to help organisations anticipate and prepare for regulatory change through horizon scanning, stakeholder engagement, and strategic response formulation (Rasoulkhani *et al.,* 2020; Chowdhury *et al.,* 2020). While differing in approach, both strands tend to view regulation as something organisations either comply with or prepare for. This paper reframes regulatory adaptation in such contexts as a form of emergent, practice-driven organisational response, emphasising how organisations interpret, negotiate, and act upon new mandates in real time, under conditions of ambiguity and structural complexity. Hence, this study asks: "How do organisations in the construction sector interpret and internalise major regulatory change, and what factors shape their adaptive responses?".

Taking the Building Safety Act 2022 ("The Act") as our case study, we examine the way professionals across the UK construction sector perceive and interpret The Act, and how this influences the steps they subsequently take to implement change within and across organisations. Through semi-structured interviews with senior professionals involved in the early stages of implementing The Act, we explore how organisational responses manifest in practice, using the Satir change model (Satir *et al.,* 1991) as a conceptual framework. The Satir model captures change as an affectively charged, non-linear journey through disruption, chaos, and eventual integration, offering a powerful heuristic to trace how construction organisations experience regulatory demands as vectors of change.

Regulatory Change and Compliance in Construction

Historically, much of the research in regulations and regulatory change in construction has focused on compliance, investigating how and why construction firms meet (or fail to meet) regulatory requirements. These studies have shown that compliance is often partial, strategic, and shaped by contextual factors such as organisational size, supply chain position, leadership, and cultural norms (Loosemore and Andonakis, 2007; Lingard *et al.,* 2012). Changes in regulations often struggle to penetrate the everyday routines of firms, particularly in fragmented and transient project settings (Winch, 2000; Dainty *et al.,* 2007; Bresnen *et al.,* 2005). This literature has significantly advanced our understanding of the socio-organisational dynamics behind regulatory adherence. However, even the more interpretive strands within this literature generally frame regulation as a fixed external demand to which organisations respond in varying degrees, rather than as an organisational change process per se.

A second and more recent strand of literature focuses on planning-oriented frameworks to support regulatory adaptation. These models typically outline structured, proactive steps that organisations can take to manage impending regulatory changes. For instance, Rasoulkhani *et al. (*2020) introduce a five-stage process: horizon scanning, stakeholder engagement, risk and opportunity assessment, response strategy development, and compliance implementation. Similarly, Chowdhury *et al. (*2020) and Alsharef *et al. (*2019) offer tools for "futureproofing" organisations and

projects against anticipated regulatory disruptions, often within the context of environmental or safety-related reforms.

These contributions are valuable in operationalising how regulatory adaptation might be managed within complex project environments. However, both the compliance and planning-oriented strands tend to treat regulation as a manageable or static input. This framing becomes particularly limiting in cases where regulation explicitly seeks transformational change, shifting not just procedures, but values, accountabilities, and culture. In such contexts, regulation introduces ambiguity, affective responses, and interpretive work that extend beyond what either retrospective analysis of adherence or structured adaptation plans can fully unpack. Understanding how organisations respond to these types of regulations requires an analytical frame that captures their lived, unfolding, and affective dimensions.

Towards an Organisational Change Perspective

An emerging body of work has started to challenge the dominant focus on compliance and planning in terms of new regulations in construction. Çıdık and Phillips (2021), for instance, show how regulatory ambitions for transformation are often absorbed and redirected by dominant cultural logics in construction, resulting in surface compliance rather than deeper change. Their work highlights the limitations of assuming regulation will drive transformation without accounting for how it interacts with organisational culture and embedded industry practices. Although they do not examine formal regulatory reforms, Aasen and Klakegg (2023) provide relevant insights by studying how organisations experienced and responded to COVID-19 restrictions. While not intended as transformational policies, these mandates produced significant internal disruption and demanded behavioural, communicative, and cultural adaptation. Similarly, de Gier *et al. (*2025) analyse organisational responses to sustainability-related regulation and certification pressures. While these policies vary in formality and strength, they often carry aspirations for systemic reform. In both cases, the authors demonstrate that externally imposed pressures, whether regulatory or policy-driven, are interpreted and enacted unevenly, shaped by institutional logics, leadership framings, and internal culture.

Taken together, these studies reinforce the argument that the more a regulation aims beyond technical compliance, the more it should be studied as interpretive, affective, and culturally embedded processes (and the less as technical compliance or managerial processes). Yet while they offer valuable insights into the organisational dynamics of response in such cases, they stop short of conceptualising regulatory change as a form of organisational change or applying organisational change models to analyse it. This paper makes that move. We argue that when regulation seeks transformational outcomes, such as those outlined in the Building Safety Act 2022, it must be understood and studied as a practice-driven change process. Our empirical focus on the early implementation phase of The Act enables us to capture how regulatory demands are experienced and responded to in real time, before response patterns become fully stabilised. In doing so, we contribute to a growing but underdeveloped line of inquiry that views regulation not only as a source of obligation, but as a vector of organisational transformation. Unlike compliance studies that focus on regulatory uptake, we focus on how regulation reconfigures organisational trajectories: not as an outcome, but as an unfolding process.

Framing Emergent Responses Using the Satir Model

To operationalise this view, we adopt the Satir model of change (Satir *et al.,* 1991) as an interpretive framework. Unlike rational or planned change models (e.g., Kotter, 1995), the Satir model explicitly addresses the non-linear, interpretive and affective dimensions of change, and can be usefully adopted to study project-based organisations (Ilyas and Hassan, 2015; Cameron and Green, 2019). Developed within psychology and counselling disciplines, the model traces how individuals perceive change as a trajectory starting with the status quo, through disruption introduced by a "foreign element", to enter a period of chaos and uncertainty. Self-realisation in the form of a "transforming idea" then triggers behavioural changes, to allow individuals to integrate the foreign element into practice and establish a new status quo.

This model is well suited to contexts like the implementation of The Act, where regulation is not just a technical requirement, but a source of ambiguity, hesitation, and cultural friction. By structuring our findings around this model, we are able to surface how organisations respond not only procedurally but affectively and interpretively to the arrival of transformational regulation. In doing so, our study contributes to an emerging line of inquiry that seeks to reframe regulatory response as organisational change. It adds conceptual clarity and analytical structure to this perspective, offering new insight into the dynamic and uneven nature of adaptation in a sector increasingly shaped by ambitious regulatory reform. This approach also offers practical insights for regulators and organisational leaders seeking to understand why transformational reforms often falter, and how more responsive pathways of change might be supported.

DATA COLLECTION AND ANALYSIS

Semi-structured interviews (labelled P1…P9) were conducted over the period of March to April 2024, around six months after The Act came into force. The selection process used purposive sampling to target senior professionals (associate director level and above) in different occupations and from different organisations. Nine semi-structured interviews were conducted with three contractors, three chartered surveyors, two clients, and one architect. To ensure that the interviews facilitate an authentic exploration of the research participant's perspectives, initial questions were intentionally broad, acting as "tour questions" (Rubin and Rubin, 2011). As the interviews progressed, the questions focused depending on the participant's responses and with particular attention to investigating the communication channels, decision-making processes, and leadership styles within organisations.

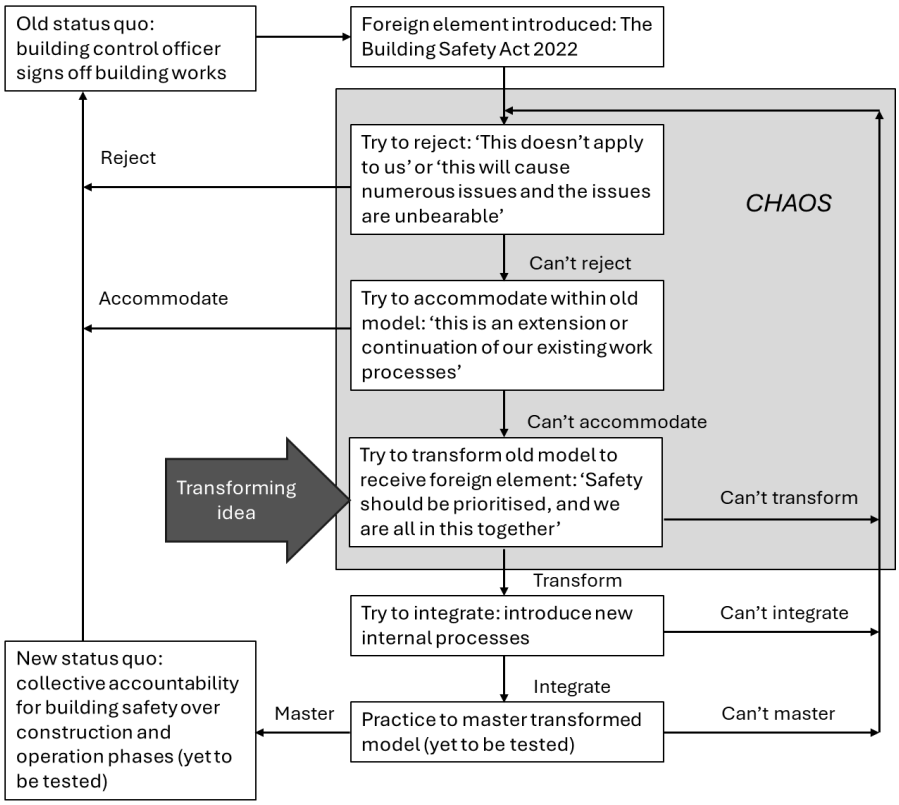
The interviews were conducted online over MS Teams and audio transcriptions were captured. A thematic analysis based on the Satir Model was undertaken, which allowed for commonalities and patterns across the interviews to be identified. Each interview was then further independently scrutinised to tease out the connections between the interviewee's interpretations of The Act and the strategic and tactical approaches taken by their organisation. This second reading also aided the identification of organisational logics and how they are bound by contextual differences relating to work portfolio, project stakeholder relationships, risk appetite, and profession-specific roles and responsibilities.

FINDINGS

The findings captured individuals' and organisations' responses to the introduction of The Act as a disruptive mandate; the confusion, resistance and tension that ensued; the

transforming ideas that triggered adaption; and examples of early integration of emerging practices. These are based on Weinberg's (1997) version of the Satir Model, as presented in Figure 1.

Figure 1: Adapted from Weinberg (1997)



The Building Safety Act 2022 as a Disruptive Mandate

The Act was introduced following publication of the Hackitt Report - a governmental review of the Grenfell Tower fire disaster in 2017 that claimed 72 lives. The primary objective of The Act is to institute a regulatory structure overseeing the complete lifecycle of higher-risk buildings, to ensure safe buildings in the design, construction, occupancy and maintenance of these buildings. The Act enforces stringent standards and guidelines, coupled with increased scrutiny facilitated by the building safety regulator, with the aim of eliminating oversight gaps. The Act also encourages greater collaboration among all stakeholders involved in building projects, fostering a shared responsibility for ensuring building safety.

The Act introduces a three-phase gateway sign-off procedure designed to enhance building safety before a building is passed over to the client. These gateways occur at critical stages: the initial planning permission, pre-construction, and completion/handover. This approach ensures that the project meets all necessary criteria before progressing to the next phase. To help the building safety regulator's sign-off at each phase, the project team compiles all necessary documentation into what is referred to as the "golden thread" of information.

Experiencing Chaos: Confusion, Resistance, and Interpretive Tensions

The Act places a strong emphasis on accountability for professional competence within the construction industry by demanding that individuals in key roles possess the necessary qualifications and expertise to carry out their responsibilities effectively. This point became a recurrent theme across the interviews, with interviewees

highlighting the need for appropriately qualified personnel to comply with stringent regulations. The task of complying with The Act becomes difficult, however, considering the lack of uniformity in how it is interpreted and enforced between different government bodies: "I've seen interpretations that vary wildly from one council to another. What's mandatory in one area is advisory in another, which makes compliance a real challenge for multi-area development" (P8, client).

The varying levels of contextual awareness and understanding towards The Act are mirrored by the different project roles, where clients, consultants, and contractors each questioned the level and ubiquity of application of The Act. The lack of official guidance at this early stage led some to interpret that it applies to all buildings regardless of size or use, while others believed it is only relevant for residential high-rises: "You've to make sure you're compliant, but you're going to make sure it fits in with what you're building and processes that you've already got in place. And it's: do they need tweaking? Do they need overhauling?" (P3, contractor). Eventually, 'higher-risk buildings' was generally accepted to refer to residential buildings over 18m in height.

The "chaos" stage was characterised by internal turmoil, where the different interpretations of The Act caused considerable confusion and anxiety to those required to make sense of The Act: "It frightens the hell out of the assets team, you know" (P2, contractor), and leading to a general feeling of scepticism and unease by the industry: "The proof will be in the pudding; I might not hold my breath" (P4, chartered surveyor).

Attempt to reject

The inability to proceed with work where organisations either cannot get insurance, or were unsure of their insured status, was a common reason given for avoiding taking on work: "the industry can't get insured on it and doesn't want to stick their head above the parapet" (P6, chartered surveyor); "I think we have to be very careful and don't inherit a role until we are sure what comes with it" (P5, chartered surveyor). Some also spoke of a widespread reluctance from industry to upskill: "I'm hearing there's a lot of building and safety inspectors wanting to retire earlier because they don't want to have to retrain and upskill themselves to comply with the Building Safety Act" (P4, chartered surveyor). As this is an industry-wide transformation, the rejection by some to embrace or participate in the change creates bottlenecks in the system that affects the entire industry, particularly in this case, where it relates to the availability of building control officers for signing off documents at critical stages of a project.

Attempt to accommodate

In some cases, The Act was conceptualised as an extension of existing best practice: "The Act isn't about introducing completely anything new or different but rather ensuring that there is increased accountability for people to adhere to existing rules" (P5, chartered surveyor). It suggests that organisations already adhering to best practice were in a better position to incorporate the new legislations as they were in effect covered by existing rules and practice. This in turn shaped how the regulatory change was interpreted, and whether it was perceived as a continuation of existing efforts or a fundamental shift requiring significant adaptation.

Transforming Idea: Realisation, Reframing, and Internal Triggers for Actual Adaptation

Satir's Model describes a "transforming idea" as an internal trigger or realisation that leads to the acceptance of the foreign element. This in turn prompts a shift in thinking or approach that eventually allows for transformational changes within the organisation to take place (Cameron and Green, 2019). The willingness to undergo organisational change requires the broad acceptance of the regulatory mandate. For The Act, this stance was underpinned not only by the desire to improve the reputation of the industry, but a moral imperative to be a part of this drive for change. This then triggered the acknowledgement that the burden of additional costs and responsibilities needed to be shared among all parties: "I suppose if you didn't allow yourself to be led by your morals… you could really cause some real financial strain for organisations. If you look at the project that we're talking about in this particular instance, some of the prelims are running at nearly £30,000 a week, and when you look at the programme implications - six months delay - you can do the maths on that. We acknowledge that this is a shared challenge at the moment, so we can grant time and wouldn't necessarily then levy financial penalties" (P9, client).

In some cases, the transforming idea described a willingness to act despite a lack of certainty: "We've always been very keen to not watch the parade go by and grasp the nettle even though it might sting a bit" (P7, architect). Referring to others in the profession who he perceived to be more risk adverse, P7 elaborates: "So I think there'll be architects out there who may find themselves… not being eligible or under consideration for certain sorts of projects by clients, because clients want consultants and contractors to make their lives easier". In framing their organisation as forward-looking, in contrast with ones that are static, P7 has described a hypothetical competitor that is stagnated in the "chaos" phase and outlined the inherent risks of inaction and being resistant to change.

Early Integration: Emerging Practices and Strategic Outlooks

The integration stage describes the experimentation and exploration of new processes, often on a temporary or trial basis, which in time becomes imbedded into the organisation to form a new status quo (Cameron and Green, 2019). At the time of the interviews, some organisations had demonstrated examples of early integration, such as the adoption of new definitions: "We've adjusted our own policies to suit the terminology and requirements of The Act because we've got clients out there saying 'What's this Building Safety Act? Is it just for high rise buildings?'" (P7, architect); or new processes: "We have something called 'the scheme procedures' that we operate within the department, and we're updating them in terms of how the team operates within the areas of sign-off gateway approvals, standard information, mandatory information, things like that" (P9, client).

One notable example describes a more committed approach: "None of the buildings we're building have to comply with this Building Safety Act. But we are adopting pretty much all the principles on this build as if they are, to prepare for the future. It's a good learning curve for us to understand what the implications would be to comply in the future and gives [the client] a good understanding as well, of the cost impacts and so on" (P1, contractor). P1 also has a view on how The Act will be applied in future: "I actually think within time that the 18m threshold is going to get reduced. So I see within five years being perhaps 12m, then five years later being 6m… in, say, 12-15 years, everything will have to be fully compliant" (P1, contractor). These

comments suggest an anchoring to a long-range vision that steers the organisation to the type of transformation and strategic change beyond current mandated requirements.

DISCUSSION AND CONCLUSION

The Building Safety Act 2022 explicitly demands transformational change from the industry for the purpose of improving the safety of our built assets. While interviewees unilaterally acknowledged and accepted the need to comply with this regulation, their organisational responses differed drastically. The Satir Model provides a framework for analysing these practice-driven responses as emergent, dynamic and adaptive, allowing for a nuanced examination of behavioural shifts of an industry often criticised as being sluggish in their reactions to change. The study found that tension towards this regulatory change was widespread and commonplace. Numerous examples illustrated how resistance by individuals can stymie industry wide efforts for change due to the creation of bottlenecks in the system. Yet there also existed examples where organisations, when being confronted by an external change mandate, proactively embraced those requirements, for the express purpose of seeking competitive advantage over their peers.

Most research on regulatory reforms in construction focuses on how implementation succeeds or fails; our approach allowed for the interrogation of how change and adaptation begin. Satir's Model expects that when the status quo is disrupted by the introduction of a foreign element, organisations will enter a period of chaos before beginning to integrate the changes necessary to formulate a new status quo. Weinberg's (1997) interpretation of the Satir Model describes several likely manoeuvres within the “chaos” phase, where the organisation may reject the change, or accommodate the change within its existing status quo and internal processes. The “accommodation” phase only proceeds if the organisation fails to continue by rejecting the change; and likewise, the “integration phase” only proceeds when attempted accommodation fails. If The Act was able to be fully accommodated by an organisation as a continuation or adjustment to existing processes (perhaps as an extension of current best practice guidelines), then the Model suggests that the organisation will revert to the status quo and fail to make the necessary changes to arrive at a new status quo in line with the rest of the industry.

While the external mandate provided the catalyst for change by creating a chasm between existing practices and required industry outcomes, organisational responses were shaped by their internal interpretive capacities. In the early stages of implementation, organisations examined the requirements of the mandate against a variety of factors, including an assessment of their in-house capabilities, the nature of their ongoing and likely future work, and their strategic positioning relative to their competitors. These assessments were then used to determine their responses. These early stances have likely ramifications for later adaptation. When asked to give their personal interpretation of what The Act is and does, interviewees who fixated on ways The Act changes the status quo, tended to then describe organisational responses that focused on meeting the new mandated requirements. Conversely, interviewees who anchored their references to a new envisioned status quo tended to drive their organisations towards transformational change beyond the mandated requirements set by The Act. These examples show that the systemic realignment required by The Act created opportunities for gaining competitive advantage, which organisations made sense of by assessing the threat of competitive disadvantages (cf. Powell, 2001).

Our findings demonstrate that where it comes to enforcing transformational change, organisational agency matters more than regulation design. In the case of systemic reforms where wholesale changes are required from multiple players in industry, the industry's responses were driven by the market dynamics between players. Organisations should anticipate confusion, misalignment, fear and frustration at the onset of regulations aimed at transformational change, and in response prioritise internal communication, leadership framing, and cultural anchoring. Continuous development is needed, where strategic responses are paired with appropriate change support mechanisms and change management processes.

Our conceptual framing and empirical findings offer new insights and a nuanced understanding of the limitations of top-down reform agendas in construction, particularly when major regulatory changes, such as the Building Safety Act 2022 (The Act), are treated solely as compliance mechanisms. As previously argued, framing such reforms as processes of organisational change helps explain the varied and often turbulent responses observed in practice. While The Act introduces a comprehensive regulatory framework aimed at improving safety and accountability, our data indicate that meaningful adaptation depends on internal reframing, leadership, and value alignment, and not merely on external mandates. The varied responses to The Act, from confusion and resistance to proactive integration, highlight the importance of organisational readiness in shaping how reforms are interpreted and enacted. Therefore, any regulation-driven reform agenda in construction must engage with the wider internal dynamics of organisations; not just whether, how much, and why they adhere to a given set of rules, as is typically the focus in compliance-oriented research. Ideally, this should be studied through methodologies embedded in practice (e.g., ethnography) to capture the symbolic and affective dimensions of established work practices and the pilot implementations of new regulations.

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DRIVE-IN DRIVE-OUT WORK AND TEMPORARY ACCOMMODATION: IMPACTS ON THE WELLBEING OF IRISH CONSTRUCTION WORKERS

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The surge in construction projects in urban Irish cities has led contractors to recruit subcontractors and labourers from rural parts of Ireland to undertake the work. As a result, a growing number of workers live in temporary accommodation during the working week before returning home at the weekend, known as Drive-In Drive-Out (DIDO) employment. Therefore, this research investigates the impact of this arrangement on the wellbeing of Irish construction workers. A mixed methods research approach was employed, combining qualitative semi-structured interviews with a quantitative questionnaire survey. Findings identify several factors that negatively influence mental and physical wellbeing, including long working hours, disrupted sleep, isolation, and limited access to facilities beyond alcohol-based social settings. These conditions contribute to stress, anxiety, fatigue, and reduced quality of life. Recommendations to mitigate these effects include providing accommodation with cooking facilities, access to gyms and community amenities, and development of shared social spaces not centred on alcohol. Overall, this research highlights that while challenges persist, opportunities for employers and policymakers exist to adopt targeted interventions that improve wellbeing for DIDO workers in Ireland's construction sector.

Keywords: Drive-In Drive-Out, employee wellbeing, Ireland, temporary accommodation, work-life balance

INTRODUCTION

The construction industry is widely recognised as one of the most hazardous sectors for worker health, with high rates of work-related illness (Campbell and Gunning, 2020). In the United Kingdom (UK) alone, the Health and Safety Executive (HSE, 2024) reported 78,000 construction workers suffering from ill-health between 2021 and 2024. Musculoskeletal disorders (MSDs) and stress, anxiety, and depression (SAD) are the most common conditions (Russell *et al.,* 2013), with around 14,000 cases of SAD accounting for 18% of the construction sector's work-related illness (HSE, 2024). According to Siddique (2017), the risk of suicide among low-skilled male construction workers is tragically three times higher than the national average, with skilled trades at double the risk (ONS, 2017). In Ireland, a significant construction boom has taken place in recent years, particularly in urban centres like

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Dublin, which has led to a surge in labour demand. The latest Central Statistics Office (CSO, 2025) figures show that over half of new housing completions are in Dublin and the Mid-East region, constituting the surrounding counties of Kildare, Louth, Meath and Wicklow. Consequently, to meet the demands of these ongoing projects, contractors increasingly rely on workers from across the island of Ireland, particularly from the North and North-West, to migrate towards the construction sites, residing in temporary accommodation during the working week to avoid impractical and unsustainable daily commutes. These 'Drive-In Drive-Out' (DIDO) arrangements, often involve hotel or rented lodging near worksites, reduce commuting time but pose significant risks to worker wellbeing.

Work-life balance (WLB) is a crucial factor, with Dainty (2012) arguing that it represents a balance between home and work lives that allows individuals to enjoy both without negatively impacting the other. Kotera *et al. (*2020) identified WLB as a strong predictor of mental health in the UK construction industry. For DIDO workers, unsocial hours, abnormal shifts, and remote job sites disrupt personal routines, social relationships and affect worker wellbeing (O'Riain *et al.,* 2018). Limited opportunities to maintain a 'third place' outside of work and home can affect relationships with family and friends, and thus, Purnell (2015) believes that this third place offers a space within which human connections supersede a space's designated purpose and become multipurpose, improving their overall quality of life. On review, much of the existing literature on wellbeing focuses on regions outside Ireland and the UK, however, workers in these areas encounter comparable challenges and circumstances (O'Riain *et al.,* 2018). Despite high interconnectivity between the issues faced by workers internationally, the specific experiences of Irish construction workers in temporary accommodation remain underexplored. Therefore, this exploratory study seeks to address this gap by investigating how living in temporary accommodation affects the mental and physical wellbeing of DIDO workers in Ireland. The research examines how these workers navigate life outside of work, the factors that negatively impact their wellbeing, and the effects of DIDO work on their personal lives, relationships, and work-life balance. Ultimately, the study aims to identify potential interventions to enhance the wellbeing of DIDO workers within the Irish construction industry.

LITERATURE REVIEW

The wellbeing of construction workers engaged in DIDO arrangements has attracted growing academic attention. Di Milia and Bowden (2007) define a DIDO worker as one who drives long distances to a job site, resides nearby during the work period, and returns home on weekends. Jackson and Ross (2025) note that this arrangement is very similar to Fly-In Fly-Out (FIFO) work which involves workers flying from their place of residence to a workplace, residing in accommodation on that workplace for an extended period while they work every day, before flying home to their place of residence for a period of respite. Labra *et al. (*2022) add that FIFO work is traditionally associated with the mining and oil industries in large countries like Australia. In Ireland, workers often adopt the DIDO set-up due to the impracticality of daily commuting, particularly from rural areas to urban cities like Dublin. Public transportation is rarely feasible for construction workers, as they must transport tools and equipment to job sites. The use of private vehicles is common which exposes them to long commutes during peak traffic hours; however, these are linked to fatigue, stress, high blood pressure, and diminished task performance (Lyons *et al.,* 2008), with negative consequences for productivity and absenteeism (Emre *et al.,* 2021; Van

Ommeren and Gutiérrez-i-Puigarnau, 2011). DIDO arrangements address these challenges by providing accommodation near job sites, reducing travel time and costs for workers while improving financial circumstances and lifestyle choices for their families (Morris, 2012). Blackman *et al. (*2014) argue that for employers, DIDO advances workforce familiarity and punctuality while minimising administrative burdens associated with hiring local labour for each new project.

Despite its advantages, living in temporary accommodation presents significant challenges to worker wellbeing. Extended time away from home often strains personal relationships (Gardner *et al.,* 2018), increases the likelihood of marital breakdowns (Taylor and Simmonds, 2009), and places greater burdens on partners. Isolation is another concern, with limited opportunities for social interaction in DIDO settings (O'Riain *et al.,* 2018). The construction industry's male-dominated culture exacerbates these issues. Donnelly (2018) and Chatmon (2020) highlight that men in this sector face increased suicide risk and are less likely to seek support for stress or depression. DIDO workers, in particular, report elevated psychological distress, worsened by loneliness, workplace bullying, and poor sleep quality (Parker *et al.,* 2018). Physical health also suffers as many workers rely on fast food due to a lack of cooking facilities, leading to poor nutrition and increased alcohol use. Lyons (2006) found that binge drinking is rampant in Ireland's construction workforce, with one in ten workers exceeding five pints of beer per night, and ten or more times in a month. Unsurprisingly, Mäkelä *et al. (*2015) state that alcohol misuse is closely linked to cardiovascular diseases, obesity, and mental health disorders. Additionally, workers in temporary accommodation report higher incidences of musculoskeletal disorders (MSDs), particularly wrist and hand pain (HSE, 2024).

Several mitigation strategies have been proposed to address these challenges. Providing choices between hotels and rented accommodation may reduce negative lifestyle effects (O'Riain *et al.,* 2018). The absence of social spaces beyond bars encourages unhealthy habits like excessive drinking or gambling, but structured support systems such as counselling, mental health education, and subsidised gym memberships can promote healthier routines (Voysey, 2012). Sibbel (2010) highlights daily phone calls and frequent contact with family members can help maintain emotional connections despite physical separation. However, most existing research focuses on Australia or the UK, and specific data in Ireland remains scant. Therefore, this study contributes by critically assessing these themes within the Irish construction sector, where contextual factors such as housing availability, rural depopulation, and subcontracting practices demand tailored interventions specific to this demographic.

METHOD

This exploratory study investigates the wellbeing of Irish construction workers residing in temporary accommodation using a mixed-methods approach. Mixed methods research integrates qualitative and quantitative techniques to capture both individual experiences and broader workforce trends (Bryman *et al.,* 2008). This design was chosen to provide both depth and generalisability in understanding DIDO-related wellbeing challenges. The qualitative component consisted of two semi-structured interviews with DIDO construction workers in different job roles: Interviewee A, a tradesperson living in hotel accommodation; and Interviewee B, a site foreman residing in rented lodging. Semi-structured interviews are well-suited to construction management research as they elicit rich, contextual insights and participants subjective experiences (Harrell and Bradley, 2009). The interviews were

conducted face-to-face at work sites using a convenience sampling approach (Saunders, 2012), with responses recorded in handwritten notes. Thematic analysis involving coding interview transcripts was applied to identify recurring issues and experiences related to temporary accommodation (Clarke and Braun, 2017).

The quantitative component involved a questionnaire survey distributed via Google Forms over five days using email, WhatsApp, LinkedIn, and printed QR codes placed on work sites. Surveys are an efficient method for gathering data from a broad population and are particularly useful for identifying trends and relationships between variables (Khatleli, 2018). The survey incorporated closed-ended and Likert-scale questions measuring experiences related to physical wellbeing, mental health, work-life balance, and social activity (Nemoto *et al.,* 2014). A total of thirty valid responses were received, and while a larger sample was targeted, exact population figures were unavailable due to the fragmented and subcontracted nature of the workforce. However, the respondents reflected a cross-section of trades and job roles, offering preliminary but diverse insights. Descriptive statistical methods were used to analyse trends in reported wellbeing outcomes, such as sleep quality and alcohol consumption. Importantly, the two data types were used complementarily: The interviews helped contextualise and explain survey trends, while the survey quantified the frequency and scope of experiences reported in the interviews. For example, individual reflections on dietary habits and feelings of isolation were supported by broader quantitative patterns in nutrition, alcohol use, and social engagement. All participants were informed of the study's purpose and assured anonymity. Informed consent was obtained, and identifying information such as company names or personal data was excluded. The mixed-methods framework provided a multi-dimensional view of wellbeing among DIDO workers in Ireland, capturing both measurable trends and lived experiences, thus offering a more comprehensive foundation for future research and policy recommendations.

RESULTS AND DISCUSSION

Due to space limitations, a selected summary of the questions from the survey is illustrated in Table 1, with areas covered such as distance from home to work, accommodation type, access to cooking facilities, reliance on fast food and positive and negative impacts of DIDO Work. This culminated into six key themes for discussion specific to this study and thus provides a foundation to explore further, supporting continuous research into DIDO and work-life balance from an Irish construction industry perspective. Beyond this preliminary study, further research is recommended to expand the scope of this investigation and explore additional strategies for enhancing worker wellbeing in similar contexts.

Theme 1 - Work-Related Factors

The findings indicate that higher pay is the most widely recognised benefit of DIDO work, cited by 93% of survey respondents. However, other perceived advantages such as job security (23%) and work variety (14%) were mentioned less frequently. Despite financial incentives, none of the participants felt DIDO work improved their WLB. Long working hours were the most frequently reported concern (86%), with 53% saying their WLB was negatively affected, and 30% citing feelings of isolation or loneliness. These findings are consistent with broader research linking long hours and irregular schedules to poor mental health outcomes in the construction sector (Afonso *et al.,* 2017). Interviewee A, who works over 50 hours a week, described his WLB as ‘very poor’, noting that early Monday commutes shorten his weekends. In

contrast, Interviewee B works 40-45 hours weekly and reported a more balanced routine. Despite these differences, job satisfaction was low overall, only 13% were satisfied with their jobs, while 33% expressed dissatisfaction. Chronic fatigue and symptoms of burnout were evident, with more than half rating their sleep quality as 2 out of 5, and 73% reporting low energy levels. These factors likely contribute to poor diet, low physical activity, and elevated risks of stress, anxiety, and depression.

Table 1: Selected Survey Discussion Points (n = 30)

Category	Response Options	Count (N)	Percentage
County of Work	Dublin	25	83%
	Wicklow	2	7%
	Cork	3	10%
Distance from Home to Work	2 - 3 hours	4	13%
	3 - 4 hours	19	64%
	> 4 hours	7	23%
Job Role	Tradesman	20	67%
	General Operative	6	20%
	Foreman	2	7%
	Management	2	6%
Accommodation Type	Hotel	25	83%
	Rented Accommodation	5	17%
Access to Cooking Facilities	Yes	5	17%
	No	25	83%
Reliance on Fast Food	Yes	25	83%
	No	5	17%
Room Sharing	Yes	0	0%
	No (room to myself)	27	90%
	Both (job dependent)	3	10%
Preferred Accommodation	Rented Accommodation	25	83%
	Hotel	4	14%
	Either	1	3%
Positive Aspects of DIDO Work	Higher Pay	28	93%
	Travel Opportunity	6	21%
	Improved Work-Life Balance	4	14%
	Job Security	4	14%
Negative Aspects of DIDO Work	Long Work Hours	26	86%
	Isolation/Loneliness	16	53%
	Disruptive Work-Life Balance	9	30%
	Lack of Job Security	2	6%
Feelings of Isolation	Yes	16	54%
	No	10	33%
	Sometimes	4	13%

Theme 2 - Accommodation-Related Factors

Accommodation type played a pivotal role in shaping worker wellbeing. Interviewee A resides in a hotel without cooking facilities, relying on fast food from delis and hotel bars for meals. He highlighted the difficulty of making healthy dietary choices under such conditions. In contrast, Interviewee B lives in rented accommodation equipped with cooking facilities, allowing him to prepare healthier meals daily. The stark difference in their experiences underscores the importance of access to cooking facilities in promoting physical health. Survey results further support these findings; 87% of respondents stay in hotels without cooking facilities, leading to reliance on fast food for lunch and dinner. This dietary pattern is linked to adverse health outcomes such as weight gain, diabetes, and heart disease. These findings directly correlate with Kenny *et al. (*2021), who investigated the factors influencing dietary habits among the Irish construction workforces. Moreover, rented accommodations

offer additional benefits, including quieter environments and greater privacy compared to hotels. These factors contribute to improved sleep quality and reduced stress levels, enhancing overall wellbeing.

Theme 3 - Social Activities and Isolation

Social isolation is a significant issue for DIDO workers due to limited evening activities in temporary accommodations. Interviewee A described repetitive evenings spent socialising with colleagues at the hotel bar, where alcohol consumption is common. He noted that some workers turn to recreational drugs like marijuana or cocaine to cope with boredom or poor sleep quality, an observation consistent with survey results showing normalised attitudes toward substance use among DIDO workers. Survey responses reveal that 67% of workers believe there is little or nothing to do in the evenings, while 73% often experience boredom. This lack of social opportunities leads many workers to spend evenings alone or engage in unhealthy behaviours such as excessive drinking or smoking, 87% agreed that DIDO workers have a higher propensity for these habits compared to others. Reduced engagement in hobbies or extracurricular activities further exacerbates stress levels; 82% reported that their ability to participate in leisure activities was negatively affected by DIDO work. These patterns align with Bowers *et al. (*2018), who identify social isolation as a common stressor, and unhealthy coping strategies such as excessive drinking as key psychosocial risks for DIDO and FIFO workers.

Theme 4 - Mental Health and Wellbeing

Mental health remains a critical concern for DIDO workers. While neither interviewee reported significant mental health issues, both acknowledged experiencing stress due to work-related factors such as long hours and isolation. Workplace bullying was also highlighted as a pervasive issue, Interviewee B recounted instances of ill-intentioned jokes and tension among colleagues during previous employment in hotels. Survey results indicate widespread mental health challenges among DIDO workers, 30% reported experiencing mental health issues, while 73% felt unsupported by their employers regarding mental health concerns. The macho atmosphere prevalent in construction workplaces discourages discussions about sensitive topics like mental health, contributing to stigma and underreporting (Parker *et al.,* 2018). While not explicitly described in the interviews, signs of emotional restraint were apparent, suggesting that emotional openness may be socially discouraged. This aligns with Hanna *et al. (*2020), who argue that construction work often encourages a form of stoicism and masculine bravura, where workers are expected to endure physical and emotional hardship without complaint. Such norms may contribute to stigma around mental health and hinder help-seeking behaviour, particularly in isolated DIDO environments.

Theme 5 - Impact on Personal Life and Relationships

The demanding nature of DIDO work adversely affects personal relationships with partners, family members, and friends. Absenteeism during the working week limits social interaction and contributes to feelings of isolation for both workers and their loved ones (Gardner *et al.,* 2018). Survey results reveal that 73% believe DIDO negatively impacts relationships with significant others, while 63% report similar effects on friendships. Interviewee A avoids serious relationships due to the demanding schedule but maintains casual connections instead. Conversely, Interviewee B actively works to sustain his long-term relationship through daily phone calls, a strategy supported by research indicating its effectiveness in maintaining

emotional connections (Sibbel, 2010). Both interviewees acknowledged challenges in balancing family responsibilities under the DIDO schedule.

Theme 6 - Future Improvements

Improving the sustainability of DIDO work requires targeted interventions across multiple areas. Survey respondents unanimously agreed that a compressed workweek would reduce stress and improve WLB, a sentiment echoed by interviewees who suggested shifting from a five-day schedule to a four-day arrangement with longer daily hours. While this suggestion may increase the length of individual workdays, the interviewees viewed it as a worthwhile compromise that would reduce the frequency of commuting, allow for more recovery time at home, and alleviate the cumulative psychological strain of being away from family throughout the week. Fitzpatrick *et al. (*2024) agree that people have an unsatisfactory work-life balance in a highly pressurised industry, and a compressed workweek is viewed as a highly desired solution to address this problem. Access to cooking facilities was identified as another critical improvement; 93% marked it as essential for temporary accommodations. Shared social spaces beyond hotel bars could provide healthier alternatives for evening activities, reducing reliance on alcohol consumption while developing social connections among workers. Subsidised gym memberships were also proposed to promote physical activity and improve mental health outcomes through exercise. Finally, enhanced employer support for mental health initiatives is crucial for addressing workplace stigma and fostering a supportive environment for DIDO workers. By implementing these measures, industry stakeholders can significantly improve the wellbeing of DIDO workers while enhancing productivity and job satisfaction across the workforce.

CONCLUSION AND RECOMMENDATIONS

Essentially, this exploratory study examined the impact of temporary accommodation on the wellbeing of Irish construction workers engaged in Drive-In Drive-Out (DIDO) work. The findings reveal a complex set of interrelated factors negatively affecting workers' physical health, mental wellbeing, work-life balance (WLB), and personal relationships. Contributing issues include long working hours, limited access to cooking facilities, poor diet, disrupted sleep, and social isolation. Social disconnection and a lack of employer-provided support structures further exacerbate these challenges. These difficulties extend beyond the workplace, limiting workers' ability to sustain meaningful relationships with family and friends, and engage in recreational or health-promoting activities. Survey responses and interviews indicate that sleep quality and energy levels are notably poor among DIDO workers, with over half rating sleep as 2 out of 5. This correlates with reports of fatigue, low physical activity, and increased reliance on fast food. While anecdotal evidence suggested that some workers may turn to alcohol or drugs, no conclusive data supports widespread use; therefore, such claims should be interpreted cautiously. Likewise, although workplace tension and exclusionary behaviour were reported by one participant, evidence of systemic bullying or burnout was not directly confirmed in the data. However, the broader construction sector literature suggests that macho workplace cultures can discourage open discussion of mental health, potentially leading to underreporting of issues like stress and anxiety.

In response, this study proposes several recommendations to mitigate the negative impacts and encourage a healthier work environment. Employers should prioritise providing accommodation with access to cooking facilities, quiet private spaces, and

shared social areas that offer alternatives to hotel bars. Subsidised gym memberships and structured wellness programs may also support both physical and mental health. A compressed four-day workweek was universally favoured among respondents as a means of improving WLB by reducing commuting demands. Employer-led mental health support initiatives, including awareness training and access to counselling, are essential to reduce stigma and foster a more open and supportive environment. Additionally, proximity to amenities and community infrastructure should be considered when sourcing worker accommodation to reduce isolation and improve overall quality of life. Future research should expand on these findings by exploring larger samples across different regions in Ireland and conducting longitudinal studies to assess the long-term effects of DIDO work on worker wellbeing. It is also recommended that further studies investigate how employers can implement structural changes such as subsidised nutrition programmes or improved welfare facilities within temporary accommodations.

Overall, this study provides a solid foundation for advancing research into the wellbeing of construction workers living in temporary accommodation. By addressing the negative impacts identified in this investigation such as poor diet, inadequate sleep, isolation, and limited employer support, industry stakeholders can significantly enhance the physical and mental health of DIDO workers while improving productivity and fostering a sustainable workforce in Ireland's construction sector. The key contribution of this research lies in its identification of actionable strategies that prioritise worker wellbeing while maintaining industry productivity, offering a pathway toward a healthier and more resilient construction workforce in Ireland.

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AN EXPLORATORY STUDY INTO CONSTRUCTION HEALTH AND SAFETY PRACTICES AND DIGITALISATION IN SOUTH AFRICA

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The construction sector in South Africa is hazardous, with a high incidence of accidents, injuries, and fatalities. This study examines current health and safety (H&S) practices and the potential of digital technology (DT) to enhance H&S performance through focus group discussions with South African construction professionals. A qualitative study was conducted through four focus group discussions involving 40 South African construction professionals. The insights from these participants were analysed using thematic analysis. Key findings revealed the reliance on reactive responses rather than preventive measures, weak enforcement of H&S regulations, inconsistent application of standards, competency deficiencies among inspectors, organisational cultures prioritising compliance over genuine H&S, and limited resources for smaller contractors. The study suggests that DT provides tools to enhance risk assessments, predict hazards, and promote proactive H&S measures, thereby offering a promising solution to the dangers faced in the construction sector. Based on these findings, the study recommends a shift toward a preventive H&S culture, more vigorous regulatory enforcement, specialised training, and the adoption of digital technologies (DT) in the construction industry. The study also recommends a collaborative approach involving organisational management, workers, and H&S professionals to improve H&S outcomes.

Keywords: construction sector; digital technology; health and safety; South Africa

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INTRODUCTION

The construction industry is among the most high-risk and hazardous industries, with high workplace accidents resulting in accidents, injuries and fatalities due to its projects' changing and complex nature (Ganah and John, 2023). This has sparked interest in health and safety (H&S) during the design and implementation of construction projects in recent years (Ganah and John, 2023). Some sources of accidents and injuries in the industry are human errors and the use of machinery and equipment (Adekunle *et al.,* 2023). These incidents affect productivity and efficiency, labour availability, poor project delivery, and escalation in labour injury claims (Aidoo *et al.,* 2024; Adekunle *et al.,* 2023). Innovations in digital tools and technologies have been advocated in existing studies as one of the measures for improving H&S and mitigating H&S hazards on construction sites, thereby preventing workers' injuries and fatalities (Ganah and John, 2023).

Digital technologies (DT) are transforming the H&S performance of industries globally, including the construction industry (Smallwood *et al.,* 2020). Some of the DT that improves H&S on construction sites include Artificial Intelligence (AI), Building Information Modelling (BIM), Internet of Things (IoT), Digital Twins, Robotics, Virtual Reality (VR), Augmented Reality (AR), and Wearable Devices (Sila *et al.,* 2024; Ganah and John, 2023). These technologies enhance H&S when integrated on construction sites (Dobrucali *et al.,* 2024; Ganah and John, 2023). Although these technologies are well deployed in industries such as manufacturing and aerospace, their adoption in the construction industry needs to be explored, as the industry is still grappling with DT (Dobrucali *et al.,* 2024; Ganah and John, 2023).

The South African construction industry (SACI) plays a critical role in the national economy, yet it struggles with significant H&S challenges. The industry's fatality rate, reported at approximately 3% (Sila *et al.,* 2024; Adekunle *et al.,* 2023), underscores the persistent issue of poor H&S performance despite the presence of H&S regulations (Malomane *et al.,* 2022). While research has explored H&S in the SACI, a notable proportion employs quantitative methodologies (e.g., Chandi *et al.,* 2018; Sila *et al.,* 2024), which may not fully capture the detailed perspectives of social actors. According to Liang *et al. (*2018), qualitative focus groups are a valuable approach for gaining in-depth insights into the perspectives and experiences of construction professionals on various issues affecting the sector. Ereiba *et al. (*2004) assert that focus group discussion (FGD) can explore participants' attitudes, experiences, and perceptions through dynamic interaction. However, they found limited use of the focus group approach in construction management research. Limited studies have employed a focus group approach to explore H&S practices and DT in the SACI.

Prior studies on H&S and DT tend to rely on quantitative methods and systematic literature reviews (SLRs) (e.g., Malomane *et al.,* 2022; Sila *et al.,* 2024), leaving a gap in understanding the lived experiences of construction professionals. Therefore, this study aims to fill this gap by exploring current H&S practices and the potential of DT to enhance H&S performance in the SACI through FGD with South African construction professionals. The research objectives are (1) to identify the key issues within current H&S practices and (2) to assess the potential of DT to improve H&S management within the SACI.

LITERATURE REVIEW

Construction Health and Safety Practice

Malomane *et al. (*2022) described H&S as the well-being and safety of humans from hazards, including programs, guidelines, and procedures that protect the safety, welfare, and health of persons engaged in work, to provide safe conditions and reduce the risk of accidents and fatalities. The construction industry is reported to have a poor H&S performance globally, with a high record of accidents on construction sites. This applies to the SACI as accidents, injuries, and fatalities among construction workers are common occurrences (Rantsatsi *et al.,* 2023; Smallwood *et al.,* 2020).

Although not among the least-performing industries in developing countries, the SACI experiences numerous challenges (Aghimien *et al.,* 2018). One such challenge is poor H&S performance (Rantsatsi *et al.,* 2023; Smallwood *et al.,* 2020). To improve its H&S performance, the SACI's H&S performance is governed by legislation (Malomane *et al.,* 2022). The H&S Act No. 85 of 1993, the Amendment Act No. 181 of 1993, and the Construction Regulation 2014 guide the H&S practice of the SACI (Sila *et al.,* 2024; Malomane *et al.,* 2022). Despite the existence of regulations on H&S in the SACI, there are challenges with H&S regulation compliance (Sila *et al.,* 2024). There is a failure to implement H&S measures on construction sites (Malomane *et al.,* 2022).

Digital Technologies to Improve Health and Safety

Due to the risky nature of construction activities, stakeholders in the construction industry have sought ways to improve the sector's H&S (Dobrucali *et al.,* 2024). DT improves H&S performance by mitigating H&S incidents on construction sites (Dobrucali *et al.,* 2024; Malomane *et al.,* 2022). According to Smallwood *et al. (*2020), unlike the traditional methods of measuring and monitoring H&S, which are often manual and come with several limitations, such as inaccurate measurement, the use of DT overcomes the limitations of the traditional methods, enabling accurate and continuous monitoring of H&S performance on construction sites. DT has been used globally to improve H&S practices in construction projects, resulting in decreased H&S concerns and incidents (Moghayedi *et al.,* 2022). For instance, the vital signs of construction workers can be monitored through wearable technologies, providing early warning signs for high-risk health issues (Smallwood *et al.,* 2020).

METHOD

This study employed an interpretivist epistemological framework to explore the application of digital technology in H&S management within SACI. This approach aligned with Bryman's (2016) and Daniel et al.'s (2023) assertion that qualitative methods are suitable for extending knowledge by exploring lived experiences. It often facilitates the acquisition of rich qualitative data from key stakeholders. A qualitative exploratory research design was adopted in the study.

A preliminary literature review provided an initial understanding of the current dialogue surrounding H&S and DT. However, the core data collection strategy relied on FGDs. This method was chosen for its capacity to explore participants' attitudes, experiences, and perceptions through dynamic interaction (Ereiba *et al.,* 2004), directly supporting the study's objective of identifying issues with current H&S practices and assessing the potential of DT in improving H&S management within the SACI. Although FGDs are acknowledged for their efficiency in generating focused

data within a limited timeframe, they can be cost-intensive due to participant recruitment (Ereiba *et al.,* 2004; Leung *et al.,* 2023). This obstacle was effectively managed through the authors' extensive professional network within South African academia and industry.

Four FGD sessions were conducted, each with ten construction professionals (totalling 40 participants). Ethical approval was secured from the University, and informed consent was obtained from all the participants before their involvement. A purposive sampling approach was employed to strategically select participants with relevant expertise and practical experience in construction H&S management within the SACI. This strategy ensured a diverse representation, including project management, H&S, public works, contracting, and academia. The participants were required to have a minimum of 3-5 years of experience in the SACI and demonstrate a comprehensive understanding of health and safety (H&S) regulations and practices. The focus groups and participants were coded as F1P1, F2P1, F3P1, and F4P1, where F1 represents Focus Group 1 and P1 represents Participant 1. F1 and F3 consist of individuals in academia and public works, with an average year of experience of 10-20 years and 5-10 years, respectively. F2 consists of individuals in public works and contracting, with an average year of experience ranging from 5 to 16 years. F4 consists of health and safety officers, construction managers, project engineers, and construction management academics with 10-20 years of experience.

Focus group sessions, which were guided by a pre-defined protocol, were facilitated by a designated moderator and supported by a note-taker within each participant group. Each session lasted 60-70 minutes. Following the individual group discussions, a convergence meeting was held where designated leaders presented key findings, fostering further discussion and data refinement. Audio recordings of the focus group discussions were transcribed verbatim and analysed thematically, adhering to Braun and Clarke's (2006) six-phase framework. The initial thematic analysis was reviewed and refined through collaborative discussions with the research team, resulting in a set of agreed-upon final themes presented and discussed below.

FINDINGS AND DISCUSSIONS

Issues with Current Health and Safety Practices in SACI

Six key themes emerged from the analysis of the FGD as shown in Figure 1.

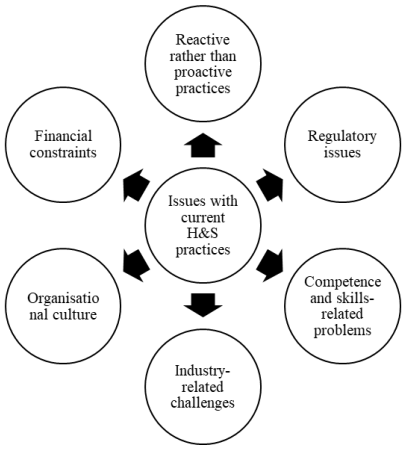


Figure 1: Issues with current H&S Practices

Reactive rather than proactive practices: Most participants observed that reactive practices, rather than proactive approaches toward H&S, are prevalent in the SACI.

F4P1 noted, "The prevailing culture in the industry is to respond to incidents after they occur rather than implement preventative measures." Many participants observed a strong emphasis on addressing issues only after incidents occur. This reactive approach creates a cycle where problems are consistently revisited without any proactive measures being taken. F4P8 stated, "We only deal with problems after they happen. It is like we wait for something bad to occur before we act."

This reactive stance leads to repeated problems rather than fostering a safe work environment. Participants also pointed out that resources are often allocated to resolving issues post-incident, instead of investing in H&S training or risk assessments from the onset. "There is no real focus on prevention; instead of putting money into training or risk assessments, it feels like we just patch things up when they break" [F4P2]. The findings of this study align with those of Sarvari *et al. (*2024), who note that construction stakeholders often adopt a reactive approach to H&S management rather than a proactive approach. The reactive approach has been heavily criticised for its numerous limitations (Sarvari *et al.,* 2024). According to the report of the Occupational Safety and Health Administration [OSHA] (2016), the proactive approach to H&S management should be the approach to adopt as it enables project participants and construction workers to collaborate in identifying and solving H&S issues before they occur, which builds trust, enhances communication and often leads to improved business performance.

Regulatory issues: The SACI's H&S practices were also linked to regulatory issues. The participants felt that although H&S regulations are in place, they are rarely enforced. This leads to a lax attitude towards compliance, perpetuating unsafe practices. According to F4P2, "The rules are there but not enforced. It is almost like they exist on paper, but no one takes them seriously." F3P1 also stated, "Our legislation in South Africa is stringent and very good; I must say, it is actually to practise the legislation that is the issue." In agreement with the report of non-compliance with H&S regulation, "I have seen that H&S standards are applied inconsistently. Some projects follow the rules closely, while others completely disregard them" [F4P10].

Participants noted that the lack of compliance with H&S regulations in the SACI was due to the lack of consequences for such action. F2P1 stated, "…there is adequate legislation to ensure that we do not have some other horrors happening on construction sites in this country, but someone is dropping their force." The study's findings show that although stakeholders in the SACI are knowledgeable about H&S regulations, there are compliance issues due to stakeholders' disregard and a lack of enforcement and consequence management. This finding is divergent from that of Aidoo *et al. (*2024), which reported that higher knowledge of H&S regulations results in higher stakeholder compliance. This study has shown that other factors such as corruption, lack of competence and skills, and even financial constraints, might be responsible for the non-compliance with H&S regulations in the SACI. The findings also align with those of Malomane *et al. (*2022) that, although H&S regulations exist, most construction industries are battling with their implementation.

Competence and skills-related issues: Concerns were raised about the qualifications and backgrounds of those responsible for enforcing H&S regulations. F4P1 stated, "Inspectors often lack a deep understanding of construction processes, making it difficult to identify potential risks or understand why certain H&S measures are necessary." This comment reflects the concern that H&S inspectors often lack in-

depth knowledge of construction processes. Participants believe the gap in understanding leads to ineffective H&S inspections and the inability to assess risks in construction activities. Participants also raised concerns about inspectors' practical experience, pointing out that many are unfamiliar with the day-to-day realities of construction work.

F4P5: "We have clients still employing agents (informal labour) who are quacks, often compromising H&S as workers prioritise immediate financial gains over H&S protocols. This may be because compliance costs are perceived as too high." Another participant (F4P2) noted: "Training is often seen as a checkbox rather than a necessity. This training is sometimes viewed merely as a regulatory requirement rather than a fundamental aspect of workplace H&S, and it undermines the potential for genuine learning and awareness among employees."

The study's findings have demonstrated that H&S training is an integral aspect of enhancing H&S. This finding aligns with that of Aidoo *et al. (*2024), who suggest that construction firms should prioritise H&S training to foster H&S knowledge and compliance, ultimately leading to more efficient and safer construction methods. According to Malomane *et al. (*2022), a focus on personnel training is needed as competence and skills are significant in H&S management (Malomane *et al.,* 2022).

Industry-related challenges: Participants identified corruption as a significant issue undermining the construction sector's H&S practice: "Corruption is a big problem in the construction industry" [F4P2]. One aspect that most participants observed was the questionable competence of H&S personnel. "…The key factor is questionable expertise. I want to put it that way because we did not use to regulate H&S in South Africa. The high incidence levels have led to the regulation to combat H&S problems. It is not a magic wand that will make me an expert" [F2P5]. In agreement, F2P7 also stated, "There is much corruption we have not seen before." Participants observed that corruption is apparent due to the lack of competency assessment of H&S officers.

The participants also mentioned that H&S practices are often considered an afterthought in project planning and execution: "H&S is often addressed too late in projects, resulting in rushed and insufficient H&S measures" [F4P1]. The findings on personnel with questionable competence handling H&S on construction sites agree with the report of Smallwood *et al. (*2020), which states that unauthorised people often fulfil the functions of H&S management on construction sites.

Organisational culture: Participants observed that the organisational culture of different construction firms influences H&S practices. The H&S culture of a reactive approach, as noted by F4P1 and F4P4, does not prevent accidents and injuries. This culture indicates a lack of prioritisation of H&S management by several organisations in the industry. Some participants opined that not prioritising H&S by SACI leadership stems from the existing culture of focusing on the cost factor above H&S. Another culture noted by participants was the lack of reporting and accountability of H&S practices on construction sites, contributing to H&S issues. There is a culture of not reporting most site accidents and incidents among organisations, which may not provide an accurate picture of H&S on most construction sites. "I feel like there is no accountability. When H&S standards are not met, those responsible are rarely held to account, creating a culture of carelessness" [F4P6].

Although there is a paucity of studies on how organisational culture affects H&S practices. The study's findings align with those of Moghayedi *et al. (*2022), who found that construction organisations in most developing countries lack a H&S culture

and a well-developed H&S system like those in developed countries. This results in increased accidents and injuries, and increased project costs due to medical expenses, litigations, delays, and project overruns (Dubrucali *et al.,* 2024). The findings on the perception of construction participants that incidents are unavoidable, resulting in a lack of interest in H&S, is aligned with van Wyk *et al. (*2021).

*Financial constraints: A*ccording to the participants, financial constraints affect H&S implementation among organisations in the SACI. F4P5 stated: "H&S compliance costs are perceived as too high." One of the participants, F3P1, observed that commercial construction projects in South Africa face funding constraints, resulting in minimal investment in health and H&S. F3P1 further stated, "From the lenders' perspective, there is investment in H&S, but the percentage is tiny. The funding is not there; the finance is not there. The projects are catered for, and the project cannot afford to overrun and cannot overspend on H&S."

Due to financial constraints, investing in H&S becomes difficult for most organisations within SACI. F4P3 noted, "Smaller firms often struggle to meet stringent H&S regulations due to limited financial and technical resources. This resource gap makes it challenging for them to implement necessary H&S protocols effectively." The study's findings align with van Wyk et al.'s (2021) findings that H&S practice requires financial investment and may deter construction project participants from complying with H&S regulations.

Potentials of Digital Technologies to Improve Health and Safety Management

Five key themes emerged from the analysis of the FGD as shown in Figure 2.

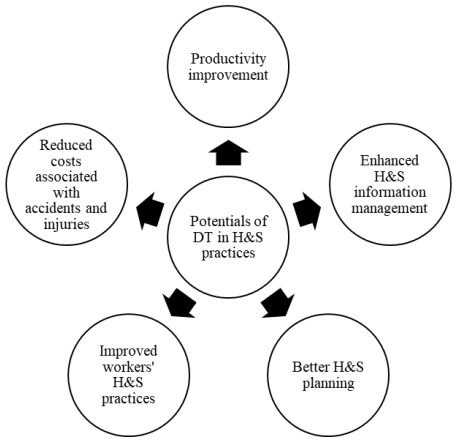


Figure 2: Potentials of DT in H&S Management

Productivity improvement: The study's participants observed that one of the areas in which DT enhances H&S in the SACI is improving the productivity of construction workers. F1P1 observed that: "DT increases efficiency and productivity of workers." When the H&S of workers are taken care of using DT, accidents and injuries on the construction site will be minimised, thereby improving workers' productivity. This study's findings align with those of Malomane *et al. (*2022), that as DT protect workers in hazardous areas through the provision of real-time data collection for H&S reporting and incident prevention, the result is greater visibility, better reporting, accountability, better communication, and ultimately, improved workers' productivity.

Enhanced H&S information management: Participants highlighted several areas in which DT enhances H&S information management. One participant [F1P1] observed that: "… DT like drone record information with models to predict health and social

plans. F1P8 noted: "DT improves the quality of H&S information reporting." Other participants noted that DT are not just for preventing accidents and injuries on sites but can monitor and record events related to the H&S of workers on site. F2P4 stated: "…DT are monitoring systems… with some detection… during certain periods or certain activities in the likelihood of accidents, it is all about bringing in AI as well to help mitigate when these things happen, but it also involves most of the technologies and more wearable sensors... To mitigate health and H&S accidents on construction sites." Additionally, F2P5 noted: "… Digital report tools to give you a report in terms of how the accident might have occurred." These participants' observations demonstrate that DT is an effective information management technology for H&S on-site. They mitigate accidents and injuries by monitoring, reporting, and storing H&S information on construction sites. The study's findings are in tandem with those of Malomane *et al. (*2022) that DT protects workers in hazardous areas using real-time data collection for H&S reporting and incident prevention, leading to better H&S information management on sites.

Better H&S planning: The study's participants observed that DT helps stakeholders plan H&S on construction sites. In making a case for improved H&S planning, F1P4 observed: "For instance, GPS takes into cognisance site location in the area of, recognising the likely accidents that may occur and then plans against such accidents." Since DT works by monitoring workers' activities on construction sites and recording and reporting incidents, these capabilities make it easy to plan H&S by eliminating likely H&S risks on construction sites. The study's findings align with those of OSHA (2016) on proper H&S planning on construction sites, providing greater visibility for workers, adequate reporting procedures and accountability, healthy communication, improved workflow, efficient monitoring, control, and data collection.

Improved workers' H&S practices: Participants of the study opined that the use of DT will enhance workers' H&S practices, mitigating accidents and injuries on construction sites. To buttress this further, one of the participants [F1P3] observed that "The biggest impact of digital technology in the H&S industry is the preservation of life. Workers will be less exposed to dangers on site, F3P8 stated: "We have robots that could go inside dangerous places. We have robotic dogs. It can save people by doing the work that is quite dangerous."

The observations made by the participants indicate that leveraging DT in H&S practices on construction sites is advantageous for construction workers, as these technologies are designed to minimise accidents and injuries and potentially eliminate worker fatalities on construction sites. This study's findings align with those of Dubrucali *et al. (*2024), who found that technology use in H&S enhances the H&S performance of construction projects. The findings also agree with Malomane *et al. (*2022) and Moghayedi *et al. (*2022) that DT improves workers' H&S by monitoring human H&S while detecting hazards and reducing accidents, injuries and fatalities on construction sites.

Reduced costs associated with accidents and injuries: The participants believe that DT is meant to identify and report risks associated with construction activities that will result in workers' accidents, injuries, and fatalities. This will improve H&S practices on construction sites. One participant [F4P1] observed that "DT will contribute to sustainability efforts, ensuring that buildings remain viable for future generations while mitigating risks associated with construction practices." F1P2

stated: “I believe DT will assist in reducing costs associated with accidents and improving overall H&S.” F3P6 opined: “I believe DT will help to identify risk factors and implement necessary H&S measures, especially during the demolition phase. Since accidents, injuries, and fatalities on construction sites will result in costs (including financial) construction projects through medical expenses, damages and loss of resources, delays in project execution, cost overruns, stoppage of work on construction site, and litigations from persons or representatives of persons affected, amongst others (Dubrucali *et al.,* 2024; Chandi *et al.,* 2018). Hence, assessing construction risks and avoiding hazards to H&S will reduce H&S costs for workers. DT is advantageous as it can even “… save people by doing work deemed dangerous to humans” [F1P8]. The costs associated with H&S issues affect businesses; reducing these costs will improve businesses' health financially, and save project costs and time (Malomane *et al.,* 2022; Chandi *et al.,* 2018).

CONCLUSIONS

This study employed FGD with South African construction professionals to identify critical issues within the current H&S practices within the SACI and explore the potential of DT to address these challenges. The findings reveal a prevalent reactive H&S management and a tendency to address H&S concerns only after incidents. Regulatory enforcement gaps and a lack of stringent consequences for non-compliance compound this reactive stance. Furthermore, competency and skills-related issues, such as inadequately trained inspectors and a general lack of H&S training, contribute to the construction industry's poor performance.

Despite these challenges, the study identified significant potential in using DT to improve H&S management in the SACI. Participants recognised DT's ability to enhance productivity, improve H&S information management, facilitate better H&S planning, improve worker H&S, and reduce costs associated with accidents and injuries. DT's capacity for real-time data collection, risk prediction, and automated monitoring was crucial for transitioning from a reactive to a proactive H&S culture.

The study contributes to the body of knowledge by providing new and deep insights into issues with current H&S practices and the potential of DT in H&S management in the SACI. It is believed that the study's findings will assist stakeholders in the SACI in focusing on mitigating the identified challenges in H&S, while exploring measures to proliferate the use of DT in H&S due to its inherent potential. The evidence presented is limited to the focus group discussions; however, future research could build on this to develop and implement specific DT solutions tailored to the SACI's unique challenges and explore methods of improving H&S culture within the SACI.

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EVERYTHING IN ITS RIGHT PLACE: HOW CIVIL ENGINEERING APPROACHES PEOPLE-FOCUSED DESIGN

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With the rise of urban living, centring people at the heart of building regenerative cities is imperative. Increasingly, civil engineers are interacting with people-focused principles, evidenced in major infrastructure projects. However, there remains limited understanding of how the civil engineering profession is interacting with people-focused ideology and whether the role of 'serving society' by the profession is effectively executed through these principles. This is important as without sufficient understanding of how civil engineering practices currently interact with people-focused principles, there remains a risk of the sector failing to achieve a more holistic approach and sustaining future communities. Through semi-structured interviews with professionals involved in UK-based 'placemaking' schemes (an example of people-focused approaches), two questions are explored: 1) how are civil engineers using formal guidance to deliver people-focused urban development projects? and, 2) in what ways do different professional identities affect how formal guidance is used? Findings present new insights into the role of the civil engineer in people-focused projects, and recommendations for future use of placemaking approaches within the civil engineering field provided.

Keywords: built environment, civil engineering, placemaking, policy, sustainability

INTRODUCTION

With the rise in urban living, efforts to integrate sustainability into civil engineering practices have increased dramatically. Requesting civil engineering to change, Jowitt (2004) stressed the critical responsibility the profession had to sustain society, ensuring 'intergenerational equity'. He requested an expansion to the traditional balancing act of environmental resource and economic well-being to further incorporate the consideration of people in design, shifting the profession towards adopting a people-focused design approach. Now, through the formation of the United Nations Sustainable Development Goals (UN SDGs), civil engineering is recognised as a key player in achieving a more sustainable world for people, place and planet (Addagada *et al.,* 2022). Specifically, in relation to its role within the built environment, goals 3 (good health and wellbeing), 9 (industry, innovation and infrastructure) and 11 (sustainable cities and communities) are critical to achieve sustainable urban places.

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However, progress is too slow (United Nations, 2024) with Reed (2007) and more recently, Plaves *et al. (*2024), calling for built environment professionals to adopt regenerative design practices (RD) seeking to not only sustain, but provide a betterment for the future. It could be through the recognition of sustainability and a growing encouragement of regeneration that a more unique, and people-focused approach to designing urban development projects is realised. The need for swift action is evident, yet arguably, those expected to deliver are challenged by a significant workload set within a working system where deviation from the norm is not mobilised with haste or ease (Lipsky, 1980). So, in a civil engineering context, it is important to understand how civil engineers are responding to these further demands to better the future and changing their focus on people.

People-focused Design: Education Developments

One approach to people-focused design is recognising the wider societal context and subsequent impact of design decisions as an important part of civil engineering. Josa and Aguado (2021:1) suggest that incorporating social science and humanities (SSH) studies within CE education shifts traditional technical problems against the backdrop of societal problems and context, helping to ensure civil engineers can 'design and plan solutions that are more socially sustainable'. Both the American Society of Civil Engineers' (ASCE) Body of Knowledge and the United Kingdom's Standard for Professional Competence and Commitment (UK-SPEC), have undergone revisions to their expectations of knowledge, skills and attitudes of professional civil engineers. As of 2019, social science and humanities knowledge is a foundational requirement for American professional civil engineers (ASCE 2019, p. XIV). The Engineering Council Accreditation of Higher Education Programmes (AHEP) 4th edition now states their learning outcomes "have a sharper focus on inclusive design and innovation, and the coverage of areas such as sustainability and ethics. The coverage of equality, diversity and inclusion is also strengthened to reflect the importance of these matters to society as a whole and within the engineering profession." (Engineering Council 2020, p. 2). However, significant barriers still exist to integrate SSH studies such as lack of guidelines (Josa and Aguado 2021) and reluctance to change (Arciszewski 2006).

Understanding the wider societal context is key to increasing focus on people within design. Yet, Soibelman *et al. (*2011) and Van den Beemt *et al. (*2020) recognise that attention must be given to the people within wider design teams too. They warn that the current curricula, set against the mass globalisation of civil engineering, limits the ability of civil engineers to work within interdisciplinary environments as their skills, knowledge and communication ability to work with other professionals is lacking. Consequently, incorporating SSH studies within civil engineering education and recognising merits of interdisciplinary learning provides evidence as to how the profession is seeking a more people-focused approach to its practices and learnings. Importantly, the expansion of curricula demonstrates how civil engineering is beginning to recognise that both collaborating with and integrating people is critical to adopting a more people-focused approach and achieving sustainable and regenerative design. This approach is being developed in other professions, like architecture (see Kevdzija and Marquardt, 2022), but its implementation by civil engineers is still understudied. Education is vital, but whether it translates to practices is equally important; guidance documents might shape this.

People-focused Design: Guidance Developments

Echoing the education reforms, Reed (2007) argues that adopting a more collaborative, 'place' specific approach to built-environment design will achieve a people-focused approach by not only sustaining communities but actively working to regenerate them for the future. The concept of 'placemaking' is common in architecture, urban planning and now increasingly, civil engineering. Placemaking is a key approach to delivering people-focused design. Yet, Ellery *et al. (*2021) warn that the concept is poorly defined, as evidenced by Lew (2017), and lacks an agreed definition within the planning, designing and building literature, hampering its effective use to benefit communities. Despite this, there has been a shift in policy and guidance towards the use of 'place' principles as a tool to ensure effective collaboration, community-led and locally relevant design is executed by the built environment community and thus, arguably achieve a more people-focused approach. Examples are detailed below.

National Planning Framework 4 and the Place Principle
The latest edition to Scotland's National Planning Framework 4 (NPF4) signifies a shift in focus on community involvement in the future design of places. It requests all development of Scotland's places are in line with the Place Principle. The Principle "promotes a shared understanding of place, and the need to take a more collaborative approach to a place's services and assets to achieve better outcomes for people and communities" (Scottish Government, 2019). The Principle focuses the design of future development for people and works towards achieving the UN SDGs.

Designing Streets and Designing Places
These are supporting documents to NPF4. Designing Places focuses on spatial design of urban spaces, whilst Designing Streets focuses on the design of urban streets. Designing Streets, increasingly used by civil engineers in city designs, introduces a new street user hierarchy, in which non-motorised road users are prioritised over private vehicles in urban streets, thus, centring people at the heart of urban street design. Whilst not mandatory, the guidance is advised as best practice and reframes streets as having a 'place' function, rather than solely to facilitate movement. Again, through 'place', a more people-focused approach is potentially realised.

Motivation for Research

Evidently, efforts have been made by the civil engineering profession to focus people within its practices. Set within a wider societal context, the incorporation of SSH studies and sustainability in CE education pushes the profession to understand the people impacted by design decisions. Turning attention to people within urban development practices is evident, for example, in the newest revision of NPF4. However, despite civil engineering being a key player in regenerating cities, there remains limited understanding of how their profession is delivering people-focused design through new policy, guidance and educational reforms, specifically through the tool of placemaking. This is important as without sufficient understanding of how civil engineering practices currently interact with these principles, there remains a risk of the sector failing to achieve a more holistic people-focused approach and sustaining future communities. Thus, the research questions are:

- How are civil engineers using formal guidance to deliver urban development projects that seek to focus people within their designs?
- How do professional identities affect the ways in which formal guidance is used within these projects?

RESEARCH APPROACH AND DESIGN

Data Collection

The data were collected as part of an initial study conducted in 2021, exploring the ways in which mental wellbeing is incorporated into the design of urban development projects. Since this study, I have gained three and a half years' professional experience working as a design engineer on active travel and placemaking projects. For the purposes of this study, the data have been re-analysed to address the new research questions, with my own experience and new knowledge guiding data analysis. A comprehensive data collection method for this study was presented as part of the CIBW099 Conference 2023 (Gilmour and Smith 2023), with a summary below.

The exploratory nature of the study called for qualitative methods, using subjective ontology and interpretivist epistemology. Therefore, semi-structured interviews were used as the data collection method to adopt a 'probe and explain' technique (Robinson 2023). Using the semi-structured form allows the interviews to be rigid enough to ensure discussion remains in scope, yet introduces a fluidity to the conversation, further allowing participants to discuss ideas on their own accord. This can be favourable when exploring subjective accounts such as design decisions, practices and thoughts within work as participants can bring to light information that the interviewer does not already know to mention. Thus, the researcher can probe for further details, allowing the respondent to explain their ideas more fully, creating a two-way data sharing process and enriching the data results. The interviews were conducted between January and March 2021 via the online platform Microsoft Teams. Their duration lasted approximately 30 minutes. Prior to interviews, all respondents received an interview guide which outlined areas of conversation to be discussed. The interviewees, shown in Table 1, were selected by purposive sampling; interviewees ranged from planning to more engineering orientated roles. Issues concerning bias were considered as part of this research design, with purposive sampling chosen as the preferred method. Further discussion regarding bias is found in Gilmour and Smith (2023).

Table 1: Participants Selected

Participant Number	Professional Role	Planning or Engineering Background
1	Manager	Planning
2	Consultant	Planning
3	Manager	Engineering
4	Design Engineer	Engineering
5	Design Engineer	Engineering
6	Co-ordinator	Engineering
7	Manager	Planning

Data Analysis

The interviews were transcribed from the audio recordings as permitted by participants and analysed using thematic analysis. As laid out by Braun and Clarke (2006), themes can either be of semantic or latent nature. This entails a choice of the level at which the themes are identified within the data and thus, changes the nature of the research design. Semantic themes are identified by the researcher and presented as literal occurring themes. Conversely, the identification of latent themes calls for a

more interpretive approach allowing for a synthesis of not only their presence but reasons for their residency within the data set. Semantic level themes were chosen for the analysis. This aligns with the critical realist standpoint adopted in the research design as the analyst can interpret the findings whilst presenting them in a realist manner.

Analysis followed the six-step thematic method laid out by Braun and Clarke (2006). The initial two steps start the analysis through firstly familiarising and generating initial codes. The following three steps require searching, reviewing and defining identified themes within the data, from the initial code set generated in step 2. The final sixth step is the resultant report of findings and summarised themes. Whilst not intended to be a strict set of rules for thematic analysis, following the six steps ensured that the analysis was thorough and structured, yielding more robust conclusions.

RESULTS AND DISCUSSION

Theme 1: Disconnect

Referencing the volume of Local Place Plans, one participant asked, "how do we do it? […] there are 56 neighbourhoods, so it would be 56 plans. How do we support them in producing these plans?" Here, almost despairingly, the participant voices the challenges met with tailoring guidance to a high volume of small-scale areas. These places exist under one local authority (LA), yet their individuality is to be reflected in their localised plans. The exasperated questioning signifies the concern over the scale of the task faced by one LA alone. Local Place Plans seek to achieve a people-focused approach through being community-led, yet here, the management and synthesis of such a large quantity of community voices seems a daunting task.

It is not only the volume of places voiced as a concern: the intricacies of local authorities are also highlighted as a challenge. One remarked "Scotland-wide different local authorities have a different set of strategic priorities". Another voiced, "standards differ within one local authority," revealing "different knowledge of what makes a good place". Thus, leading to what one called a "patchwork quilt of quality". Hence, challenges exist enforcing guidance on a local scale: how are professionals able to deliver locally tailored projects, if standards differ and clear internal disconnection exists within LAs?

Participants also discussed the ways in which guidance documents related to one another, revealing another challenge in their implementation. One said, "if it's written properly, the national policy should be channelled through the local plan to understand." Here, the use of the word 'if' suggests a degree of uncertainty in the connectivity of policy documents, despite this being their aim. Echoed by another, this uncertainty is shown through the hopeful (and idealistic) alignment of guidance, "I would hope, in every case that it would be a response to the national planning framework […] these policies would ideally be aligned in some way or Local Place Plan would be aligned to their transport plan." Clearly, there exists an aspiration to use guidance that speak to one another, yet the premise of this is communicated as an 'ideal' arrangement, and not one that is a current reality. Thus, a key barrier to people-focused design is highlighted: with a high volume of different guidance not reflecting one another, fragmented understanding and subsequent use is evident.

Theory vs Practice

Strikingly, the level to which placemaking theory was understood and then executed to achieve a people-focused approach was criticised by several participants. One

remarked that "the knowledge base isn't really there around what the theory is and […] what makes a good place". On the surface, this can show the fragmentation of theoretical knowledge of placemaking within the field, and thus, despite guidance being used by civil engineers, a deeper understanding of why and how this is to be used is missing. Yet, it is important to consider this further. How are civil engineers expected to implement appropriate theory into practice, if the guidance itself is viewed as disconnected? As noted above, there exists key disconnections in relating national policy on the local scale, as well as navigating different approaches within the multitude of local authorities themselves.

Definitions also seemed hazy. During interviews, placemaking as a concept was discussed at length. However, its definition was kept brief, and at times, not explained at all. When it was explained, numerous elements of an urban development project (process and product) were listed by participants. For example, one explained, "Throughout this interview, […] when I'm talking about travel, I am also talking about placemaking as a part of that", clearly indicating a synonymous definition of placemaking with travel. Echoing this synonymity, another continuously used the phrase "active travel and placemaking", interchangeably. One expanded further saying, "creating a more amenable space where people feel more comfortable and making it less hostile, making it safer", clearly connecting the concepts of placemaking and people-focused design. The common use of the placemaking term, yet the lack of detailed definition echoes concerns raised by Ellery *et al. (*2021) regarding the lack of consistent definitions of placemaking. They argue that without a consistent theoretical understanding of what placemaking is, its effective use within practice is stalled. If a concept is vaguely understood, it risks existing as a common term, not common practice.

When discussing the idea of theory in practice, notable comments were made by participants with regards to an engineer's role. One planner remarked "And I think when the engineering factor start[s] to come into it […] a lot of this sort of idealism of planning a place gets lost". One participant, with an engineering background, saw their input of green infrastructure as being "partly a nod to that", with 'that' referring to placemaking theory. By recognising this as only a 'nod' to it, suggests an almost side-lined approach to engineering interventions and an engineer's role in placemaking approaches, as part of people-focused projects. However, this is arguably to be expected, as predominant literature around a people-focused approach and the built environment resides outside civil engineering such as urban design, planning and architecture for example, Kevdzija and Marquardt (2022). Courage (2021) emphasizes the integral role community has in achieving successful placemaking, with the synergy of architects, urban designers, planners, developers, to name but a few - but no mention of civil engineers. This is interesting as it not only emphasizes the fragmentation in guidance, but it allows the second research question to be explored: how do professional identities affect the ways in which formal guidance is implemented within urban development projects?

Theme 2: Identities

The theme of identities was established through the re-occurrence of discussions surrounding roles, responsibilities and the structure of projects. The theme allowed a deeper exploration of the different characters, processes and values held by personnel within the built environment sector. Thus, a deeper understanding is developed of

how this guidance is being used to focus on people, and how different identities within the built environment sector affect its usage.

Conflicting Identities

One participant, from a planning background, argued that with a "very sort of strict engineering sense of safety and wellbeing […] an engineer will argue that they're protecting your wellbeing". Continuing, they expanded on the strict engineering interventions being a product of engineering thoughts such as "we have to have rails up to protect us […] a junction is so wide that it [has] to have signals" and "cars are moving so quickly that there has to be controlled crossings everywhere because people need to be controlled". Another planning background participant remarked, "an engineer would argue, they make the place safer and better and so, better for your wellbeing. But I think a planner or an architect, [or] urban designer might have a different view." Probed to elaborate on this different view, the participant explained, "…if you put a continuous footway in there, it would give that psychological cue that people have the right of way." One engineer expressed a notable reluctance to changing the traditional way of thinking saying, "whether it be engineers or whether it be [the] general public, […] some people can be a bit reluctant to the idea of […] changing the thought process." Whilst not explicitly comparing the planning view against their own, the engineer's comments still indicate a possible rigidity within the mindset of engineer's when it comes to adopting people-focused approaches.

Here, comments indicate that despite both professional identities seeking to focus the design on people and their safety, the interventions of the planning vs engineering side conflict. The planner sees the engineer as working in a top-down approach, with the belief that once behaviour is controlled and enforced by tangible engineering design, safety is achieved. Yet, the planning thought process follows a more bottom-up approach, allowing people (rather than vehicles) to dictate street design, aligning more people-focused thought processes evident within placemaking principles in Designing Streets. Notably, efforts to ease tensions between engineering vs planning views have been at the heart of new urban development design policy in Scotland for years (Llewellyn 2008). Yet, these discussions suggest that engineers are still perceived as adopting more traditional views of physical segregation to enhance safety, and thus, their professional identities could obstruct the application of more people-focused interventions, as seen in placemaking guidance, that seek to change the built environment in a people-responsive way, rather than vehicle serving.

Strong individuals

The interviews also highlighted the significance of individual identities and their influence on executing meaningful, unique designs. One emphasized that they retained "very strong individual characters" such as "someone charismatic and who really believes in the strategy to help deliver it". Another revealed a "personal connection with project management," helped convince the importance of incorporating more social or softer elements in design. Here, it seems that despite guidance encouraging a shift in design thinking towards tailoring to community needs, the influence of strong individuals dominates project outcomes. It is important to recognise that these comments may reveal reflections of a few individuals on a few projects, and therefore, may not wholly represent the field. However, my own experience within the field confirms that in certain projects, this can be the case. Efforts are being made to adopt more people-focused design approaches, yet their delivery in line with formal guidance may not solely be governed by the guidance itself. The guidance exists within a complex work setting, where project teams and

their working circumstances such as time pressures, influence, connections etc. may also affect people-focused outcomes (Lipsky, 1980).

Community identity and the civil engineer

A concluding, and important finding in this study was the interaction of the identities of both the civil engineer and the community and its influence on guidance use. Participants considered the act of "designing for all" as an act of "juggling" and overcoming the "challenge of striking a balance" with vulnerable groups within the community that "usually have conflicting needs". The language used by participants frames the community as a challenge to overcome, rather than an integral component to be embraced for successful design, encouraged by formal guidance. The progression of the National Planning Framework within Scotland, and its subsequent supporting documents, has been towards a more local, collaborative approach to community planning and design, yet little conversation concerned itself with the inclusion of the community within design processes or outcomes, other than to reference the challenge of its incorporation. Notably, this echoes the concerns raised by Lucena (2013) regarding civil engineers assuming the 'expert' role in projects, whilst the community remains the 'non-expert', thus revealing the challenging reality of collaborating with the community to develop long-term, benefitting designs for people.

Despite civil engineers' increasing interactions with people-focused guidance, the traditional dominance of technical expertise in their education may limit understanding of community collaboration theory and thus, their ability to execute more holistic, people-focused design. However, it is important to reflect on not just the individual engineer, but the system in which they operate. Whilst it could be argued that a traditional mindset limits the implementation of more collaborative approaches, the evident disconnected, rigid and resource deficient system in which civil engineers work importantly signifies the complexity of adapting a more collaborative approach (Lipsky, 1980).

CONCLUSIONS AND RECOMMENDATIONS

This study looked to explore the ways in which civil engineers are adopting a people-focused design approach in urban development projects, specifically using various formal 'placemaking' guidance. Generally, the way in which national guidance was required to be localised was viewed as a significant challenge, both by the volume of places, and the apparent differences within the teams delivering the projects within local authorities. Strikingly, inadequate understanding of placemaking theory and its subsequent integration into practice was expressed by many. This was considered understandable as placemaking (as a tool to enable a more people-focused approach) is still hazily defined in the literature. However, for it to have such dominance within key guidance and policy raises concerns for its effective implementation. Greater clarity is needed on a universal definition of placemaking - through this, a clearer way of integrating people within design will be realised.

This lack of understanding also became evident in the contrast shown between professional identities within urban development projects. Despite current guidance calling for a people-focused approach, engineers were perceived as exhibiting strict, top-down, 'expert' roles whilst the planning side of the sector assumed bottom-up, collaborative design practices. Engineering input was viewed by some engineers as an 'add-on' to placemaking, instead of forming an integral role. This traditional view was also seen in commentary surrounding the engineer and the community. Framed

as a challenge to overcome, collaboration with the community seemed outside the engineer's remit. Focusing on people in design requires a deeper understanding of society, community and people's needs. Yet findings point clearly to disconnections between an engineer's understanding, professional identity and role within placemaking projects to achieve a more people-focused design output.

It is recommended that for people-focused design practices to become common place in civil engineering, critical emphasis must be placed on the civil engineer's ability to collaborate with the community. Current guidance assumes that the built environment community are well-versed in collaborative practices and thus, community-led, design-led approaches can be adopted smoothly. Findings suggest that members of the planning side of the BE sector exhibit more experience in relation to collaborative initiatives, with civil engineers perceived by their wider community as remaining stuck in traditional views. However, findings also point to the complexity of people-focused ideology such that systemic changes in both the working environment and educational reforms are still required to allow civil engineers to achieve more collaborative practices, in line with guidance.

It is recommended that further research looks to observe and analyse the ways in which guidance is used specifically by civil engineers to develop a rich understanding of current theoretical understanding, perspectives and role of the civil engineer in people-focused urban development projects, to ensure regenerative, people-focused designs are realised. Thus, a deeper understanding can be gained of the various, complex barriers that exist to people-focused design implementation.

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THE INTERPLAY BETWEEN STRESS, ANXIETY, AND DEPRESSION IN THE CONSTRUCTION INDUSTRY: SUBSTANTIATING THE KNOWLEDGE GAP

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Mental health challenges, including stress, anxiety, and depression, are increasingly recognised as pressing concerns within the construction industry due to its high-pressure environment. However, stress, anxiety, and depression do not exist in isolation but form an evolving cycle that can impact the construction professional's life and work productivity. This study aims to identify what research, if any, examines the interplay between stress, anxiety, and depression in the construction industry. It employs a systematic literature review (SLR) to investigate this relationship. The findings suggest that while stress is well-documented in the construction industry, its evolving relationship with anxiety and depression remains underexplored, with limited research addressing their combined effects. This study makes an essential contribution as the subjects of stress, anxiety, and depression are often investigated in isolation. Its originality is substantiating the research gap by focusing on their specific interplay. The findings turn the lens back on academics to explore this further, which can better inform policy and practice.

Keywords: interaction, mental health, systematic literature review, well-being

INTRODUCTION

Mental health challenges in construction are increasingly recognised as growing concerns, yet research often overlooks the interconnected nature of stress, anxiety, and depression. Ireland's construction industry has experienced continuous transformation over the past three decades, experiencing economic growth and decline cycles, impacting the workforce across the sector (Sweeney, 2021). External challenges, such as the 2008 global financial crisis and the COVID-19 pandemic, intensify psychological strain in an already high-risk environment (Winkler, 2024). Despite the known prevalence of mental health challenges in construction, such as stress, anxiety, and depression, literature frequently examines these issues in isolation, thereby failing to account for the ways they manifest in occupational settings. The Health Service Executive reports that stress, anxiety, and depression totalled 54% of lost working days due to poor mental health (Health Service Executive, 2019, cited in CIOB, 2020). Stress is widely recognised as a persistent and critical issue in the sector (Lingard and Francis, 2004; Vaux and Dority, 2020, cited in Bruce *et al.,* 2024) with construction managers experiencing high levels of workplace stress, which can

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negatively affect their wellbeing (Leung *et al.,* 2011). Moreover, research demonstrates that the compounding impact of increased stress and strain leads to burnout and ultimately can lead to mental health challenges such as anxiety and depression (Kamardeen and Sunindijo, 2017; Bowen *et al.,* 2014; Haynes and Love, 2004, cited in Chan *et al.,* 2020). However, this relationship may not be unidirectional. Evidence suggests that stress often acts as a precursor to anxiety and depression. Additionally, it is plausible that anxiety and depression influence stress, creating a cyclical effect rather than a linear process. This review, informed by Lazarus and Folkman's (1984, cited in Love *et al.,* 2010) theory of stress appraisal, supports this understanding that stress is cyclical. According to this model, stress manifests through an interaction between the individual and the environment. If stress is prolonged, it can trigger serious mental health challenges, which in turn can intensify stress (Love *et al.,* 2010), thus creating a feedback loop. In the construction context, this reinforces how one stressor can lead to further mental health challenges. By applying this model, the review highlights the importance of addressing the interplay of stress, anxiety, and depression collectively rather than in isolation.

Moreover, 70% of construction employers report poor mental health among staff, with the main challenge being stress, yet underreporting remains a persistent issue (CIF, 2020). However, with these insights, the literature addresses each one or all three of stress, anxiety, and depression in isolation within the construction industry, highlighting a critical gap. The concept of interplay, defined as 'the way in which two or more things or people affect each other' (Oxford Dictionaries, n/d), suggests that these mental health challenges do not work alone but interact in an interdependent, continuous cycle.

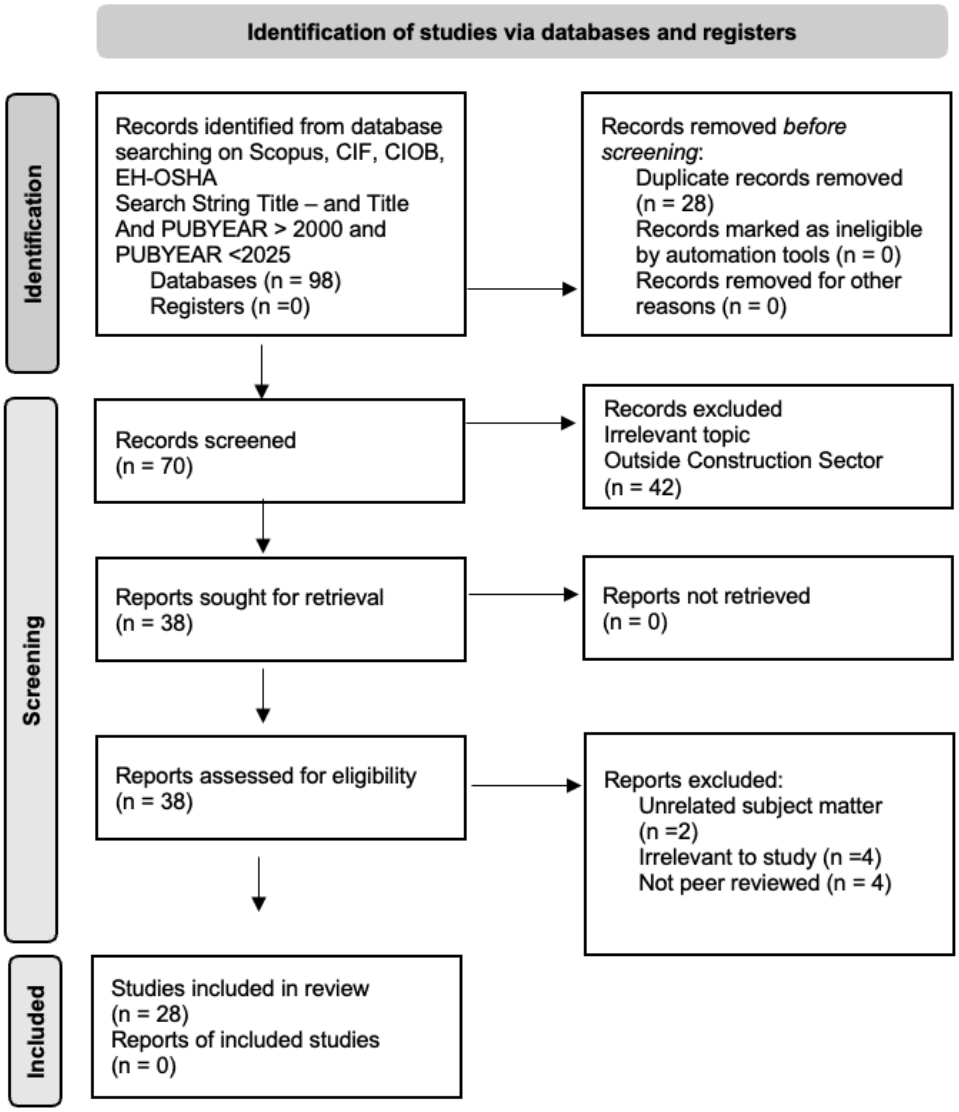
While studies explore stress, anxiety, and depression individually or as two or more factors together (Carmichael *et al.,* 2016; Nwaogu and Chan, 2022), they stop short of investigating their interplay. Even where Chan *et al. (*2020) argue the importance of studying depression and anxiety simultaneously to determine their dominance and their associated stressors in the sector, the analysis omits the moderating role of stress. Without a clear theoretical framework that outlines the relationship between stress, anxiety, and depression, initiatives remain reactive and often ineffective. To address this gap, the study investigates the following research question: How does the interplay between stress, anxiety, and depression affect mental health outcomes in the construction industry? This study evaluates current research through an SLR to assess whether an understanding exists and, if not, how future work can begin to comprehend this interplay and lay the foundation for future interventions unique to the construction workforce.

METHOD

This study employs a systematic literature review (SLR) guided by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework to ensure a rigorous approach. This review aims to investigate the current knowledge of stress, anxiety, and depression in the construction sector with a focus on identifying gaps in the interplay. The inclusion criteria comprise peer-reviewed journal articles, government and industry reports, and empirical studies (2000-2025) focusing on mental health in the construction sector. This timeframe was selected to capture early discussion on workplace mental health and recent post-COVID-19 insights. The exclusion criteria include studies outside the construction industry, non-peer-reviewed sources, and publications irrelevant to the subject matter or non-English language to

ensure relevance and reliability. The research is conducted across a peer-reviewed academic search engine (Scopus). Industry sources such as the CIF (Construction Industry Federation), CIOB (Chartered Institute of Building), and EU-OSHA (European Agency for Safety and Health at Work) were included. Scopus was chosen due to its extensive peer-reviewed research database, while the CIF and CIOB provide industry-specific insights. The investigation resulted in 98 papers initially identified. The purpose of excluding the remaining seventy papers, where twenty-eight were duplicates, and forty-two were either irrelevant to the study, unrelated to the subject matter or outside the scope of the construction industry. For example, papers discussing mental health by Pierce *et al. (*2020) and anxiety and depression by Sathyanarayanan *et al. (*2022) were excluded as they were unrelated to the construction industry. Finally, 28 papers were included in the analysis for the SLR. Search terms included "stress in construction workers", "depression in construction workers," "anxiety in the construction industry", "mental health in construction sector", and "workplace wellbeing in construction". Studies were screened at three levels: (1) Title screening, (2) Abstract screening, and (3) Full-text review. Figure 1 illustrates a PRISMA flowchart showing the identification, screening, eligibility, and inclusion process of the studies reviewed.

Figure 1: PRISMA Flowchart



LITERATURE REVIEW

This section presents the key findings from the systematic literature review and discusses the interplay of stress, anxiety, and depression in the construction industry.

Stress, Anxiety, and Depression - The Interplay

Mental health challenges in construction are often interconnected, creating a cycle where workplace stressors lead to anxiety and, if unaddressed, contribute to depression. Although this progression is frequently cited, the literature offers limited insight into the underlying factors connecting these challenges. For instance, high stress levels are prevalent in the Irish construction sector, with 97% of construction professionals reporting experiencing stress annually, 87% experiencing anxiety, and 70% experiencing depression (CIOB, 2020). These figures lack context around causality and may risk bypassing these multifactorial challenges.

The literature suggests that individuals in construction face a higher rate of mental health challenges. Yet, these issues remain a distant relation to physical health and safety (Oswald *et al.,* 2019, cited in Franklin *et al.,* 2022). Thus, an investigation as to why this remains the case is needed. Bowen *et al. (*2013) suggest that many stressors arise when workers sense an imbalance between work demands, their environment or individual resources, yet this limits the scope by failing to connect stress with mental health challenges such as anxiety and depression. Key stressors include being unable to relax, feeling low, impaired concentration, and social withdrawal (Franklin *et al.,* 2022) and can impair workers' health, work performance, and connections (Houtman, 2005, cited in Bowen *et al.,* 2013). This highlights the critical need to investigate the compounding effects of stress leading to anxiety and depression. For instance, Love *et al. (*2010) indicate that construction contracting professionals experience higher stress and lower support levels than consulting professionals, emphasising the need to investigate stress and the ripple effect. The harmful effects of stress have an unavoidable ripple effect that extends from individuals to their families, communities, and society (Bowen *et al.,* 2013) yet focusing solely on stress cannot fully portray an extensive picture of the co-occurring impacts that lead to anxiety and depression. Franklin *et al. (*2022) highlight gaps in how substantial stress impacts mental health, yet this study falls short of investigating the full interplay.

The sector is slow to make significant changes to improve mental health outcomes due to men in construction not engaging in activities outside of their workday (Franklin *et al.,* 2022). With depression and anxiety, the most studied mental health illnesses in the manual labour sector of the construction industry (Roy *et al.,* 2024), it is this escalating development that needs interventions that not only focus on stress but also investigate how anxiety and depression develop. Building on this, Jung *et al. (*2020) argue that work environment-related factors influence depression and anxiety, yet their analysis omits how these factors interact over time. While Love *et al. (*2010) suggest that, due to the difference in job roles, an individual can become more prone to work-induced anxiety depending on their role position, highlighting the need to investigate the factors that contribute not only to anxiety but the interplay elements of stress and depression.

Additionally, the mix of risk-taking behaviours, such as substance abuse and not seeking health advice, combined with occupational stressors, can lead to a decline in an individual's mental health and an inefficient work-life balance (Sherratt, 2018, cited in Hulls *et al.,* 2022). Similarly, negative coping strategies, such as the use of alcohol and drugs and distraction techniques, can lead to increased stress, anxiety, and

depression (Gomez-Salgado *et al.,* 2023). Yet, these studies stop short of exploring the dynamic interplay. While work stress is a high-risk factor for depression (Tanışman *et al.,* 2014; Boschman *et al.,* 2013, cited in Nwaogu *et al.,* 2019), it is often addressed in isolation rather than as part of a broader interplay. Depression influences individual perceptions and behaviours and can impact work performance and adversely impact work safety. Depression has also been noted to be highly likely to be generated by 'job demand and job control' imbalances (Jung *et al.,* 2020). Considering how these pressures interact with anxiety and stress, it tends to lead to a narrow focus, without a full investigation of the interplay. Bruce *et al. (*2023) synthesize multiple studies linking work stress and mental health challenges.

However, these reviews note an absence of research investigating the interplay of work-related factors that cause mental health challenges and suicide (Sunindijo and Kamardeen, 2017, cited in Bruce *et al.,* 2023). While the literature acknowledges that stress, anxiety, and depression co-exist, there is minimal investigation into how these challenges compound one another. A recurrent limitation across the literature is the compartmentalisation of mental health challenges. For example, Poon *et al. (*2013) note that long-term stress can cause burnout, leading to workplace accidents that adversely impact on the company with days lost from absenteeism. This study overlooks the relationship between anxiety and depression, an omission that weakens the understanding of how workers' mental health can deteriorate.

The emotional toll of enduring a multitude of stressors can lead to anxiety, low energy, and lack of self-esteem (Leung *et al.,* 2012, cited in Enshassi *et al.,* 2015). However, these mental health outcomes are not isolated; they interact dynamically and mutually reinforce one another. For example, physical stressors substantially impact an individual and lead to more serious health issues. In contrast, mental stressors have compounded effects in dealing with lapses in concentration and negative thought processes (Wahab, 2010, cited in Enshassi *et al.,* 2015). In the Irish-based organisation of the Chartered Industry Federation (CIF) report, 68% note that liaising with a physically unwell employee would be more manageable than one experiencing mental health challenges (CIF, 2020).

Notably, the CIF (2020) identifies stress as a significant issue; it does not examine how unresolved stress manifests as anxiety and depression or how these challenges might increase stress through absenteeism or interpersonal conflict, hence creating a continuous feedback loop. It points to a broader industry response that these challenges are treated separately rather than as an interconnected relationship. With the impacts of workplace stress and anxiety highlighted earlier by the CIOB (2020), stigma can then prohibit workers from seeking the necessary support for mental health challenges. Workers continue to suffer in silence, which often contributes to stigma, which is an integral aspect of the interplay between stress, anxiety, and depression. From the literature, there can be stigma and shame connected to men in construction going through mental health challenges, who are then unwilling to seek support. Thus, this exacerbates the situation with mental health challenges being disregarded and hidden (Clarke *et al.,* 2020). While construction companies appreciate the importance of staff wellbeing, managing mental health in the working environment remains challenging. The following section will investigate identified gaps and propose future research investigations.

Identified Gaps in the Interplay

Existing literature examines stress, anxiety, and depression extensively, yet often as discrete entities. This approach fails to recognise how these challenges interact, and by ignoring this interplay, research risks producing ineffective solutions to these mental health challenges. As Arensman *et al. (*2023) identified a critical gap, noting the need for workplace interventions that target 'non-clinical and clinical symptoms' of anxiety and depression, as no multi-level tool currently exists. This highlights the urgent need for co-created, evidence-based interventions tailored to the construction sector. Similarly, Cedstrand *et al. (*2022) argue that health interventions should be collaboratively created at an organisational level rather than placing responsibility solely on the individual.

A holistic, co-produced approach could positively influence the working environment and overall quality of life (Cedstrand *et al.,* 2022). Cheng *et al. (*2022) further emphasize that professionals with more organisational wellbeing resources create a more supportive working environment, positively impacting employee mental health. Despite existing efforts, Duckworth *et al. (*2022) find that current interventions are ineffective underscoring the urgent need for actionable solutions. Additionally, cultural barriers also contribute to poor mental health outcomes, with Aurelius *et al. (*2024) emphasising the need to change the industry's prevailing 'macho culture'. Many construction professionals felt a lack of trust in the workplace's offerings of mental health services as access often requires management approval (Wittenhagan and Meurk, cited in Aurelius *et al.,* 2024).

Furthermore, the uncertainty of what to do when a colleague or the individual themselves faces mental health challenges emphasizes the need for interventions (Aurelius *et al.,* 2024). Hulls *et al. (*2022) further outline how this culture discourages men from speaking about their mental health, reinforcing stigma, and causing a barrier to seeking support. Addressing the interplay of stress, anxiety, and depression is key to challenging these cultural norms and vital in creating impactful mental health interventions.

Despite these challenges in the sector, effective coping mechanisms are slow to be introduced. Nwagou and Chan (2022) highlights building resilience contributes to improved mental health outcomes and suggested how information technology is a vast area to help improve the wellbeing and safety of construction professionals. However, Oswald *et al. (*2019) reaffirmed the need for evidence-based interventions, noting that while studies on mental health in construction are expanding, most have used similar research approaches without identifying concrete solutions. This limits the progress of addressing the interplay where each factor can reinforce and intensify the others. Recognising the growing concern, the European Commission (EC) has prioritised Mental Health, which has led to a Healthy Workplaces Campaign (EC, 2021).

The initiatives focus on new and bypassed occupational stressors in the construction industry, reinforcing the need for targeted industry-specific mental health strategies. However, without deeper understanding of how these stressors contribute collectively to stress, anxiety, and depression, interventions may fail to address the full problem.

To substantiate the knowledge gap, Table 1 presents key findings from built environment literature highlighting critical research blind spots. Table 1 establishes that stress, anxiety, and depression are prevalent within the construction industry. A consistent theme across the literature is that these challenges are co-occurring rather than how they interact over time. While some research highlights coping

mechanisms, leadership factors or workplace stressors, they are examined in isolation without the investigation of a broader mental health interplay. Studies that do acknowledge the progression of stress to other mental health challenges often stop short of analysing the underlying factors. Therefore, there remains a significant gap in understanding how stress, anxiety, and depression interact in the context of the construction industry.

Table 1: Critical Review of the Interplay

Literature and Key Findings	Critical Review
Arensman *et al.* (2023) - A multi-level approach targeting both the company, and the individual reduces burnout, anxiety, stress, and stigma.	Treats stress and anxiety separately, misses how stigma may influence anxiety and depression.
Aurelius *et al.* (2024) - Workers lack knowledge on dealing with mental health challenges.	Highlights education gap: lack of awareness which allows stress to remain unrecognised or how it evolves into anxiety/depression.
Bowen *et al.* (2014) - Chronic stress harms individuals and society.	Stress is a fundamental trigger but does not explore its transition into anxiety or depression.
Bruce *et al.* (2024) -Interpersonal conflict is a high stressor.	Identifies conflict as a primary stressor but omits how it contributes to the onset of anxiety and depression.
Carmichael *et al.* (2016) - High stress among project managers negatively impacts both wellbeing/performances.	Notes stress impact but omits how it links to anxiety/depression; suggests a holistic approach for wellbeing programs.
Cedstrand *et al.* (2022) - Research on organisation level of mental health is limited.	Focuses on stress only; Excludes interplay with anxiety/depression which limits the scope.
Chan *et al.* (2020) - Need for research that promotes health instead of a focus on risks.	Highlights need for addressing depression and anxiety simultaneously but does not link with stress.
Cheng *et al.* (2022) - Stressful environment affects wellbeing; leaders should focus on employee needs and feelings.	Draws attention to leadership roles in wellbeing; Does not investigate how long-term stress influence the interplay.
Clarke *et al.* (2020) - Mental health affects industry/economy and given minimal attention.	Links impact of stress and stigma without critically analysing how stress leads to anxiety and depression.
Dodanwala and Santoso (2024) -Stress may predispose workers to mental health conditions such as depression.	Lacks inclusion of anxiety as a co-occurring aspect, missing opportunity to investigate how stress, anxiety, and depression interact in a cyclical manner.
Duckworth *et al.* (2022) - Stress, anxiety, and depression linked to poor quality of sleep, which exacerbates fatigue and depression.	Points to outcomes of interplay (fatigue, sleep) but not the interplay itself.
Enshassi *et al.* (2015) - Stress within the organisation is a major factor leading to burnout, organisational and behavioural stress.	Highlights stress and anxiety as a prevalent job-related outcome but not how it leads to depression.
Eyllon *et al.* (2020) - 68.2% of workers report stress, anxiety, or depression due to work.	Shows prevalence but treats them as distinct entities without investigation in the interplay.
Franklin *et al.* (2022) -Highlights low awareness in how serious stress is and the detrimental impact.	Companies are focused on growth than on employee wellbeing; Falls short of how stress may lead to anxiety and depression.
Gomez-Salgado *et al.* (2023) -Emphasis risk factors that can impact on levels of stress and anxiety.	Notes maladaptive coping strategies can lead to stress, anxiety, and depression. Acknowledges their co-occurrence but doesn't investigate interplay.
Hulls *et al.* (2022) - Stress is viewed as an inevitable part of the industry; intensified by economic pressures.	Treats conditions as individual aspects rather than investigating their compounded effect. Framing stress as inevitable may mask how stress can evolve.
Ibem *at al.* (2011) - Stress can be manifested into anxiety, anger, and depression among construction professionals.	Acknowledges progression from stress to other mental health challenges but lacks analysis into how these factors interact over time.
Jung *et al.* (2020) -Depression and anxiety negatively impacts work/ influenced by work.	Connects anxiety/depression but does not explore how stress might act as a precursor to these factors.
Langdon and Sawang (2017) - Identifies that stress, anxiety, and depression and exposure long term can lead to suicidal ideation.	Identifies the co-existence but stops in the investigation of how the interplay factors interact over time.
Leung *et al.* (2024) - 17.9 million workdays are lost in 2020 due to stress, anxiety, and depression. Highlights need emotional factors related to stress should be investigated.	Frames challenges in parallel rather than interconnected nature. Further exploration of how organisational culture may influence the interplay.
Love *et al.* (2010) - Need for an understanding around how and why stress is experienced.	The analysis identifies stressors than investigating the interaction among the interplay factors.
Nwaogu and Chan (2022) -Those who use emotion-focused strategies had higher levels of depression/anxiety; whereas those who use problem-focused strategies had reduced levels.	Shows how coping strategies influence mental health outcomes but does not investigate how stress triggers the onset of anxiety and depression collectively.
Nwaogu and Chan (2019) - High rates of suicide globally occur in construction due to stress/anxiety/depression.	Emphasizes need for further investigation into individual coping mechanisms; Lacks approach of how stress may act as a precursor to other challenges.
Oswald *et al.* (2019) - Suggest mental health as a problem but notes lack of studies on how to enhance outcomes.	Explores mental health in general rather than examining the relationship between the interplay.
Roy *et al.* (2024) - Highlights prevalence and risk factors of stress, anxiety, and depression.	Presents factors in isolation missing the interaction between the interplay.

CONCLUSIONS

The prevalence of research on stress, anxiety, and depression is well documented; however, they don't exist in isolation but form an evolving cycle that can impact the construction professional's life. These challenges intertwine in a cycle that remains poorly understood in the construction sector. 98 papers are initially identified in this SLR, down to 28 for inclusion. This gap reflects a shortfall in how mental health is managed within the industry, with a lack of literature on the interplay. The review emphasizes the urgent need for holistic mental health interventions and frameworks within the construction sector. Future research should focus on co-designed and co-produced mental health interventions that include perspectives from employees, management, and occupational health professionals. Furthermore, addressing both clinical and non-clinical symptoms and implementing individual coping strategies, team-based support, and organisational policies is vital. Moving forward, studies must examine the impact, if any, of the interplay between these three challenges of stress, anxiety, and depression. To support this, the above findings should guide further research and inform practical solutions that promote mental health in the construction industry. This study paves the way for future empirical research to test targeted interventions for the construction sector.

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WORKPLACE INCIDENT REPORTING: A CASE STUDY OF THE NIGERIAN CONSTRUCTION SECTOR

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The complex nature of the construction activities, equipment involved and associated work environment creates the potential for increased incidence occurrence. The risk is significantly higher in Low to Medium Income Countries (LMIC) where negligence, non-compliance with safety rules and poor management commitment towards a positive safety culture prevails. Relatedly, it undermines the reliability of incident data in understanding workplace risks and development of adequate policies and procedures in these work environments. The present study assessed Nigerian construction workers perceptions and barriers associated with incident reporting and advanced measures, aimed at improving reporting culture to aid incident investigation process. An online cross-sectional survey encompassing forty questions was categorised into seven key sections and administered. The results revealed a significant percentage of the study population, comprising of construction workers, were under-reporting incidents or not reporting any form of incidents. To strengthen the reporting culture among workers, a blame culture that encourages negative consequences related to workplace incident exists, and this must be addressed appropriately.

Keywords: workplace accident; blame culture; incident; near miss; reporting culture

INTRODUCTION

The construction industry has been characterised by under-reporting of incidents making the incident statistics sources of some nations unreliable as they present unrealistic estimates of the actual figures (Heuvel *et al.,* 2017; Kamoli *et al.,* 2022). This under-reporting of incidents exists both at the individual and organisational levels. At the individual level, it involves the failure of workers to report workplace injuries and illnesses to internal authorities at their workplaces, while at the organisational level, there is under-reporting of reportable injuries and illnesses by businesses to the regulatory bodies (Probst *et al.,* 2019; Kamoli *et al.,* 2022). Another dimension to organisational level under-reporting is when organisations manipulate safety records by under-reporting incident and injury figures while presenting their Health and Safety performance data during the contract bidding process (Egwunatum and Awo-Osagie, 2019). Under-reporting of incidents results in the utilisation of inaccurate information and the consequences include inadequate incident investigation

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procedure, ineffective policies and recurrence of workplace incidents (Kamoli et., al 2021). It has been estimated that around 33% of reportable incidents were not reported to the Health and Safety Executive under Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) in the United Kingdom (HSE, 2007).

Numerous regional studies have shown that the current system for generating national estimates of work-related injuries and illnesses significantly underreports both chronic conditions and acute injuries (Kamoli *et al.,* 2022; Ehiaguina *et al.,* 2024). The fundamental reason behind this commonly observed underreporting is that there exists a heavy reliance on self-reporting by employers and sometimes employees, resulting in significant biases and inaccuracies. In addition, the nature of the injury illnesses (acute or chronic), workplace culture and dynamics, along with statistical and administrative challenges at workplace further complicate the rates of reporting, as evidenced in studies conducted in Sweden, South Korea and Nigeria. It has also been established that policy and regulatory factors tend to play a crucial role in governing the injury and illness reporting rates (Ehiaguina *et al.,* 2024). It is important to note that the above outlined context discusses only the immediate or proximal causes of the accidents and may limit a comprehensive understanding of deeper accident causation. Theoretical frameworks such as the Systems-Theoretic Accident Model and Processes (STAMP) framework emphasize that accidents often arise from complex interactions between multiple system levels, including latent organisational and managerial factors (Zhang *et al.,* 2022). Well established models like the Reasons's Swiss Cheese model, commonly used in high hazard industries, illustrates how systemic weaknesses can align with active failures leading to accidents (Reason, 2016). By only considering immediate causes, there is a risk of overlooking deeper systemic and organisational issues that may predispose a system to eventual failure and increased incident frequency.

The construction industry is a hazardous industry, and the hazardous nature becomes more pronounced in a developing country like Nigeria due to inaccurate and unreliable safety records, outdated regulations and frequent workplace incidents. There is a high rate of work-related incidents in the Nigerian construction sector, and many go un-reported due to poor record-keeping and reporting by organisations (Agwu and Olele, 2014). Nigeria is experiencing steady growth in construction activities, but this is not commensurate with the health and safety performance (Okoye *et al.,* 2016), as workers are continually exposed to several health and safety risks such as fall from heights, vehicle incidents, cement burns, fractures, bodily injuries and backpain (Afolabi *et al.,* 2021). These workplace incidents result in pain to the victims, de-motivate workers, increases project costs, lowers productivity, delays project progress and damages the reputation of organisations (Okolie and Okoye, 2012). The Factories Act 2004 of Nigeria contains the legal requirements for the safety, health and welfare of every Nigerian worker. Embedded in this piece of legislation are legal obligations for reportable incidents with punishment for non-compliance set at N1,000 (less than £2), an amount incomparable with such an offence (Adaeze, 2021).

A strong correlation between the construction sector and the Nigerian economy exists as the growth of the construction industry leads to significant economic development (Oladinrin *et al.,* 2012). The construction sector contributed 3.88% to the nation's Gross Domestic Product (GDP) in 2015 (Abubakar *et al.,* 2018) while the projection for Nigeria's construction market is an annual growth rate of 3.2% from 2021 to 2050 (National Bureau of Statistics, 2015). The Nigerian construction worker is exposed to

several safety and health issues which include respiratory diseases, musculoskeletal disorders (MSDs), injuries to body and eyes, fractures and dermatitis (Afolabi *et al.,* 2021). In the construction safety literature pertaining to Nigeria, one study on 60 building construction sites revealed that the top causes of incidents were, lack of adherence to safety procedure, non-use of personal protective equipment, use of defective equipment and use of substandard construction materials, leading to injury from equipment, stepping on sharp objects and fall from heights (Orji et al.,2016). Non-compliance with safety rules among workers has also been mainly ascribed to negative safety attitudes and reflecting poor commitment by management towards a positive safety climate (Moda *et al.,* 2022).

Furthermore, periodic inspections and safety audits by competent personnel are vital in assessing compliance with safety procedures and improving the safety performance of the Nigerian construction industry (Ayangade and Ikpo, 2021). While the number of work-related incidents in the construction sector in Nigeria is high, a lot of these incidents are not reported by contractors to the appropriate ministry and this affects the reliability of the Nigerian incident data (Agwu and Olele, 2014). Under reporting of incidents affects the implementation of health and safety policies as well as the prevention of injuries and illnesses (Adetunji *et al.,* 2021). In addition, it was established that increasing the health and safety awareness of personnel in the construction industry in Nigeria will have the highest impact in enhancing the reporting occupational incidents (Kamoli *et al.,* 2022). While previous studies have examined under reporting of incidents and injuries at the organisational level in the Nigerian construction industry, the present study assessed barriers to under-reporting of workplace incidents at the individual level with an aim to improve the incident reporting culture.

METHOD

A quantitative non-experimental research design involving the use of survey questionnaires was used to study the opinions of a representative sample within a population. The survey study was cross-sectional to collect data at a specific point in time. The questionnaire was developed using information from existing literature and the authors past experiences working in the construction industry in Nigeria. Pilot study was conducted to determine its suitability and quality in support of the planned research study. The questionnaire was distributed to one university lecturer, four construction health and safety professionals, and three construction workers in Nigeria to give their feedback concerning the validity, relevance, inclusiveness, and clarity of the survey questions. Feedback received was used to revise the questionnaire for the actualisation of the research aim. The final research survey questionnaire comprised of seven sections encompassing thirty-nine closed-ended questions and one open-ended question.

Only construction workers in the Nigeria construction industry, above the age of 18 years, participated in the study. The set of criteria used to ascertain workers eligibility to participate in the study were workers between 18 and 65 years, only construction workers working in Nigeria, construction workers (scaffolders, painters, electricians, labourers, plumbers), and construction workers who can read, write and have access to internet facility; exclusion criteria - construction workers outside Nigeria, construction managers, architects, designers, office personnel in construction companies. The URL link to the survey questionnaire was sent out via email messages, WhatsApp messages and selected construction industry professional bodies social media platforms (to

enhance participation in the survey). Prior to completion of the survey, participants were assured of their right to withdraw or refrain from answering any or all the questions of the questionnaire at the participant information page. The participants were able to access the questionnaire only after their consent was obtained digitally. The Nigerian construction sector has an estimated population size of 7 million construction workers. To achieve a 5% acceptable margin of error and a confidence level of 95%, the appropriate sample size using the sample size calculator (Moda *et al.,* 2022) was determined to be 385. In total, 386 responses were obtained and the data from these responses were used to inform the study findings. The survey data were collected between 28th June 2022 and 5th August 2022.

Statistical Package for Social Sciences (SPSS) (v.28) was used for the data analysis. Descriptive statistics were used to describe demographic characteristics of the study population, perceptions, knowledge and barriers to incident reporting. Pearson correlation was applied to measure the degree of association between the demographic data collected and barriers to incident reporting, incident management experiences and perceptions associated with incident reporting.

RESULTS AND DISCUSSION

A total of 386 respondents completed the questionnaire and 40% of the respondents are between 36-44 years (40%) and 42.6% had 1-10 years' experience in construction. Table 1 shows the respondents knowledge of the importance of incident reporting in the workplace. Majority of the respondents (83%) had sound knowledge of what an incident entails which includes injury to worker, damage to equipment and near-misses (e.g., worker being almost injured). Forty-six (46) of the respondents, representing 12% of the participants, were not knowledgeable about what constitutes an incident. With a high proportion of the respondents in the age brackets 27-35 years (33%) and 36-44 years (40%), the group of construction workers falling between 27 and 44 years accounted for 73% of the Nigerian construction workers. The construction industry is a male dominated industry, and this was reflected in our study with 80% of the respondents being males and only 15.1% females. These coherent metrics of age and gender distribution among our study respondents indicates that our study population is an acceptable representation of the real-time global and regional construction worker populations.

Table 1: Respondents knowledge on the importance of incident reporting

Knowledge Assessment	Yes, n (%)	No, n (%)	Not Sure, n (%)
Does an incident include all the following: injury to worker, damage to equipment and worker being almost injured?	318 (83.0)	46 (12.0)	19 (5.0)
Do you know it is important to report all incidents?	370 (96.6)	9 (2.4)	4 (1.0)
Do you know reporting of incidents enables management to be aware of the issues and hazards in the workplace?	377 (98.5)	2 (0.5)	4 (1.0)
Do you know reporting of incidents will allow for proper investigations to be carried out to determine the causes?	371 (96.9)	5 (1.3)	7 (1.8)
Do you know reporting of incidents/incidents helps to improve the health and safety measures in the workplace?	369 (96.6)	3 (0.8)	10 (2.6)
Do you know that you are to report incidents/incidents helps to prevent it from happening again?	371 (96.6)	6 (1.6)	7 (1.8)

The greater proportion (96.6%) of the respondents agreed on the importance to report all workplace incidents Table 1. Relatedly, 98.5% of the construction workers surveyed were positive that reporting incidents would enable management to be aware of the hazards as well as the health and safety issues in the workplace. Ninety-six percent (96.9%) of the respondents affirmed that reporting of incidents allowed for proper investigations to be carried out to determine the causes, while 1.3% differed and 1.8% maintained a 'not sure' position on the issue. This knowledge is vital as it guides workers in identifying incidents to report them appropriately (Kamoli *et al.,* 2022). Table 2 showed 41.6% of the respondents either agree or strongly agree that they would not report an incident if nobody was injured in the process, and this was the topmost reason for their refusal to report workplace incidents (Table 2).

Table 2: Reasons for the under-reporting of incidents in the workplace by construction workers

Incident reporting barrier	Strongly Disagree (%)	Disagree (%)	Agree (%)	Strongly Agree (%)
Nobody was injured because of the incident	55 (14.4)	168 (44.0)	96 (25.1)	63 (16.5)
Lack of proper response from management from previous reports	35 (9.2)	189 (49.9)	102 (26.9)	53 (14.0)
The fear of losing one's job	48 (12.5)	186 (48.3)	106 (27.5)	45 (11.7)
It may result in the punishment of co-worker	44 (11.5)	196 (51.0)	116 (30.2)	28 (7.3)
The reporting tool is complex	40 (10.4)	214 (55.9)	113 (29.5)	16 (4.2)
The fear of being punished / victimized by management	42 (11.0)	202 (52.7)	98 (25.6)	41 (10.7)
Lack of awareness on how to report incidents	50 (13.1)	209 (54.7)	93 (24.3)	30 (7.9)
Someone was injured but not a serious one	78 (20.5)	213 (55.9)	68 (17.8)	22 (5.8)

Cross-tabulation of key barriers to incident reporting in relation to construction workers' years of experience is shown in Figure 1. Across all experience levels, the most common reason for not reporting incidents was the perception that nobody was injured because of the incident. This was particularly prevalent among workers with 21-30 years of experience (53%) and those with 1-10 years (45%), suggesting a persistent cultural norm in the industry that prioritises outcomes (i.e., injury or damage) over proactive safety practices like near-miss reporting. A notable trend across experience groups was the fear of being punished or victimised by management, which was reported by 45% of workers with 0-1 years of experience and increased slightly with years of experience, peaking at 50% for the most experienced group (21-30 years). This finding implies apprehension regarding retaliation is not limited to early-career workers, but remains an entrenched barrier across career stages, reflecting a systemic issue in safety culture and trust.

Similarly, lack of proper response from management was a significant barrier across all groups, with the highest incidence (59%) reported by those with over 20 years of experience. Possibly due to repeated exposure to unaddressed reports, experienced workers may develop cynicism toward the incident reporting process. The findings highlight that while some barriers, like procedural awareness, diminish with experience, others—such as fear of retaliation, lack of management response, and normalisation of under-reporting—persist or even increase over time. The perception of the Nigerian workers to the reporting of incidents is described in Table 3 where one

third of the respondents (36.5%) felt that incident investigation process was mainly for supervisors and managers and 64.5% confirmed that construction workers are not involved in the incident investigation process (Table 3).

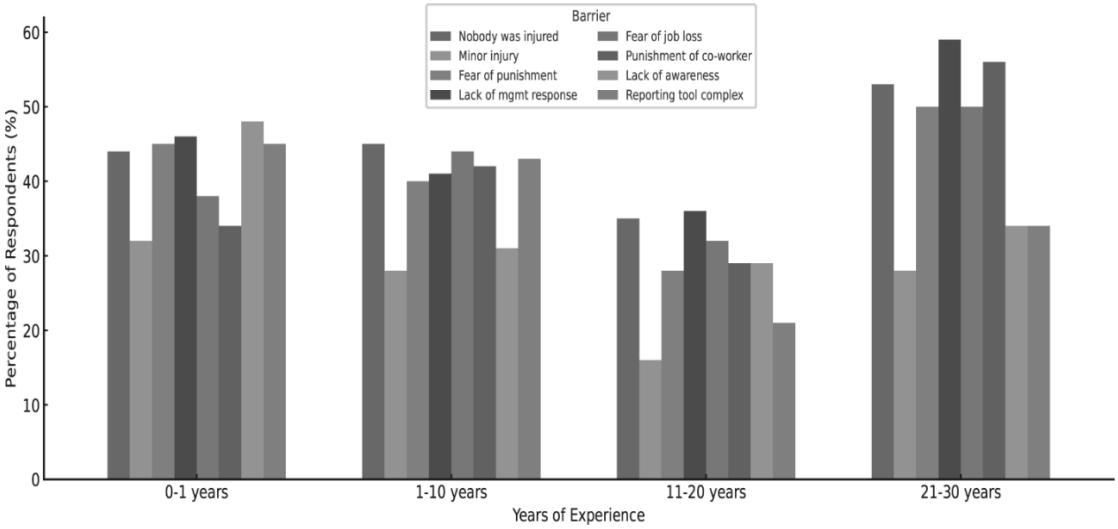


Figure 1: Cross tabulation of incident reporting barrier with years of experience

Close to half of the respondents (44.4%) believed that reporting a workplace incident may put them in some sort of trouble. Ninety-Four respondents, which represented 24.7% of the study population, believed that incidents should only be reported when it had resulted in an injury to a worker or equipment/property damage. It has been reported that some organisations blame and punish workers for causing workplace incidents and this has resulted in the under-reporting of workplace incidents (Eskandari *et al.,* 2017).

Table 3: Nigerian construction workers perceptions to incident reporting

Nigerian construction worker perceptions to incident reporting in the workplace	Strongly Disagree, n (%)	Disagree n (%)	Agree n (%)	Strongly Agree, n (%)
Reporting of incidents is the responsibility of health and safety personnel	56 (14.7)	213 (55.7)	87 (22.8)	26 (6.8)
The incident investigation process is for supervisors and managers	67 (17.5)	176 (46.0)	118 (30.8)	22 (5.7)
Reporting of incidents may put me in trouble	30 (7.8)	183 (47.8)	146 (38.1)	24 (6.3)
Reporting of incidents should be done only when there is injury to personnel or property damage	87 (22.8)	200 (52.5)	69 (18.1)	25 (6.6)
As a construction worker, I should be trained on incident reporting before/during construction projects.	12 (3.1)	15 (3.9)	167 (43.7)	188 (49.3)
Reporting of incidents is not effective as management will not respond positively	66 (17.3)	191 (50.0)	89 (23.3)	36 (9.4)

Table 4 shows the incident management experiences of the Nigerian construction workers. The documented response showed that 86.5% of them responded positively to having received some level of training on incident reporting, while 80% had been informed about the incidents which occurred on their construction sites or projects. This shows that the respondents have a good level of awareness and communication regarding workplace incidents, which aligns with studies emphasising the role of training and communication in effective safety management and incident reporting (Hinze *et al.,* 2013). However, only 35.5% of the respondent either agree or strongly

agree that they are involved in any investigation process when necessary, indicating a gap in participatory safety practices (Table 4). This limited involvement may reflect a top-down approach to incident reporting and management, which can hinder safety outcomes at the workforce level (Reason 2016; Probst *et al.,* 2019). On management's response to incidents, 72.2% of the construction workers responded that management responded swiftly when incidents were reported and an overwhelming majority (90%) of the respondents agreed that they were aware of the different channels created by management for the reporting of incident in the workplace. Although these are positive indicators, the received responses showed that that 19.5% of the respondents and their colleagues have either been punished or victimised for reporting a workplace incident and is a significant cause of concern. Fear of retaliation can severely undermine trust in reporting systems leading to underreporting, as observed in several studies on organisational safety culture (Probst *et al.,* 2019).

Table 4: Incident management experiences of the Nigerian Construction workers

Incident management experiences	Strongly Disagree, n (%)	Disagree, n (%)	Agree, n (%)	Strongly Agree, n (%)
As a construction worker, I am trained on incident reporting before/during construction projects.	10 (2.6)	41 (10.9)	229 (60.4)	99 (26.1)
As a construction worker, I am informed about the incidents which has occurred on the construction site	19 (5.0)	57 (15.0)	205 (53.9)	99 (26.1)
The lessons learned from incidents on the construction site are shared with us.	18 (4.8)	59 (15.6)	198 (52.7)	101 (26.9)
I/my colleague is/are involved in the investigation processes	35 (9.1)	212 (55.4)	106 (27.7)	30 (7.8)
Management responds quickly to incidents reported.	20 (5.2)	87 (22.6)	221 (57.6)	56 (14.6)
I am aware channels to report incidents	8 (2.1)	30 (7.9)	255 (66.9)	88 (23.1)
The incident reporting channels are effective and result in positive responses from management	13 (3.4)	86 (22.8)	215 (56.9)	64 (16.9)
I/my colleague have been punished/victimized for reporting an incident	43 (11.3)	263 (69.2)	55 (14.5)	19 (5.0)

The perception of the respondents that incidents should only be reported when there had been an injury to personnel or damage to property, in addition to most of the workers being oblivious to the importance of reporting near-miss incidents, indicates that reporting of near-miss incidents, a proactive approach to resolve hazards and prevent the occurrence of injury to personnel or damage to property, is very much lacking (Sheikhtaheri, 2014). Majority (93%) of the respondents agreed that construction workers should be trained on incident reporting to improve the incident reporting culture. This would help in blame-free reporting and learning from incident causative factors, an important component emphasized by global organisations on safety (WHO, 2022). To effectively investigate an incident, 63.5% of the respondent disagree with the view that leaving the investigation to supervisors and managers might not efficient but rather carrying every party along is seen as a better strategy (Table 3). It is vital that management and workforce are involved in the incident investigation process for a beneficial outcome as the inclusion of workers or their representatives in the investigation process would allow the harnessing of their practical knowledge when defining appropriate corrective actions (HSE, 2007).

Additionally, this would drive home the message that incident investigation is for the benefit of everybody in the workplace.

CONCLUSION

The complexities of construction activities coupled with the negligence and non-compliance with safety measures has significantly increased the risk of exposure to incidents in the Nigerian construction industry. This study gave insights into the knowledge level, perceptions and the reasons for under-reporting of incidents with a view to improve the incident reporting culture. In the current study, it was observed that more than 1/3rd of the participating construction workers attested to not reporting a workplace incident and this needs urgent intervention. It was further evident that employees are hesitant to report on-site occurrences due to reasons like job security concerns, and even when reported, the level of responsiveness and immediate action from senior management was found highly lacking. Hence, there is a need for organisations to focus on encouraging workers to report workplace incidents even if nobody was injured in the process, without the fear of losing their jobs. Considering the high perception among the construction workers that incidents should be reported only when there had been an injury to personnel or damage to property implied that near misses were not viewed as actual incidents and there exists an urgent need for management to enhance safety awareness on this subject, especially among Nigerian construction workers. It is important to note that the study primarily focused on the perceptions and experiences of construction workers within the Nigerian construction industry. As a result, the findings may not be fully generalisable to all construction sectors and geographic areas, especially considering the diversity in organisational practices and varying regional safety enforcement levels. In addition, the study relied on self-reported responses from workers, which may be subject to response bias.

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DIGITALISATION OF OCCUPATIONAL SAFETY AND HEALTH IN CONSTRUCTION: A CROSS-NATIONAL PERSPECTIVE

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Construction remains one of the most hazardous sectors worldwide, driving interest in digital technologies to enhance Occupational Safety and Health (OSH) management. This study explores the current state, benefits, challenges, and future directions of OSH Digitalisation in the construction industries of the UK, Canada, and South Korea. A structured cross-national questionnaire survey yielded 74 valid responses from professionals across the three countries. Results show that while technologies like Building Information Modelling (BIM), Artificial Intelligence (AI), and drones are widely used, the overall level of OSH Digitalisation is moderate. Significant differences emerged based on job roles, company size, and national context. Common challenges included resistance to change, lack of technical skills, and regulatory issues. Strategic priorities differed: Korean respondents favoured "Offering Financial Incentives from the Government," while UK professionals emphasized "Providing Training and Support for Staff." Nevertheless, there was broad consensus on the future importance of technologies such as AI and Machine Learning (ML). This study addresses a critical gap by providing a comparative, data-driven view of digital OSH transformation and offers insights for policymakers, industry leaders, and researchers.

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INTRODUCTION

Construction has long been regarded as one of the most hazardous sectors worldwide, accounting for a disproportionate number of injuries and fatalities each year (Jeong and Jeong, 2022). While construction sites have always involved dynamic conditions, complex subcontracting structures, and human-related uncertainties such as fatigue and cognitive overload, the increasing availability and affordability of digital technologies in recent years have opened new possibilities for innovation in Occupational Safety and Health (OSH) management. Rather than assuming that these technologies are inherently necessary or universally effective, this study examines how such tools are perceived, adopted, and prioritised across diverse national and organisational contexts. It explores the socio-technical and institutional conditions under which digital transformation in construction safety emerges and evolves, moving beyond reactive risk control toward more proactive, data-driven strategies (Li, 2019).

In response to these evolving challenges, digital technologies are gaining momentum as a transformative force capable of shifting safety management from reactive risk control toward proactive and data-driven strategies (Li, 2019).

Over the past decade, technological advancements have introduced a range of digital tools for enhancing OSH in the construction sector. These include Building Information Modelling (BIM), Artificial Intelligence (AI), Internet of Things (IoT), drones, wearable sensors, Virtual and Augmented Reality (VR/AR), and cloud-based analytics platforms (Tender *et al.,* 2023). These tools support early hazard detection and real-time safety integration throughout the project lifecycle. Digitalisation is increasingly viewed not just as an efficiency tool, but as a driver of systemic transformation (Na *et al.,* 2023).

However, the adoption of digital OSH tools varies significantly across regions, sectors, and roles. Factors such as national policy maturity, workforce skills, regulatory incentives, organisational structure, and cultural attitudes shape how these technologies are perceived and implemented. For instance, the UK has taken a policy-led approach to safety digitalisation, promoting BIM integration and Design for Safety principles through public-sector mandates (Ramos Martín *et al.,* 2023). Canada emphasizes training and stakeholder collaboration, especially in wearable technology and remote monitoring applications (Vanderstichelen *et al.,* 2024). South Korea, despite its advanced digital infrastructure, has traditionally exhibited conservative digital adoption in the construction industry (Na *et al.,* 2023).

Beyond national differences, organisational characteristics such as company size, leadership commitment, and employee digital literacy also influence adoption patterns. Small and medium-sized enterprises (SMEs) may lack the resources or capacity to implement digital OSH tools, while larger firms tend to have better access to technical support and investment capital (Lei *et al.,* 2018). Furthermore, individual factors such as job role, age, and familiarity with technology can affect both the willingness and ability of workers to engage with digital systems (Stara *et al.,* 2022).

This complex interplay of macro- and micro-level variables calls for a more integrated understanding of how digital OSH technologies are adopted and utilised.

While there is growing literature on the technical potential of various digital tools for OSH improvement, few studies have comprehensively compared adoption patterns, benefits, and barriers across countries or organisations. Most existing research remains technology-specific, sector-limited, or geographically focused. There is a noticeable gap in empirical, cross-national studies that examine digitalisation in OSH from a multidimensional perspective—integrating national context, organisational attributes, and user experiences (Xu *et al.,* 2024; Na *et al.,* 2023).

This study addresses that gap through a structured, comparative survey conducted across the United Kingdom, Canada, and South Korea—three countries with contrasting institutional frameworks, regulatory approaches, and levels of digital maturity. Specifically, the research seeks to: (1) Assess the current level of digital technology adoption in OSH across countries; (2) Identify perceived benefits and barriers to digitalisation in construction safety; (3) Explore how digital OSH adoption varies by country, experience, job role, and company size; and (4) Examine preferred strategies and performance indicators used to promote digital safety.

By analysing a combination of demographic, perceptual, and contextual data, the study offers cross-national insights into how construction professionals engage with digital transformation in OSH. The findings aim to inform both academic research and practical decision-making in developing more inclusive, resilient, and scalable digital safety strategies within the global construction sector.

METHODS

Development and structure of the Questionnaire survey

The questionnaire used in this study was developed based on a comprehensive review of the literature concerning the adoption of digital technologies in Occupational Safety and Health (OSH) management within the construction sector. The instrument was grounded in conceptual frameworks such as the Technology Acceptance Model (TAM) and supported by empirical findings from Na *et al. (*2023), Xu *et al. (*2024), and Li (2019). The questionnaire targeted professionals in the construction sector across the UK, Canada, and South Korea to capture cross-national insights. These countries were selected for their differing emphases and contexts in construction safety digitalisation, offering valuable insights into a range of regulatory frameworks and technological environments.

To capture a multidimensional understanding of stakeholder perceptions and practices, the questionnaire was structured into four thematic sections, including **Demographics and Professional Background, Current Level of Digitalisation, Perceived Benefits and Outcomes,** and **Future Strategies and Key Performance Indicators (KPIs).**

To ensure relevance and clarity, the survey was piloted with a small group of industry experts and revised based on their feedback. The same questionnaire was used across all three countries to maintain consistency, while allowing for minor linguistic and cultural adjustments where necessary.

Data Collection and Sampling

To capture diverse and comparative insights, the survey was distributed across the UK, Canada, and South Korea —countries that reflect varied digital OSH landscapes shaped by different policy environments, technological readiness, and cultural

contexts. The UK tends to adopt a policy-driven and standardised approach (Ramos Martín *et al.,* 2023), Canada places emphasis on decentralisation and training (Vanderstichelen *et al.,* 2024), and South Korea illustrates the integration of advanced technologies within a traditionally cautious adoption culture (Na *et al.,* 2023). These variations provide a meaningful basis for cross-national comparison.

Data were collected online (Sep 2024-Mar 2025) via purposive and snowball sampling through professional networks in the UK, Canada, and Korea (Etikan *et al.,* 2016). The survey was distributed through professional networks, associations, and academic contacts. Participants were eligible if they had at least one year of experience in construction and were engaged in roles related to safety, project management, or digital technology.

A total of 74 valid responses were collected: 47 from the UK, 12 from Canada, and 15 from South Korea. Incomplete and duplicate responses were excluded. The final sample reflected a reasonable balance across job roles and company sizes, ensuring meaningful cross-national comparisons.

Participation of the survey was voluntary, and respondents were informed about the study's purpose and data handling practices. Personal identifiers were not collected, ensuring anonymity and compliance with research ethics standards.

Data Analysis

Descriptive statistics were used to analyse frequency distributions, and Pearson's Chi-square test was used to explore relationships across countries. Where necessary, adjacent response categories were grouped to meet expected cell count assumptions. Given the limited sample sizes, particularly in Canada and Korea, these results are interpreted as exploratory rather than confirmatory (Jeong and Jeong., 2021; Lei *et al.,* 2018).

In cases of low expected cell counts, some categorical responses were grouped to meet assumptions. Nonetheless, all statistical findings are presented as indicative, not confirmatory

- **Null Hypothesis (H_0):** No significant difference exists across countries.
- **Alternative Hypothesis (H_1): A** significant difference exists across countries.

The hypothesis testing was applied to variables such as job role, technology use, benefits, and barriers, with significance set at $p < 0.05$. This mixed descriptive-inferential approach enabled the identification of statistically significant national differences in digital OSH adoption. The methods adopted in this study ensure a robust, comparative, and statistically grounded understanding of how digital OSH technologies are perceived and implemented across diverse construction contexts.

RESULTS

This study examined digitalisation in OSH management across South Korea, Canada, and the United Kingdom, focusing on professional and organisational profiles, technology usage patterns, observed outcomes, and strategic preferences. Tables 1-4 present comparative results supported by Pearson's Chi-square tests. For visual clarity, response categories have been grouped in the summary table. However, the reported Chi-square statistics were calculated using the original, ungrouped data. Due to small sample sizes in several subcategories, particularly within the Canadian and Korean datasets, certain groups were aggregated to enhance interpretive clarity.

Therefore, Chi-square test results should be interpreted with caution as indicative rather than confirmatory.

Demographics and Professional Background

Significant variations were observed in job roles ($\chi^2 = 13.85$, $p = 0.01$). UK participants were more frequently health and safety managers (11/29), reflecting different national approaches to OSH governance, whereas Korean respondents were predominantly "Construction managers" (9/15). Company size also differed significantly ($\chi^2 = 8.37$, $p = 0.04$): All Korean respondents were from "Large firms", while UK and Canadian respondents were distributed across "Micro to Large firms".

Table 1: Respondents' Backgrounds by Country: (a) Job Role, (b) Company Size, and (C) Education Level

Category	Subcategory	UK	Canada	Korea
Job Role	Construction manager	1	2	9
(a)	Health and Safety Manager	11	2	0
	Project Engineering	2	2	0
	Quality Manager/ Production Manager/ Quantity Surveyor/ Commercial Manager	2	0	0
	Other	12	5	6
Company Size	Micro/Small/Medium	12	7	0
(b)	Large (250+)	19	5	15
Education Level	Bachelor or below	13	3	7
(c)	Master	14	4	2
	Ph.D.	4	3	6

In terms of educational attainment, most respondents in the UK (14/31) and Canada (4/12) held "Master's degrees". In contrast, a higher proportion of Korean respondents held "PhDs", which can be attributed to their job composition—many Korean respondents were academics or professors rather than field-based professionals. The Chi-square test for education level showed no statistically significant differences ($\chi^2 = 9.78$, $p = 0.28$), indicating relatively similar baseline capacities for engaging with digitalisation.

Current Level of Digitalisation in OSH

Table 2: Current digitalisation levels in OSH: (a) Current level of digitalisation and (b) Digital technologies for OSH

Category	Subcategory	UK	Canada	Korea
Current level of digitalisation	Highly Digitalised	2	0	0
(a)	Moderately Digitalised	5	4	5
	Slightly Digitalised	16	8	10
	Not Digitalised	3	0	0
Digital technologies for OSH	AI/ML	10	5	8
(b)	AR/VR/MR	7	3	11
	BIM	12	8	14
	Off-site construction	7	6	1
	Others	31	19	28

As shown in Figure 2, despite having robust technological infrastructure, most respondents across countries rated their workplaces as only "Slightly digitalised" ($\chi^2 = 3.10$, $p = 0.37$). This likely reflects the inherent complexity of construction environments, where, unlike manufacturing, site variability makes it difficult to apply a standardised set of digital tools. As a result, decision-makers may selectively adopt only a few technologies deemed feasible. Technology preferences also varied: The UK emphasized "AI/ML" (10/67) and other digital OSH tools aligned with long-term government strategies (Egan, 1998). Canada demonstrated a more balanced adoption

pattern, with a focus on "off-site construction" technologies and "BIM" (14/41), reflecting its decentralised governance and emphasis on context-specific training approaches. Korea prioritised "BIM" (14/62), largely due to mandatory BIM implementation for public construction projects (Kim *et al.,* 2020), and "VR/AR/MR" (11/62) for safety training (An *et al.,* 2020).

Observed Outcomes and Perceptions

Table 3: Perceived OSH Improvements from Digital Initiatives by Country

Category	Subcategory	UK	Canada	Korea
Successful digital initiatives for OSH performance	Safety and Health Monitoring	9	7	14
	Audits and Inspections	12	4	3
	Incident Reporting	11	4	5
	Safety and Health Decision Making	5	3	8
	Safety and Health Education and Training	10	8	11
	Hazard Identification	13	5	6
	Others	54	48	30

Reported improvements in OSH outcomes, as perceived by respondents, varied significantly by country ($\chi^2 = 37.82$, $p = 0.00$).

In the UK, respondents reported perceived improvements in "Hazard identification" (13/114) and "Audits and inspections" (12/114), aligning with the country's long-established, regulation-driven approach to construction safety. The UK has made significant progress in safety outcomes since the 1990s and is now considered one of the safest countries in terms of construction fatalities (Rawlinson and Farrell, 2010).

Canadian respondents most frequently cited improvements in "Safety education and training" (8/79), consistent with their collaborative, workforce-focused safety culture. These patterns demonstrate how national regulatory environments shape perceptions of where digital tools have the most value, while Korean respondents reported enhanced "Safety monitoring" (14/77) and "Safety education and training" (11/77), consistent with their high levels of technical adoption. Since 2020, the South Korean government has enacted stronger safety regulations, such as the Occupational Safety and Health Act and the Serious Accidents Punishment Act (Jeong and Jeong, 2021). Consequently, company leaders have become more proactive in adopting safety technologies to mitigate liability and reduce accident rates.

Future Strategies and Performance Indicators

Table 4: Future Strategies and Performance Indicators by Country: (a) Challenges in adopting digital tech, (b) Strategic Preferences, and (c) Preferred KPIs

Category	Subcategory	UK	Canada	Korea
Challenges in adopting digital tech (a)	Resistance to Change	12	8	14
	Lack of Technical Skills among Staff	15	7	2
	Integration with Existing Systems	17	6	5
	Data Privacy Concerns	14	10	6
	Others	39	18	19
Strategic Preferences (b)	Financial Incentives from the Government	14	5	15
	Developing Industry-wide Standards	17	7	7
	Collaboration between Industry and Academia	14	5	2
	Engage in Change Management	9	5	0
	Implementing Clear Data Security Policies	10	7	0
	Providing Training and Support for Staff	19	7	3
	Others	14	8	2
Preferred Key Performance Indicators (KPIs) (c)	Industry Standards	14	9	6
	Employee Engagement	17	8	7
	Near-Miss Reporting Rate	10	6	13
	ROI	10	4	15
	Others	84	44	49

"Resistance to change" emerged as the most cited barrier overall (34/192) and was particularly prominent in South Korea (14/46), though the difference across countries approached significance ($\chi^2 = 13.02$, $p = 0.09$). Korean organisations, despite having access to advanced technologies, face institutional and behavioural barriers. This reflects a misalignment between digital readiness and organisational adaptability, consistent with the Socio-Technical Systems theory, which emphasizes the need for joint optimisation between people and technology (Jeong and Jeong, 2024).

Strategic preferences varied significantly across countries ($\chi^2 = 17.36$, $p = 0.01$). However, these findings should be interpreted with caution due to the limited number of responses from Canada and Korea, which may affect the stability of the statistical inference.

UK participants prioritised structured "training programs" (19/97) embedded in professional practice (Sherratt, 2010), while Korean respondents favoured "governmental financial incentives" (15/29). Canadians expressed relatively balanced support across several strategies, including collaboration and benchmarking.

Preferred key performance indicators (KPIs) converged internationally, with "ROI", "near-miss reporting rates", and "employee engagement" emerging as the most common ($\chi^2 = 16.31$, $p = 0.70$). UK respondents emphasized "employee engagement" (17/135), reflecting their professionalised OSH culture. In Canada, benchmarking against "industry standards" (9/71) was more prominent, aligning with their decentralised yet structured safety evaluation approach. Korean respondents prioritised "ROI" (15/90), consistent with their focus on cost-justification of new technologies.

Discussion and Interpretation: A Socio-Technical and Institutional Perspective

South Korea faces persistent resistance to digital transformation in OSH practice, despite strong infrastructure and digital literacy levels. The study captures subjective perceptions shaped by organisational culture, professional expectations, and optimism bias, and systemic constraints like weak incentives and risk-averse cultures, explaining why digital OSH transformation doesn't follow a straightforward technological progression.

This aligns with Socio-Technical Systems (STS) theory, particularly the principle of joint optimisation (Baxter and Sommerville, 2011), which holds that technology alone cannot succeed without organisational and cultural alignment. In Korea, hierarchical decision-making and institutional conservatism often suppress experimentation, reinforcing outdated practices. Jeong and Jeong (2024) similarly found that Korean stakeholders often perceive new technologies as uncertain and difficult to control. In large firms, senior leadership tends to prioritise stability over innovation, weakening incentives to adopt emerging solutions.

As Trist (1981) emphasized, successful digital transformation requires the co-evolution of tools, people, and policies. Korea's case illustrates a decoupling between technological readiness and behavioural integration. Moving forward, Korean organisations must complement infrastructure investment with adaptive routines—such as feedback loops, pilot testing, and cross-functional learning—to effectively integrate digital tools into daily safety management.

By contrast, the UK and Canada have different approaches to digital OSH implementation. The UK has robust institutional frameworks, while Canada's

decentralised model allows regional autonomy and fosters innovation but may lead to fragmentation.

Comparison with Previous Research

This study addressed key knowledge gaps in the digitalisation of occupational safety and health (OSH) by exploring four dimensions. A cross-national survey revealed varying levels of digital maturity—Korea led in BIM adoption due to public-sector mandates, yet most countries reported only slight digitalisation, indicating that infrastructure alone is insufficient. Perceived benefits and barriers to digitalisation were identified, though findings are based on small, self-reported samples and should be viewed as exploratory. Digital adoption varied by country, job role, and company size; in Korea, resistance was common in large, hierarchical firms, while in the UK, adoption correlated with the presence of safety managers. Preferences for promoting digital safety also differed: Korea favoured financial incentives, the UK emphasized training, and Canada leaned toward benchmarking. However, there was broad agreement on key performance indicators, including ROI, near-miss reporting, and employee engagement.

Practical Implications

The findings provide critical implications for improving digitalisation strategies in each country. In South Korea, efforts must extend beyond mandated technology adoption to focus on cultural adaptation, worker engagement, and stronger management commitment. In the United Kingdom, continued professionalisation and structured training—particularly for SMEs—will further integrate digital OSH tools into organisational practices. In Canada, the decentralised, collaboration-based model would benefit from the introduction of national benchmarking standards to balance local flexibility with strategic coherence.

CONCLUSIONS

This study examined the digitalisation of occupational safety and health (OSH) practices across South Korea, Canada, and the UK, underscoring that effective implementation depends not only on technology but also on socio-cultural and institutional readiness. Organisational structures and governance contexts significantly influence digital adoption. Despite national differences, convergence in key metrics—such as ROI, near-miss reporting, and employee engagement—suggests potential for international benchmarking.

This study does not measure actual safety outcomes based on field data but reflects participants' perceptions, which may be shaped by internal narratives, professional norms, or optimism bias. Thus, any discussion of "benefits" must be understood as perceived rather than empirically validated effectiveness.

From these insights, we propose country-specific strategies: The UK could enhance safety infrastructure through structured professional training, standardisation, and SMEs support, while Canada could establish national benchmarks through digital training and knowledge-sharing platforms.

The research reveals that digitalisation preferences, strengths, and barriers vary across contexts, offering guidance for tailoring OSH strategies. In Korea, infrastructure must be accompanied by institutional incentives and leadership renewal. Policy maturity, institutional culture, and professional ecosystems shape digital transformation. The UK and Canada show structured governance and collaborative learning environments

support sustained adoption. Future research should employ longitudinal or mixed methods designs to explore leadership and institutional design, with a focus on fostering the integration of digital tools.

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BUILDING A SAFER TOMORROW: TRIPARTITE ENGAGEMENT AND CO-CREATION FOR ENHANCED DESIGN FOR OCCUPATIONAL SAFETY AND HEALTH IN MALAYSIA

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The Construction (Design and Management) (CDM) Regulations have been instrumental in advancing design for occupational safety and health (DfOSH) in the UK, contributing to improvement in construction safety and health since 1995. Following this model, Malaysia introduced the Occupational Safety and Health (Construction Work) (Design and Management) Regulations 2024 to formalise DfOSH practices. However, its implementation presents challenges. This study systematically reviewed 17 Malaysian DfOSH-related publications to identify prevailing challenges and propose actionable solutions. Key challenges include insufficient integration of DfOSH in university curricula, lack of designer competency in hazard mitigation, fragmented project delivery systems, and weak enforcement due to limited regulatory resources. Using thematic analysis, findings informed the development of a Tripartite Engagement Framework based on the Triple Helix Model and Institutional Theory. The framework articulates the synergistic roles of academia (education and research), industry (application and culture), and government (policy and enforcement) in advancing DfOSH. By aligning efforts across stakeholders, this study offers a structured pathway for embedding DfOSH as a core component of construction safety, ensuring compliance with new regulations while cultivating a proactive safety in Malaysia.

Keywords: Design for Safety; tripartite; collaboration; construction; Malaysia

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INTRODUCTION

The construction industry remains one of the most hazardous sectors worldwide, consistently exhibiting elevated accident and fatality rates (Sarvari *et al.,* 2024). To address this, various countries have introduced regulations that integrate occupational safety and health (OSH) considerations into the initial design stages of construction projects. For instance, the United Kingdom (UK) introduced the Construction (Design and Management) (CDM) Regulations 1994 and later refined in 2007 and 2015 (Health and Safety Executive (HSE), 2015). The CDM fosters a collaborative approach among clients, designers, contractors, and workers, enhancing risk management and reducing accidents across the project lifecycle.

Drawing inspiration from the UK's success in improving construction safety and health outcomes, Malaysia introduced the Occupational Safety and Health in Construction Industry (Management) (OSHCI(M)) guideline in 2017. Grounded in DfOSH principles, this guideline encourages stakeholders to prioritise safety and health from project inception (Che Ibrahim and Belayutham, 2020). Subsequently, Malaysia enacted the Occupational Safety and Health (Construction Work) (Design and Management) Regulations 2024 (Department of Occupational Safety and Health (DOSH), 2024), which mandate that designers, clients, and contractors incorporate safety and health requirements during the design phase to eliminate or substantially mitigate hazards prior to construction. Despite these developments, Malaysia remains in the early stages of DfOSH regulatory implementation, grappling with challenges (Che Ibrahim *et al.,* 2024).

Since the inception of OSHCI(M) in 2017, scholarly attention to DfOSH in Malaysia has increased significantly (Yusoff *et al.,* 2025; Che Ibrahim *et al.,* 2022), encompassing topics such as organisational capabilities (Che Ibrahim *et al.,* 2024), extent of engagement in DfOSH practices (Christermaller *et al.,* 2022), DfOSH education (Samsudin *et al.,* 2021) and academic perception (Tajul Ariffin *et al.,* 2020). Although these studies highlight DfOSH's potential to transform OSH outcomes in Malaysian construction, they predominantly focus on specific stakeholder groups or isolated thematic areas. Notably, there is a scarcity of research exploring tripartite engagement, which is defined as the dynamic interplay among key stakeholders in academia, industry, and government, despite its recognised importance for driving effective policy, regulation, and cultural transformation (Etzkowitz and Leydesdorff, 2000). As DfOSH evolves from a voluntary guideline (OSHCI(M)) to a mandatory regulation (i.e., CDM Regulation 2024) understanding the intersection of stakeholders' challenges and needs, alongside collaborative strategies to sustain DfOSH adoption, becomes increasingly imperative (Toole *et al.,* 2017).

This study represents an initial exploration within a wider initiative to advance DfOSH in Malaysia through collaboration among academia, industry, and government. Building on prior research within Malaysian context that related to DfOSH, this paper pursues three primary objectives: First, to outline the challenges faced by academic, industrial, and governmental stakeholders in implementing DfOSH; second, to propose potential context-specific solutions for its effective integration; and third, to develop a tripartite engagement model that outlines collaborative pathways to transition DfOSH from a legal obligation to an embedded operational practice in Malaysia.

Construction safety remains a critical challenge due to persistently high accident rates, necessitating a coordinated, multi-stakeholder approach. Effective safety management

extends beyond site-level interventions, requiring active engagement from government agencies, industry practitioners, and academic institutions. Government entities play a pivotal role as regulatory architects, establishing policies that mandate safety integration across the construction lifecycle. The Prevention through Design (PtD) initiative by the National Institute for Occupational Safety and Health (NIOSH) in the United States emphasizes hazard elimination at the design stage to reduce occupational injuries. Similarly, the Hong Kong Housing Authority's Pictorial Guide to Planning and Design for Safety integrates safety considerations from project inception (Hong Kong Housing Authority, 2016). Singapore's Design for Safety (DfS) Regulations (2016) require systematic risk assessments and mandate the involvement of certified DfS professionals for large projects (Toh *et al.,* 2017). Meanwhile, the UK's CDM Regulations legally bind clients, designers, and contractors to proactively manage health and safety risks. The Principal Designer role, introduced under CDM, ensures safety coordination during the design phase, reinforcing the UK's commitment to hazard mitigation.

Within the industry, stakeholders have increasingly adopted DfOSH principles to minimise workplace incidents. Empirical studies suggest that integrating safety considerations during design significantly reduces accident rates (Behm, 2005) while lowering the financial and operational costs associated with reactive corrective measures (Gangolells *et al.,* 2010). Technological advancements, particularly Building Information Modeling (BIM), further support risk identification before construction begins. Through 3D modeling, safety simulations, and enhanced communication, BIM enables project teams to address hazards such as work-at-height risks proactively (Zhang *et al.,* 2015). Additionally, integrating BIM with virtual reality (VR) enhances safety training, allowing workers to rehearse critical tasks in a simulated environment and pre-emptively mitigate potential hazards (Sacks *et al.,* 2015).

Academia plays an essential role in construction safety by generating research-driven insights, developing educational programs, and fostering innovation. Through the efforts of academia, DfOSH research has evolved to include management frameworks, competency development, technological advancements, and sustainability considerations (Che Ibrahim *et al.,* 2022). By analysing best practices and emerging technologies, academia provides empirical foundations for refining regulations and enhancing safety strategies. Moreover, integrating DfS (and more broadly OSH) into university curricula ensures that future professionals are equipped to embed safety and health within project planning and execution (Wilbanks, 2015). Hands-on learning experiences, industry-academic collaborations, and specialised coursework help to embed and reinforce DfS knowledge, nurturing a proactive safety mindset among graduates (Toole *et al.,* 2017).

Despite progress in government regulation, industry adoption, and academic research, challenges remain in achieving seamless coordination among these three groups of key stakeholders. Effective tripartite engagement requires sustained dialogue, strategic alignment, and a shared commitment to continuous improvement. While government regulations establish the foundation for robust DfOSH practices, industry practitioners must internalise and implement these practices, while academia also bridges knowledge gaps through research and education. By leveraging government oversight, industry implementation, and academic innovation, DfOSH implementation (and more broadly construction OSH management) can be significantly improved, reducing occupational risks and enhancing project outcomes in Malaysia and beyond.

METHOD

This study employs an exploratory research design, framed as a Systematic Literature Review (SLR) to examine the challenges and potential solutions for integrating DfOSH in Malaysia. Given that DfOSH principles have been embedded in the OSHCIM guidelines since 2017, it is imperative to assess the progress and challenges encountered over the past eight years.

The SLR approach is particularly valuable for this conceptual investigation as it allows for systematic synthesis of existing empirical evidence related to DfOSH in Malaysia while enhancing transparency and replicability. This approach leverages a broad range of qualitative and quantitative data sources (Creswell, 2014). Furthermore, SLR is well-suited for policy and framework-oriented studies, enabling researchers to integrate insights and identify patterns across contexts (Doolan and Froelicher, 2009). The SLR followed four main steps: (1) a structured database search using predefined keywords; (2) screening and removal of duplicates and irrelevant studies; (3) application of inclusion and exclusion criteria based on focus, context, and quality; and (4) in-depth thematic analysis of the final selected studies to extract core challenges and proposed solutions.

The data selection process involved a structured search strategy within the SCOPUS database, utilising relevant keywords associated with DfOSH and its application in Malaysia's construction sector. The search terms included:

TITLE-ABS-KEY ("Prevention through Design" OR "Design for Safety" OR "Safety in Design" OR "Design for Occupational Safety and Health" OR "Construction Design and Management" OR "Safety by Design" OR "Design for Construction Safety" OR "Design risk management" OR "Construction Hazards Prevention through Design" OR "Occupational Safety and Health in Construction Industry (Management)" OR "PtD" OR "DfS" OR "OSHCIM" OR "DfCWS" OR "DfCS" OR "DfOSH" OR "CHPtD") AND ("Construction") AND ("Malaysia")

Boolean operators were systematically applied to ensure a focused and comprehensive search. While no time filter was imposed during the initial query, this was intentional to allow inclusion of all potentially relevant literature regardless of publication year. However, the final selection consisted exclusively of studies published from 2015 onwards, reflecting the current DfOSH regulatory and practice context in the Malaysian construction industry. The search yielded 23 papers, comprising 11 conference papers, ten journal articles, and two books. After an initial screening process, which involved removing incomplete studies and those unrelated to the construction sector in Malaysia (e.g., studies focusing on the oil and gas industry or conducted in other countries), the dataset was refined to 20 papers. A further round of screening ensured that selected studies specifically addressed DfOSH implementation challenges and potential solutions, resulting in a final sample of 17 articles.

While this sample size may appear modest, the selected studies represent the most relevant, recent, and peer-reviewed works directly aligned with the study's scope. The inclusion criteria focused on quality, relevance, and thematic depth rather than volume, ensuring rigorous and focused analysis.

A thematic analysis approach (Braun and Clarke, 2006) was employed to systematically synthesize the secondary data sets. The analysis followed an iterative four-step process: 1) Familiarisation: The researcher engaged in an in-depth review of the 17 articles; 2) Coding: Thematic coding was conducted to categorise relevant

excerpts on challenges and solutions that aligned with three domain academia-industry-government; 3) Theme Development: The identified codes were grouped into overarching themes, including "regulatory alignment," "technical capacity," "training gaps," and "organisational culture; 4) Integration: The findings were compared across various domain to ensure convergent validity.

The synthesized insights were then mapped onto the conceptual framework incorporating the Triple Helix model introduced by Etzkowitz and Leydesdorff (2000) and Institutional theory (Scott, 2014) providing a conceptual understanding of how tripartite engagement influences DfOSH implementation in Malaysia.

RESULTS

The implementation of DfOSH in Malaysia faces substantial challenges across three key stakeholders: Academia, industry, and government. Despite increasing awareness of DfOSH principles, persistent barriers hinder their integration into higher education, construction practices, and regulatory frameworks. The following discussion outlines the stakeholder-specific challenges of DfOSH adoption and its potential solutions.

The implementation of DfOSH in Malaysia faces significant barriers across academia, industry, and government, limiting its widespread adoption. Universities struggle to integrate DfOSH into engineering and construction curricula, offering minimal structured content on designing for safety (Che Ibrahim *et al.,* 2021). Many graduates enter the workforce without fundamental safety design knowledge, reinforcing a reactive approach where safety is seen as a contractor's responsibility (Samsudin *et al.,* 2021; Tajul *et al.,* 2020). Overcrowded technical programs further restrict inclusion of DfOSH-related topics, while weak academia-industry collaboration limits real-world exposure opportunities for students (Che Ibrahim *et al.,* 2022c). Additionally, funding constraints hinder specialised training modules, simulation software acquisition, and research in proactive hazard mitigation (Che Ibrahim *et al.,* 2021).

The construction industry faces low awareness and competency among design professionals. Many architects and engineers lack training in risk assessment, hazard control, and construction sequencing, leading to poor safety integration at the design stage (Che Ibrahim *et al.,* 2022a; Ismail *et al.,* 2021). The fragmented project delivery system, where contractors, designers, and clients work in silos, further weakens safety collaboration (Che Ibrahim and Belayutham, 2020; Christermaller *et al.,* 2022). Additionally, low management commitment, especially among SMEs stems from the perception that safety increases costs rather than offering long-term benefits (Che Ibrahim *et al.,* 2024). The lack of clear regulatory guidance further contributes to inconsistent implementation (Hussain *et al.,* 2023).

At the government level, weak enforcement, evolving regulations, and financial constraints pose major challenges. Regulatory bodies such as the Department of Occupational Safety and Health (DOSH) experience staffing shortages and limited funding, leading to inconsistent enforcement of DfOSH policies (Hussain *et al.,* 2023). The introduction of the Occupational Safety and Health (Construction Work) (Design and Management) Regulations 2024 has created uncertainty, as stakeholders struggle to understand their roles (Che Ibrahim *et al.,* 2024). Furthermore, insufficient stakeholder engagement between government agencies, industry, and academia restricts collaboration and knowledge-sharing regarding DfOSH (Belayutham *et al.,* 2019). Budget constraints further limit inspector training, awareness campaigns, and

large-scale safety initiatives, weakening compliance and industry-wide adoption (Belayutham *et al.,* 2019).

A multi-faceted approach across academia, industry, and government is essential for effectively integrating DfOSH in Malaysia. A critical step in academia is for universities to integrate DfOSH into engineering and architecture curricula by embedding risk assessment, hazard mitigation, and DfOSH principles. Regulatory bodies like the Engineering Accreditation Council could mandate DfOSH components to standardise safety education (Che Ibrahim *et al.,* 2021). Faculty training programs can be enhanced to keep educators updated on emerging safety methodologies and digital tools. Strengthening university-industry collaboration through guest lectures, site-based learning, and research partnerships can improve practical exposure (Che Ibrahim *et al.,* 2022c). Increased funding for research and BIM-integrated safety modules can further improve DfOSH education (Che Ibrahim *et al.,* 2021).

Within the construction industry, capacity-building programs can equip designers and project teams with skills in hazard analysis, risk assessment, and prevention through design (Che Ibrahim *et al.,* 2022b; Ismail *et al.,* 2021). Workshops and demonstration projects can further enhance competency (Che Ibrahim *et al.,* 2022a). Strengthening organisational safety culture through structured design reviews and project audits will ensure systematic risk mitigation (Che Ibrahim *et al.,* 2024). Top management commitment is crucial where firms must establish clear safety objectives, allocate resources, and incentivise proactive safety integration (Che Ibrahim *et al.,* 2024). Collaborative project delivery methods like Integrated Project Delivery (IPD) can improve stakeholder coordination and embed safety at all project stages (Christermaller *et al.,* 2022; Che Ibrahim *et al.,* 2022b). Standardising DfOSH guidelines, digital safety checklists, and BIM-driven risk management platforms can enhance consistency in implementation (Hussain *et al.,* 2023).

For the government sector, regulatory agencies like DOSH need more trained enforcement personnel and digital tools for inspection and data analytics to improve oversight (Hussain *et al.,* 2023; Belayutham *et al.,* 2019). Clearer DfOSH regulations, practical guidelines, and industry consultations can reduce ambiguity and ensure compliance. Institutionalising multi-stakeholder collaboration through working groups comprising academia, industry, and policymakers will help refine safety practices (Hussain *et al.,* 2023). Financial incentives like tax deductions, reduced insurance premiums, and government grants can further drive adoption (Belayutham *et al.,* 2019). Lastly, embedding DfOSH into national policy agendas and securing high-level commitment from policymakers will ensure sustained enforcement and long-term improvements (Che Ibrahim and Belayutham, 2020).

DISCUSSION

To enhance tripartite engagement in DfOSH within the academia-industry-government nexus, this framework integrates two theoretical perspectives: The Triple Helix Model (Etzkowitz and Leydesdorff, 2000) and Institutional Theory (Scott, 2014). The Triple Helix Model elucidates the collaborative knowledge generation and innovation processes between academia, industry, and government, while Institutional Theory clarifies the mechanisms through which DfOSH becomes entrenched in organisational practices via coercive (regulatory or legal mandates), normative (professional standards and shared values), and mimetic (imitation of successful peers under uncertainty) pressures. While Institutional Theory explains how organisations respond to institutional pressures, the Triple Helix model adds unique value by

providing a dynamic lens to understand how the three institutional spheres co-produce knowledge, drive innovation, and negotiate overlapping roles in shaping policy, education, and industrial practices. Institutional Theory has long been influential in policy implementation literature, particularly emphasising how institutional settings shape policy outcomes (Rothstein, 1992). Rothstein highlights that institutional arrangements integrating key stakeholders directly into implementation processes enhance policy legitimacy and effectiveness. Similarly, Hill and Hupe (2014) argue that understanding the institutional context, including administrative structures, interorganisational networks, and prevailing norms, is vital for successful policy execution in complex, multi actor environments such as construction. They emphasize that misaligned institutional settings can create implementation gaps, whereby policies are formally adopted but insufficiently enacted due to conflicting norms or incentives. These complementary perspectives provide a structured approach to understanding how DfOSH knowledge is generated, disseminated, and institutionalised within the construction sector as shown in Figure 1.

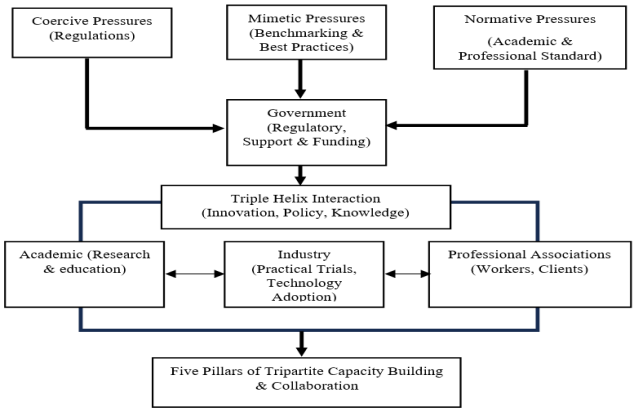


Figure 1: A Conceptual DfOSH Tripartite Engagement Framework

In this framework, government plays a critical role in enforcing coercive pressures (regulations) through policies such as Occupational Safety and Health (Construction Work) (Design and Management) Regulations 2024, inspections, and accreditation standards. In addition, government support extends to funding and incentives that promote safety research and industry adoption of DfOSH best practices. Academia contributes through normative pressures (academic and professional standards) by embedding DfOSH principles into engineering curricula, conducting research on DfOSH, and collaborating with industry to demonstrate real-world applications (Che Ibrahim *et al.,* 2021; Zhang *et al.,* 2015). Professional associations, including engineers, architects, and safety professionals, reinforce normative pressures by integrating safety-by-design competencies into certification and training programs (Che Ibrahim *et al.,* 2022c; Ismail *et al.,* 2021).

Industry drives implementation by operationalising DfOSH strategies through practical trials and technology adoption, integrating hazard prevention at the design stage, and refining best practices via pilot projects and continuous professional development (Che Ibrahim *et al.,* 2022a). Mimetic pressures (benchmarking and best practices) further encourage industry-wide adoption, as firms emulate early adopters that demonstrate improved safety outcomes and cost efficiencies (Che Ibrahim *et al.,* 2022b). This benchmarking effect strengthens Triple Helix Interaction, where knowledge, policy, and innovation continuously evolve through academia-industry-government collaboration.

The successful institutionalisation of DfOSH depends on Five Pillars of Tripartite Capacity Building and Collaboration, which were synthesized from a content analysis of the identified challenges and potential solutions related to DfOSH implementation, as discussed in the data. They represent key thematic areas that emerged to support effective institutionalisation through coordinated efforts among government, industry, and academia. Collaborative Policy and Regulatory Alignment ensure coherence between government regulations, industry standards, and academic research. Integrated Education and Training Ecosystem embeds DfOSH principles in curricula, industry training, and professional certification programs.

Organisational and Cultural Readiness promotes safety-first mindsets among professional, firms, and clients. Resource and Technological Enablers leverage funding, technological tools (e.g., BIM-based safety), and research support to facilitate adoption. Continuous Evaluation and Feedback Loops implement performance tracking, stakeholder engagement, and policy refinements for sustained DfOSH integration. By synthesising the Triple Helix Model and Institutional Theory, this framework ensures that DfOSH is not only adopted but sustained through systemic institutionalisation. The Triple Helix Model fosters ongoing knowledge development and policy innovation, while Institutional Theory reinforces compliance through regulatory enforcement, professional competency standards, and benchmarking. Over time, these combined mechanisms will position DfOSH as a fundamental pillar of construction safety and health in Malaysia, ensuring safer work environments and a more resilient industry.

CONCLUSIONS

This study has provided an in-depth examination of the challenges and potential solutions regarding implementing DfOSH in Malaysia through the lens of academia, industry, and government. The findings reveal that despite growing recognition of DfOSH principles, several persistent and specific barriers impede its effective integration. These include insufficient integration of DfOSH into engineering and architecture curricula, low competency among design professionals in hazard identification, fragmented project delivery systems, and weak regulatory enforcement capacity. Addressing these barriers requires a multi-faceted approach including potential solutions such as emphasising enhanced academic curricula, industry capacity-building, and strengthened governmental oversight to ensure DfOSH transitions from a regulatory requirement to an ingrained industry practice.

A key contribution of this study is the conceptualisation of a Tripartite Engagement Framework for DfOSH Implementation, drawing from the Triple Helix Model and Institutional Theory. This framework highlights the collaborative role of academia in knowledge generation, industry in operationalising safety measures, and government in enforcing regulatory mandates. The framework responds directly to the key challenges by aligning responsibilities and resources across stakeholder domains, embedding safety into academic standards, strengthening design-stage safety integration through industry collaboration, and clarifying regulatory enforcement mechanisms. Future research should focus on empirically validating the effectiveness of this tripartite framework in real world project environments.

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ACCIDENTS ANALYSIS IN CONSTRUCTION ROAD PROJECTS: DETERMINING MEASURES AND SOLUTIONS FOR THE CAUSES OF UTILITY STRIKES

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This research investigates utility strikes in construction road projects, identifying their causes and proposing a detailed set of preventive measures. Drawing from 10 UK-based case studies classified as 'dangerous occurrences' (near-misses with significant harm potential) and 'lost time' incidents (events causing work stoppages), purposive sampling was employed to ensure diversity in incident type, utility involved, and project context. Through qualitative analysis using NVivo 12 software, 33 distinct causes were identified, and 40 corresponding measures were developed. These causes and measures were categorised into worker-related domains, such as human error and lack of training, and work-related domains, including equipment failure and poor planning, thereby revealing clear patterns in incident causation. A correlation analysis established links between causes and measures, which formed the foundation for a three-phase Utility Strike Prevention Plan that includes Pre Event, Event, and Post Event stages. This research not only contributes to academic discourse by bridging gaps in existing safety literature but also offers a practical, actionable framework for construction managers, policymakers, and safety officers to enhance project safety, reduce operational disruptions, and protect worker wellbeing.

Keywords: cause of incidents; measures; utility strike; case study; safety management

INTRODUCTION

Utility strikes, incidents where underground services such as gas pipelines, water mains, electrical cables, or telecommunications lines are inadvertently damaged during construction, represent a critical safety and operational challenge in road projects. In the UK, the problem is exacerbated by an extensive and often aging network of buried utilities, many of which lack accurate or up-to-date documentation, including Ordnance Survey maps. These strikes frequently occur during excavation or trenching activities due to inadequate pre-construction surveys, reliance on outdated utility maps, insufficient use of Cable Avoidance Tools (CAT) and Genny scanners,

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Sarvari, H, Edwards, D J and Rillie, I (2025) Accidents Analysis in Construction Road Projects: Determining Measures and Solutions for the Causes of Utility Strikes, *In:* Thomson, C and Neilson, C J (Eds) *Proceedings of the 41st Annual ARCOM Conference,* 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 429-437.

and the absence of robust risk assessments or Permits to Dig/Excavate as mandated by HSG47 guidelines. The consequences range from minor delays to catastrophic events like gas explosions or widespread power outages, as reported by the Health and Safety Executive (HSE), with gas and electrical incidents posing the greatest risk due to their potential for immediate and severe harm.

The economic toll of utility strikes is profound and multifaceted. Direct costs, including repairs to damaged infrastructure, legal liabilities, and compensation, often exceed £50,000 per incident, according to industry estimates from the Construction Industry Research and Information Association (CIRIA). However, indirect costs—such as project delays, lost productivity, increased insurance premiums, and reputational damage to contractors—can escalate these figures exponentially, sometimes reaching into the hundreds of thousands. Beyond economics, the human cost is even more alarming. Workers face risks of burns, electrocution, or crush injuries, with fatalities occurring in the most severe cases. Communities near construction sites may also suffer, experiencing service disruptions (e.g., water or electricity loss) or evacuations due to hazardous leaks. For instance, a 2019 gas main strike in Leeds resulted in the evacuation of 200 homes and a £120,000 fine for the contractor, illustrating the cascading effects of such incidents.

Despite advances in utility detection technology and regulatory frameworks like the Construction (Design and Management) Regulations 2015 (CDM 2015), utility strikes persist, suggesting that current approaches are insufficient. Previous research, such as Metje et al. (2015), has classified causes like poor utility mapping and operator error, while Koschmann et al. (2020) highlighted communication breakdowns and inadequate training. Yet, these studies often stop short of offering comprehensive, actionable solutions. This paper addresses that gap by shifting the focus from mere identification of problems to the development and implementation of targeted measures.

The research objectives are: (1) To systematically identify and categorise measures that mitigate utility strikes, grounded in real-world evidence from 10 UK case studies. (2) To establish precise correlations between these measures and their underlying causes, ensuring relevance and effectiveness. (3) To propose a comprehensive Utility Strike Prevention Plan, a preventive methodology that integrates 40 targeted measures across three phases—Pre-Event (planning), Event (execution), and Post-Event (recovery)—to provide a structured, actionable framework for construction managers, policymakers, and safety officers. This methodology aligns with UK regulatory frameworks, including the CDM 2015 and HSG47, to enhance project safety, reduce operational disruptions, and protect worker wellbeing.

The 10 case studies, selected for their diversity in utility type (e.g., gas, water, electricity) and incident severity, provide a robust dataset. They include ‘dangerous occurrences’ (near-misses with high potential for harm) and ‘lost time’ incidents, where work was halted due to injury or damage. By analysing these events, this research uncovers not only what goes wrong but also how to prevent it, offering a solution-oriented perspective that builds on established UK procedures, such as HSG47 and CDM 2015. Unlike prior studies, which often focus on isolated causes or solutions, this work integrates 33 identified causes with 40 targeted measures into a novel, three-phase Utility Strike Prevention Plan. This plan addresses gaps in the application of existing regulations by providing a structured, evidence-based

framework that enhances practical implementation, ensuring alignment with industry standards while offering actionable insights for safer construction practices.

LITERATURE REVIEW

Utility strikes represent a persistent issue in construction safety research, with extensive studies documenting their frequency and impacts. Maree et al. (2021) conducted a foundational statistical analysis, revealing that over 60% of utility strikes in the United Kingdom result from inadequate detection methods or dependence on outdated utility records, a challenge exacerbated by the intricate nature of urban infrastructure. Sarvari et al. (2020b) shifted attention to human factors, attributing approximately 50% of such incidents to operator inexperience, ineffective team communication, or non-compliance with safety protocols. Aven (2022) adopted a wider perspective, pinpointing systemic deficiencies, including inadequate pre-construction risk assessments, variable safety standards among contractors, and insufficient accountability in project planning, as critical contributors. The Health and Safety Executive's HSG47 guidelines emphasise the importance of accurate utility mapping, the use of CAT and Genny scanners, and the implementation of Permits to Dig/Excavate to prevent utility strikes, yet compliance remains inconsistent due to time pressures and resource constraints.

Efforts to reduce utility strikes have traditionally been categorised into three primary approaches: technological, procedural, and training-based measures, often aligned with the ERIC principle (Eliminate, Reduce, Isolate, Control) as outlined in CDM 2015. Technological solutions, such as Ground Penetrating Radar (GPR), electromagnetic locators, and Geographic Information Systems (GIS), have become increasingly adopted for their capacity to map subsurface utilities (Li et al., 2014). However, their effectiveness is limited by factors such as soil conditions, operator proficiency, and the inability to detect non-metallic utilities, such as plastic water pipes.

The critical role of CAT scanners, mandated by HSG47, is often underutilised due to inadequate training or rushed schedules, leading to misinterpretations of scan data (Metje et al., 2015). Procedural strategies, encompassing mandatory permit-to-work systems, comprehensive utility surveys, and standardised risk assessment protocols, have been endorsed by Sarvari et al. (2024a). These align with the ERIC principle by prioritising elimination and reduction of risks through thorough planning and control measures, such as detailed work plans and Design Risk Management (DRM). However, their success is frequently undermined by inconsistent application or resistance from project teams facing stringent deadlines. Training-based initiatives, promoted by Bourassa et al. (2016), focus on enhancing workers' skills in hazard identification and equipment operation, yet their integration into broader safety frameworks, such as Management Arrangements under CDM 2015, often remains inadequate, constraining their influence on systemic risks.

Significant limitations in these approaches emerge from the literature. Li et al. (2014) criticise the excessive dependence on technology without corresponding advancements in operator training, citing cases where misinterpretations of GPR and CAT scanner data precipitated utility strikes. Sarvari et al. (2024b) highlight procedural shortcomings, such as omitted utility verification steps or inadequate work plans, as indicative of a gap between policy formulation and practical execution. Historical instances, such as the 2015 reliance on inaccurate utility maps in a Manchester project, which resulted in a £200,000 water main rupture, underscore the

necessity for a more comprehensive strategy. The absence of robust Management Arrangements and Principles of Prevention, as advocated by CDM 2015, further exacerbates these issues. This study addresses these gaps by proposing an integrated framework that unifies technological, procedural, and training-based measures into a cohesive prevention strategy, aligned with HSG47 and the ERIC principle. Solutions are structured into three phases—Pre-Event (planning), Event (execution), and Post-Event (recovery)—to ensure comprehensive coverage across the project lifecycle. By tackling both immediate causes, such as operator error, and deeper systemic issues, such as deficient planning, this work advances utility strike prevention significantly, offering a practical blueprint for enhancing safety in construction practices.

METHOD

This research adopted a qualitative case study approach to investigate utility strikes in UK construction road projects, leveraging real-world incidents to derive evidence-based insights into their causes and preventive measures. The methodology was designed to align with the study's objectives: (1) to identify and categorise measures mitigating utility strikes, (2) to establish correlations between causes and measures, and (3) to develop a three-phase utility strike prevention plan compliant with UK regulations such as the CDM 2015. A qualitative approach was chosen for its ability to provide an in-depth, contextualised understanding of complex phenomena, enabling the exploration of both worker-related and work-related factors in utility strikes.

Case Study Selection

Ten UK-based case studies were selected using purposive sampling to ensure diversity in incident type, utility involved, and project context. Cases were categorised as either 'dangerous occurrences' (near-misses with high harm potential, as defined by HSG47) or 'lost time' incidents (events causing work stoppages due to injury or damage). The selection criteria included: (1) Incident Severity: Cases with significant safety or operational impacts, ensuring relevance to high-risk scenarios; (2) Utility Diversity: Representation of various underground services (gas, water, electricity, telecommunications) to capture a broad range of strike scenarios; (3) Project Context: Inclusion of urban and rural projects to account for varying infrastructure complexities; and (4) Data Availability: Access to comprehensive documentation, including HSE reports, contractor logs, worker interviews, and site safety audits. This purposive approach ensured a robust and representative dataset, as summarised in Table 1.

Data Collection

Data were collected from multiple sources to provide a comprehensive view of each incident, adhering to the principles of triangulation to enhance validity. Sources included: (1) HSE Incident Reports: Official records detailing incident circumstances, outcomes, and regulatory violations; (2) Contractor Logs: Internal documentation of project activities, equipment use, and safety measures; (3) Worker Interviews: Semi-structured interviews with operatives, supervisors, and site managers to capture firsthand perspectives on incident causes and mitigation; and (4) Site Safety Audits. Data collection was guided by ethical considerations, with informed consent obtained from interviewees and data anonymised to protect confidentiality.

Data Analysis

Data analysis was conducted using NVivo 12 software in a rigorous two-stage qualitative coding process to identify causes and measures systematically. Stage 1:

Open Coding involved extracting specific causes (e.g., 'inadequate training,' 'outdated utility maps') and measures (e.g., 'mandatory retraining,' 'enhanced utility mapping') from raw data. This stage ensured that all relevant factors were captured without preconceived categories. Stage 2: Thematic Coding grouped these into worker-related (e.g., human error, fatigue, miscommunication) and work-related (e.g., equipment failure, poor planning) domains, aligning with the ERIC principle to structure preventive strategies. For example, the cause 'lack of training' was correlated with the measure 'mandatory retraining' based on its recurrence in eight cases, supported by narrative evidence from interviews and reports.

To ensure analytical rigor, two researchers independently coded the data, achieving an inter-coder agreement rate of 92%. Discrepancies were resolved through consensus discussions, enhancing reliability. The analysis identified 33 distinct causes and 40 corresponding measures, which were cross-referenced to establish causal relationships. These findings formed the basis for the three-phase Utility Strike Prevention Plan, ensuring that proposed measures were grounded in empirical evidence and tailored to address both immediate and systemic risks. The methodology's robustness lies in its systematic, evidence-based approach, which integrates real-world data with UK regulatory frameworks to produce actionable outcomes for construction safety management.

Table 1: Characteristics of the 10 utility strike case studies

Case No.	Category	Utility type	Incident potential	Incident severity	Incident location	Incident duration	Weather condition	Nature of injury
1	Dangerous occurrence	Gas	Low	High (serious)	Site	≥ year	Cloudy	No
2	Dangerous occurrence	Gas	Low	Medium	Site	≤ week	Cloudy	No
3	Lost time	Water	Low	Medium	Site	≤ month	Clear	Yes
4	Lost time	Water	Low	Medium	Site	≥ 6 months	Clear	Yes
5	Lost time	Water	Low	High (serious)	Site	≤ week	Clear	Yes
6	Lost time	Water	Low	Medium	Offsite	≤ month	Clear	Yes
7	Dangerous occurrence	Electric	Low	High (serious)	Site	≥ month	Clear	No
8	Dangerous occurrence	Electric	Low	High (serious)	Site	≤ week	Clear	No
9	Lost time	Telecom	Low	Medium	Offsite	≥ month	Cloudy	Yes
10	Lost time	Telecom	Low	Medium	Site	≥ month	Clear	Yes

RESULTS AND DISCUSSION

The analysis of the 10 case studies yielded 33 unique causes of utility strikes, reflecting a mix of worker-related (e.g., operator inexperience, fatigue, miscommunication, procedural non-compliance) and work-related factors (e.g., inadequate utility detection, outdated records, insufficient risk assessments, equipment malfunctions). From these, 40 measures (as shown in Table 1) were developed and organised into Pre-Event, Event, and Post-Event categories, aligning with the Principles urid Prevention and Management Arrangements under CDM 2015, as well as HSG47 guidelines. These measures form a comprehensive toolkit for preventing utility strikes, addressing both immediate risks and systemic weaknesses through Planning & Control and Design Risk Management (DRM).

In the Pre-Event phase, measures such as detailed utility mapping and Risk Assessment Method Statements (RAMS) development align with Planning & Control by ensuring risks are eliminated or reduced before work begins, as per the ERIC principle. For instance, utility mapping combines historical records, CAT and Genny

scans, and on-site verification to address inadequate surveys and outdated maps, a cause identified in seven cases. RAMS development, reviewed by all stakeholders, incorporates Design Risk Management by embedding safety considerations into project planning, reducing risks like operator error (noted in eight cases). The Event phase emphasises real-time risk mitigation through measures like dynamic risk assessments and increased inspection frequency, which support Management Arrangements by ensuring continuous oversight and compliance with HSG47's emphasis on safe systems of work. For example, dynamic risk assessments, conducted before shifts or after environmental changes, were linked to reduced operator errors in five cases. The Post-Event phase focuses on learning and recovery, with measures like root cause analysis and safety bulletins aligning with CDM 2015's requirement for ongoing improvement. These measures address systemic issues, such as poor communication (noted in six cases), by fostering industry-wide learning through platforms like the CITB.

The novelty of this study lies in its integration of these measures into a cohesive, three-phase Utility Strike Prevention Plan that operationalises established concepts like Planning & Control, Principles of Prevention, and Management Arrangements. Unlike prior studies that offer isolated solutions, this plan ensures seamless integration with existing safety management systems like ISO 45001, enhancing their utility without necessitating radical changes. By grounding the measures in empirical data from 10 diverse UK case studies, the plan provides actionable, context-specific solutions that address both immediate and systemic causes, offering a significant advancement over predictable outcomes in prior research.

Table 1: Measures and solutions for utility strikes

Group	Measure	Related Causes
Pre Event	Preparedness for risk response	Inadequate documentation or documentation control and emergency procedures in place for the specific task; Insufficient organisation of the planning of works to be undertaken
	Reviewing the competence of the team leader	Inadequate leadership or supervision or specific operation on-site; No or insufficient competence or awareness or experienced leaders & managers (information, instruction and training)
	Reviewing the qualification of the operators	Unskilled, unqualified and inexperienced operator/worker for the work activity; Ignoring the training provided by operators/workers (information, instruction and training)
	Reviewing the existence of suitable and sufficient project methods	Insufficient quality or availability of procedures, guidelines, method statements, risk assessment and manuals (procedures); Inappropriate or insufficient safety control measures designed or implemented
	Reviewing the permit to work by site managers and supervisors	Failure to obtain work permission from the project's manager for certain duties; Incorrect issue of licences & permits (routine violation)
	Classification of the incidents based on potential and severity	Inadequate documentation or documentation control and emergency procedures in place for the specific task; Insufficient organisation of the planning of works to be undertaken
	Field investigation before entering and exiting the machine and facilities	Operator/worker failure to identify the hazards; Inappropriate workplace layout
	Ensuring operators' awareness of roles, responsibilities and resources	Unclear operator/worker roles and responsibilities; Operators/workers who are unfamiliar with site layout and the site-specific controls

	Ensuring that RAMS are requested, reviewed and approved for all supply chain activities	Non-application of the agreed risk assessment method statement (RAMS) procedure by the team; Insufficient quality or availability of procedures, guidelines, method statements, risk assessment and manuals (procedures)
	Assessing the equipment suitability plus relevant subjects based on DRA	Inappropriate selection and use of plant, machinery or equipment for work; Poor quality, condition and/or suitability of materials, plant, machinery and equipment
Event	Increasing inspection frequency for new teams & reviewing the previous inspections' findings	Operator/worker error in utilising plant, machinery and equipment; non-application of the agreed RAMS procedure by the team
	Ensuring that there are enough skilled site managers available	Inadequate leadership or supervision or specific operation on-site; No or insufficient competence or awareness or experienced leaders & managers (information, instruction and training)
	Stepping up leadership visits	Inadequate leadership or supervision or specific operation on-site; Leadership failure to adequately manage and plan operational aspects of the work task
	Suitable and sufficient handover when changing the operators	Operators/workers who are unfamiliar with site layout and the site-specific controls; Poor communication between organisation or team members
	Focusing on engaging with operatives on compliance with procedures	Non-application of the agreed RAMS procedure by the team; Failure to adhere to a safe system of work (SSoW)
	Constantly risk assessment throughout the whole of the job to identify additional hazards and record them within the site-specific risk assessment (SSRA) by Operatives	Operator/worker failure to identify the hazards; Inadequate documentation or documentation control and emergency procedures in place for the specific task
	Ensuring the new teams have the necessary competence and experience to undertake the work	Unskilled, unqualified and inexperienced operator/worker for the work activity; Operators/workers who are unfamiliar with site layout and the site-specific controls
	Reviewing the current permit for the suitability of content for the project	Failure to obtain work permission from the project's manager for certain duties; Incorrect issue of licences & permits (routine violation)
	Ensuring that the site handover briefing is completed for the restart of the work	Poor communication between organisation or team members; Operators/workers who are unfamiliar with site layout and the site-specific controls
	Ensuring the safety measures for the restart of the work	Failure to adhere to a safe system of work (SSoW); Inappropriate or insufficient safety control measures designed or implemented
Post Event	Implementation of disciplinary measures in accordance with the instructions in the event of negligence	Overlooking or neglecting basic safety by operator/worker (operators' overconfidence in their ability); Human error - lapse and routine violation of instructions & regulations
	Review of other work tool types on the market to determine safer options	Inappropriate selection and use of plant, machinery or equipment for work; Poor quality, condition and/or suitability of materials, plant, machinery and equipment
	Deployment safety, health, environment and quality (SHEQ) for checking the site after incidents	Inappropriate workplace layout: Unsuitable physical conditions and other influences that have a disadvantageous effect on human functioning (error enforcing conditions)
	Organising a handover briefing after incidents	Poor communication between organisation or team members; Operators/workers who are unfamiliar with site layout and the site-specific controls
	Checking and ensuring the wellbeing of the people involved in incidents	Imposed duress upon operators/workers to complete the task by the client; Unsuitable physical conditions and other influences that have a disadvantageous effect on human functioning (error enforcing conditions)

Training & re-briefing the safety process to operators involved in incidents	Ignoring the training provided by operators/workers (information, instruction and training); Unskilled, unqualified and inexperienced operator/worker for the work activity
Reviewing the logistics arrangement by involved firms in incidents	Insufficient organisation of the planning of works to be undertaken; Inappropriate workplace layout
Producing a safety bulletin shared across the group and wider utility industry for shared learning	Poor communication between organisation or team members; Lack of availability, incorrect or complexity of buried utility drawings and other relevant information
Reviewing the competence of workers and operators after incidents	Unskilled, unqualified and inexperienced operator/worker for the work activity; No or insufficient competence or awareness or experienced leaders & managers (information, instruction and training)
Cooperation control to support the main replacement programs after incidents	Insufficient organisation of the planning of works to be undertaken; Poor communication between organisation or team members
Evaluating the effectiveness of HSE and QMS performance monitoring system	Inadequate documentation or documentation control and emergency procedures in place for the specific task; Insufficient quality or availability of procedures, guidelines, method statements, risk assessment and manuals (procedures)
Reporting dangerous occurrences to HSE	Human error - lapse and routine violation of instructions & regulations; Failure to adhere to a safe system of work (SSoW)
Briefing out safety bulletin to raise awareness of work tools within restrictive work areas (such as the bottom of excavations)	Inappropriate selection and use of plant, machinery or equipment for work; Operator/worker error in utilising plant, machinery and equipment
Focusing on training in relation to continual risk assessment of the work area and recording on an SSRA	Operator/worker failure to identify the hazards; Inadequate documentation or documentation control and emergency procedures in place for the specific task
Issuing the safety alert regarding the importance of dynamic risk assessment (DRA)	Operator/worker failure to identify the hazards; Inadequate documentation or documentation control and emergency procedures in place for the specific task
Emphasis on continuous communications and attention to incident reporting regulations	Poor communication between organisation or team members; Human error - lapse and routine violation of instructions & regulations
Ensuring the presence of first aid on-site	Insufficient safety equipment, devices, personal protective equipment (PPE) for a specific task; Unsuitable physical conditions and other influences that have a disadvantageous effect on human functioning (error enforcing conditions)
Challenging unsafe acts or instructions	Overlooking or neglecting basic safety by operator/worker (operators' overconfidence in their ability); Human error - lapse and routine violation of instructions & regulations
Training and policies for safe machine use	Operator/worker error in utilising plant, machinery and equipment; Inappropriate selection and use of plant, machinery or equipment for work
Issuing a Toolbox talk (TBT) to support the understanding of the hazards and associated risks whilst working	Operator/worker failure to identify the hazards; Ignoring the training provided by operators/workers (information, instruction and training)

CONCLUSIONS

The identification of 33 causes and 40 measures in this study offers a comprehensive understanding of utility strikes, resulting in the development of a three-phase Utility Strike Prevention Plan that addresses risks holistically. By prioritising solutions over mere diagnosis, this research provides construction professionals with a practical

framework to enhance safety, safeguard project timelines, and ensure compliance with regulations such as CDM 2015. The plan's phased structure, encompassing preparation, execution, and recovery, facilitates proactive risk management, continuous monitoring, and post-incident resolution, thereby establishing a cycle of ongoing improvement. The broader implications of this research are significant. A reduction in utility strikes not only improves public safety by minimizing service disruptions and mitigating environmental hazards, such as gas leaks that contribute to carbon emissions or water losses that exacerbate resource shortages but also generates substantial economic benefits. Savings achieved through fewer incidents can be allocated to innovation, including the development of advanced detection technologies or enhanced worker training programs. For instance, a 10% reduction in utility strikes across UK road projects could yield annual savings of millions, according to cost estimates provided by CIRIA.

Future research should aim to quantify the cost-benefit ratio of the proposed plan by evaluating implementation costs against financial savings derived from averted incidents. Comparative studies could also examine the plan's adaptability across diverse contexts, such as rural construction projects or international settings with varying utility infrastructures. Furthermore, exploration of technological innovations, including artificial intelligence for predictive risk modelling and augmented reality for utility visualisation, is recommended. For practitioners, this study serves as an immediate, actionable resource designed to protect workers and projects, contributing to a safer and more sustainable construction industry.

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THE STATE OF SOUTH AFRICAN CONSTRUCTION HEALTH AND SAFETY

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Previous research, media reports, and statistics indicate that the South African construction industry is experiencing major challenges in terms of health and safety (H&S). A quantitative study was conducted among a range of construction industry stakeholders' courtesy of an online survey to determine, inter alia, their rating of the South African construction industry, and the top ten challenges, and the top ten interventions in terms of improving construction H&S performance. Findings include: the construction industry is rated above average relative to 34 and below average relative to 216 / 250 aspects / parameters related to H&S and is not H&S compliant. Conclusions include: the construction industry in general is not committed to H&S, which is attributable to a poor H&S culture. Recommendations include strong H&S leadership and management commitment, optimum H&S culture, H&S compliance and regulatory enforcement, optimum H&S education, training, and competency, adequate budgeting for H&S, optimum risk management and planning for H&S, consistent application of H&S standards, enhanced H&S statistics, and addressing of socio-economic pressures.

Keywords: challenges; construction; health and safety; performance

INTRODUCTION

The South African construction industry generates a high level of injuries relative to construction industries globally. Based upon a total of 298 069 workers insured by The Federated Employers Mutual Assurance Company (RF) (Pty) Ltd (FEM) (2025) for the year 2024, the fatality rate (FR) was 20.1 / 100 000 workers, the accident rate (AR) was 2.19 / 100 workers, and the disabling injury incidence rate (DIIR) was 0.29 or 0.29 / 100 workers. The FR does not compare favourably with the FRs of the Australian and United Kingdom (UK) construction industries, namely 2.1 for 2021 (Safe Work Australia, 2023), and 2.1 in 2022 / 2023 (Health and Safety Executive, 2024), respectively.

The most recent construction H&S 'status report' is 'Construction Health and Safety in South Africa Status and Recommendations' published on 11 June 2009 by the Construction Industry Development Board (cidb) (2009). Furthermore, given the paucity of literature relative to overall H&S performance in South African construction, media reporting of multiple fatality 'accidents', and anecdotal evidence with respect to H&S in South African construction, a study was conducted. The aim of the study was to determine the state of South African construction H&S, which

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effectively constitutes the knowledge gap. The objectives, relative to this paper, include, inter alia, to determine:

- the performance of the South African construction industry relative to 250 construction health and safety aspects / parameters
- South African construction's current H&S status in terms of Anglo American's H&S journey model, and
- the top ten challenges in terms of improving the H&S performance of the South African construction industry.

LITERATURE REVIEW

The Current State of Construction Health and Safety in South Africa

To date, South Africa has produced basically one report that focuses on the state of H&S in the construction industry, namely 'Construction Health and Safety in South Africa Status and Recommendations' (cidb, 2009), which was commissioned in response to major challenges in the South African construction industry. The report affirmed that improving H&S remains a key priority for the industry and for the cidb. It also highlighted significant concerns, such as inadequate enforcement of the Construction Regulations and an Occupational Health and Safety (OHS) Inspectorate that is both understaffed and lacking in construction-specific expertise. The same is also the case with the construction workforce. A study conducted by Raliile *et al. (*2021) reported minimal correlation between management's knowledge of H&S legislation and their commitment to its implementation, revealing no statistically significant relationship between the two. Furthermore, management's application of the Construction Regulations was found to be insufficient, indicating an ongoing need to strengthen both awareness of legal requirements and management's role in promoting construction worker wellbeing.

In addition to legislative enforcement challenges, the sector suffers from outdated and incomplete construction H&S statistics, the most recent data from the Compensation Commissioner dates to 1999, and the Compensation Fund is widely perceived as ineffective to date (cidb, 2009; Smallwood, 2024). At the organisational and site levels, poor H&S performance is often linked to inadequate management commitment, poor supervision, and insufficient training. Further contributing factors include limited worker involvement, low personal risk awareness, and pressures associated with tight project timelines. According to the cidb report, several areas for improvement were identified: using public procurement as a tool to drive H&S performance; improving data collection and reporting; introducing minimum competency standards for client-appointed H&S agents; establishing a national H&S agency for awareness and research; building capacity within trade unions; integrating H&S into tertiary built environment education, and supporting small and emerging contractors through targeted development initiatives. However, 15 years later, most of these issues remain a concern (Smallwood, 2024).

H&S Media Reports

According to the Department of Employment and Labour (DEL) (2024), approximately eight workers die each month in the South African construction industry due to H&S shortcomings. Contributing factors include inadequate training, poor enforcement of H&S protocols, and a prevailing culture of non-compliance. It was highlighted in the DEL's media release post-George building collapse, which claimed 34 lives in May 2024, that the nation does not possess a culture of

compliance. Not only is the cost of accidents dire in South Africa, but behind every number, there is a family affected, and children left without a parent. Since 2019, the Compensation Fund has paid over R20 billion in claims in the construction sector alone. The claims were related to severe injuries, loss of limbs, and fatalities. Decent work deficits in the sector are exacerbated by inadequate H&S measures, limited training, pressure to meet deadlines, and a lack of accountability where H&S breaches occur, which often go unpunished.

These concerns point to a broader systemic issue within the South African construction industry. As Smallwood (2024) asserts, construction H&S is a multi-stakeholder issue requiring an integrated effort coordinated by a single-point responsible party, someone well-versed in both H&S and quality management. Smallwood criticises the prevailing 'H&S culture' within the industry, which is plagued by 'safetyitis' at the expense of occupational health, primary health promotion, mental health, and wellbeing, the prioritisation of cost and time over H&S, and the belief that H&S is an expense rather than a core value. Other cultural flaws include the dehumanisation of workers, over-reliance on reactive (trailing) indicators rather than proactive (leading) measures, and an acceptance of incidents as 'accidents' rather than as a 'failure of management'. These insights underscore the need for a cultural and structural overhaul to reduce preventable fatalities and create healthier, safer, more dignified work environments in the sector.

Smallwood (2024) further attests that the prerequisite for achieving optimal H&S outcomes in construction is the establishment of a foundation built on respect for people, people-centred values, a strong H&S culture, both surface and core competencies, and emotional intelligence. This also necessitates comprehensive construction skills training and tertiary built environment education that integrates construction H&S and quality management as core components. However, the prevailing structure of the industry, characterised by a fragmented environment, absence of barriers to entry, pseudo-registration of contractors, and the exclusion of H&S and quality management as registration or appointment criteria, undermines progress in these areas. A paradigm shift is essential in terms of how H&S is perceived, promoted, and implemented. While legislation provides a foundational framework, it reflects minimum standards rather than better practices. As such, a commitment to continuous improvement must guide the sector, underpinned by the belief that 'people are our most important resource' and 'H&S is a profit centre', both of which should serve as unifying calls to action across the built environment.

The South African Construction H&S legislative and regulatory frameworks obligate all stakeholders involved in the construction process, especially the client, designer and contractors, to possess appropriate qualifications in construction H&S (Haupt, 2024). Furthermore, H&S considerations ought to be integrated throughout every phase of a construction project, from initial conceptualisation through to the eventual deconstruction of the facility at the end of its life cycle. Despite this, many higher education institutions and professional accrediting bodies in South Africa have not addressed the limited inclusion of construction H&S in academic programmes that prepare built environment professionals for practice. It is worth considering the extent to which registered professionals working on projects are exposed to construction H&S content during their tertiary studies. Furthermore, training institutions must be evaluated and accredited with specific regard to the inclusion of construction H&S in their curricula.

METHOD

Research Method and Sample Strata

Phase 1 of the study adopted the quantitative method due to the predominating nature of the data required. The online questionnaire included Section A in the form of the respondents' demographic data and Section B, the study-related data. Section A included nine questions, and Section B five questions, two of which were five-point Likert Scale-type questions, the first of which included 250 aspects / parameters (variables). These were derived from, inter alia, cidb (2009) and Smallwood (2018; 2024). The remaining question was open-ended, namely the 'top ten challenges in terms of improving the H&S performance of the South African construction industry.

The pilot stage of Phase 1 of the study included a 168 construction multi-stakeholder convenience sample, and 412 members / contacts of the Association of Construction Health and Safety Management (ACHASM). The cover letter, including, inter alia, the rationale for the study and the URL for the online survey, was circulated on 20 March, and the data was downloaded on the evening of 28 March, at which time 64 responses were received. Of the 412 e-mails sent to ACHASM members / contacts, two e-mail addresses 'bounced', 29 were duplicates, and 23 were suppressed as they were invalid, resulting in a net sample stratum of 358, which added to 168, results in a net total of 526, and a response rate of 1.2% (64 / 526). The data was exported in MS Excel and analysed using SPSS to compute primarily frequencies and a measure of central tendency in the form of a mean score (MS) to rank variables.

FINDINGS

In terms of the demographics of respondents, 15.6% were female, and 84.4% were male. The mean age was 48.4 years, the youngest being 26 years and the oldest 70 years. The mean years of construction experience was 20.8, the lowest 4 years and the highest 50 years. Respondents cited 29 occupations - Directors (15.0%), Construction H&S Managers (15.0%), SHEQ / SHERQ / HSEQ (10.0%), Construction H&S Agents (8.3%), and Project Managers (6.7%) predominated. The respondents identified 109 qualifications relative to 9 disciplines. The predominating levels of education (identified by > 10 respondents) were Certificate (22.0%), HND / Adv Dip / BTech (19.3%), M / MSc (15.6%), N Dip. (11.0%), B / BSc (Hon) (11.0%), and PhD (10.1%). The predominating disciplines (identified by ≥ 17 respondents) were H&S (26.6%), Construction Management (21.1%), Civil Engineering (15.6%), and Safety Management (15.6%). Given these demographics, the respondents can in general be deemed experienced and educated.

Respondents were required to rate the South African construction industry relative to 250 construction H&S aspects / parameters in terms of a five-point Likert type scale where 1 = very poor, 2 = poor, 3 = average, 4 = good and 5 = very good. An 'unsure' option was presented as there was a likelihood that not all respondents would have an intimate understanding of all 250 aspects / parameters, which were consolidated from previous studies conducted by the lead author. Table 1 presents the ratings of 34 aspects / parameters in terms of percentage responses and mean scores (MSs) between 1.00 and 5.00, based upon a weighting of the percentage responses.

Due to the 250 aspects / parameters, and page limitations, the discussion is limited, and summarised as follows:

- 5 / 250 (2.0%) aspects / parameters were rated > 3.40 ≤ 4.20: between average to good / good.
- 162 / 250 (64.8%) aspects / parameters were rated > 2.60 ≤ 3.40: between poor to average / average, and
- 84 / 250 (33.6%) aspects / parameters were rated > 1.80 ≤ 2.60: between very poor to poor / poor.

The reason for presenting the 34 aspects is that their MSs are > 3.00, which indicates that in general their rating is above average, as opposed to below average. Notably, no MSs are > 4.20 ≤ 5.00, which would indicate between good to very good / very good. Furthermore, only the top 5 / 250 (2.0%) MSs are > 3.40 ≤ 4.20, which indicates the aspects / parameters are rated between average to good / good - ACHASM, South African Institute of Occupational Safety and Health (SAIOSH), Construction H&S Officers (CHSOs), and Construction H&S Managers (CHSMs) (Contribution to CH&S), and Federated Employers Mutual Assurance (FEM) (Processing and payment). ACHASM and Saiosh are professional associations, construction and generic, respectively. However, Saiosh contributes to construction H&S courtesy of, inter alia, informing her members and accrediting construction H&S continuing professional development (CPD). FEM is the licenced mutual workers' compensation insurance provider for construction.

The next 29 aspects / parameters include the Federated Employers Mutual Assurance (FEM), and Master Builders South Africa (MBSA), and Master Builders Associations (MBAs) (Contribution to CH&S) ranked 6th to 8th, followed by the Construction Regulations (Legislation), tower cranes, H&S representative training, equipment manufacturers e.g., scaffolding (Contribution to CH&S), mobile cranes, H&S induction training, South African Council for the Project and Construction Management Professions (SACPCMP) (Contribution to CH&S), Occupational Health and Safety Act (OHSA) (Legislation), Compensation for Occupational Injuries and Diseases Act (COIDA) (Legislation), first aider training, South African National Roads Agency Limited (SANRAL) (Contribution to CH&S), and plant manufacturers (Contribution to CH&S) ranked 9th to 20th. FEM, the MBSA, and MBAs were recognised for their contribution to construction H&S in the cibd (2009) report. It is notable that the primary legislation applicable to construction, namely the Construction Regulations, the OHSA, and COIDA are rated above average. Then, the inclusion of tower cranes, equipment manufacturers e.g., scaffolding (Contribution to CH&S), and mobile cranes is notable as they represent an important resource, namely plant and equipment. H&S representative training, and H&S induction training represent training, and the latter is critical as it 'sets the scene' on projects. The SACPCMP registers, inter alia, Construction H&S Agents (CHSAs), CHSMs, and CHSOs and has a major responsibility in terms of assuring the competence of such registered persons. SANRAL is responsible for the development and maintenance of road infrastructure and has the potential to influence construction H&S as a major public sector client.

Construction management commitment (Top level), Construction Managers (Top level), Engineering Council of South Africa (ECSA), and CHSAs (Contribution to CH&S), toolbox talks (In general), and South African National Standards (SANS) (Sufficient H&S related standards) are ranked 21st to 26th. Given the role of management commitment to H&S, the inclusion of Construction Managers (Top level) is notable. ECSA registers, inter alia, a range of engineers involved in construction, and in given situations clients are required to appoint CHSAs to fulfil

their H&S responsibilities on projects. SANS standards include SANS 10085 and thus play a major role in H&S.

Client satisfaction, H&S management systems (H&SMSs), administration, personnel hoists, daily H&S task instructions (DH&STIs), Construction Managers (Operational level) (Contribution to CH&S), HIRA, and H&S Representatives (Contribution to CH&S) are ranked 27th to 34th. Client satisfaction (relative to H&S) is notable, however, the MS of 3.05 is barely above 3.00. H&SMSs are critical as administration, and DH&STIs. Construction Managers (Operational level) are responsible for the management of the physical construction process and therefore, directly influence H&S, and H&S Representatives, although a part-time function, is a legal requirement in terms of the OHSA.

Table 1: Rating of the South African construction industry relative to 34 construction H&S aspects / parameters

Aspect / Parameter	Response (%)							
	Unsure	Very poor	Poor	Average	Good	Very good	MS	Rank
Association of Construction Health and Safety Management (Contribution to CH&S)	18.0	0.0	11.5	24.6	29.5	16.4	3.62	1
Federated Employers Mutual Assurance (FEM) (Processing and payment)	27.9	1.6	3.3	24.6	34.4	8.2	3.61	2
South African Institute of Occupational Safety and Health (SAIOSH) (Contribution to CH&S)	18.0	1.6	14.8	18.0	32.8	14.8	3.54	3
Construction H&S Officers (Contribution to CH&S)	8.1	1.6	16.1	22.6	41.9	9.7	3.46	4
Construction H&S Managers (Contribution to CH&S)	6.5	3.2	11.3	30.6	37.1	11.3	3.45	5
Federated Employers Mutual Assurance (FEM) (Contribution to CH&S)	24.2	1.6	9.7	32.3	24.2	8.1	3.36	6
Master Builders South Africa (MBSA) (Contribution to CH&S)	18.0	3.3	8.2	32.8	32.8	4.9	3.34	7
Master Builders Associations (MBAs) (Contribution to CH&S)	20.0	1.7	13.3	26.7	33.3	5.0	3.33	8
Construction Regulations (Legislation)	6.3	7.9	15.9	22.2	36.5	11.1	3.29	9
Tower cranes	17.5	4.8	6.3	38.1	28.6	4.8	3.27	10
H&S representative training	12.9	3.2	16.1	30.6	30.6	6.5	3.24	11
Equipment manufacturers e.g., scaffolding (Contribution to CH&S)	17.2	4.7	9.4	37.5	25.0	6.3	3.23	12
Mobile cranes	14.3	3.2	12.7	34.9	31.7	3.2	3.22	13
H&S induction training	6.5	4.8	21.0	24.2	37.1	6.5	3.21	14
South African Council for the Project and Construction Management Professions (SACPCMP) (Contribution to CH&S)	14.1	6.3	17.2	28.1	21.9	12.5	3.20	15
Occupational Health & Safety Act (Legislation)	6.2	9.2	15.4	27.7	30.8	10.8	3.20	16
Compensation for Occupational Injuries & Diseases Act (Legislation)	10.9	6.3	17.2	29.7	28.1	7.8	3.16	17
First aider training	6.5	4.8	16.1	38.7	29.0	4.8	3.14	18
South African National Roads Agency Limited (Contribution to CH&S)	27.9	8.2	8.2	26.2	26.2	3.3	3.11	19
Plant manufacturers (Contribution to CH&S)	15.6	4.7	14.1	40.6	18.8	6.3	3.09	20
Construction management commitment (Top level)	7.9	6.3	20.6	31.7	25.4	7.9	3.09	21
Construction Managers (Top level) (Contribution to CH&S)	6.3	7.9	15.9	34.9	30.2	4.8	3.08	22
Engineering Council of South Africa (ECSA) (Contribution to CH&S)	19.4	4.8	21.0	21.0	30.6	3.2	3.08	23
Toolbox talks (In general)	6.5	6.5	17.7	38.7	24.2	6.5	3.07	24
Construction H&S Agents (Contribution to CH&S)	7.7	9.2	12.3	36.9	30.8	3.1	3.07	25
South African National Standards (SANS) (Sufficient H&S related standards)	20.0	5.0	15.0	31.7	26.7	1.7	3.06	26
Client satisfaction	6.3	4.8	17.5	41.3	28.6	1.6	3.05	27
H&S management systems	12.7	3.2	19.0	39.7	22.2	3.2	3.04	28
Administration	4.8	3.2	20.6	44.4	23.8	3.2	3.03	29
Personnel hoists	21.3	4.9	11.5	42.6	16.4	3.3	3.02	30
Daily H&S Task Instructions	7.9	3.2	23.8	34.9	28.6	1.6	3.02	31
Construction Managers (Operational level) (Contribution to CH&S)	6.5	6.5	21.0	33.9	29.0	3.2	3.02	32
Hazard identification and risk	6.5	8.1	17.7	35.5	29.0	3.2	3.02	33
H&S Representatives (Contribution to CH&S)	8.1	9.7	16.1	37.1	21.0	8.1	3.02	34

Figure 1 presents the current H&S status of South African construction using Anglo American plc's H&S journey model (Foster and Hoult, 2013). The H&S journey model was adapted for the study as a benchmark tool based on the 'safety maturity model', developed by Anglo America plc to assess the level of compliance and effectiveness with the standards-based safety management system. The model is unique in that it is directly linked to an organisation's H&S management standards and any cultural elements. It has been successfully used by teams of managers, supervisors, and workers to assess the maturity of H&S management systems.

The percentage responses presented above the five stages in the journey are notable, especially relative to 'Basic' (56.4%) and 'Reactive (30.9%). The resultant MS of 1.65 between 1.00 and 5.00, which is ≥ 1.00 < 1.80, indicates the status is between 'Basic' and 'Reactive', and that South African construction is non-compliant. This finding presents an alarming 'perception' relative to the finding that 52.5% of contractors were determined to be H&S non-compliant during visits to 1 415 construction sites by the Department of Labour (DOL) inspectors during a 'construction blitz' (cidb, 2009).

Figure 1: Current H&S status of South African construction

56.4%		30.9%		5.5%		5.5%		1.8%
Basic	→	Reactive	→	Compliant	→	Proactive	→	Resilient
Little interest in H&S – doing the minimum to get by. Exposed to significant H&S issues.		Aware that H&S is an issue but usually responding to issues. Systems are forming, but immature.		H&S is a core part of doing business. Focus is on compliance with systems and processes.		Starting to get ahead of the game – anticipating and preventing H&S issues.		World class H&S performance – creating a process of continuous improvement / innovation.

Table 2 presents the top ten challenges in terms of improving the H&S performance of the South African construction industry in terms of themes and the patterns identified, which are discussed in more detail below. The most frequently identified challenges to improving H&S were lack of leadership and management commitment. Respondents revealed that management often perceives H&S as a financial burden as opposed to an investment. Most of the responses expressed negative sentiments attributed to the absence of managerial accountability and lack of visible leadership in promoting a healthy and safe working environment. Respondents also commented on the ego of the managerial team and referred to Section 8 of the OHSA, which highlights the duties of the employer not being considered.

Respondents reported weak legislative and regulatory compliance, and inadequate enforcement emerged prominently. Respondents expressed frustration over insufficient monitoring and lenient penalties, notably referenced as "R200 penalties as a joke", which respondents considered ineffective. This regulatory gap allows widespread disregard for H&S standards, significantly impeding progress.

Inadequate and ineffective training was frequently emphasized as a critical challenge. Respondents noted the absence of robust training programmes and the lack of ongoing professional development, resulting in a lack of competent and adequately skilled H&S professionals.

Poor H&S culture such as attitudes for prioritising productivity over H&S, was consistently identified. Workers frequently accept unsafe practices due to socio-

economic pressures - job security, while supervisors often ignore H&S protocols, prioritising speed, and convenience over compliance.

Most respondents highlighted that limited funding, and financial constraints impact the implementation of effective H&S measures. Smaller firms and contractors particularly struggle to allocate adequate resources, causing compromised H&S practices.

The inadequacy of proactive risk management strategies was repeatedly cited. Respondents revealed that the nature of HIRAs is superficial and often considered mere administrative tasks for the sake of compliance, rather than critical H&S tools.

Communication gaps arising from language and cultural diversity in South Africa with 11 spoken official languages were emphasized as a serious challenge to H&S compliance. Misunderstandings due to poor communication and the low education status of workers contribute to incidents and non-compliance issues.

Frequent reliance on subcontractors and informal labour arrangements was noted as sources of inconsistent H&S standards and oversight. The nature of the industry is fragmented and hinders uniform implementation of effective H&S practices.

Poor data collection, incident reporting, and monitoring systems emerged as substantial issues. Underreporting and incomplete reporting were frequently highlighted, and this prevent accurate assessments of industry health and safety performance and obstructing targeted improvements.

High unemployment and poverty contribute to unsafe workplace practices as workers often feel compelled to accept working in hazardous conditions due to fear of job loss. This fear also reduces the likelihood of incident reporting, perpetuating unsafe working environments, and limiting opportunities for corrective actions.

Table 2: The top ten challenges in terms of improving the H&S performance of the South African construction industry

Theme	Patterns identified
Leadership and Management Commitment	• Perception of H&S as a cost, not an investment • Lack of accountability and visible leadership • Ego
Compliance and Regulatory Enforcement	• Weak regulatory monitoring and enforcement • Insufficient penalties e.g., ineffective low fines
Education, Training, and Competency	• Absence of robust training programmes • Lack of CPD
H&S Culture and Worker Behaviour	• Prioritising productivity over H&S • Acceptance of unsafe practices due to socio-economic pressures
Financial and Resource Allocation	• Insufficient funding for H&S measures • Financial strain in smaller firms
Risk Management and Planning	• Superficial or administrative approach to risk assessments • Inadequate proactive H&S planning
Communication, Language, and Cultural Barriers	• Miscommunication due to diverse language groups • Cultural differences impacting compliance
Industry Fragmentation and Subcontractor Management	• Reliance on subcontractors resulting in inconsistent H&S standards. • Lack of oversight
Data, Reporting, and Monitoring Issues	• Poor incident reporting and monitoring • Underreporting leading to inaccurate H&S assessments
Socio-economic Factors	• High unemployment and poverty driving acceptance of unsafe work • Fear of job loss reducing incident reporting

DISCUSSION

Given that the South African construction industry was rated below average relative to 34 of 250 (13.6%) construction H&S aspects / parameters, the construction industry can be deemed to have a major challenge in terms of performance. This is underscored by the current H&S status of South African construction, which is between 'basic' and 'reactive' based upon a MS of 1.65, and therefore South African construction can be deemed non-compliant. This finding aligns with the 2009 cidb report, which revealed that less than 50% of the contractors were compliant with the H&S requirements. The reactive approach is no surprise given the 6 May 2024 George building collapse, resulting in 34 fatalities. This was followed by a series of 'blitz' inspections in the region. Furthermore, South African construction industry H&S statistics, inter alia, the fatality rate are the ultimate 'outcome' measure of performance. Clearly, interventions are required.

Although the interventions to improve H&S in the South African construction industry were not presented due to space constraints, they in essence respond to the top ten challenges in terms of improving the H&S performance of the South African construction industry in terms of themes and the patterns identified as presented in Table 2. Improvements are inferred relative to 'leadership and management commitment', strong visible H&S leadership, and management accountability and involvement are advocated. With respect to 'compliance and regulatory enforcement' stricter monitoring and enforcement and effective penalties and legal action are advocated. Accessible and affordable training programmes, and CPD are advocated relative to 'training, education, and competency'. In terms of 'H&S culture and behaviour', promoting H&S-first culture, and encouraging positive behavioural change are advocated. Adequate budgeting for H&S measures, and financial support for small medium enterprises (SMEs) are advocated relative to 'financial and resource allocation'. With respect to 'risk management and planning' thorough risk assessments and proactive planning are advocated. Multilingual training materials, and inclusive communication strategies are advocated relative to 'communication, language, and inclusivity'. In terms of 'Industry and subcontractor management' formalisation of subcontractor practices, and consistent application of H&S standards are advocated. Accurate incident reporting and data analysis systems, and adoption of modern H&S technologies are advocated relative to 'data, reporting, and technology adoption'. With respect to 'socio-economic and labour practices' addressing socio-economic pressures and ensuring fair and safe labour practices are advocated.

CONCLUSIONS

Given the rating of the construction industry relative to 250 aspects / parameters, it can be concluded that the construction industry in general is not committed to H&S. Furthermore, given the current H&S status of South African construction, the construction industry can be deemed non-compliant in terms of H&S. Given that the construction industry in general is not committed to H&S and can be deemed to be non-compliant in terms of H&S, it can be deemed to have a poor H&S culture, which manifests itself in inadequate commitment to H&S. The building collapse in George, South Africa, 6 May 2024, which claimed 34 lives, was the ultimate proof that there is a major problem in South African construction in terms of H&S. Recommended interventions were included in the 'Discussion' section.

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A SYSTEMATIC REVIEW OF THE APPLICATION OF INDUSTRY 4.0 TECHNOLOGIES IN CONSTRUCTION SAFETY MANAGEMENT

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The adoption of Industry 4.0 technologies has reshaped traditional approaches to Construction Safety Management (CSM), offering more intelligent, efficient, and integrated solutions. However, while numerous studies explore the practical application of individual technologies, there remains a lack of a comprehensive and up-to-date review that synthesizes these developments across the CSM landscape. Existing reviews are often limited by narrow scopes, outdated data, or insufficient thematic depth. This study addresses this gap by presenting a Systematic Literature Review (SLR) of 148 articles published between 2013 and 2024, using PRISMA guidelines coupled with science mapping analysis. Through bibliometric evaluation and thematic analysis, the review identifies evolving trends, regional and institutional collaborations, research clusters, and gaps. The findings reveal key technologies such as Building Information Modelling (BIM), Artificial Intelligence (AI), and Virtual Reality (VR) as dominant in CSM applications. This study provides a comprehensive conceptual framework, critical insights, and actionable guidance for future research and practice in digitalised safety management.

Keywords: construction safety management, digital technologies, industry 4.0, systematic literature review, science mapping

INTRODUCTION

The accelerated digital transformation in the construction sector has reshaped construction safety management (CSM) from a traditional management-driven practice to a technology-driven approach (Zhou *et al.,* 2015; Zhang *et al.,* 2023). Emerging technologies have been examined for delivering intelligent, efficient, and integrated changes to CSM practice (Liu *et al.,* 2020). For instance, Kim *et al. (*2016) explored Building Information Modelling (BIM) for effective hazard identification; Hussain *et al. (*2024) employed Virtual Reality (VR) to enhance safety training performance; Ding *et al. (*2013) applied the Internet of Things (IoT) to connect diverse sensors and technology system for early hazards detection and accident prevention. Given their broad implementation and potential benefits, Industry 4.0 technologies have become a worthwhile research focus in the CSM context.

Since current studies mainly focusing on the practical application of individual technologies in CSM, a holistic review with in-depth thematic analysis remains

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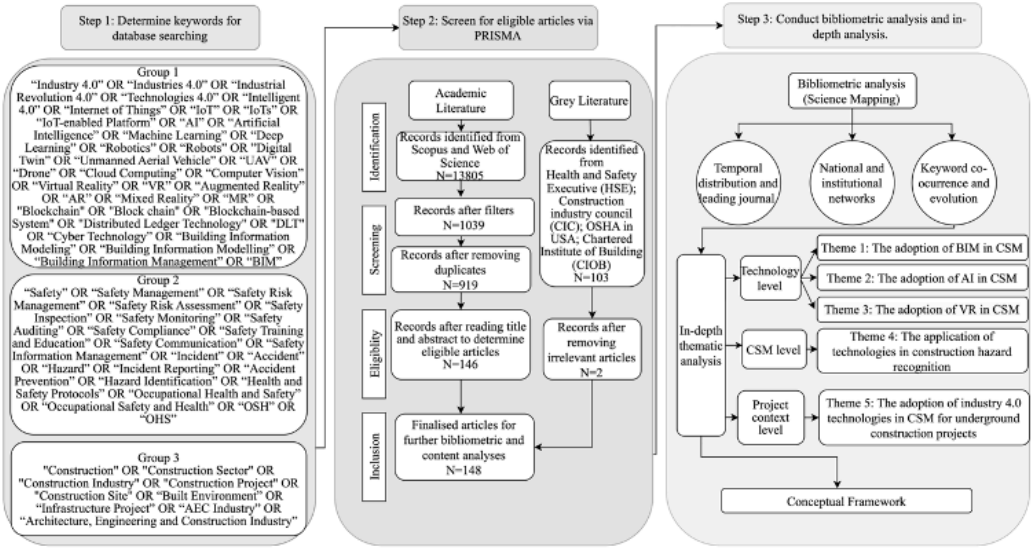
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lacking. Existing review papers typically suffer from limited scope, outdated sources and insufficient thematic depth, compromising their accuracy and reliability. For instance, Liu *et al. (*2020) provided a bibliometric review of literature published before 2019 without thoroughly addressing recent trends. Similarly, Soares Júnior *et al. (*2021) examined only 12 papers supplemented by surveys and interviews, which could yield incomplete findings due to limited data and low respondents' consensus. Besides, Kasim *et al. (*2021) analysed 30 papers, identifying drivers and barriers to technology adoption, but failed to connect specific technologies with distinct CSM areas. In response, this research intends to undertake a more comprehensive and logical SLR to deliver a well-organised investigation on the application of Industry 4.0 technologies in CSM. Compared with other reviews, it makes several contributions. Firstly, it expands the research scope by retrieving 148 articles through Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) from 2013 to 2024. Secondly, it provides an in-depth thematic discussion, highlighting the technology contributions in CSM. Finally, a well-structured conceptual framework was generated to illustrate the key findings, limitations and future directions. Thus, this research offers valuable insights for both academics and practitioners, providing guidance and supporting decision-making.

METHOD

This research employs a systematic literature review (SLR) approach, following the PRISMA guidelines to define keywords, select optimal databases, and apply predefined inclusion and exclusion criteria (See Table 1), ensuring a transparent and rigorous selection procedure (Babalola *et al.,* 2023). A total of 148 articles were included: 146 academic publications from Scopus and Web of Science, and 2 grey literature articles from CSM-related institutions. Due to the limited search functionality and inconsistent content structure of the grey literature sources, many retrieved articles were too general. Therefore, after careful screening, only 2 out of 103 grey literature sources were retained as supplementary materials to academic literature in the database of this research. The overall methodology process is illustrated in Figure 1.

Figure 1: Blueprint for the research methodology



FINDINGS

Bibliometric Analysis

For the bibliometric analysis, this research utilised the Citespace software to create various scientific mappings. These mappings visualise the temporal distribution trends, national and institutional collaboration networks, co-occurrence of keywords, and the evolution of keywords of the selected papers (Zamani *et al.,* 2024). Hence, this analysis provides an extensive depiction of the complex interrelationships within applying Industry 4.0 technologies in CSM.

Table 1: Filter criteria for the application of Industry 4.0 in CSM

Inclusion Criteria	Exclusion Criteria
Peer reviewed articles, including journal article and reviewed articles	The article is part of conference or book
No time limitation	The article is not written in English
Research area: Construction Building Technologies; Architecture; Business, Management and Accounting	The article is not the selected research area
Language: English	Articles without full text

Temporal distribution analysis

The temporal distribution trend of the selected articles is presented in Figure 2, reflecting the overall development of the research field and supporting future forecasting (Zhang *et al.,* 2023). As illustrated in Figure 2, the number of publications has experienced an overall upward trend over the past 12 years. Before 2019, the annual publication counts were relatively stable, remaining in single digits. Then, the initial rise commenced in 2020 and accelerated significantly in 2022. This observed trend aligns with findings from previous reviews on the digital transformation of construction project management, which also noted a substantial rise in publications after 2019 (Zhang *et al.,* 2023). This alignment suggests that, driven by the broader digitalisation wave, the technology application in CSM has gained more attention over the past 5 years, and it is expected to continue evolving, with increasing research interest.

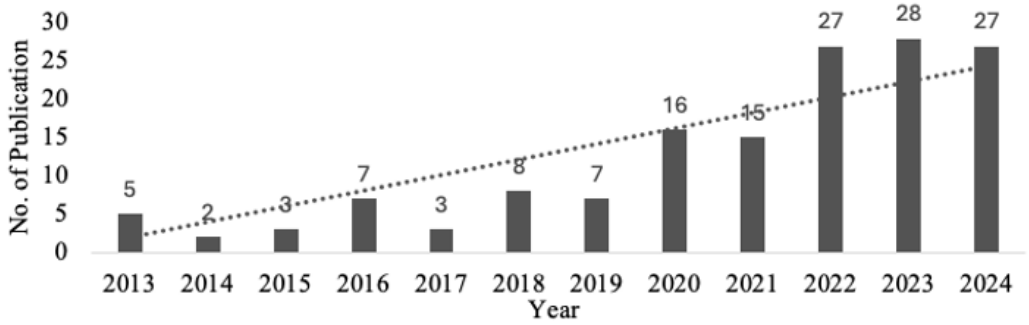


Figure 2: Annual publication trend

Top 9 leading journals analysis

This research presents the major journals of the selected articles to provide an overview of the publication landscape. Figure 3 displays the top 9 journals with at least three relevant articles, highlighting key sources of publication. These journals facilitate academic communication and serve as a foundation for the future development of this field (Zamani *et al.,* 2024). As shown in Figure 3, Automation in Construction is the leading journal, contributing the highest number of publications.

This journal focuses on implementing information technology across the architectural design, construction, and maintenance phases (Aghimien *et al.,* 2020), proving its position in engineering and technology disciplines. Other notable journals, such as Buildings, Journal of Construction Engineering and Management, and Engineering Construction and Architectural Management, also hold substantial authority and relevance, positioning them as essential venues for sharing novel insights related to the application of Industry 4.0 technologies in the CSM for further research.

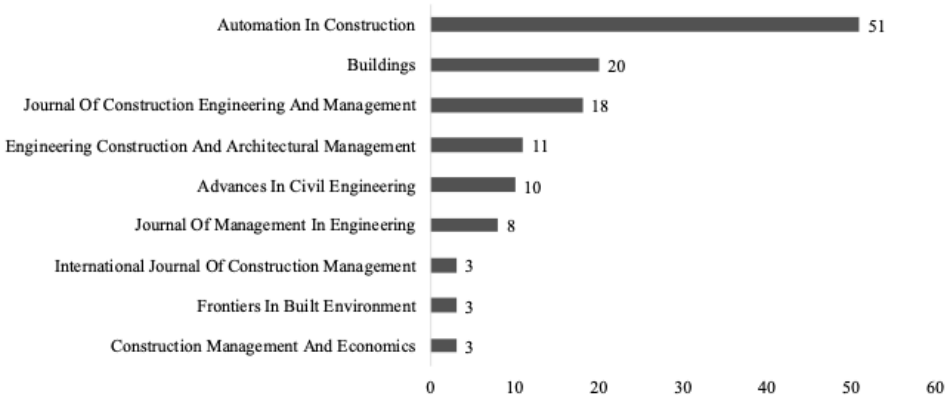


Figure 3: Top 9 leading journals

Regional distribution analysis

Then, this research examined the regional distribution of publications using collaboration network maps, emphasising the geographical collaborations and enabling researchers to find potential collaborators (Ali *et al.,* 2024; Akinlolu *et al.,* 2022). Figure 4(a) illustrates several representative countries, including China, the United States (USA), South Korea, Australia, and the United Kingdom (UK), which are the most active areas, indicating their pivotal role. Additionally, these countries also have high centrality, as indicated by the purple circles. This finding suggests that researchers from these nations have made notable contributions to the field and maintain a positive attitude towards international collaboration.

Figure 4: Regional collaboration network maps: (a) National network map and (b) Institutional network map

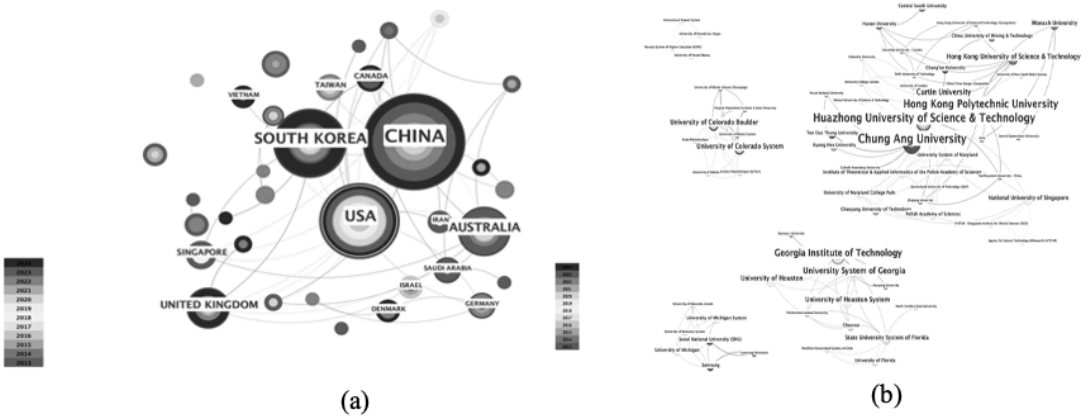


Figure 4 (b) presents five main institutional collaborative networks, with Chung Ang University, Huazhong University of Science and Technology, Hong Kong Polytechnic University, Georgia Institute of Technology, the University of Colorado Boulder among the most productive, aligning with the national-level distribution discussed

earlier. However, it is noteworthy that most collaborations remain within the same or neighbouring countries. For instance, institutions in Hong Kong primarily collaborate with those in mainland China and South Korea, with limited interactions involving institutions in the USA and Australia. Similarly, institutions in the USA tend to establish partnerships within their country. To enhance the generalisability of findings, future research could benefit from broader international collaboration.

Keyword co-occurrence and evolution analysis

This research also created a keyword co-occurrence map to evaluate the trends of research themes in the field, providing deeper insights and highlighting potential directions for future research (Kim and Kim, 2024). Figure 5 displays the principal keywords proposed in the eligible articles, each appearing more than 25 times and divided into three groups. Group 1 presents several advanced technologies that have received significant attention in the research field, including Building Information Modelling (BIM), Computer Vision (CV), Machine Learning (ML), and Augmented Reality (AR), with CV applications primarily driven by deep learning (DL) algorithms. The colour variations of the nodes indicate that they have been consistently examined since approximately 2019, demonstrating their ongoing relevance and potential for future research. Group 2 involves various CSM aspects, such as hazard identification, accident classification and management, highlighting those popular CSM subdivisions with great concern. Group 3 contains several terms of the construction industry. Accordingly, future research is encouraged to adopt technologies to explore those directions, paving the way for innovative studies.

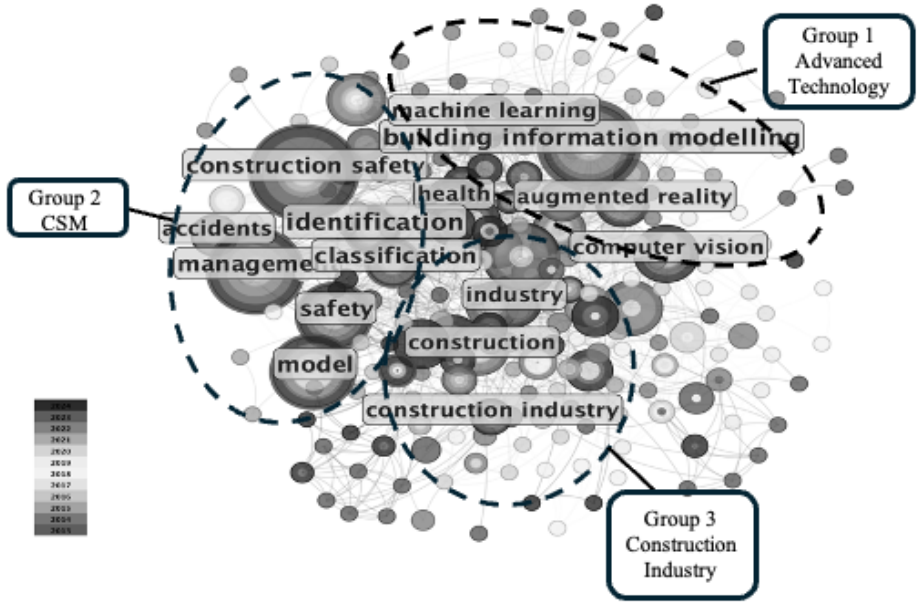


Figure 5: Keyword co-occurrence network

To further analyse the evolution of keywords within this field, this research clusters the identified keywords into distinct groups and demonstrates their evolution over time (Zamani *et al.,* 2024). Figure 6 illustrates seven primary keyword clusters within the research field, validating the findings from the keyword co-occurrence analysis. Among these clusters, BIM (#0) and VR (#5) originated early in the research landscape (appeared in 2013) and have maintained sustained attention. Additionally, CV (#1) and Underground Construction (#3) also appeared relatively early but have experienced decreased attention by 2024, reflecting a recent decrease in the popularity of this study. Other clusters, such as ML (#2) and Hazard Recognition (#4), appeared

slightly later (between 2013 and 2015) and have maintained their prominence over time. Finally, 4D BIM (#6), a newly developed technology, surfaced post-2015 and gained significant attention around 2020. This novel technique integrates a time dimension into traditional BIM models, enabling the visualisation of the construction process from any temporal point or place within the virtual project environment, offering a more immersive viewpoint for the construction project (Crowther and Ajayi, 2021). From the CSM perspective, it concurrently promotes researchers to address more safety management challenges by accounting for temporal dynamics within the whole construction process to improve the performance of CSM.

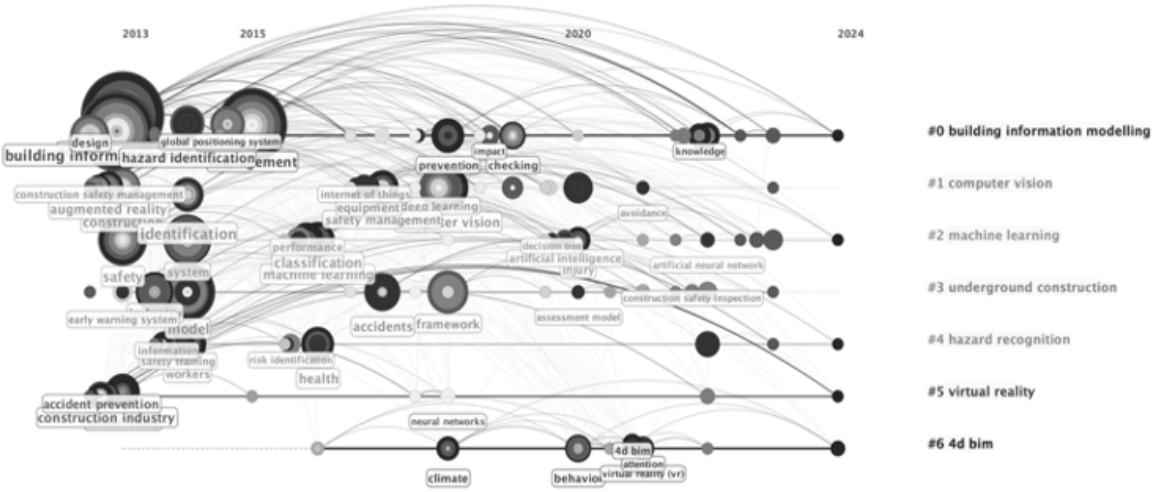


Figure 6: Keyword timeline evolution

DISCUSSION

This research provides an in-depth thematic discussion based on the keyword evolution analysis. This section is structured into five themes across three dimensions: technological level, specific CSM practice, and construction project context. It systematically examines the application and effectiveness of key Industry 4.0 technologies, such as BIM, AI and VR, within critical CSM domains, including hazard identification. Finally, the findings are synthesized into a comprehensive conceptual framework, guiding future research directions and industry practice.

Theme 1: The adoption of BIM in CSM (Cluster #0 and #6)
BIM has been widely explored to improve the CSM performance due to its unique features, such as generating visualised models, fostering multi-party collaboration, and facilitating information sharing. For instance, Kim *et al. (*2016) employed BIM to visualise the construction process and support automated hazard identification, while Yuan *et al. (*2019) demonstrated its potential in accident prevention during the design stage. Other studies have also utilised BIM to identify safety risk factors (Xiahou *et al.,* 2022), verify compliance with safety rules during inspections (Li *et al.,* 2022), and support safety planning for temporary structures, such as scaffolding (Kim *et al.,* 2018). BIM has also been integrated with other intelligent techniques to enable advanced safety functions. For example, Kulinan *et al. (*2024) investigated the integration of BIM with DL to simulate a realistic construction site and develop an advanced real-time safety monitor system, improving overall worker safety.

Theme 2: The adoption of AI in CSM (Cluster #1 and #2)
ML and CV have received growing attention for improving CSM performance via different aspects. For instance, ML models have been trained to predict the likelihood of potential safety accidents and their associated injury outcomes (Koc *et al.,* 2021; Choi *et al.,* 2020). Meanwhile, CV has been primarily adopted for construction safety monitoring, mainly adopt DL algorithm. They are mainly used to detect unsafe worker behaviours, such as unauthorised entry into hazardous areas (Mei *et al.,* 2023) and improper wear or use of personal protective equipment (PPE) (Lee *et al.,* 2023).

Theme 3: The adoption of VR in CSM (Cluster #5)
VR has been utilised as a valuable tool to enhance safety training and education in CSM. Compared to traditional methods, VR offers an immersive and interactive learning environment, allowing users to experience simulated construction hazards without direct exposure to physical risks. This approach has increased participants' engagement in training activities (Yan *et al.,* 2022). Recent studies have explored the combination of VR and AI, enabling interactive question-and-answer sessions during training (Hussain *et al.,* 2024).

Theme 4: The adoption of advanced technologies in construction hazard recognition (Cluster #4)
Adopting Industry 4.0 technologies for hazard identification is another popular theme in current research. Many studies have focused on developing automated hazard identification systems by BIM to visualise hazardous areas on construction sites and support proactive risk management (Kim *et al.,* 2016). Moreover, AR has also been explored for this purpose, with some studies suggesting that head-mounted AR devices may help improve workers' hazard recognition in simple construction contexts (Liu *et al.,* 2024). Furthermore, DL has also been applied to develop an intelligent safety Question-and-Answer (Q&A) system, which extracts experiential knowledge from historical data to support hazard identification (Tian *et al.,* 2023).

Theme 5: The adoption of advanced technologies in CSM for underground construction projects (Cluster #3)
From a broader perspective, due to the inherent complexity and high-risk conditions of underground construction projects, CSM in this specific project environment has also been widely discussed (Yu *et al.,* 2024). The studies on this theme mainly explored using Cyber-Physical Systems (CPS), such as Digital Twins (DT) and the IoT, to support early risk warnings and safety hazard identification during underground construction activities. This allows project stakeholders to perform real-time hazard detection and take proactive actions to prevent severe accidents (Yu *et al.,* 2024; Ding *et al.,* 2013).

These five themes reflect an emphasis on specific technologies and their applications across corresponding CSM areas. However, wearable technologies, such as smart helmets, sensor-embedded clothing, and exoskeletons, did not emerge as a standalone theme in this analysis, as they are often integrated with other technologies, including IoT and robotics. Nevertheless, since wearables represent a growing interest in CSM (Manu *et al.,* 2023), future studies would benefit from examining wearable systems more explicitly as a distinct domain within CSM. In addition, most studies are conducted through small-scale or experimental settings. Therefore, further empirical research is also expected to assess the effectiveness of technology in the real world and provide practical constraints of the technology to avoid optimism.

Conceptual framework

Based on the key findings and discussion section, this research proposes a conceptual framework, as depicted in Fig 7. This framework exhibits the implementation of key emerging technologies (distinguished by different line types) in diverse aspects of CSM and highlights their contribution to enhancing safety performance. Afterwards, this research also summarised several existing limitations in relevant articles and outlined potential future directions. These insights provide valuable guidance and suggestions for researchers conducting further investigations.

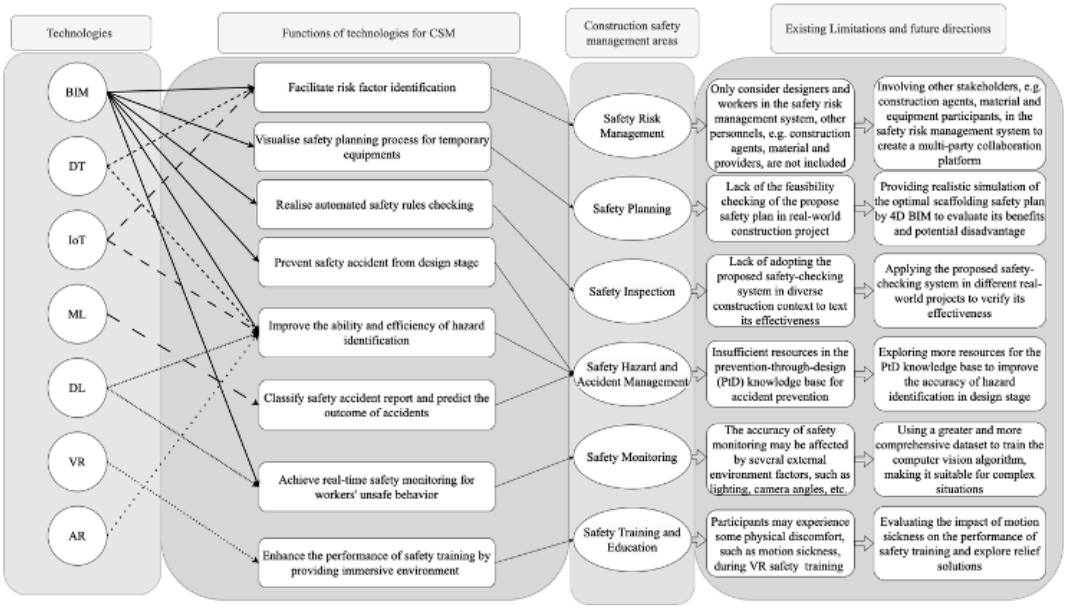


Figure 7: Conceptual Framework

CONCLUSIONS

This research investigates the application of Industry 4.0 technologies in CSM through an SLR, employing a bibliometric analysis to examine the key attributes of the selected articles with an in-depth thematic discussion. It aims to identify the overall research landscape, collaboration networks, and critical themes within the research field. The findings reveal an upward trend in existing publications, with notable contributions from countries such as “China”, “the USA”, “South Korea”, etc. Besides, this research also performed a keyword co-occurrence and evolution analysis to identify the widely applied emerging technologies, such as “BIM”, “VR”, and highly concerned CSM subdivision, which is “Hazard Recognition”. Subsequently, an in-depth thematic discussion followed, detailing the specific applications of these technologies alongside a comprehensive conceptual framework.

Based on the findings, this research offers valuable contributions to both academic research and practice. For academics, this research offers a clear insight into the status of this research field, including its development trends and promising future directions. Thus, this research extends the existing body of knowledge and facilitates future development. Additionally, the findings also provide practical guidance for project decision-makers by identifying the widely adopted technologies in practice. Thus, it can help practitioners make informed decisions and reduce safety incidents that result in economic losses.

While this research provides a structured overview, several limitations still remain. Firstly, the findings primarily focused on individual technologies and their applications in narrow CSM contexts, limiting insights into the integrated use of multiple technologies across broader CSM domains. Secondly, Health-related issues were also underrepresented in the in-depth discussion, despite it is also considered as a critical topic in CSM. Thirdly, certain specific technologies, such as “robotic and autonomous systems” and “wearable technologies”, were not sufficiently addressed, despite attracting growing attention in this domain. Therefore, future studies are encouraged to explore both the distinct roles of individual technologies and their integrated impact in a broader CSM framework, with more attention to health-related challenges and the adoption of more emerging technologies like "Wearable systems", "Exoskeletons" and "Autonomous robotics" to investigate their potential impact on CSM.

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HUMAN RESOURCES MANAGEMENT

THE FUNCTIONS OF PROJECT MANAGEMENT OFFICE MODELS FOR CONSTRUCTION SMES: A DELPHI STUDY IN SAUDI ARABIA

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The functions of project management offices (PMOs) vary from one organisation to another. Accordingly, a PMO can offer considerable benefits tailored to an organisation's needs by enhancing efficiency, consistency, and strategic alignment. Moreover, the roles of PMOs differ depending on organisational demands, particularly in relation to specific functions. As such, they play a crucial role in ensuring project success by providing structure, governance, and support. In construction small and medium-sized enterprises (SMEs), managerial shortcomings are often a key cause of project delays, especially when acting as subcontractors. This study aims to explore the applicable functions of PMOs for Saudi construction SMEs. A Delphi technique was employed as a qualitative method, focusing on the executive level of construction practitioners. The findings revealed that the most important PMO functions for Saudi construction SMEs are controlling performance data from projects, scenario planning and strategic analysis, identifying project priorities, improving team mentorship, and integrating technologies. This study makes a significant contribution to understanding the key functions of PMOs within the Saudi construction industry and supports the establishment of PMOs to enhance project delivery.

Keywords: functions; PMO; construction; SME; Saudi Arabia

INTRODUCTION

Small and medium-sized enterprises (SMEs) in Saudi Arabia play a key role in the Kingdom's transformative Vision 2030 (Khan and Iqbal, 2020). According to the Saudi Contractors Authority (SCA), the construction industry comprised approximately 39,200 small and 5,070 medium-sized construction enterprises in 2021, employing around 576,100 workers in small enterprises and 524,300 in medium enterprises (SCA, 2024). SMEs are critical to the construction sector, delivering numerous projects under tight schedules and financial constraints, unlike larger construction corporations (Thomas, 2022). However, SMEs in Saudi Arabia face challenges such as limited access to financing, regulatory barriers, and labour shortages. In response, the government established the Small and Medium Enterprises General Authority, Monsha'at, to simplify procedures and expand financing opportunities (Kayani and Alzaid, 2025). Founded in 2016, Monsha'at operates independently to regulate, support, and develop SMEs, with the goal of increasing their contribution to GDP from 20% to 35% by 2030.

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The growing complexity of business projects has heightened the need for centralised project coordination. Effective project governance involves a value system, defined responsibilities, and standardised processes and policies to achieve organisational objectives in the best interests of stakeholders (Muller, 2009). Many organisations still execute projects ad hoc, without formal project management methodologies, often resulting in suboptimal outcomes. To address this, new organisational structures such as the Project Management Office (PMO) have been introduced to enhance project execution and reduce resource inefficiencies (Monteiro *et al.,* 2016). In August 2015, the Saudi government launched the National Programme to Support Project Management, Operation, and Maintenance in Public Entities (Mashroat) to improve public project oversight (Mashroat, 2025). Six years later, the government established the Expenditure and Project Efficiency Authority (EXPRO), consolidating Mashroat and the Spending Efficiency Achievement Centre into a single national PMO body responsible for overseeing all public projects (EXPRO, 2025). EXPRO has since played a vital role in delivering Vision 2030 objectives (Vision, 2025). Despite the growing recognition of PMOs in large-scale projects, their role in SMEs is often underestimated, and PMOs may be viewed as unnecessary (Pansini and Terzieva, 2013). Moreover, their implementation is sometimes criticised for creating costly overheads (Osman *et al.,* 2024).

This research seeks to identify the most valuable PMO functions for SMEs in the Saudi construction industry. SMEs currently considering the adoption or restructuring of a PMO may benefit from a clear understanding of the most applicable PMO functions. Kerzner (2009) emphasized that modern enterprises increasingly integrate PMOs into their organisational structures, describing the PMO as one of the most significant developments in project management in recent decades. To achieve this aim, the study has four objectives: (1) to identify the nature and extent of PMO functions as documented in the literature, (2) to examine the implementation of these functions in construction SMEs in Saudi Arabia, (3) to rank the most influential PMO functions for these SMEs, and (4) to define a suitable PMO model for SME use. The novelty of this study lies in its focused exploration of the evolving role of PMOs in Saudi construction SMEs, highlighting how PMO models can be selected or adapted to suit enterprise needs. Accordingly, the research aims to identify the most important PMO functions for SMEs in the Saudi construction sector, supporting authorities in establishing an appropriate PMO model for this context.

METHOD

This research employed a qualitative approach combining both primary and secondary sources. The secondary source comprised a systematic literature review, while the primary data were collected using a modified Delphi method (MDM). A comprehensive set of 29 PMO functions - coded F1 to F29 - was identified through the literature as potentially influencing the development of a PMO model. These functions were then assessed in relation to their relevance and impact on SMEs within the Saudi construction industry. To capture expert insight, the MDM was selected as a suitable research tool capable of eliciting informed judgements. The systematic review focused on publications containing keywords such as ‘project management office’, ‘PMO type’, ‘PMO model’, and ‘PMO functions’. Searches were conducted across several academic databases, including the Saudi Digital Library (SDL), Web of Science, Emerald, and Scopus, covering the period from 2005 to 2024. This process initially yielded 32 articles, of which 12 were ultimately deemed directly relevant to the research. These included three books, four Q1 journal articles, and five

conference papers or proceedings from the Project Management Institute (PMI) and collectively informed the literature section. The Delphi method is widely regarded as a valid qualitative approach. It incorporates elements of traditional quantitative techniques such as questionnaire surveys (MacCarthy and Atthirawong, 2003) and involves the use of repeated questionnaires with feedback between rounds to develop consensus on a specific topic (Haven *et al.,* 2020). The technique seeks the views of a panel of experts to assess the degree of consensus and resolve any disagreement (Henchion and McIntyre, 2005). In this study, the MDM was employed to reach expert agreement on the most applicable PMO functions for construction SMEs in Saudi Arabia, using a 75% group consensus threshold.

Typically, MDM is conducted in two rounds, during which experts respond to predefined topics rather than generating them. The aim is not to build new themes but to reach agreement on the topics presented (Sossa *et al.,* 2019). Most studies use two rounds, as more than two may result in increased panel attrition (McMillan *et al.,* 2016). Accordingly, this study adopted a two-round modified Delphi process specifically designed to build consensus among a panel of practitioners from the Saudi construction industry. Consensus was defined as either ≥75% agreement among participants on a 10-point scale or a standard deviation (SD) of less than 1.0 (Christie and Barela, 2005). These figures were interpreted qualitatively to represent the degree of consensus. Consensus is commonly evaluated using statistical measures such as the proportion of participants selecting a single response, the interquartile range (IQR), or the SD. To assess the validity of SD as a consensus measure, both SD and IQR were calculated for each simulated Delphi statement (Franc *et al.,* 2023). Table 2 presents the median, SD, and IQR values for all items. The MDM process involved the development, distribution, collection, and analysis of questionnaire data (Padel and Midmore, 2005). The research design comprised three phases: First, identifying relevant PMO functions from the literature; second, constructing a questionnaire to measure the perceived importance of each function for Saudi construction SMEs; and third, distributing the questionnaire in two rounds. The first round gathered expert ratings on the importance of each function, while the second round provided feedback from the first and sought final consensus. A 10-point Likert scale was used, with 1 indicating 'not at all important' and 10 indicating 'extremely important'. The MDM technique requires the explicit selection of experts; therefore, four categories of qualified participants were chosen: CEOs, general managers, directors, and chairmen. Each participant was required to be a member of a recognised board and to have at least 15 years of experience in the construction industry, spanning both public and private sectors. Participants were identified and selected from government agencies (e.g., the Saudi Contractors Authority) and the construction sector (e.g., the Ministry of Commerce's list of top construction companies engaged in SME-related projects). The questionnaire link was then distributed to these individuals. In total, the survey was sent to 87 practitioners. The first round received 31 responses, and the second round received 27. The participants represented the five main regions of Saudi Arabia: Riyadh, Makkah, the Eastern Province, Hail, and Asir. The participants' levels of education were also recorded.

LITERATURE REVIEW

PMOs have evolved from performing clearly defined functions to undertaking more complex and varied roles, adapting to changing organisational and industry demands (Aubry *et al.,* 2008). PMOs vary significantly across organisations depending on their objectives, structures, and sectors. This variability has led to confusion in the

standardisation of project management practices and the formalisation of PMO roles. PMOs serve a range of functions, from supporting project managers to offering strategic oversight; however, organisations tend to customise PMOs to suit their specific contexts and needs (Hobbs and Aubry, 2007). According to Pinto (2016), PMOs can be classified by three mutually exclusive scopes (departmental, enterprise, and project-programme) and seven potential approaches: Strategic, strategic-tactical, strategic-operational, tactical, tactical-operational, operational, and strategic-tactical-operational. The appropriate PMO type for a given organisation results from a combination of its scope and one of these seven discrete approaches. Oliveira *et al. (*2017) noted that a range of PMO models and functions has been proposed by various authors. Nonetheless, organisations face challenges in determining which functions to apply within specific industries, and discrepancies between theory and practice further complicate implementation. The current research therefore focuses on 29 PMO functions, representing nine distinct PMO models, as a normative and prescriptive view of the potential roles and functions of PMOs. A Project Support Office (PSO) is a specialised unit within an organisation that provides consultancy for project management activities at administrative, technical, and strategic levels, ensuring consistency, efficiency, and compliance with project management methodologies. The PSO typically encompasses three key functions: Planning and scheduling project activities, providing project management tools, and improving document management (Fitzgerald, 2008). The Project Management Office for Centres of Excellence (PMoCE) is a critical structure that supports effective project execution within Centres of Excellence (CoEs). PMoCE emphasizes investment in people through knowledge sharing and provides governance, strategic alignment, and best practices. It ensures effective planning, execution, and monitoring in line with the organisation's mission and objectives. The PMoCE typically comprises three main functions: Enhancing team mentorship, upgrading team skills, and promoting knowledge sharing among project managers (Hubbard *et al.,* 2015). The Programme Management Office (PgMO) operates at a higher organisational level, managing multiple interrelated projects within a programme. It plays a crucial role in optimising resources, mitigating risks, and enhancing overall efficiency. The PgMO typically includes three core functions: Recruiting and developing project managers, promoting project selection, and aligning projects with strategic objectives (Project Management Institute [PMI], 2013). The Supporter PMO serves an administrative function at the organisational level to ensure operational efficiency. It may take various forms, including project support offices, executive sponsors, mentors, and external stakeholders. Supporter PMOs influence decision-making, risk management, and project effectiveness by bridging gaps in resources, expertise, and collaboration. Their typical functions include providing project status updates, identifying risks and issues, and maintaining project archives (Unger *et al.,* 2012).

An Enterprise PMO is a governance entity within an organisation that enables real-time project data to support project, programme, and portfolio management activities, ensuring alignment with strategic objectives, optimising resource utilisation, and delivering business value. Its main functions include planning scenarios and strategic analysis, establishing a governance framework, and reporting and controlling initiatives (Crawford, 2010). Similarly, a Project Office is a centralised unit that provides data to higher authorities to support consolidated project management. It ensures alignment with business objectives, standardises methodologies, and enhances resource efficiency. Evolving from an administrative role to a strategic function, it influences decision-making in complex environments and typically performs functions

such as managing individual projects, developing operational plans and budgets, authorising adjustments, and controlling progress reports and documentation (Garfein, 2005). The Basic PMO oversees multiple projects and supports consistent execution by introducing standardised templates, reporting mechanisms, and project lifecycle models. Its key functions include establishing project management standards, developing processes for project selection, and controlling project performance data (Hill, 2008). A Business Unit PMO is a specialised structure within a larger enterprise that manages multiple projects within a specific business unit or division. It connects the central PMO and individual projects to ensure alignment with unit-specific goals, resources, and operational strategies. It's typical functions are managing multiple projects, integrating technologies, managing project resources, and identifying project priorities (Hubbard *et al.,* 2015).

The Controller PMO is responsible for a large, complex project and plays a critical role in industries where cost efficiency and budget control are essential. It ensures fiscal discipline by supporting decision-making through data, applying information management standards, and recommending corrective measures when necessary (Unger *et al.,* 2012). Taken together, the PMO functions identified across the literature are as follows: 1) planning and scheduling project activities, 2) providing project management tools, 3) enhancing document management, 4) improving team mentorship, 5) upgrading team skills, 6) sharing knowledge between project managers, 7) recruiting and developing project managers, 8) promoting project selection, 9) aligning with strategic objectives, 10) providing project status updates, 11) identifying risks, 12) maintaining project archives, 13) planning scenarios and conducting strategic analysis, 14) establishing governance frameworks, 15) reporting and controlling initiatives, 16) managing individual projects, 17) developing operational plans and budgets, 18) authorising adjustments, 19)controlling progress reports and documentation, 20) establishing project management standards, 21) developing project selection processes, 22) controlling performance data from projects, 23) managing multiple projects, 24) integrating technologies, 25) managing project-specific resources, 26) identifying project priorities, 27) supporting decision-making through data, 28) applying information management standards, and 29) suggesting corrective methods.

FINDINGS

The study examined the importance of 29 PMO functions, represented by nine PMO models, in the context of construction SMEs in Saudi Arabia. The findings showed that five functions achieved strong consensus, ten achieved moderate consensus with potential for implementation, eight received very low consensus in terms of median values but were marked by uncertainty due to high SDs, and six functions failed to achieve consensus. Section A presented the demographic characteristics of the participants. In line with the MDM requirement for expert participants, all respondents had over 15 years of experience in the construction industry and represented either the public or private sector. There were 31 participants in round one and 27 in round two. The five main regions of Saudi Arabia—Riyadh, Makkah, Eastern Province, Hail, and Asir—accounted for 84% of participants, who were also largely in senior managerial roles and highly educated. In round one, 45.2% of participants were from the public sector and 54.8% from the private sector, while in round two the proportions were 44.4% and 55.6%, respectively. Regarding experience, 61.3% of round one respondents had between 15 and 19 years of experience and 38.7% had more than 20 years, compared with 66.7% and 33.3%

respectively in round two. Regional representation in round one was Riyadh (29%), Makkah (22%), Eastern Province (26%), Hail (10%), and Asir (13%); and in round two, Riyadh (26%), Makkah (22%), Eastern Province (26%), Hail (11%), and Asir (15%). The roles of respondents in round one was CEO (13%), general manager (32%), director (26%), and head of department (29%), while in round two they were CEO (11%), general manager (33%), director (26%), and head of department (30%). In round one, 55% held a postgraduate degree and 45% a bachelor's degree; in round two, 33% held a postgraduate degree and 67% a bachelor's degree.

Section B evaluated the importance of 29 functions of PMO. Five functions achieved strong consensus in both rounds, with a median ($\tilde{x} \geq 70\%$), low SD, and IQR less than 1 in round one, and showed further improvement in round two. These top five functions were: (1) control performance data from projects ($x = 9.00$, $SD = 0.68$, $IQR = 1.0$ in round one; $x = 10.00$, $SD = 0.57$, $IQR = 1.0$ in round two), (2) plan scenarios and strategic analysis ($x = 9.0$, $SD = 0.85$, $IQR = 1.0$ in round one; $x = 9.0$, $SD = 0.66$, $IQR = 1.0$ in round two), (3) identify project priorities ($x = 8.0$, $SD = 0.87$, $IQR = 1.0$ in round one; $x = 9.0$, $SD = 0.74$, $IQR = 1.0$ in round two), (4) improve team mentorship ($x = 8.0$, $SD = 0.96$, $IQR = 1.0$ in round one; $x = 9.0$, $SD = 0.79$, $IQR = 1.0$ in round two), and (5) integrate technologies ($x = 7.0$, $SD = 1.01$, $IQR = 2.0$ in round one; $x = 8.0$, $SD = 0.63$, $IQR = 1.0$ in round two). Ten other PMO functions reached consensus in round one through median ($\tilde{x} \geq 70\%$) despite semi-high SDs (ranging from 1.28 to 1.64) and mostly IQRs between 1.5 and 2.5. These functions improved in round two, with more moderate SDs (ranging from 0.91 to 1.63) and better IQRs (between 1.0 and 2.0). These were: Plan and schedule project activities, provide project management tools, enhance document management, maintain project archives, provide management for a solitary project, develop operational plans and budgets, control progress reports and documentation, manage resources within projects, apply information management, and suggest corrective methods. The function ‘maintain project archives’ achieved consensus in round one ($x = 8.00$, $SD = 1.30$, $IQR = 1.5$) and showed improved IQR in round two ($x = 8.00$, $SD = 1.29$, $IQR = 1.0$).

Eight functions of PMO achieved weak consensus in round one, with a median ($\tilde{x} \geq 70\%$), very high SD (ranging from 1.42 to 1.73), and mostly high IQRs (ranging from 2.0 to 3.5). These functions improved in round two, maintaining consensus median ($\tilde{x} \geq 70\%$) with more moderate SDs (ranging from 1.19 to 1.62) and a consistent IQR of 2.0. These eight functions are: (1) upgrade team skills, (2) share knowledge between project managers, (3) recruit and develop project managers, (4) promote project selection, (5) provide project standing, (6) identify risk issues, (7) establish PM standards, and (8) develop processes for project selection. Six PMO functions did not achieve consensus in either round. In round one, they had a median below the threshold ($\tilde{x} < 70\%$), very high SDs (ranging from 1.52 to 1.91), and mostly high IQRs (ranging from 3.0 to 4.0). In round two, these functions showed only slight improvement, with median still below 70%, moderate SDs (ranging from 1.32 to 1.51), and high IQRs (ranging from 2.0 to 3.0). These functions are: (1) align with the strategies, (2) establish a governance framework, (3) report and control initiatives, (4) authorise adjustments, (5) manage multiple projects, and (6) support decision-making through data. Although these six functions failed to reach consensus, some are indirectly reflected in higher-ranked PMO functions. The low score for ‘align with the strategies’ reflects the lack of clear strategic direction in SMEs. Similarly, ‘establish governance framework’ highlights the absence of a governance structure,

while ‘report and control initiatives’ points to weak implementation of initiative management in SMEs. The result for ’authorise adjustments’ suggests that SMEs typically adjust naturally during project work, without requiring formal authorisation. ‘Manage multiple projects’ failed due to the scale and diversity of projects exceeding typical SME capacity. Lastly, ‘support decision-making through data’ scored poorly because of the general lack of available data to inform decisions.

Table 2: Findings details - Median - SD - IQR

	Round 1 (29)			Round 2(27)				Round 1 (29)			Round 2(27)		
	Mdn	SD	IQR	*Mdn*	SD	IQR		*Mdn*	SD	IQR	*Mdn*	SD	IQR
F1	8.00	1.64	2.0	8.00	1.48	2.0	F16	8.00	1.60	2.5	8.00	1.26	1.0
F2	7.00	1.28	2.0	7.00	0.91	1.0	F17	7.00	1.45	2.0	7.00	1.10	2.0
F3	8.00	1.60	2.5	8.00	1.42	2.0	F18	6.00	1.91	4.0	6.00	1.44	3.0
F4	8.00	0.96	1.0	9.00	0.79	1.0	F19	7.00	1.68	2.5	7.00	0.92	1.0
F5	7.00	1.73	3.0	7.00	1.53	2.0	F20	7.00	1.62	2.0	7.00	1.62	2.0
F6	7.00	1.59	3.0	8.00	1.37	2.0	F21	7.00	1.42	2.0	7.00	1.45	2.0
F7	7.00	1.56	2.5	7.00	1.31	2.0	F22	9.00	0.68	1.0	10.00	0.57	1.0
F8	7.00	1.54	3.0	8.00	1.39	2.0	F23	6.00	1.52	3.0	6.00	1.39	3.0
F9	6.00	1.63	3.5	6.00	1.51	2.0	F24	7.00	1.01	2.0	8.00	0.63	1.0
F10	7.00	1.57	3.0	8.00	1.19	2.0	F25	8.00	1.37	2.0	8.00	1.08	2.0
F11	7.00	1.58	2.5	7.00	1.47	2.0	F26	8.00	0.87	1.0	9.00	0.74	1.0
F12	8.00	1.30	1.5	8.00	1.29	1.0	F27	6.00	1.67	3.0	6.00	1.32	2.0
F13	9.00	0.85	1.0	9.00	0.66	1.0	F28	8.00	1.38	2.0	8.00	1.41	2.0
F14	6.00	1.73	3.0	6.00	1.45	3.0	F29	8.00	1.59	2.0	8.00	1.63	2.0
F15	6.00	1.55	3.0	6.00	1.31	3.0	X						

DISCUSSION

Many attempts to establish PMOs have failed due to insufficient prioritisation of organisational requirements when implementing PMO functions (Perry, 2009), even though most large organisations already maintain a PMO. In the context of Saudi Arabia’s construction industry, SMEs represent a significant segment, with over 978,000 SMEs registered, 20.7% of which operate in the construction and building sector (Monsha’at, 2025). These enterprises often face disorganised project delivery due to the nature of specialised task execution (Elhassan, 2019). The structure of a PMO model is shaped by a defined set of functions and should correspond to the size and needs of the organisation. According to Pinto (2016), a PMO may be categorised within one of three mutually exclusive scopes, departmental, enterprise, or project-programme, and aligned with one of seven approaches: Strategic, strategic-tactical, strategic-operational, tactical, tactical-operational, operational, or strategic-tactical-operational. These approaches, along with scope, form a conceptual framework for a suitable PMO model. The findings of this study clearly indicate that SMEs in the Saudi construction industry require a tailored set of functions, with the top-ranked being control of performance data from projects, followed by scenario planning and strategic analysis, identification of project priorities, improved team mentorship, and the integration of technologies. However, unlike large corporations, SMEs often lack the financial resources and capacity to establish comprehensive PMOs. The prioritised functions in this study reflect a need for a customised model that draws from several existing types, including the Basic PMO, Enterprise PMO, Business Unit PMO, and PMoCE. This aligns with the Project Management Institute’s (2021) assertion that project management involves the application of best practices in knowledge, competencies, processes, tools, and techniques—an inherently complex and resource-intensive undertaking. The scale of SMEs also points to a lack of internal PMO expertise, consistent with Osman *et al. (*2024), who identified the absence of qualified PMO personnel and the high cost of implementation as major barriers. Furthermore, PMOs are often perceived as unnecessary within SMEs, and their role tends to be undervalued (Pansini and Terzieva, 2013). Some publications in different contexts have addressed the challenges facing SMEs, including financing SMEs in construction (Amupolo, 2013), a comparative study of problems facing small

building contractors (Mafimidivo and Iyagba, 2015), and a study on sustainable challenges and opportunities experienced by funded SMEs (Sheehama and Shihomeka, 2017). However, the findings here reveal inconsistency with those studies, as the top five ranked functions and others represent diverse PMO models rather than a defined PMO. The ten PMO functions that achieved medium consensus and the eight that achieved low consensus are a mix from all nine PMO models. These findings align with Pinto (2016), who stated that the type of PMO for an organisation is a mixture of its scope and one of seven discrete approaches. However, six functions related to strategy, initiatives, governance, and data management failed to achieve consensus. This may reflect the size of SMEs and a lack of high-level management perception, as SAMA (2025) defines small enterprises as generating revenue of SAR 3 to 40 million with 6 to 49 full-time employees, and medium enterprises as generating SAR 40 to 200 million with 50 to 249 full-time employees.

CONCLUSIONS

SMEs are a critical part of the construction industry, particularly in relation to subcontracting. SMEs in the Saudi construction sector are in urgent need of applying PMO concepts, as they share key operational characteristics with large construction firms that have already implemented PMOs. This research identified the most important PMO functions applicable to Saudi construction SMEs. A total of 29 functions were evaluated. The top-ranked functions were Control performance data from projects, plan scenarios and strategic analysis, identify project priorities, improve team mentorship, and integrate technologies. These findings offer valuable insights for practitioners and administrative bodies, clarifying the current landscape and providing practical implications for PMO application. In contrast, six PMO functions failed to achieve consensus: (1) align with strategies, (2) establish governance frameworks, (3) report and control initiatives, (4) authorise adjustments, (5) manage multiple projects, and (6) support decision-making through data. The remaining 18 functions reached consensus at low to medium levels. While this study highlights key PMO functions required by Saudi construction SMEs, further research is needed to generalise the findings through a quantitative approach. Such work could improve understanding of SME needs in the Saudi construction sector and support the development of effective PMO implementation.

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AN EXPLORATION OF INTERPERSONAL CONFLICT CAUSATION FACTORS IN THE BUILT ENVIRONMENT

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Conflict has become synonymous with the construction sector. Researchers and practitioners alike have made numerous efforts to address this blight. Despite the abundance of literature present, interpersonal conflict remains ever-present. This study aims to identify the commonality of occurrence of interpersonal conflict causation factors in the built environment (BE). A comprehensive literature review takes place identifying 184 conflict causation factors. 15 semi-structured interviews take place with industry professionals during a content validation phase identifying 47 factors to be classified as 'Human' conflict causation factors. 62 participants complete a questionnaire to identify the commonality of each Human factor using a 1-5 Likert scale ranging from 'Never' to 'Always'. The top three most common factors are Difference in personality, Difference in views, and Pressure/Expectation/Workload. High standard deviation values present across results are indicative of the complexities at play when addressing conflict causation. These findings highlight the importance of increased soft skills training in the sector.

Keywords: construction; disagreement; dispute; misalignment

INTRODUCTION

The true origin of human nature transcends time and remains a subject of debate, with explanations for fundamental emotions and behaviours, such as love, violence, and conflict, often provided through religion and philosophy (Euwema and Giebels, 2024). Despite ambiguities surrounding its origins, human nature is inherently intertwined with conflict, holding a prominent place in civilisation's history. Ancient manuscripts depict a variety of disputes ranging from clan misalignments to inter-imperial war as far back as the times of Mesopotamia. These conflicts were often driven by more ‘simplistic’ motives such as land and resources; however, as society has evolved, so too have the manifestations of human conflicts. Modern misalignments are far more complex social and economic entities spreading across all aspects of life. In recent years, the manifestation of these conflicts in an organisational context has become a hot spot for academic and practitioner research alike. Above all sectors, the construction industry has long been characterised by its conflict-burdened environment and the adversarial nature in which it operates. The construction sector holds several unique qualities that distinguish it from any other, making it a breeding ground for conflict/dispute creation. Projects are fast-paced, complex by nature, and rely heavily on the cooperation of a multitude of stakeholders who all have varying interests, often resulting in formal dispute processes occurring. The industry’s

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reputation is not unfounded, with the statistics on construction disputes utterly condemning the sector globally. The value of disputes in construction globally in 2020 exceeded $48.5 billion, and extension of time requests (EOT) accrued close to 600 years (Jagannathan *et al.,* 2021). The relationship between conflict and poor performance is irrefutable and acknowledged as a primary source of project inefficiency (Zouher Al-Sibaie *et al.,* 2014).

With Alternative Dispute Resolution (ADR) continuing to be the front foot of the industry regarding dispute resolution. ADR methods are now commonly implemented into standard contract forms as an attempt to prevent disputes. Popular types of ADR are adjudication, arbitration, negotiation, mediation, dispute review boards, and dispute resolution advisor systems. This research takes a step back from holistic conventional studies, which take a wider view on conflict causation. This study focuses exclusively on "Human" conflict causation factors as classified by a content validation process. Interpersonal conflict emerges throughout all stages of a project's lifecycle, and although literature identifying interpersonal conflict as commonplace within the construction industry is plentiful (Meng, 2012; Brockman, 2014) there is limited cognisance of the commonality of specific triggers. Having a complete and comprehensive understanding of the manifestation of conflict because of personnel dynamics can provide a unique insight for improving organisational culture and operational effectiveness. Once there is a clear cognisance of the specific Human conflict triggers within the BE, the ability to construct an effective and efficient individualised framework to avoid such pitfalls will subsequently follow.

Interpersonal Conflict Causation Factors: A Review

As part of broader research investigating personality and interpersonal conflict in the BE, a literature review identifies more than 180 conflict causation factors. This paper focuses on a subset of these (47) classified as "Human" factors through a content validation process which is discussed further in the method section.

Behaviour and Discipline

Inter-dependent tasks are commonplace within the industry and are often used in the creation of competent project schedules (Srour, *et al.,* 2013). Subsequently, any indiscipline when conducting duties or while acting within any capacity of employment can cause conflict between personnel and or organisations (Adeyemi and Aigbavboa, 2020). Indiscipline can manifest in many forms such as disrespect, complaining, and flat-out disobeying instruction. The manifestation of this indiscipline is usually associated with professionals who are difficult to contact and absent (Kipyego, 2013). These professionals also struggle to apply discipline to others, which compounds the issue.

According to Adeyemi and Aigbavboa (2020), this indiscipline encompasses a variety of issues ranging from dishonesty, nepotism, drunkenness, and misappropriation of funds to minor matters like inadequate commitment to work and refusal to take responsibility. Conflict causation factors related to employee indiscipline are commonplace in the literature with numerous factors such as unpunctuality to work, loitering, and opportunistic behaviour being identified (Colin, *et al.,* 1996; Mitropoulos and Howell, 2001; Ejohwomu, *et al.,* 2016; Adeyemi and Aigbavboa, 2020). The emergence of conflict because of this indiscipline often stems from the reliance of one professional on another's successful completion of their task. However, this is a double edge sword as in direct contrast to this, Saiti (2015), identified the emergence of conflict resulting from one professional identifying that if

another is successful in their pursuit of a goal, this subsequently prevents the realisation of their own goal. This is often referred to as "misalignment/difference in goals" and has been highlighted by several authors. (Salleh and Adulpakdee, 2012; Makaya and Ndofirepi, 2012; Longe, 2015).

As the construction workforce diversifies so too do the personality types of personnel employed within the sector. Factors such as different upbringings have been cited as contributing to influencing personality types (Isa, 2015). Differences in personalities have been identified by, Saiti (2015), Heather (2016), and Adeyemi and Aigbavboa (2020), as being key conflict drivers. An interesting finding of Adeyemi and Aigbavboa, (2020), suggests that a reluctance to recognise these varieties in personality types contributes to conflict initiation.

These personal incompatibilities encompass numerous causation factors noted by academics including opinions, differences in values, and negative attitudes, (Acharya, *et al.,* 2006; Salleh and Adulpakdee, 2012; Kipyego, 2013). Differences in personality types can result in professionals articulating their viewpoints in contrasting styles resulting in a clash among the parties (Mudis and Yambo, 2015). In this regard, employees can at times struggle to interpret colleagues' moods/attitudes with the interpretation of escalation/de-escalation highlighted by Acharya, *et al. (*2006).

Managerial Issues

In a study titled 'How constructive is construction law?", Jones, (1994), highlighted ten main sources of construction conflict with number one simply being labelled 'management'. Although close to 30 years old Jones's identification of management as a driving force of conflict remains true. Despite advances in the understanding of critical components of successful management, authors such as Shawa, *et al. (*2018), and Tariq and Gardezi, (2023), still identified management as a key issue concerning conflict creation. The word "management" encompasses a large array of tasks, interactions, and situations within the construction industry. More specific issues intricately linked to managerial duties have been identified such as vested interests, professional culture problems, favouritism, tribalism, bribery, and a dictator leadership style (Tshuma, *et al.,* 2016; Ejohwomu, *et al.,* 2016).

Communication and Misalignments

Conflict resulting from poor, incomplete, or absent communication channels is perhaps the most cited human factor (Jones, 1994; Cheung and Yiu, 2006; Waldron, 2006; Acharya, *et al.,* 2006; Brockman, 2014). The literature shows numerous studies highlighting different issues that essentially fall under the communication umbrella. For example, Miktus and Mitkus, (2014) highlighted "deprived communication" as a primary conflict factor, Waldron, (2006), suggesting that "misunderstandings" were a primary trigger. Correspondingly "misinterpretations" were cited by authors as conflict causation factors. Misinterpretation of client's requirements, misinterpretation of contract information, interpretations, misunderstanding, and confusion are all symptoms of poor communication practices, which have been identified in the literature (Waldron, 2006; Miktus and Mitkus, 2014; Ejohwomu, *et al.,* 2016). Saiti, (2015), stated that poor information processes, bad timing, poor human relationships, and poor encoding of messages were all conflict contributors.

Perceptions play a pivotal role in conflict creation with Brockman, (2014), citing perceived levels of effort and perceived safety issues as conflict drivers. In their previously mentioned study, Miktus and Mitkus, (2014), provide a unique perspective on construction conflict. This study suggests that it is likely that the true causes

identified in the literature are not the original causes. This study goes on to classify the causes identified in the literature as "Obviously wrong, potentially right but unclear formulated causes and true causes of conflict". Initially, poor communication was the sole causation factor Miktus and Mitkus, (2014), deemed as a true cause of conflict within the construction industry. Based on "practical experience" Miktus and Mitkus, (2014), hypothesized that communication accounted for 90% of all construction conflicts. The conclusion of this study shows that the effects of psychological defence and unfair behaviour are also being identified as true causes of conflict. Various other human causation factors have been highlighted in the literature such as tick-box mentality, home/life issues, people getting defensive, and lack of team pressure/ expectations (Bristow and Vasilopoulos,1995; Brockman, 2014; Miktus and Mitkus, 2014; Ejohwomu, *et al.,* 2016).

This study focuses on investigating the prominence of specific conflict causation factors. The shift in focus to create a comprehension of the commonality of specific conflict causation factors may better inform the creation of conflict management and avoidance policy by allowing for a more nuanced approach. Table 1 illustrates the 47 interpersonal conflict causation factors utilised as part of this study.

METHOD

A literature review was conducted identifying 184 conflict causation factors in the BE. These factors are initially categorised into five key themes Human (59), Organisational (45), Contractual (26), Environmental (49) and other (5). To ensure academic rigour content validation takes place to assess the thematic classification of factors. Although metric-based validity tools such as CVI and CVR are often used, due to the number of conflict factors present (184) this method is deemed to be impractical. Similarities can be drawn to Zamanzadeh, *et al. (*2015) where the attempt to implement a CVI with a large data set proves challenging resulting in a more relaxed average score method. In addition to the challenge of thematic overlap, cognitive overload and the introduction of bias due to fatigue are concerns. Pilot and Beck, (2006) confirm that the application of content validity indices to large data sets is challenging. Consequently, a qualitative approach is taken to content validation in the form of 15 semi-structured interviews. Interviews take place with industry personnel in managerial roles or higher currently employed in the BE in the Republic of Ireland (ROI).

Both in person and online mediums are utilised for interviews depending on participant preference. Participants are provided with the full list of 184 factors identified in the literature review. To facilitate trust and in line with Harvey, (2011), no audio or visual recording takes place. Due to large data sets shorthand notes are implemented with Rutakumwa, *et al. (*2020), discussing the effectiveness of this method. It is important to note that the primary focus of these interviews was to discuss the classification of the factors, no detailed discussion around frequency, cause, effect or process took place. This resulted in responses often being short such as "for me it is a human factor" or "I would have to disagree with the initial classification and suggest it is moved to organisational". Upon completion of the interviews, notes are consolidated, resulting in 11 factors being removed, 28 factors amalgamated due to being interpreted as the same, 14 factors being reworded to ensure clarity, and 34 factors facing re-classification. This results in 47 factors being classified as human factors and therefore relevant for this study.

No	Factor	Source	No	Factor	Source
1	Banter/Horseplay	(Brockman, 2014)	25	Mentality of contractor	(Acharya, et al., 2006)
2	Bribery	(Adeyemi & Aigbavboa , 2020)	26	Misappropriation of funds	(Adeyemi & Aigbavboa , 2020)
3	Communication (Interpersonal)	(Jones, 1994; Cheung & Yiu, 2006; Waldron, 2006; Acharya, et al., 2006; Brockman, 2014)	27	Misinterpretation of client's requirements	(Ejohwomu, et al., 2016)
4	Complaining about work	(Adeyemi & Aigbavboa , 2020)	28	Misunderstanding & confusions	(Sykes, 1996; Miktus & Mitkus, 2014)
5	Cultural Differences	(Jones, 1994)	29	Negative attitudes	(Acharya, et al., 2006)
6	Dictator leadership style	(Tshuma, et al., 2016)	30	Negligence	(Colin, et al., 1996)
7	Difference ways of carrying out the same Task	(Acharya, et al., 2006)	31	No clear conclusion to a disagreement / argument	(Adeyemi & Aigbavboa , 2020)
8	Differences in goals	(Salleh & Adulpakdee, 2012; Longe, 2015; Makaya & Ndofirepi, 2012)	32	Opportunistic behaviour	(Mitropoulos & Howell, 2001)
9	Differences in personality	(Isa, 2015)	33	People getting defensive	(Miktus & Mitkus, 2014)
10	Differences in values	(Kipyego, 2013)	34	People unsure of their role	(Kipyego, 2013).
11	Differences in views	(Salleh & Adulpakdee, 2012)	35	People wanting a certain outcome that suits themselves	(Ejohwomu, et al., 2016)
12	Dishonesty	(Adeyemi & Aigbavboa , 2020)	36	Perceived Levels of Competence/Effort	(Brockman, 2014)
13	Disobeying instruction	(Adeyemi & Aigbavboa , 2020)	37	Perceived Safety Issue	(Brockman, 2014)
14	Disrespect	(Adeyemi & Aigbavboa , 2020)	38	Poor human relationships	(Saiti, 2015)
15	Drunkenness	(Adeyemi & Aigbavboa , 2020)	39	Pressure/Expectation/Workload	(Jones, 1994)
16	Excessive Correspondence	(Acharya, et, al,. 2006)	40	Refusal to take responsibility	(Adeyemi & Aigbavboa , 2020)
17	Favouritism/Nepotism	(Tshuma, et al., 2016; Adeyemi & Aigbavboa , 2020)	41	Tick box mentality	(Ejohwomu, et al., 2016)
18	Frustration	(Adeyemi & Aigbavboa , 2020)	42	Unfair behaviour	(Miktus & Mitkus, 2014)
19	Home/Life Issues	(Brockman, 2014)	43	Unpunctuality to work	(Adeyemi & Aigbavboa , 2020)
20	Inadequate Commitment to Work	(Adeyemi & Aigbavboa , 2020)	44	Unrealistic Expectations	(Jones, 1994; Bristow & Vasilopoulos, 1995; Yiu & Cheung, 2007)
21	Information not shared correctly	(Miktus & Mitkus, 2014)	45	Varied experiences	(Salleh & Adulpakdee, 2012)
22	Lack of team spirit	(Bristow & Vasilopoulos, 1995)	46	Work force splitting into groups	(Adeyemi & Aigbavboa , 2020)
23	Language Barriers	(Ejohwomu, et al., 2016)	47	Workmanship (Individual)	(Jones, 1994; Brockman, 2014)
24	Loitering (Hanging around)	(Adeyemi & Aigbavboa , 2020)			

Table 1: Interpersonal Conflict Causation Factors

As the primary focus of the research revolves around the frequency with which a participant experiences specific conflict factors a Likert scale is utilised. Likert scales are an extremely powerful method of data collection used in social science research first developed in 1932 (Allen and Seaman, 2007). The scale titles are "Never, Rarely, Sometimes, Often and Always." The use of named categories is user-friendly and provides a better participant experience (Dillman, *et al.,* 2014). The responses are then given numerical values ranging from 1 to 5 assuming that the interval is the same between each option (Willits, *et al.,* 2016). Participant particulars along with a personality assessment accompany the 47 human factors on the questionnaire as part of the wider research plan. The selection criteria for participants to contribute to this study is that persons are 'currently employed in the BE in a management capacity in the ROI'. This is due to several reasons, primarily due to the central role managers play in the construction sector often acting as the go-between coordinating all tasks on site. Persons employed in management within the sector often find themselves in mitigating, managing, and resolving conflict making them perfect candidates for this study. The questionnaire is initially distributed on Microsoft forms to 36 known industry personnel who fit the research criteria. Snowball sampling is then utilised where participants are encouraged to send the questionnaire onto their colleagues of which also fit the criteria. As often noted as a characteristic of snowball sampling the total number of eligible participants who received the questionnaire beyond the initial distribution cannot be known (Parker, *et al.,* 2019). 62 questionnaires are returned. Relevant data is then extracted, analysed and presented transparently. A list of the

most highly prevalent factors is created. Informed discussion around the results, implications and potential future works ensues.

RESULTS AND ANALYSIS

Upon completion of the data gathering stage, all results are formatted, analysed and presented in a systematic fashion, ensuring clarity and consistency. Each participant has indicated on a Likert scale (1=Never, 5= Always) their frequency of experience with 47 human conflict causation factors in the BE. To identify the most frequently experienced factors, mean score (m) analysis took place. Standard deviation (SD) values were also calculated to provide insight into the level of agreement amongst participants. High SD values are indicative of variance in experience or contextually driven difference, with low SD values highlighting commonality in experience of certain factors. Factors were then tabulated and ranked in descending of (m) scored from 1-47 and present in Table 2.

No	Factor	M	SD	No	Factor	M	SD
1	Differences in Personalities	3.71	0.86	25	Mentality of Contractor	3.06	1.10
2	Differences in Views	3.69	0.95	26	Poor Human Relationships	3.06	0.86
3	Pressure/Expectation/Workload	3.60	0.95	27	No Clear Conclusion to a Disagreement / Argument	3.03	0.97
4	Different Ways of Carrying Out Same Task	3.55	1.00	28	Opportunistic Behaviour	3.03	1.04
5	Frustration	3.55	0.80	29	Misinterpretation of Client's Requirements	3.00	1.09
6	Communication (Interpersonal)	3.52	0.76	30	People Unsure of Their Role	2.98	1.00
7	Differences in Values	3.47	0.95	31	Unpunctuality to Work	2.87	1.02
8	Negative Attitudes	3.47	0.94	32	Workmanship	2.87	1.03
9	Dishonesty	3.44	1.10	33	Perceived Safety Issue	2.84	1.02
10	Misunderstanding & Confusion	3.44	0.78	34	Banter/Horseplay	2.79	0.94
11	Refusal to Take Responsibility	3.40	1.03	35	Favourtism/Nepotism	2.76	1.07
12	Unrealistic Expectations	3.40	0.98	36	Varied Experience	2.76	0.99
13	Disrespect	3.39	1.03	37	Negligance	2.74	1.17
14	People Wanting a Certain Outcome that Suits Them	3.39	0.84	38	Excessive Communication	2.73	1.07
15	Ditactor Leadership Style	3.31	1.08	39	Unfair Behaviour	2.73	0.95
16	Tick Box Mentality	3.27	0.93	40	Work Force Spliting into Groups	2.69	1.03
17	Differences in Goals	3.26	0.94	41	Cultural Differences	2.47	0.94
18	Complaining about Work	3.24	1.02	42	Home/Life Issues	2.45	0.99
19	Information not Shared Correctly	3.23	0.89	43	Loitering (Hanging around)	2.42	1.08
20	Disobeying Instruction	3.19	1.16	44	Misappropriation of Funds	2.34	1.18
21	People Getting Defensive	3.16	1.05	45	Language Barriers	2.29	1.17
22	Inadequate Commitment to Work	3.15	0.99	46	Drunkenness	1.94	1.20
23	Lack of Team Spirit	3.13	0.91	47	Bribery	1.60	1.11
24	Perceived Levels of Competence/Effort	3.10	1.00				

Table 2: Frequency and SD of Interpersonal Conflict Causation Factors

Correlation (r) analysis also took place. Due to the relatively small sample size (n=62) the (r) values should not be interpreted as statistically robust. The (r) values are used to provide nuanced observations into how certain factors may have a conceptual link.

DISCUSSION

In this section, authors interpret the results transforming analytical data into informed discussion around the frequency and distribution of interpersonal conflict causation

factors in the BE. The discussion follows a three-section structure addressing high, moderate and low scoring factors. Findings indicate a wide range of results with mean score analysis across all 47 factors showing a scoring range of (m=1.60) bribery to a (m=3.71) Difference in personalities.

There is much existing literature documenting the role 'difference in personalities' plays in construction conflict, with these findings compounding its presence and highlighting its prevalence within the sector. There is little surprise in the high levels noted with modern construction forces increasing in both size and diversification. Differences in views and values score the second and seventh most cited factors with (m=3.69) and (m=3.47) respectively. A strong correlation is observed between a difference in views and values with (r=0.79). This is suggestive that participants may interpret these factors to hold similar meanings or often find that when in conflict centre around disparity of views their values are often simultaneously misaligned. These factors 'Difference in personality' (SD=0.86), 'Difference in views' (SD=.95) and 'Difference in values' (SD=.95), form a tight cluster with a strong literary consensus of the close links between personality; one's values and their views. The moderately high standard deviations values are indicative of reasonable agreement amongst participants while highlighting the individualised nature of personal sensitivities. 'Pressure/Expectation /Workload' is also amongst the high scoring traits with an (m=3.60) which aligns strongly with the sectors interdependence between tasks seen at all stages of project life (Srour, *et al.,* 2013). Similarly, we see a reasonably high SD value of (SD=0.95) suggestive of an overall agreement of its prevalence yet alluding to its presence being reliant on other factors such as project specific environments or job roles.

While highlighting the most cited factors provides a solid insight into construction conflict, it is equally important to address those which placed moderately. Factors scoring in a range of (m=2.80 to (m=3.38) yield interesting results when one focuses on the variation and correlation to other factors. For example, 'Disobeying Instruction' placed as the 20th most common factor with (m=3.19) accompanied by a (SD=1.16), suggesting highly polarised opinions amongst respondents. This again speaks to the incalculable number of factors at play in an active construction environment, which translates into disparity in the experience of conflict causation factors. A strong correlation is observed between 'Disobeying Instruction' and 'Disrespect' (r=.60), alluding to the potential for one to feel personally disrespected when their instructions are not followed. The complex managerial structure on large construction projects often leaves ambiguity in command chains, with leaner managerial structures arising across different sub-contractors. The commonality of 'People unsure of their role' (m=2.98) may further validate this real-life manifestation of the industry's structure.

When looking at some of the lower scoring factors it is of interest that 'Bribery' (m=1.59), 'Drunkenness' (m=1.95), 'Misappropriation of Funds' (m=2.33) and 'Negligence' (m=2.74) are amongst the most 'taboo' factors included in the questionnaire. In isolation it may be hard to draw conclusions from this, however when viewing in conjunction with SD scores where (SD= 1.10, 1.19, 1.18, and 1.17) respectively these four factors account for 4 of the 6 highest SD scores seen. The disparity in responses inclines one to lean towards the implications of social desirability bias and the tendency for persons to underreport undesirable or sensitive issues (Krumpal, 2013). Although possible and contextually likely given the cultural norms associated with the construction sector, this disparity in exposure may again speak to the lack of consistency in the project environment across the industry. While

some environments may enforce policy and procedures which dilute these behaviours others may turn a blind eye. Overall, results indicate a consensus of top interpersonal conflict causation factors. However, the high SD scores generally seen across all factors are indicative of the nuanced complexities in place when dealing with conflict in the BE. To acknowledge these complexities, these findings must be considered part of a wider conversation on conflict in the sector.

CONCLUSIONS

This study aims to identify the commonality of occurrence of interpersonal conflict causation factors in the BE. Findings highlight a strong interpersonal misalignment present, with Differences in personality, Differences in views, and Differences in goals, all placing in the 10 most experienced factors. The strong correlation observed between these traits further alludes to an overarching sense of personality driven misalignments in the sector. Different ways of carrying out the same task and general frustration are also identified as causation factors commonly experienced. Factors that scored moderately such as disobeying instruction and people being unsure of their role are consistent with the fragmented inconsistent managerial structures in place across the sector. Low ranking factors namely, Drunkenness, Bribery, Negligence and Misappropriation of funds, spark interesting discussion with these factors accounting for 6 of the highest SD scores shown. Further investigation may be required to deduce whether social desirability bias may be present, or if it is the manifestation of vastly different integrity/policy enforcement across different projects. Overall, this research provides a comprehensive summation of the commonality of interpersonal conflict causation factors in the BE. The overarching presence of large SD in data aligns with the complexities present in the sector with a multitude of variables influencing conflict causation. Due to the strong representative of individualised causation factors such as disparity in views and values, the industry may benefit from the introduction of more comprehensive soft skill training programs. This will allow professionals to navigate through this difference in personality and opinions, assisting in the mitigation of the most cited factors.

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PERSONALITY TRAIT DISTRIBUTION OF CONSTRUCTION MANAGERS IN THE REPUBLIC OF IRELAND: THEORETICAL RELEVANCE TO CONFLICT MANAGEMENT

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The study of personality has long been at the centre of much organisational management research. Understanding the personological composition of its workforce allows organisations to provide tailored resources, training and management leading to better outcomes. The relationship between personality traits and a variety of organisational phenomena has been explored, such as the relationship between personality and conflict management. Despite the acknowledgement of such relationships, analysis of the distribution and commonality of personality traits at the managerial level in the Republic of Ireland (ROI) built environment is absent. 62 construction professionals currently working in the Irish construction sector carry out the Big Five Inventory. Results are scored in five categories, Extraversion, Neuroticism, Openness, Conscientiousness and Agreeableness. Conscientiousness is the most dominant trait with 30 participants scoring highest in this category. Agreeableness is second with 17. The prominence of these traits is suggestive of an integrating and compromising approach to conflict management amongst Construction managers (CM) in the ROI. These findings are used to create informed discussion on the distribution of personality traits among CMs in the ROI.

Keywords: big five inventory, conflict, dispute, personality traits

INTRODUCTION

Modern organisations are complex, ever-changing, multifaceted entities. The challenges one faces when operating in a modern construction firm are immeasurable, making conflict a defining characteristic of the sector. The ICC, (2024), report found the aggregate value of construction disputes in 2022 to be a staggering $113b, condemning figures for the sector. Despite its size, the Republic of Ireland does not differ from this trend. The sheer volume of moving parts in large-scale construction is astounding, with a variety of stakeholders, whose interests rarely align in full, exacerbating the already litigious sector. O'Connor, *et al. (*2023), note the conflict-prone sector is often driven by its highly competitive, male-dominated, pressurised environment, resulting in both on and off-site tensions. The prevalence of conflict in the ROI construction sector cannot be overstated. A study carried out on Irish apprentices highlighted that 64% had experienced conflict at work, with 1 in 5 citing it as a primary reason for questioning their future in the sector (O'Neill, *et al.,* 2023).

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The presence of high levels of conflict in the built environment is irrefutable. Meng, (2012), suggests that the sources of these conflicts will vary from project to project.

External causes such as 'project complexity, contractual issues and economic fragility' garner much attention when discussion ensues; however, it is vital to equally examine human factors that may influence our workforce's approach to conflict. Personality traits play a pivotal role in one's perception and approach to interpersonal interactions. The Big Five personality model is utilised in built environment studies, including those investigating their link with conflict management styles Verwey, *et al. (*2023) and team composition Danja, *et al. (*2021). However, the prominence of each trait within the construction management workforce in the ROI remains unknown. The reliability and simplicity of the Big Five personality trait framework; Openness, Conscientiousness, Extraversion, Agreeableness, and Neuroticism, make it the perfect medium in which this study examines the personality of construction managers in the ROI. The distribution of these traits and investigation into their potential links to conflict follow. This research aims to directly address the distribution of personality traits among management within the sector. Firstly, the literature review features an exploration of the literature on both construction conflict and personality. The comprehension of the frequency of personality traits and their conflict tendencies may ultimately better inform organisational conflict management policy in the built environment. This aligns with Gao, *et al. (*2020), who suggest managers should take personality traits into account during task allocation.

LITERATURE REVIEW

Conflict and construction have long been synonymous, with the industry possessing a uniquely effective ability to create disputes, unparalleled to other sectors. While investigation into varied external conflict causation factors such as economic instability, home/life issues and project complexity are present (Brockman, 2014), researchers have begun to increasingly focus on the role of individuals, more specifically personality traits, in the shaping of conflict in an organisational setting (Ayub, *et al.,* 2017). The Big Five personality framework comprising of O.C.E.A.N. is widely implemented when investigating how personological factors influence workplace interactions and conflict (Soomro, *et al.,* 2023). A progressing body of knowledge is revealing the influence of personality traits on conflict in an organisational context. Given the highly competitive and adversarial environment in which the construction sector operates, comprehension of the personological composition of its workforce is essential for efficient and effective conflict management strategies (Khalid, 2015). This review analyses current literature on personality traits and their relationships with conflict, allowing for informed discussion on the influence of each trait once the distribution of the workforce is realised.

Extraversion is defined by one's tendency to be assertive and social, to feel good and to look for excitement (Costa and McCrae, 1992). Those scoring highly in extraversion tend to gain energy from social situations and are highly functioning in social environments. Positive emotionality and reward sensitivity are common amongst this trait type, with a higher level of positive emotions and increased motivation by positive outcomes and opportunities (Watson and Clark, 1997; Lucas, *et al.,* 2000). In an organisational context, extroverts typically thrive in leadership roles and tend to have better career outcomes with Green, *et al. (*2016), finding extraverted CFO's and CEO's earning 6-11% higher salaries. However, this

predisposition to proactive communication results in a higher likelihood of engaging in conflict. Broadly speaking, extroverts tend to address conflicts directly rather than avoiding them. Tashchian, *et al. (*2014), found extraversion to be a strong predictor of dominant, compromising and integrative conflict management approaches. Wood and Bell, (2008) compound this, finding extroverts to be more likely to impose their views to push preferred outcomes (dominating conflict approach). While high extroversion scores can be an indicator of the likelihood of addressing conflict directly, the escalation of those conflicts typically relies on the presence of other traits such as agreeableness (Ann and Yang, 2012). If there is a concurrent absence of agreeableness, the conflict is more likely to escalate. Similarly, an extravert's ability to discuss underlying tension, paired with the presence of agreeableness, can result in a compromising approach.

Costa and McCrae, (1992) characterise openness to experience as one's willingness to engage in new/novel ideas and perspectives. The desire for variety and novel experiences, which may drive an openness to interpersonal diversity, has garnered much academic interest. The manifestation of openness in an organisational context can be beneficial, having a positive relationship with creativity and adaptability (Abu Raya, *et al.,* 2023). This is not a recent discovery, with early works such as Barrick and Mount, (1991), finding open employees to be more receptive to training and consequently, seeing more gain. Broadly speaking, those who are more open-minded are more tolerant to other values, beliefs and ideas which may reduce bias and facilitate understanding (Abu Raya, *et al.,* 2023). Collaborative conflict resolution strategies have been shown to be positively related to openness, while being negatively related to avoidant approaches (Tehrani and Yamini, 2020). The predisposition to a willingness to engage and accept new ideas allows persons to create unique solutions to problems and leads to better outcomes in diverse environments. Although individuals scoring high in openness are typically better equipped to handle conflict, they may see increased conflict frequency in certain environments. Causation is found in Moss, *et al. (*2007), which concludes that individuals tend to be more committed to organisations that 'facilitate the expression of their traits'. Consequently, open individuals in traditionally structured work environments such as construction, may question policies and procedures.

Conscientiousness is the propensity to be organised, persistent, and goal orientated, as well as exercising restraint and self-discipline (Costa and McCrae,1992), defining characteristics being dependability, orderliness and achievement orientation (Rothmann and Coetzer, 2003). In an organisational setting, conscientiousness is one of the best predictors of job performance. This holds across sectors, ranging from sales representatives to police officers (Rothmann and Coetzer, 2003). Interestingly, conscientiousness is a weaker predictor of managerial performance, where openness and neuroticism tend to play a more significant role. In built environment studies such as Gao, *et al. (*2020), conscientiousness is seen to have a strong correlation with safety behaviours, aligning with the organisation and self-discipline required to follow protocols coherently. The ability to follow procedures can reduce task error, reducing conflict forming because of perceived work volume. A study related to traits and negotiation outcomes found conscientiousness to be linked to the facilitation of better outcomes (Abdullah and Baki, 2016), further highlighting the ability of those high in conscientiousness to keep the discussion focused and organised. Conscientiousness is also heavily linked to the effectiveness of conflict management, accounting for 10% of the variance, as seen in Barbuto, *et al. (*2010). Integrating and compromising

conflict management approaches are positively related to conscientiousness, while Tehrani and Yamini, (2020) study show mixed results in the relationship to avoiding, dominating and obliging styles. Ling, *et al. (*2020) provide an interesting insight into how a construction project manager's agreeableness and conscientiousness may improve over time.

The propensity to be benevolent, obedient, modest, and trusting is referred to as agreeableness (Costa and McCrae, 1992). Persons exhibiting high agreeableness are typically good-natured, modest and trusting (Abdullah and Baki, 2016). In an organisational context, agreeable employees often exhibit pro-social behaviour and are seen as supportive by colleagues. Ling, *et al. (*2020) found agreeableness to be positively related to a concern for people, not production, with agreeable project managers sometimes struggling to be decisive. The same works noted the ability of agreeable PMs to foster teamwork and care for employee wellbeing. In relation to conflict, the agreeableness trait is associated with a preference for an integrating, compromising and obliging conflict management style (Ejaz, *et al.,* 2012). This may be a result of the prioritisation of positive outcomes over personal relationships. Occasionally, at the expense of their interests, agreeable individuals will still show a strong preference towards the obliging conflict management style (Priyadarshini, 2017). This association with a need for harmony is not new with early works such as Jones and White, (1985), discussing agreeable individuals as being more likely to avoid confrontation, typically in search of a more diplomatic solution. Conversely, dominating conflict management styles, where one is typically seen as valuing control over collaboration, are negatively related to agreeableness. Meaning those showing lower agreeableness scores are more likely to employ this dominating style in their pursuit of resolution (Jones and White, 1985). High levels of agreeableness have been noted across several studies as being critical for creating collaborative and cooperative workplace interactions (Jones and White, 1985; Ejaz, *et al.,* 2012; Priyadarshini, 2017). Seminal works such as Costa and McCrae, (1992), suggest it to be the most dominant personological factor in shaping interpersonal dynamics in general. More modern studies identify it as a significant predictor of conflict management approach (Abdullah and Baki, 2016). It is often most effective when explaining what neuroticism is to describe it as the inverse of emotional stability. In essence, it is the predisposition to experience unpleasant emotions like anxiety and despair (Costa and McCrae, 1992). These strong emotions often have profound implications on one's life. Highly neurotic people are often prone to moodiness, anger, anxiety, and depression (Abdullah and Baki, 2016). Costa and McCrae (1992), name impulsivity, self-consciousness and vulnerability to stress as prominent facets of neuroticism. Barrick and Mount, (1991), yielded conflicted results showing that neuroticism (or its manifestations; worrying, high-strung, emotional) tends to be a predictor of lesser job performance, generally speaking. However, the same study suggests a neurotic individual may perform better in high-performance jobs. The possibility that high-stress jobs cause one to exhibit traits associated with neuroticism is of course possible, with Barrick and Mount, (1991), suggesting causation in the interpretation of the results due to data size. Construction safety related studies show a negative relationship with neuroticism and safe behaviour, suggestive that anxious and or impulsive individuals may struggle with following protocol. In relation to conflict, anxious individuals may be likely to perceive a situation as threatening or confrontational and react or withdraw as a result. Tehrani and Yamini, (2020) shows the positive correlation between neuroticism and avoiding strategies in conflict. This could initially help individuals manage their anxiety but may result in conflict

escalation due to allowing issues to fester. If found in a situation where unavoidable, individuals may display outbursts of anger during conflict. In contrast to the other four factors during meta-analysis, neuroticism is shown to be negatively related to integrative conflict management strategy (Tehrani and Yamini, 2020). Ling, *et al. (*2020), found that construction PMs high in neuroticism struggle with work efficiency and leadership effectiveness.

This literature review provides a foundation onto which an informed discussion surrounding the influences of personological traits on conflict management strategies adopted by CMs in the ROI can take place. While the relationship between personality traits and conflict management styles is present in the literature, there remains a lack of clarity as to the commonality of these traits amongst CMs in the ROI. Given the highly competitive environment in which the construction sector operates, comprehension of personality distribution amongst managers may enhance leadership, team cohesion and reduce conflict escalation. This study addresses this gap by providing clarity to the distribution of these traits and discussing the potential implications on conflict within the sector.

METHOD

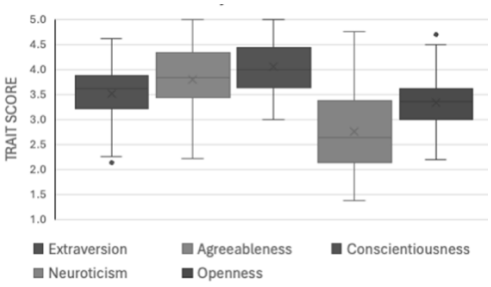
A complete and comprehensive review of appropriate literature is carried out, with this study adopting a quantitative survey-based approach to investigate the personological composition of construction managers in the ROI. A quantitative approach is essential to allow for objective measurement, analysis and replicability. The use of numerical data allows for a reduction in bias and the ability for cross-cultural comparisons (Marsella, *et al.,* 2000; Ling, *et al.,* 2020). The selection of the Big Five model is justified due to its widespread validation and application in built environment personological studies, including those investigating the relationship between personality trait and conflict management strategies (Ahmed, *et al.,* 2010). Rather than re-establish the relationship between these traits and conflict, this paper aims to analyse personality trait prevalence amongst construction CMs in the ROI, providing industry / regional-specific insights into the conflict tendencies of these traits. The study sample consists of 62 construction managers currently employed in a management capacity in the ROI. In line with Tutz, (2023), a non-probability sampling method is used for its practicality in accessing participants from a specialised workforce. The chosen personality assessment method is the Big Five Inventory-44, a comprehensive well validated questionnaire consisting of 44 Likert scale questions. The selection of the Big Five Inventory can be justified by its simplicity, ease of comprehension and wide adoption in organisationally focused research. The Likert scale is a five-point answer key with 1 = Strongly disagree, to 5 = Strongly agree. Questionnaires are administered online to limit both logistical issues and the introduction of in-person bias. Participants provide informed consent before they begin. Participants remain anonymous to ensure their comfort, in line with Harvey (2011), while simultaneously stimulating honest responses, which are critical when administering personological assessments (Vésteinsdóttir, *et al.,* 2019). Adherence to both institutional and psychological research best practice is followed where anonymity and privacy are crucial (Dienlin and Metzger, 2024). Analysis of the assessment results takes place, allowing for the determination of the distribution of personality traits amongst construction managers in the ROI. Structured discussion ensues, presenting the traits and allowing for comprehension of the implications and conflict tendencies of each personality trait. The primarily analytical approach allows for a clear visualisation of trait frequency and distribution, with structured discussion

allowing for the comprehension of the implications. With literature so widely aware of the strong relationship between conflict strategy and personality traits Ejaz *et al. (*2012); Priyadarshini, (2017); Tehrani and Yamini, (2020), the analysis of distribution allows for insights into potentially industry-wide tendencies. The sample size (n=62) limits the generalisation of the findings; however, smaller sample sizes are still widely accepted in exploratory works (Andrade, 2020). As part of an ongoing research plan, findings provide initial insights into the personological composition of management in the built environment, while also providing a foundation for future works to build upon.

RESULTS AND ANALYSIS

Upon completion of data collection, results are formatted and analysed accordingly. Figure 1 depicts a box and whisker plot displaying a summary of the findings. A box plot is selected to represent the finding due to its multifunctionality, displaying median, mean and variability, while also showing the outliers (Nuzzo, 2016). The box itself represents the middle 50% of scores, with the whiskers extending to enclose the expected data spread. The horizontal lines show the median with the 'x' representative of the mean, allowing for comparison. Singular dots illustrate outliers. Conscientiousness has the highest mean (m) (m=4.05), with a standard deviation (SD) of 0.49. The widespread outliers present in neuroticism show a high level of variability in the emotional stability of respondents. The depiction of the mean as higher than the median in neuroticism suggests that it is slightly right skewed, with several high scores dragging the mean up. Extraversion and agreeableness showed a moderate mean (m=3.51) and (m=3.79) respectively. Both traits show consistent distribution, with standard distributions of (SD=0.55) and (SD=0.61). Finally, openness has a slightly lower mean (m=3.33) but showed moderate constancy.

Figure 1: Personality Trait Distribution



DISCUSSION

It is important to note that although this study did not directly measure the relationship between traits and CM styles, the following discussion utilises pre-existing research highlighting the relationships between specific traits and conflict behaviours. These interpretations should be framed as part of a wider discussion on conflict in the built environment. The structure of this discussion follows from the literature review and takes place on a trait-by-trait basis. Results indicate a moderately high mean (m=3.51) with a narrow interquartile range, indicative of consistency of extroversion scores across participants. Outliers are few, showing limited extremes within the data, with a high of 4.63 and a low of 2.13. When looking at comparable results from a large data source such as Rentfrow, *et al. (*2015), where n=386,375, extroversion scores appear above average (m=3.24). This may be reflective of above average levels of reward sensitivity, assertiveness and sociality as shown in the works of Watson and Clark, (1997) and Lucas, *et al. (*2000).With integrating, compromising,

and dominating conflict management styles relationship with conflict established, Tashchian, *et al. (*2014), the escalation of conflict is often contingent on the presence of other traits such as agreeableness (Ann and Yang, 2012). A correlation (r) (r=0.35) between extroversion and agreeableness alludes to a moderate correlation between the traits. Participants may benefit from the positive social implications often associated with extroversion, while the presence of other traits may mitigate the potential downsides of its singular dominance noted in previous research. Extraversion scored as the highest trait for only 4 of the 62 participants.

Openness shows a strong relationship to positive organisational outcomes, namely creativity, adaptability and a collaborative approach to conflict resolution (Tehrani and Yamini, 2020; Abu Raya, *et al.,* 2023). Like extroversion, openness was the highest scoring trait of only 4 out of the 62 participants. Additionally, when looking to compare large data sets for contextualisation, it is found that (m=3.33) is lower than the (m=3.67) seen in Rentfrow, *et al. (*2015) study of the general population in the UK. This suggests that openness is not a defining characteristic of management in the built environment. With openness typically associated with thriving in creative and flexible environments, the low levels of openness seen in this sample may align with the rigid structure of the built environment. However, the lack of openness may hinder positive conflict resolution, with high openness linked to a collaborative approach to conflict resolution. Conscientiousness is by far the most dominant trait among participants (n=30), accounting for the highest scoring trait of nearly half of all respondents. This is a positive finding for Irish built environment management, with Rothmann and Coetzer, (2003), citing conscientiousness as one of the most robust predictors of job performance. The high levels of conscientiousness present in the sample may indicate a preference for integrating and compromising conflict management styles, both associated with conscientiousness in previous research (Tehrani and Yamini, 2020). Barbuto, *et al. (*2010), found that conscientiousness accounted for 10% of the variance seen in conflict management styles, suggesting that structured, resolution-based strategy associated with conscientiousness may contribute to more positive conflict outcomes. The (m=4.05) is significantly higher than the (m=3.65) seen in Rentfrow, *et al. (*2015) suggestive that the sample does possess high levels of conscientiousness. With an (r= -0.39), conscientiousness is moderately negatively correlated to neuroticism. This may indicate that those high in conscientiousness may be less prone to the negative traits often associated with neuroticism, such as emotional instability and stress.

Despite the reputation of the sector, agreeableness stands as the second most dominant trait, with a (m=3.79) and accounting for 17 participants highest scoring trait. The prominence of agreeableness is a predictor of an integrative, compromising and obliging approach to conflict management (Ejaz, *et al.,* 2012). The high levels of agreeableness present in the sample (m=3.79) may be indicative of a predisposition toward positive, relationship-focused conflict management, with previous research linking agreeableness to an integrative and compromising management style. There is also a moderate correlation between agreeableness and extroversion (r=0.39), which can produce a positive balance between assertiveness and empathy to engage in effective conflict management and avoid dominating styles. Despite the prominence of agreeableness among the participants, it is important to provide a broader context to the results. A wider study on the UK general population cited a (m=3.79) for agreeableness, meaning that management in the built environment may be less

agreeable overall. It is important to note the limitations of comparing personality data from different regions.

Neuroticism was the dominant trait for 7 participants in the study. With neuroticism characterised by emotional instability, anxiety and lesser workplace effectiveness, it is not something typically associated with strong or positive conflict management. The (m=2.75) is still a relatively moderate result, with (m=2.97) being indicative of the Rentfrow, *et al. (*2015), general UK population study. Interestingly, neuroticism possessed the largest standard deviation amongst participants (SD=0.81), showing a large variability in the emotional stability of construction managers in the ROI. There is a strong negative correlation between extraversion (r=-0.60) and a moderate negative correlation with conscientiousness (r=-.39), aligning with existing literature suggestive that those lacking emotional stability display a lower desire to socialise and self-manage. Neuroticism is the lowest scoring trait of 26 participants, which may allude to a lower propensity for avoiding conflict management styles, with previous research highlighting the relationship between neuroticism and such styles.

CONCLUSIONS

This paper aims to investigate the distribution of the Big Five personality traits amongst construction managers currently employed in the ROI. This is to allow for an understanding of the personological composition of the managerial workforce, while also allowing for informed discussion related to the potential implications on conflict seen within the sector. The most dominant trait is conscientiousness, accounting for the highest scoring factor of 30 participants with a (m=4.05), which aligns with a structured and integrative approach to conflict management. Agreeableness is found to be the second most dominant with a (m=3.79), a finding which contradicts the traditional view of managers in the built environment. The findings show conscientiousness and agreeableness together account for the highest scoring personality trait of 75% of participants. This may be indicative of a predisposition towards integrating, compromising and obliging conflict management styles, with previous research highlighting these relationships. There is a high variability seen in neuroticism, indicative of a lack of consistency in emotional regulation amongst different managers. Tailored training to increase emotional regulatory skills may better equip managers to have a unified approach to conflict management. It is important to acknowledge that although 62 participants are significant, large-scale generalisation must be avoided until a larger data set is available. This study provides theoretical insights into both the personological composition of CMs in the ROI and how dominant traits may result in a predisposition toward certain conflict management strategies, as highlighted in previous research. However, it is also important to understand that both personality and conflict are complex, multifaceted, nuanced constructs and these findings should be implemented as part of a wider conversation to acknowledge all relevant factors. This paper is part of wider research which aims to investigate the relationship between personality traits and specific conflict causation factors in the built environment.

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STRATEGIC SUCCESSION PLANNING OF SMES IN THE BUILT ENVIRONMENT: DEVELOPMENT OF A FRAMEWORK TO ADDRESS THE KNOWLEDGE GAP

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Strategic succession planning (SSP) is essential for Small and Medium Enterprises (SMEs) longevity and continuity, yet its application in the built environment remains underexplored. Despite the acknowledged importance of SSP, empirically validated models in the context of SMEs in the built environment are scant. This paper conceptually validates this knowledge gap by mapping existing academic literature. Factors influencing SSP within SMEs internationally are mapped, the results of which are used to formulate a conceptual framework from related fields, which can be applied in this discipline. By synthesising current knowledge, this research highlights the paucity of studies in the field of the built environment, onto which a proposed framework is developed, based on wider disciplines. The value of this work is that it subsequently validates the need for a tailored, bespoke SSP framework, to support business continuity, maintain competitiveness, and foster sustainable growth in built environment SMEs. The value proposition lies in the contribution to literature on the subject, particularly in the discipline, by addressing a currently under-theorised area, which is crucial for the sector's resilience.

Keywords: strategic management; strategic planning; knowledge management; leadership transition

INTRODUCTION

Small and Medium Enterprises (SMEs) are fundamental to economic progress, stimulating job creation, innovation, and overall competitiveness (Bibi *et al.,* 2023). They serve as the bedrock of entrepreneurial activity and are essential for both employment levels and economic prosperity (Bibi *et al.,* 2023). Strategic planning is a cornerstone of SME success, providing a framework for understanding their current standing, defining their future aspirations, and establishing the necessary objectives to achieve them (Murphy, 2013). Within this strategic framework, strategic succession planning (SSP) emerges as a critical component of robust organisational management, ensuring the continuity and long-term health of these vital economic entities. The need for research on SSP in the built environment sector arises from the reality that, although the academic exploration of succession planning has a legacy that traces back to the early 20th century and has seen considerable evolution, its distinct implementation in this field remains unexamined (Perrenoud, 2020; Perrenoud *et al.,*

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Tracey, M and Spillane, J P (2025) Strategic Succession Planning of SMEs in the Built Environment: Development of a Framework to Address the Knowledge Gap, *In*: Thomson, C and Neilson, C J (Eds) Proceedings of the 41st Annual ARCOM Conference, 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 491-500.

2017). The construction industry has traits that require customised approaches to succession planning, as emphasized by the demand for research specific to the industry (Kim, 2010). In this setting, effective succession planning is vital due to the accounting principle of 'going concern,' which presumes the ongoing operation of established entities (Bibi *et al.,* 2023), even though the tenures of their leaders are limited. The built environment sector is also vulnerable to a range of disruptions (Armstrong *et al.,* 2021), from significant crises to ordinary change management. Moreover, change in the built environment sector is often impeded by organisations choosing short-term solutions instead of making structural adjustments (Thompson *et al.,* 2023). As a result, succession planning is increasingly viewed as a strategic necessity for boosting organisational performance and ensuring long-term growth (Salau *et al.,* 2022), especially within SMEs in the built environment, where leadership changes can profoundly affect project continuity, client relations, and the preservation of specialised expertise. This study is inspired by the realisation that, even with an extensive body of knowledge and established best practices in succession planning, the methods for effective, consistent, and systematic implementation are still ambiguous (Ip, 2009, 2006), especially within built environment SMEs, where empirically supported models are absent (Gunnoe, 2015; Perrenoud, 2012; Salau *et al.,* 2022). This discrepancy is crucial because SSP has far-reaching consequences, influencing political arenas due to its effects on economic stability (Ip, 2006; Salau *et al.,* 2022), leading government entities to promote proactive planning within SMEs (Ip, 2009). Current studies indicate that SSP is frequently subjective, shaped by personal experiences and organisational settings (Ip, 2009; Ip *et al.,* 2006), which obstructs the adoption of systematic methods and highlights the necessity for customised strategies that cater to the distinct project-oriented nature and unpredictable market of the built environment (Perrenoud *et al.,* 2017).

The limited empirical investigations concentrated on this sector, compounded by the elevated failure rates of small enterprises resulting from insufficient succession planning (Salau *et al.,* 2022), emphasize the critical importance of this research endeavour. This study aspires to identify optimal practices and innovative methodologies that SMEs within the built environment sector can adopt to enhance their succession planning frameworks; thus, securing their enduring viability and prosperity within an ever-evolving industry context. Although succession plans entail a distinctive and frequently personal aspect, it is essential to consider the diverse elements constituting an organisation's structure and culture; hence, the objective of this research is to integrate the pertinent literature to derive overarching themes that establish a regulatory framework and robust foundation for crafting effective succession strategies congruent with the unique requirements and values of these organisations. Considering the context, the principal research inquiry through the lens of examining the literature is articulated as; what determinants/value criteria and obstacles affect the efficacy of SSP?

METHOD

This study employed a critical literature review, conducted with a systematic approach, to meticulously analyse, synthesize, and evaluate existing scholarship pertinent to SSP within SMEs in the built environment. Its aim was to critically assess current understanding, identify key determinants, value criteria, and obstacles (as per the research question: what determinants/value criteria and obstacles affect SSP efficacy in this context?), and thereby establish a robust foundation for the proposed conceptual framework (Grant and Booth, 2009). The systematic search for literature

involved querying academic databases and employing citation chaining, with no specific end date applied to capture foundational work, though recent publications were prioritised for contemporary relevance. Key databases, including Google Scholar (for broad academic and grey literature reach), ProQuest, Taylor and Francis (for extensive peer-reviewed journal collections), and ResearchGate (for contemporary research and networking), were utilised. Search terms robustly combined core concepts, such as ("succession planning" OR "leadership transition") AND ("construction" OR "built environment") AND ("SME" OR "small and medium enterprise"). Citation chaining (Wohlin, 2014) from pivotal articles was then applied to identify further significant contributions.

A two-stage screening process (title/abstract review, followed by full-text assessment), adhering to systematic principles (Moher *et al.,* 2009), guided study selection. Inclusion criteria were designed to prioritise publications offering substantial and nuanced insights into SSP determinants, value criteria, or obstacles within SMEs, specifically those with clear applicability to, or focus on, the built environment. This rigorous selection process yielded a core set of 28 publications. These were determined to be pivotal to the research question, collectively providing a rich and comprehensive evidence base essential for the depth of critical analysis undertaken in this study. Key data, arguments, and conceptual elements concerning SSP were then meticulously extracted from this curated corpus. A thematic synthesis was subsequently performed, involving an iterative process of coding the extracted data to identify, critically evaluate, and categorise recurring concepts and challenges. These distilled themes (Table 1) directly informed the architecture and development of the proposed conceptual framework (Figure 1), providing a critically appraised foundation for future scholarly inquiry.

LITERATURE REVIEW AND DISCUSSION

Determinants and Value Criteria

This literature review addresses this deficit by analysing existing scholarship, identifying research gaps, and building a foundation for future inquiry. Key themes emerging from this analysis (summarised below and detailed in Table 1) inform the creation of a SSP framework.

Strategic Alignment and Pre-requisites

Rothwell (2005) highlights that effective succession planning must be intricately aligned with the overarching strategy of the organisation to guarantee continuity and uphold superior performance. Success is contingent upon proactive planning that is propelled by robust internal leadership commitment. Barnett *et al. (*2008) asserts that organisations are required to meticulously evaluate their strengths and weaknesses to establish explicit priorities, formulating plans that are both documented and adaptable. Comprehending both internal dynamics and external adversities, such as market fluctuations and evolving workforce values, is essential, considering the historical inclination to overlook planning and the disparity between acknowledging its necessity and achieving successful execution (Sullivan *et al.,* 2013).

Organisational Culture and Knowledge Management

A supportive company culture that prioritises collaboration and knowledge sharing, championed by senior management, is fundamental for effective succession (Fong *et al.,* 2009). With demographic shifts like the retirement of experienced employees, mechanisms are vital for capturing and transferring valuable knowledge, particularly

unspoken or 'tacit' expertise (Gabriel *et al.,* 2020). Flynn *et al. (*2018) recognises that valuing employees' intellectual capital as paramount. Developing leaders at all levels prevents the loss of crucial experience, and the overall organisational culture must align with business objectives to support the succession process. The built environment sector relies heavily on experiential, often site-based, tacit knowledge. The retirement of experienced employees poses a significant risk of knowledge loss. Intellectual capital is tied to technical expertise, project history, and client insights. In the built environment sector, there is limited research in what the most effective, practical methods for capturing and transferring complex, context-specific knowledge.

Timing and Transition

Rothwell (2011) asserts that initiating succession planning early provides a distinct strategic advantage, preventing operational delays caused by leadership vacancies. This requires proactive workforce planning to anticipate future needs, potential retirements, and departures, thereby addressing talent gaps before they become critical (Barnett *et al.,* 2008). Rather than a one-off event, succession planning should be treated as a continuous, ongoing process involving regular assessment and candidate preparation (Ibrahim *et al.,* 2021). Ensuring smooth leadership transitions, potentially using defined handover periods, is essential for minimising disruption and facilitating effective knowledge transfer.

Recruitment, Selection, and Leadership Development

Organisations must carefully weigh promoting internal candidates against hiring externally, often adopting a balanced approach to leverage both existing knowledge and fresh perspectives (Gabriel *et al.,* 2020). Barnett *et al. (*2008) emphasizes that the selection processes should be rigorous, prioritising long-term potential over solely current performance. Hor, *et al. (*2010) builds upon this by asserting the Identification of future leaders early allows for targeted development, providing the necessary training and experiences, such as mentoring and practical assignments. These leadership development initiatives are most effective when tailored and explicitly aligned with the company's strategic goals (Bibi *et al.,* 2023).

Performance Monitoring and Evaluation

Obianuju *et al. (*2021) highlights that incorporating clear performance metrics and transparent incentives within the succession plan helps track candidate progress and enhances employee motivation. Gunnoe, (2015) reinforces this and asserts it is crucial to regularly evaluate the overall effectiveness of the succession strategy, assessing its impact on organisational outcomes and ensuring its continued alignment with strategic objectives. This evaluation, which should consider the company's unique context and potentially use statistical methods (Salau *et al.,* 2022), allows for necessary adjustments to keep the plan relevant and effective. Further research is urgently needed on specific operational challenges facing project-based SMEs in the built environment. A priority is creating effective methods for capturing and sharing essential tacit/experiential knowledge inherent to this sector, reducing workforce retirement risks. Future research should also examine how these SMEs' unique project-driven nature and resource constraints affect strategic planning execution, appropriate leadership training for technical staff, knowledge-sharing cultures in changing teams, and relevant succession success metrics. Addressing these research needs is crucial for developing customised frameworks to improve resilience and lower high failure rates in leadership transitions within this vital sector.

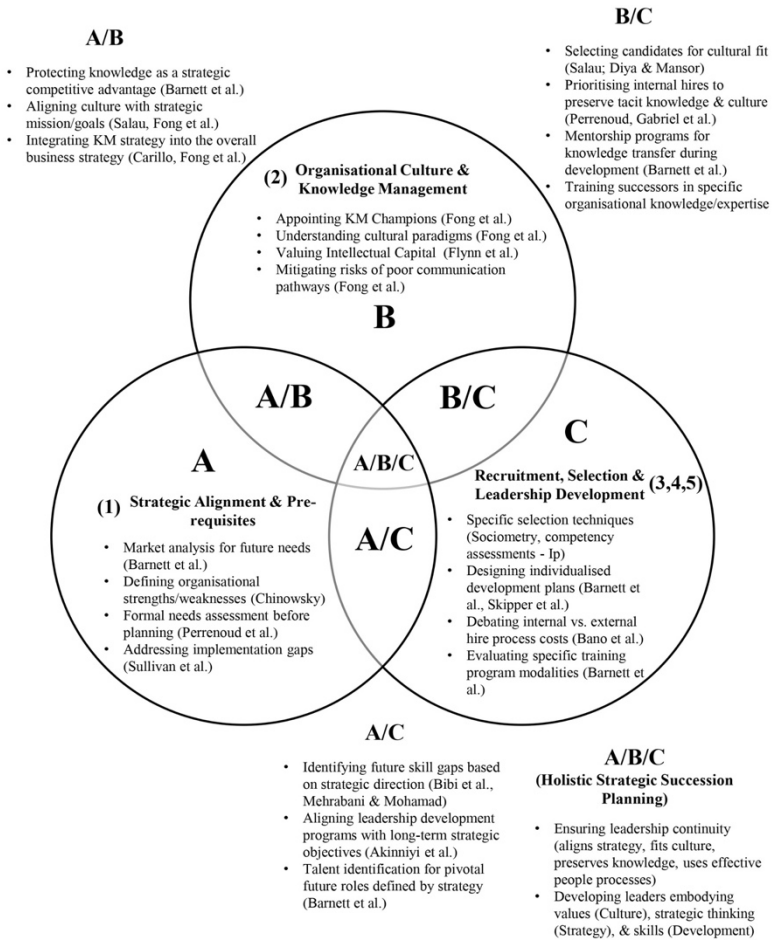
Following a thematic analysis of the chosen literature, key elements were identified, including determinants, criteria (Table 1), and obstacles.

Table 1: Strategic Succession Planning Main Themes, Sub-Themes and Scholars

Main Theme	Sub-Theme	Relevant Scholars
Strategic Alignment and Pre-requisites		
	Integration with Strategic Goals	Gabriel *et al.,* (2020), Rothwell (2005), Sullivan *et al.,* (2013), Carrillo *et al.,* (2004), Chinowsky (2001), Bibi *et al.,* (2023)
	Formalisation and Documentation	Wang (2004), Barnett *et al.,* (2008)
	Understanding Internal and External Dynamics	Perrenoud *et al.,* (2017), Sullivan *et al.,* (2013), Rothwell (2011), Bano *et al.,* (2022), Perrenoud (2012), Handler and Krams (1988)
	Extent of Implementation and Pre-requisites	Perrenoud *et al.,* (2017), Sullivan *et al.,* (2013), Rothwell (2011), Miller (2005), Obianuju *et al.,* (2021), Barnett *et al.,* (2008), Flynn *et al.,* (2018)
Organisational Culture and Knowledge Management		
	Culture of Knowledge Sharing	Fong *et al.,* (2009), Flynn *et al.,* (2018)
	Preservation of Intellectual Capital	Flynn *et al.,* (2018), Perrenoud *et al.,* (2020), Fong *et al.,* (2009), Rothwell (2005), Carrillo (2004), Gabriel *et al.,* (2020), Perrenoud (2012), Diya and Mansor (2019), Obianuju *et al.,* (2021)
	Culture Alignment	Fong *et al.,* (2009), Salau (2022), Flynn *et al.,* (2018)
Timing and Transition		
	Proactive Planning and Timely Implementation	Rothwell (2011), Barnett *et al.,* (2008), Ibrahim *et al.,* (2021), Skipper *et al.,* (2008), Bibi *et al.,* (2023), Ip *et al.,* (2006)
	Smooth Transition and Knowledge Transfer	Sullivan (2013), Skipper *et al.,* (2008), Gunnoe (2015), Ip (2009), Barnett *et al.,* (2008)
	Addressing Talent Gaps	Gunnoe (2015), Rothwell (2011), Perrenoud *et al.,* (2017)
4Selection, and Leadership Development		
	Internal vs. External Candidates	Perrenoud (2017), Bano *et al.,* (2022), Gabriel *et al.,* (2020), Payne *et al.,* (2018)
	Rigorous Selection Processes	Barnett *et al.,* (2008), Bibi *et al.,* (2023), Mehrabani and Mohamad (2011), Thompson *et al.,* (2023), Gunnoe (2015), Skipper *et al.,* (2008), Hor, F. C. *et al.,* (2010), Ip (2009)
	Targeted Leadership Development	Gunnoe (2015), Barnett *et al.,* (2008), Bibi *et al.,* (2023), Wang *et al.,* (2004), Skipper *et al.,* (2008), Salau *et al.,* (2022), Akinniyi *et al.,* (2018)
Performance Monitoring and Evaluation		
	Explicit Performance Metrics	Obianuju *et al.,* (2021), Gunnoe (2015), Akinniyi *et al.,* (2018)
	Evaluation of Development Programs	Akinniyi *et al.,* (2018), Gunnoe (2015), Salau *et al.,* (2022), Wang *et al.,* (2004)

The findings from this analysis informed the development of the conceptual framework shown in Figure 1. As highlighted by Jabareen (2009), conceptual frameworks serve to organise information and guide research. This framework synthesizes the literature themes identified, providing a descriptive map of SSP components. Furthermore, it prescriptively offers SMEs an adaptable structure for developing robust succession strategies, aiming to aid understanding of SSP's multifaceted nature for leadership continuity. While the thematic analysis provided descriptive insights from the literature, the conceptual framework synthesizes these findings into a structured representation to enhance understanding.

Figure 1: Conceptual Framework: Integrated Core Pillars of Strategic Succession Planning



Obstacles to a Successful Strategic Succession Plan

Successfully executing SSP requires more than just defining criteria; it demands a clear understanding and proactive mitigation of potential barriers. Failure to address these obstacles can compromise the entire process and therefore an understanding of these coincides with the core pillars identified in figure 1. Based on an analysis of the literature, the following key challenges consistently emerge as threats to the efficacy of SSP:

Organisational Challenges

Organisational challenges in succession planning include dealing with an unsuitable or disinterested successor, where the prospective heir may lose interest or lack the necessary skills and qualifications (Perrenoud *et al.,* 2017), noting that choosing an unprepared successor can have negative consequences (Perrenoud *et al.,* 2013). Insufficient employee development due to a lack of adequate training programs can

hinder the preparation of potential successors (Perrenoud *et al.,* 2017; Salau *et al.,* 2022; Stadler, 2011). Communication failures regarding succession planning processes and expectations (Perrenoud *et al.,* 2017), and the absence of clear organisational objectives to guide the process are also significant hurdles (Ip *et al.,* 2006). Barnett *et al. (*2008) highlights organisations may fail to prioritise future leadership needs, focusing solely on replacing specific roles, or experience "planning paralysis" where managers recognise the importance but fail to act, often seeing retirement as distant (Obianuju *et al.,* 2021; Heitner, 2012). Further issues include prioritising immediate replacement over nurturing internal talent (Barnett *et al.,* 2008), a lack of dedication to talent management from SME owners hindering the creation of a talent pool (Salau *et al.,* 2022), an insufficient understanding of knowledge management for transferring critical knowledge (Carrillo, 2004), internal resistance and company politics (Ip *et al.,* 2006), and the need for effective performance management systems to identify and develop potential successors (Ip *et al.,* 2006).

Leadership and Management Challenges

As indicated by Barnett *et al. (*2008) leadership and management challenges involve low confidence among organisational leaders in their current succession planning efforts, often believing them to be inadequate or broken. Furthermore, upper management, despite acknowledging its importance, can ironically be a primary obstacle to effective leadership transition strategies (Perrenoud *et al.,* 2017). Ip *et al. (*2006) reinforces this point in stating a lack of sufficient engagement and support from the CEO in the succession planning process also presents a significant challenge.

Resource and Financial Constraints

Resource and financial constraints pose significant barriers, especially for SMEs which often lack the financial and human resources to dedicate to comprehensive succession plans (Bibi *et al.,* 2023; Ip *et al.,* 2006). The direct costs associated with developing and implementing succession planning initiatives (Ip *et al.,* 2006), coupled with insufficient time and resources allocated for the necessary employee training and development, further compound these difficulties (Gunnoe, 2015; Ip *et al.,* 2006).

Financial and Legal Considerations

Financial and legal considerations include a lack of clarity and understanding regarding the various ownership transfer options, particularly for business owners nearing retirement (Perrenoud *et al.,* 2013). Perrenoud et al. (2013) drawing on Hawkey (2002) and Sherman (2003) highlights the difficulty in obtaining an accurate valuation of the business for potential sale or transfer is another common issue. Challenges also arise in securing the necessary capital to fund the succession process, especially for takeovers or reorganisations (Perrenoud *et al.,* 2013; citing: FEE, 2000; Hawkey, 2002; Sherman, 2003). Navigating the intricate legal obligations associated with business transfer, such as changes in legal form and ensuring business continuity, requires careful attention (Co-Operatives, 2003; FEE, 2000; Ip *et al.,* 2006). Finally, understanding and managing the tax issues associated with different types of business transfers (disposal and retention) is crucial (FEE, 2000; SBS, 2004; Ip *et al.,* 2006).

Family Business Specific Challenges

Ip *et al. (*2006) highlights that family businesses encounter specific challenges where personal relationships and emotional ties can complicate the succession process. Disagreements among family members regarding the direction and future of the business can hinder effective planning (Ip *et al.,* 2006). Additionally, family-owned businesses often favour personal, relationship-centred approaches to successor

development, which contrasts with the more formalised, task-oriented methods preferred by non-family businesses, potentially creating conflict or hindering a consistent approach (Ip 2006).

CONCLUSIONS

This literature review has been a targeted examination of the current state of knowledge regarding SSP, confirming a critical deficit in research tailored specifically to the unique operational context of project-based SMEs within the built environment sector. While broad challenges to succession planning are acknowledged in wider scholarship, their specific expression and effect within built environment SMEs remain significantly under-explored. Core principles like strategic alignment and talent development are evident, yet their direct applicability and effectiveness in the built environment is lacking and requires investigation. The importance of this study lies in highlighting this critical knowledge gap. The built environment sector's reliance on experiential, often tacit, project-based knowledge, coupled with the typical resource constraints and project-driven nature of SMEs, makes generic succession approaches inadequate. This lack of sector-specific frameworks can contribute to high failure rates in leadership transitions, risking invaluable intellectual capital and threatening business continuity - a concern for industry stability. Consequently, there is a compelling need for further research that transcends general principles to address the unique attributes of this sector. The conceptual framework presented in this paper provides a robust foundation for developing such tailored approaches. Crucially, although every organisation uses its own set of value criteria, this framework can be employed to develop effective and focused succession strategies that directly meet the needs and fundamental values specific to that organisation. Future empirical investigations must prioritise practical solutions, focusing explicitly on areas vital to built-environment SMEs, including: developing effective methodologies for capturing and transferring crucial tacit knowledge; the cultivation of skilled successors, including relevant leadership pathways for technical specialists; understanding how project lifecycles and resource limitations shape planning; navigating industry-specific risks; addressing precise business valuation challenges; fostering robust knowledge-sharing cultures; and establishing meaningful metrics to gauge succession success in this context. Addressing these gaps through focused future research is not merely an academic endeavour; it is an essential step for empowering built environment SMEs with the tailored strategies and resources required for effective and sustainable leadership transitions. For industry practitioners, such focused inquiry offers tangible pathways to enhance organisational resilience, competitiveness, and long-term viability, mitigating failure rates and securing critical expertise for the future. This research directly contributes vital insights to strategic management and SME literature, advancing theoretical understanding in a complex and currently under-theorised area crucial for the continuity and success of these economic contributors.

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INFRASTRUCTURE DEVELOPMENT

A REVIEW OF VALUE FOR MONEY ASSESSMENT APPROACHES IN PUBLIC PRIVATE PARTNERSHIP PROJECTS

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Public Private Partnerships (PPPs) create investment opportunities by optimising the combined use of private and public resources for project financing. They bring technical expertise, foster innovation, enhance efficiency, and enable effective risk sharing. Additionally, PPPs have the potential to deliver value for money (VfM) throughout the lifecycle of the project, offering a compelling alternative to traditional public procurement methods. While studies on VfM assessment in PPP arrangement exist, there is a limited body of literature that thoroughly examines best practices for assessing VfM. This study employs a systematic literature review to examine the approaches used for assessing VfM in PPP infrastructure projects. A total of 28 peer-reviewed publications from Scopus database and Google Scholar were identified and analysed. The findings reveal that public sector comparator, cost benefit analysis, competitive bidding method and outline business case are mainly used to assess VfM in PPPs. Furthermore, researchers highlighted the necessity for combined use of qualitative and quantitative factors in VfM assessment process. The findings contribute insights that will lead to the development of hybrid models for VfM assessment in PPP projects.

Keywords: public private partnership, systematic literature review, value for money

INTRODUCTION

Public Private Partnerships (PPPs) have become a fundamental approach for delivering public infrastructure globally. PPPs, a popular procurement strategy for financing large-scale projects is being increasingly adopted by governments worldwide to accelerate infrastructure development (Zhao *et al.,* 2023). Current researchers such as Osei-Kyei and Chan, (2017) state that PPPs are used to accelerate infrastructure development in both developed and developing countries through collaborative arrangements between public and private sector. Several governments have resorted to PPPs to deliver infrastructure as such partnerships help make the best use of private and public resources including finances, expertise and experience to improve and expand infrastructure assets and services (World Bank, 2013). In PPP arrangements, risks are shared among the stakeholders, the private sector focuses on financing, designing, construction and operation whereas the public sector aims at ensuring that regulations are in place and public interests are met (Grimsey and Lewis,

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2005b; Yescombe, 2011). PPP offers viable solutions in providing finances, leveraging private sector efficiency and innovation for infrastructure projects, however, choosing PPP over other procurement methods should aim at delivering the best value for money (VfM) by considering economic and social objectives rather than relying completely on efficiency factors (Almarri, 2023). The appeal of PPPs lies in their potential to deliver more efficient infrastructure projects than traditional procurement, offering investment opportunities for innovation, shared responsibilities and accelerated delivery of public infrastructure. VfM in PPP arrangement is essential to ensure that infrastructure projects deliver economic, operational and social benefits that justify their cost. Current researchers state that existing studies have contextualised that VfM is an innate feature of PPPs, although various definitions have been provided, a comprehensive and unequivocal understanding of VfM remains absent (Zhao, 2024).

Various approaches are used in assessing VfM in PPP projects. Akintoye *et al. (*2003) state that VfM assessment process involves comparing PPPs with public sector benchmarks to evaluate lifecycle efficiencies, cost savings and performance outcomes. According to Burger and Hawkesworth, (2011), VfM assessments are vital as they provide a careful analysis of potential benefits and risks over the long-term period of PPP contracts. VfM in PPPs is typically evaluated through models such as Public Sector Comparator (PSC), Cost Benefit Analysis (CBA), Outline Business Case (OBC) and Competitive Bidding Method (Grimsey and Lewis, 2005a; Liu, *et al.,* 2023). VfM assessment process is aimed at identifying whether the proposed PPP project can achieve benefits such as accelerated project delivery, improved service quality and reduced lifecycle costs through private sector innovation, experience and expertise. However, establishing VfM is complex and requires potential negotiations, accounting for transaction costs, and factors like accountability and transparency to avoid negative public sector perceptions and cost overruns (English and Baxter, 2010). According to Zhao *et al. (*2023), the PSC is used as a benchmark in VfM assessment in many countries. The PSC compares the proposed cost of a public-sector led project with a PPP project to assess the potential benefits (Yescombe, 2011). However, the PSC has limitations as it emphasizes on quantitative financial metrics, such as internal rate of return (IRR) and net present value (NPV) and overlook the qualitative aspects which include service quality, innovation and social impacts (Grimsey and Lewis., 2005). Additionally, Jasiukevičius and Vasiliauskaitė, (2018) highlights that PSC method is complex and faced with ongoing criticism due to subjective assumptions and approaches used in various countries with respect to risk transfer and discount rate.

PPP projects assess VFM using a whole life cycle approach incorporating long term design, construction, operation and maintenance. Contrary to non-PPP projects, VFM assessment approaches involve detailed private financing, risk transfer analysis and comparison with a PSC. Also, VFM assessment model emphasize on performance-based outcomes making it more comprehensive than in traditional procurement. VfM assessment approaches vary significantly across countries (World Bank, 2013). Existing literature primarily describes models such as the PSC, CBA and other risk transfer models but offers limited insight into how these models can be effectively applied in specific contexts. While (Yescombe, 2011) and Grimsey and Lewis, (2005a) provide detailed explanations of VfM models like the PSC, they do not systematically examine what constitutes best practice in the practical application of these models. Researchers in countries such as the United States, United Kingdom,

China, and India are actively addressing concerns related to the application of the PSC method. They are developing tailored frameworks specific to their countries and projects, recognising that contextual factors often prevent a one-size-fits-all approach.

METHOD

This study will adopt a five-stage procedure for conducting a systematic literature review. The procedure includes i) the formulation of questions, ii) locating and identifying relevant studies, iii) selecting and evaluating studies, iv) analysing or synthesising findings and v) reporting results (Denyer and Tranfield, 2009).

Initial Search and Selection of Relevant Articles

Scopus and Google Scholar are the main databases used to search for relevant articles using suitable keywords. Scopus database has limited papers but provides comprehensive peer-reviewed and recent published articles related to this research (Eshun *et al.,* 2021). Similarly, Google Scholar was used because it has significantly expanded its coverage over the years, therefore, considered a powerful search engine for reliable scholarly literature (Halevi *et al.,* 2017). In addition, Martín-Martín *et al. (*2018) state evidence of free availability of a wide range of articles in Google Scholar which provide trends and patterns in the common approaches used for assessing VfM. Reference was made to other PPP review papers in guiding the choice of databases selected which state that Scopus and Google scholar provide a wider coverage of research themes with latest publications of studies (Akomea-Frimpong *et al.,* 2023). The following search string and synonyms were used to search in both Scopus database and Google Scholar: TITLE-ABS-KEY ("value for money assessment" OR "value for money evaluation" OR "value for money framework" OR "value for money method" OR "value for money analysis" AND "public-private partnership" OR "public private partnership" OR "public-private partnerships" OR "PPPs" OR "private finance initiative" OR "PFI") AND (LIMIT-TO(DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp")) AND (LIMIT-TO (SRCTYPE , "j") OR LIMIT-TO (SRCTYPE, "p")) AND (LIMIT-TO (LANGUAGE, "English")).

Table 1: Summary of articles retrieved

	Total articles	Total after exclusion	Relevant articles
Scopus	51	41	17
Google Scholar	2350	136	11
Total	2401	177	28

As shown in Table 1, the initial search yielded a total of 2401 articles. Inclusion and exclusion criteria were applied to filter the results, considering the type of document, source and language used. Only articles and conference papers were selected, and sources included journals and conference proceedings. Additionally, the search was restricted to English language publications, while the search time limit was unrestricted to provide a broader range of articles for the historical background of the study.

Figure 1 illustrates the PRISMA flow diagram, outlining the identification, screening and eligibility of studies included in the review. The screening and filtering of the articles used the inclusion and exclusion criteria. The search limited to: (i) the articles related to VfM in PPPs, (ii) articles which described the VfM assessment approaches

in PPPs and (iii) articles published in relevant journals as referenced by most authors in PPP studies. The study excluded duplicate articles. The selected articles for inclusion were peer-reviewed papers related to PPPs, hence, provide a positive impact to the research. While 28 articles may be considered a small number it is justified based on similar studies. For example, Osei-Kyei and Chan, (2018), used only 16 articles in their review, and Helby-Petersen, (2019) reviewed 21 articles. Therefore, using 28 articles in this review is considered appropriate.

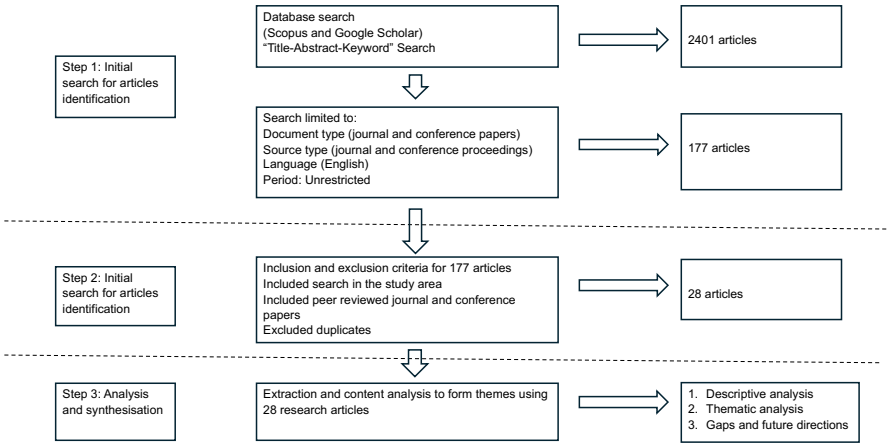


Figure 1: PRISMA Framework

FINDINGS

Value for Money Assessment Approaches in Public Private Partnerships

There are various approaches to VfM assessment in PPP projects globally. The public sector comparator, cost benefit analysis, outline business case and competitive bidding methods are the most used approaches in many countries; however, other countries such as India, China, USA, and UK have also developed country specific and project specific VfM assessment approaches. VfM is essential in evaluating and justifying PPPs, thus, VfM assessment ensures that PPPs deliver superior project outcomes compared to traditional method. However, the models for assessing VfM face notable critiques, ranging from their conceptual and theoretical underpinnings to their practical application.

Public Sector Comparator (PSC)

The Public Sector Comparator (PSC) VfM assessment model typically compares the whole life-cycle costs and benefits of the PPP model to a PSC. Liu *et al. (*2018) states that governments worldwide have been increasingly adopting PSC model for assessing VfM to guide in deciding whether to use PPPs over traditional procurement methods in delivering public infrastructure projects. The PSC model is used as a benchmark in VfM assessment in many countries such as UK, Australia, China, Canada, Netherlands, South Africa, and Japan (Zhao *et al.,* 2023). Despite its use globally, several issues arise. Jasiukevičius and Vasiliauskaitė, (2018) highlight that PSC model is complex and faced with ongoing criticism due to subjective assumptions and approaches used in various countries with respect to risk transfer, future cash flows and discount rates. Grimsey and Lewis, (2005) concurs with the sentiments in this recent study and argues that the PSC receive much criticism in the choice of the two large NPV due to a lot of assumptions in risk calculation and

transfer. The subjective judgement in quantifying and allocating risks between the public and private partner leads to inconsistencies in evaluating whether the risk allocation is optimal and justifiable. The PSC calculations are quantitative in nature, with much emphasis on financial cost savings rather than a holistic view of quality improvements, innovation and social value. Critics argue that overemphasising cost savings may undermine policy objectives, such as equitable access to services and environmental sustainability (Hodge and Greve, 2017).

The PSC model is a valuable tool for assessing VfM in PPP projects, nonetheless, it has received much criticism. Recognising and addressing the limitations through broader evaluation criteria, methodological innovation and transparency can significantly improve the PSC's effectiveness as a decision-making tool. Incorporating qualitative metrics to expand the PSC framework to include non-financial factors such as environmental, equity and social impacts may provide a comprehensive and more holistic VfM assessment approach.

Cost Benefit Analysis (CBA)

The Cost Benefit Analysis (CBA) is one of the widely used VfM assessment models that compares the economic feasibility of a project. It provides monetary value after calculating cost and benefits of whole lifecycle of a project by considering many qualitative factors in the assessment process to guide in decision making. While CBA aims at offering a systematic and rational approach to resource allocation, the methodologies for VfM analysis face notable criticisms from conceptual underpinnings to practical application and ethical considerations. The direct financial impacts can be quantified easily; however, challenges may arise to express the intangible factors such as social equity, environmental quality and cultural heritage in monetary terms leading to oversimplification of significant complex issues (Beukers *et al.,* 2012). The choice of discount rate to calculate the NPV is subjective and lacks consensus, therefore, a low discount rate inflates long-term benefits, for example environmental sustainability, whereas a high discount rate undervalues them (Curry and Weiss, 2023). It is argued that the estimation process may be bias driven by institutional and political pressures to justify the proposed project, therefore, there may be risk of cost underestimation and benefit exaggeration leading to poor decision-making (Volden, 2019).

Evaluating the economic feasibility of the proposed project, CBA remains valuable tool, however, its limitations must be addressed to better support equitable and sustainable decision-making. Incorporating Multi Criteria Decision Analysis (MCDA) to integrate multiple dimensions of project impacts to the CBA will strengthen the handling of qualitative factors and equity considerations. Inclusivity, transparency and distributional concerns may be tackled by an intensive stakeholder engagement throughout the CBA process. Different groups may be considered and valued appropriately by applying equity weights to costs and benefits. Finally, the reliance on monetisation can be addressed by integrating non-monetary indicators such as environmental quality indices to provide a more comprehensive VfM assessment approach which has considered multiple project impacts.

Competitive Bidding Method

The competitive bidding model analyses and selects contractors or partners for the proposed project. This approach depends on competitive tendering process, where bids are compared based on predetermined criteria such as compliance with project requirements, cost, time and quality. Although the competitive bidding model

encourages competition, ensures transparency and value for money, it is criticised for its methodological shortcomings, theoretical assumptions and practical limitations. This common approach primarily prioritises the lowest bidder, at the expense of long-term value and quality. This may result in bidders offering underestimated project costs or unrealistic schedules leading to poor project outcomes (Volden, 2019). The competitive bidding approach may not sufficiently account for qualitative factors such as adaptability, stakeholder engagement and innovation, which are essential factors in development of complex and large-scale infrastructure projects (Grimsey and Lewis, 2005c).

The competitive bidding model encourages competition, accountability and transparency in the procurement process, however, its emphasis on the lowest successful bidder challenges the use of the method on innovative and complex infrastructure projects. Incorporating qualitative factors and lifecycle metrics to complement the cost-focused evaluations will ensure a balanced decision-making process. There is need to adopt robust prequalification mechanisms to ensure that only capable and competent bidders participate in the competitive bidding process may reduce the risk of low-quality bids. Finally, leveraging technological tools such as having digital platforms to manage the bidding process will not only reduce administrative burdens but also enhance transparency in public procurement.

Outline Business Case (OBC)

The Outline Business Case (OBC) model analyses the best option for delivering the project by comparing alternatives such as PPPs versus traditional procurement. It is done at the early stages of project development to justify the investment, assess feasibility and facilitate decision-making. The OBC uses a structured framework to define project objectives, evaluate options and come up with the preferred delivery option. Despite the systematic approach, the OBC receives criticism for its implementation challenges, methodological limitations and potential biases. Volden, (2019) states that the OBC relies more on assumptions about costs, risk allocations, benefits and demand forecast which may lead to misjudgements on the selection of the best option for delivery and result in uncertainties and significant variations. It is argued that the evaluation criteria may be overly simplified, with much focus on cost and risk leaving out important considerations such as long-term adaptability, social equity and innovation (Grimsey and Lewis, 2005a).

The OBC is beneficial for analysing the best option to deliver a project. However, the limitations with this approach can be addressed by enhancement of stakeholder engagement. Expanding the scope to include qualitative metrics such as innovation, environmental sustainability and social equity may provide a holistic approach in the use of OBCs. Adopting methodologies that will consider adaptability, transparency and flexibility to address uncertainties.

A comparison of the models to VfM assessment in PPPs is provided in Table 2. The table outlines the focus of each model, together with its strengths and weaknesses.

CONCLUSIONS

In conclusion, PPPs is being increasingly used globally. VfM in PPP arrangement is essential to ensure that infrastructure projects deliver economic, operational and social benefits that justify their cost. The four commonly approaches used are the public sector comparator, cost benefit analysis, competitive bidding method and outline business case. Although these approaches are valuable tools for assessing VfM in

PPPs, they are faced with various limitations which may be addressed by integrating qualitative metrics to cost-focused evaluations throughout the project lifecycle. The choice of approach depends on market maturity, data availability, government capacity and project stage.

Table 2: Comparison of approaches to VfM assessment

VfM Models	Focus	Strengths	Limitations	Critique
Public Sector Comparator (PSC)	Finances and risks adjustment comparison	Quantifies the financial benefits, hence facilitate objective decision-making Incorporates risk calculation and transfer Emphasizes whole lifecycle costing	Relies heavily on assumptions. Fails to capture dynamic real market environment Can be manipulated to favour PPP or public delivery	It is quantitative, therefore societal benefits may be overlooked Requires regular updates to reflect market trends To be paired with CBA for robust VfM assessment
Cost benefit analysis (CBA)	Socio-economic benefits	Captures wider economic, environmental and social impacts Comprehensive process as it considers many factors in the assessment process which helps in decision making	It incorporates benefits that are complex and cannot be quantified. Valuing intangible factors such as time saved, or pollution avoided may bring biasness	Due to PPPs focus on financial viability, this approach may be underutilised It can be more effective if used with other models such as the PSC
Competitive bidding method	Respond to market environment	It relies on competition to deliver innovation and best price It is dynamic as it adjusts to actual market conditions rather than assumptions	Market driven VfM can fail if bidders are unqualified or few Requires long procurement timelines and high transaction costs	Effective where market conditions are favourable Should be paired with other approaches such as PSC for a robust VfM assessment
Outline business case (OBC)	Strategic and financial planning	Evaluates project need, affordability, strategic fit, apart from VfM Long-term VfM including during delivery and monitoring Often used to align with national guidelines	Subject to biasness, conclusions can be influenced by pre-determined preferences Resource intensive to do detailed analysis Lack quantification assessment	Requires regular updates due to changes in market conditions, risks and policies Useful model to guide early decision-making in PPPs Effective if used with quantitative assessment models such as PSC

The findings highlight the importance of integrating multiple VfM assessment tools to provide a comprehensive basis for informed decision-making. Moreover, VfM assessment should be tailored to specific project context, considering factors such as market maturity and institution capacity. This study recommends a staged VfM assessment approach that combines the PSC and CBA during project appraisal, validate assumptions through competitive bidding, and incorporates all findings into the OBC structure. Such an approach supports the development of hybrid models that effectively capture both economic and financial dimensions of project evaluation.

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PROGRAM MANAGEMENT OF CONSTRUCTION PROJECTS: AN ACTION RESEARCH

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Effective governance of a program of construction projects is essential to reach its intended objectives and benefits. The literature has reported several key challenges, including adopting Project Management Information Systems (PMIS), utilising risk management, and implementing robust stakeholder engagement. These program duties can be integrated into the centralised responsibility and authority of a Program Management Office (PMO). Via action research, this paper analyses the role of the PMO and the critical success factors of establishing program management in a public technical university in Italy that has undertaken a program of nine overlapping educational and research building projects, totalling 300 million euros in investment. The findings reveal that the creation of a PMO was central to both improving program governance processes and enhancing project delivery and performance management. The PMO played a critical role in standardising planning and monitoring practices, integrating data flows, and fostering communication between top management and project managers. The implementation of the PMO facilitated real-time information exchange and improved decision-making.

Keywords: Action research; project management; risk; construction planning; management information systems

INTRODUCTION

A program of construction projects is typically a complex venture that requires substantial capital investment, extensive planning, monitoring, and coordination across multiple stakeholders. The governance of such programs constitutes a critical element in strategic planning (Khan *et al.,* 2019) and effective governance is essential to ensure the attainment of the intended program objectives and expected benefits. Governance in this context refers to the frameworks, policies, and processes that guide decision-making, management, accountability, and performance monitoring throughout the program lifecycle, usually delegated to a Program Management Office (PMO) (Monteiro *et al.,* 2016).

Via action research, this paper illustrates the challenges and practices of the governance and management of a program of nine public construction projects of educational and research facilities, totaling a capital investment of € 300 million, carried out by Politecnico di Torino, a major public technical university in Italy,

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acting as the owner and main sponsor of the initiative. The research questions are: RQ1) to explore the role and extent to which a PMO can contribute to effective governance and management of a program of construction projects, and RQ2) to identify the Critical Success Factors (CSFs) for a PMO implementation. By CSFs, we mean the key activities an organisation must perform well to achieve its goals. They align with strategic objectives and help guide the use of resources and managerial attention (Pinto and Slevin, 1987).

The paper is structured as follows. First, we give the pertinent literature. Second, we present the case study and illustrate the action research. Then, we analyse the results of the research questions. We conclude with the discussion of results and implications.

Construction Program Management Literature

Governance involves the responsibilities of directing, overseeing, and controlling a program of interrelated projects. Tightly linked to the governance is the management of the program, which comprises the duties of coordination and execution (PMI, 2017). The literature highlights key challenges in program governance and management, including: 1) the complexity of governing multiple interrelated projects and aligning them with organisational strategy, 2) directing diverse stakeholder expectations and ensuring effective cross-functional communication, and 3) securing financial control through proper funding and cash flow management (Shehu and Akintoye, 2010). Several tasks can be done to tackle those challenges, and a set of success variables are reported under four emerging themes, such as: establishing PM infrastructure, promoting PM practices, PMO structuring, and organisational support (Ershadi *et al.,* 2021). The literature also highlights gaps in risk management and program performance monitoring (Shehu and Akintoye, 2010), which this paper addresses through the implementation of a dedicated Project Management Office (PMO) and a tailored Project Information System (PMIS) dedicated to program and project planning and monitoring (Li *et al.,* 2015; Wong and Zhang, 2013). These two components, when combined, enable integrated reporting, risk mitigation, and stakeholder alignment in a complex public construction program.

To this end, the program governance and management duties can be integrated into the centralised responsibility and authority of a PMO, a function to help ensure compliance, accountability, effective coordination, financial management, risk management, performance monitoring, and evaluation (Shehu and Akintoye, 2009). The implementation of a PMO providing oversight and strategic reporting capabilities and the effective support, coordination and management of the program are the measures of an effective system (Too and Weaver, 2014).

Moreover, the PMO functions as an instrument of organisational change management. Beyond its role in operational oversight, the PMO actively enables change by providing training and operational support, and encouraging integration across technical, procurement, and executive teams (Bredillet *et al.,* 2018; Ershadi *et al.,* 2021; Simard and Aubry, 2024). In particular, the PMO acts as a boundary-spanning entity, also connecting top management with project managers and facilitating vertical communication across organisational levels (Simard and Aubry, 2024). A PMO co-evolves with its environment, adapting through feedback loops between its artefactual, performative, and ostensive components (Bredillet *et al.,* 2018). Its ongoing transformation is driven by both internal managerial initiatives and external pressures, as observed in the case presented in this paper, which jointly shape its structure and

practices. This dynamic capability enables the PMO not only to coordinate activities but also to support the alignment of project-level practices with organisational strategic objectives (Bredillet *et al.,* 2018).

Several studies have analysed the process and identified CSFs affecting the effective implementation of the PMO. Al Khoori and Hamid (2022) reported project flexibility; politics and change resistance in stakeholders; alignment and accountability; efficient resources; risk management; effective leadership and team management. Singh *et al. (*2009) identified having a strong PMO champion, starting small and demonstrating the value of the PMO, obtaining support from opinion leaders, hiring an experienced program manager who understands the organisation, bringing the most talented PMs into the PMO implementation team, adopting a flexible change management strategy, and standardising processes prior to PMO implementation as the main areas of successful implementation.

The Case Study

The owner of the program, Politecnico di Torino, is a highly ranked public technical university in Italy with 40,000 students and approximately 1,500 permanent faculty members offering education and doing research and technology transfer in varied engineering, design, and architectural disciplines. To expand its capacity, it launched a major program of overlapping construction of nine new green and brownfield buildings for research in aerospace, digital transformation, automotive, and education. The 250-million euros program started in 2022. The various buildings are scheduled to go into operation from late 2026 to 2028. Each project is managed by an owner's Project Management Team. The program is financed with 30% of public grants from the Italian Ministry of University and Research, 30% of equity capital, and 40% of debt sources of financing borrowed from the European Investment Bank.

To enable Program Management capacity, in October 2022 the Board of Directors decided to introduce a new Program Management function, to support the activities of the Project Managers in the project implementation process, ensure strategic alignment, plan and monitor the execution of the program, manage stakeholders, information and communications, monitor the achievement of the expected benefits relating to time, cost, quality, environmental efficiency, and user satisfaction. The new Program Management capacity was implemented through the definition of a new PMO, the introduction of a PMIS, and the redesign of administrative processes. As part of the PMO, the main author of this paper, a Professor of Project Management from the university itself, was hired as the consulting Program Manager Advisor (PMA) to ensure effective stakeholder management, cost and time planning and monitoring, risk mitigation, and financial control at the program level.

The case was selected as suitable for studying the RQs because it exemplifies a public body tackling PMO implementation challenges within the legal and regulatory constraints typical of the public sector (Rebuglio *et al.,* 2025a). Moreover, the authors had direct access through action research.

The Action Research

Methodology

Action research was carried out by the authors of this paper. The authors were proactive change agents in relation to the case (Svejvig *et al.,* 2021). In such a way, the implementation process followed the typical iterative steps of action research in organisational development (Martinsuo and Huemann, 2021; Kampf *et al.,* 2023).

The owner and PMA jointly diagnosed the problem and planned the required actions. Then, actions were executed. Finally, the results phase included actual changes in behaviour resulting from corrective action steps taken following the second stage. In addition to the program's data about the time and cost performance, the results were derived from the authors' experience and notes, and through semi-structured interviews conducted with top management, Project Managers, and the members of the newly established PMO. Interviewees were asked to assess with a Likert scale and comment on a list of possible CSFs derived from the literature.

Plan

The existing Facilities Department used to have project technical and management competencies but mainly lacked cash flow management and financial control abilities, risk management practices, and program coordination. With a focus on software tools, Project Managers already used planning tools individually (e.g., Microsoft Project); however, they faced common problems typical of non-customised PMIS. The main issues were the lack of data integration, which made it difficult to create clear and consistent reports for top management, and the difficulty for Project Managers to gain a shared and complete view of all projects (Li *et al.,* 2015; Wong and Zhang, 2013).

Within this context, the need to introduce Program Management approaches was driven by two main objectives: 1) Top management requires monitoring data. The university's strategic body, the board of directors, requires a reporting tool that provides real-time visibility into ongoing projects and their progress status. 2) Financial management requires project cash flow forecasts. The financial offices require cash flow forecasts to support financial planning and loan management.

To overcome these problems, the action plan included: the establishment of a PMO with the appointment of two full-time staff with Program and Portfolio competencies, the creation of a Program Steering Committee with regular monthly review meetings, and the development and roll-out of a tailored Project Management Information System (PMIS) for integrated project and program budget and time scheduling, risk analysis and cashflow planning and monitoring (Kock *et al.,* 2020).

A “Monitoring PMO” was decided to be implemented: this kind of PMO monitors project compliance with methodologies and standards and performs integrated monitoring and regular reporting at the program level (Tsaturyan and Müller, 2015). Some project-focused duties were also assigned to the new PMO including consulting, mentoring, and training services to help project managers and their project teams to better interact with the program office. The PMO was also given institution-wide responsibilities with Project Management standards, methods, information tools, and project performance data archives. The PMO was intended to target the performance improvements of both the projects and the people involved in the program.

Actions Executed

The PMO took several actions according to the plan, as designed and supervised by the consulting PMA.

The new structure consists of three teams that work in an integrated manner together with the Facilities Department charged with Planning, Management, Construction and Safety Department (PROGES): the Masterplan Team, the Program Manager Advisors team, and the PMO. The teams are composed of both teaching staff and technical-administrative staff in the University roles. The Masterplan Team develops the planning activities, and the Program Manager Advisors team monitors and controls

the intervention program in the Construction, Energy, Time and Cost and Environment areas of expertise through the operation of the PMO.

The main activities of the PMO include support for feasibility, planning and scheduling, monitoring and control of time and cost, providing information methods and tools suitable for decision-making. The main responsibilities assigned to the PMO are: 1. consulting, mentoring, training and assistance in planning and monitoring activities to the Project Managers on individual projects, 2. development of PM standards, methods, processes, IT systems and data archives, 3. improvement of project performance, and 4. employees training.

As for the process, the PMO required all Project Teams to comply with the integrated Public Procurement Law and PMI Standard for Program Management Fourth Edition (PMI, 2017). Project planning and monitoring processes are integrated into the Program Management Plan and Reporting process, which consists of quarterly re-baselining based on progress and Earned Value Management data.

As for the PMIS, the PMO selected and tailored the integration of a Project Planning software tool (i.e.: Project Web App) with a Business Intelligence reporting system (i.e.: PowerBI) to optimise cash flow planning and enable continuous progress tracking, performance monitoring, and financial control. A web-based monitoring dashboard with custom drill-down reporting was made. A Risk Management tool is also being integrated into the program process and PMIS. However, it is still in its early development and cannot be reported in this paper at this stage.

As for training and skills development, the PMO arranged training sessions for project teams and promoted continuous skills development by providing ongoing support and facilitating adoption of Project and Program Management best practices.

RESULTS

Here we link our case study to existing knowledge and connect the contributions with our findings for theory testing (Martinsuo and Huemann, 2021). The results were derived from the authors' experience and notes, and through interviews conducted with top management, Project Managers, and the members of the newly established PMO.

The Role of PMO in Program Governance and Management

According to RQ1, based on the actions required, executed, and observed changes in behaviours, we can summarise that the PMO was crucial in providing standardised planning and monitoring practices for individual projects, data collection and integration, improved project performance, and employees' training. This case shows that a PMO can be of great value as a promoter of project success and a key ingredient for better usage of resources (Santos and Varajão, 2015). In fact, the exchange of real-time communications and data between top management, Project Managers, and the Facilities Department's staff was favoured by the proactive role of the PMO and the crucial functionalities of the integrated PMIS.

More specifically, the duties of the PMO included the following: 1) Standardisation of processes and communications with the Management Offices and other functions involved, aimed at eliminating duplication, 2) Creation of a dynamic Project and Program Management PMIS for financial planning and monitoring of time, cost, cash flow, and risks, 3) Standardisation of project activities by providing for well-defined disbursements and/or collections in terms of time within the time schedules of the

entire procedure, structured by the Project Managers in collaboration with the PMO, 4) Standardisation of the technical economic frameworks of the projects to attribute each economic resource to the activities of the schedule prepared during the planning phase, 5) Dynamic extraction of the reporting of current and expected cash flows, the analysis of performance time, cost, and cash flow according to the Earned Value Analysis technique, which can be shared with stakeholders for a timely update of the progress and efficiency of the investment program, 6) Simulation of economic-financial scenarios that examine new initiatives of which one wants to know the possible financial impact over time.

The CSFs of the PMO implementation

As for the RQ2) aimed to identify the CSFs of a PMO implementation, we can list several factors supporting stewardship approaches in the context of successful program management (Joslin and Müller, 2016).

Involving Project Managers from the beginning in defining approaches, context analysis sessions, goal setting, and Project Management education and training was crucial.

Adopting a transparent and inclusive approach helped mitigate initial resistance to changes and the use of the software. This model reflects the differing perspectives that may exist at the interface of the act of governing a program and the act of providing management support to the program (Crawford *et al.,* 2008). In this case, the owner emphasized the provision of both governance and management support and the need to build trust among stakeholders for governing the program (Ruijter *et al.,* 2021).

Introducing a tailored PMIS, suitable for the context and equipped with a reporting system for strategic project data progress tracking, was vital to ensure the program's cost and time performance. As of March 2025, the program is experiencing an overall 5% cost increase and a 10% schedule delay. The combination of a document flow system and structured information flows was very supportive of prompt and real-time communications of progress and Earned Value Management data, as well as of the distribution of reports and documentation at the program level (Rebuglio *et al.,* 2024).

DISCUSSION

This paper presents a case study of a PMO established to monitor a program of construction projects, analysing both processes and results. From the beginning, it was clear that the main need of top management was to have reliable monitoring data. This aligns with the literature, which identifies monitoring as one of the primary roles of a PMO (Monteiro *et al.,* 2016).

An interesting aspect was that the implementation of the PMO progressed together with the implementation of a tailored PMIS (Rebuglio *et al.,* 2025b). This was not planned in advance but emerged naturally during the process, driven mainly by the requirement of ensuring data availability for top management. Efforts focused on three main directions: managing organisational change, introducing the PMO, and implementing the customised PMIS. The PMIS was the core mean through which the PMO was successfully implemented and the availability of the PMIS at the project level made it easier for the PMO operation at the program level and the coordination of the projects. In this context, the PMO became a key driver of change (Simard and Aubry, 2024), both in adopting and using the PMIS and in supporting overall change

management activities. Due to this interaction, the PMIS became a crucial CSF of the PMO implementation.

A central element was the need to create a structured information flow between Project Managers, the PMO, and top management. This reflects the known challenges of integrating PMIS tools (van Besouw and Bond-Barnard, 2021; Ottaviani *et al.,* 2023), especially when used by project owners (Jahanger *et al.,* 2021). Before introducing the PMIS, the organisation had a typical situation in which communication across departments occurred mainly through informal and fragmented methods, such as phone calls and emails (Wong and Zhang, 2013). These fragmented exchanges were later reconstructed into reports for top management. Introducing a single integrated tool for scheduling and monitoring, combined with a centralised business intelligence system, significantly improved not only the IT infrastructure but also the organisation's structure and procedures.

IMPLICATIONS AND LIMITATIONS

This action research proves that the establishment of a PMO is essential to obtain efficient and effective program governance and management. Its CSFs are related to both the processes of implementing the PMO and the results of the execution of the program. Process-oriented CSFs refer to the key activities, practices, or behaviors that must be carried out effectively during an organisational operation to ensure success. These factors focus on how success is achieved, the means, rather than the end (Pinto and Slevin, 1987). Result-oriented CSFs are the key outcomes or performance goals that must be achieved for a project, process, or organisation to be deemed successful. They focus on what must be accomplished, the ends or performance results of the program (Shenhar *et al.,* 2001).

From a process-oriented perspective, the PMO provides support and training to facilitate the transition. From a results-oriented perspective, it plays a key role in ensuring the effective execution of the program. This includes coordinating activities, ensuring correct software usage, and helping stakeholders interpret business intelligence data. This reaffirms the key role of program data management and that supporting PMIS tools are crucial for dealing with projects, programs, and portfolio management, acting as critical success factors, and it demonstrates that digital governance has a positive correlation with the success of a program (El Khatib *et al.,* 2022).

Also, this research shows the way that a PMO can be created within an owner public entity and that the implementation of a digital PMIS for increased transparency and accountability is one of its CSFs.

This paper poses limitations in both the case study and the method. The research is affected by the background of the action research, namely: the individual contribution of the PMA, the Italian public works legislation, and the background competencies of the technical and managerial staff involved in the Facilities office of the case university. Also, the action research methodology is limited to analysing the specific case study, and general implications may be affected by different contextual CSFs.

CONCLUSION

This action research highlights how the need for reliable, real-time information was the principal driver for establishing a program management structure. The introduction of a dedicated PMO and the adoption of an integrated PMIS proved vital

in standardising processes, improving communication between top management and individual project teams, and ensuring tighter control over costs and schedules.

The main identified CSFs can be summarised as: 1) early involvement and training of Project Managers, which helped minimise initial resistance, transparent, 2) inclusive stakeholder engagement, fostering trust and consensus, 3) adoption of a tailored PMIS with solid reporting features to accurately track financial and schedule performance, and 4) the establishment of structured data flows to ensure continuous communication among the PMO, Project Managers, and top management. Overall, the PMO has played a pivotal dual role: it integrated data and processes on the one hand and led the organisational change on the other. The tailored PMIS used by the PMO became the key enabler for bridging the operational and strategic levels, allowing for precise tracking of cost and schedule data and thus more informed decision-making.

This case study confirms that a well-implemented PMO, supported by digital tools for planning and control, adds significant value to the governance of complex programs, especially in public organisations subject to strict administrative and legal frameworks. Although complete automation and integration of data remain challenging, the benefits observed to date underscore how such solutions enhance accountability, transparency, and overall program success.

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PLATFORM THINKING IN CONSTRUCTION: A CASE STUDY OF THE REFURBISHMENT OF EXISTING INFRASTRUCTURE

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Although the numerous benefits of product platforms spur increasing interest in their application in construction, the transfer of manufacturing principles to construction, especially refurbishment projects, remains challenging. Defining the dimensions and degree of modularity is difficult when interacting with an uncertain and variable physical asset and a complex socio-technical interaction between performing the necessary work activities and the use of the asset by users, tenants or operators. A case study of a national railway infrastructure renewal programme is presented, drawing data from project documents, and analysing to understand the constraints which determine potential forms of modularity. The findings show that the process of module definition is a socio-technical dynamic between the physical asset which defines 'what' activities need to be performed and the users who define 'when' and 'where' the activity may be performed. The process is iterative, and the quality is refined using the criteria of Cohesion and Coupling. The findings contribute to the implementation of platform theory in refurbishment projects with a model of module definition and refinement including the socio-technical dimension of modularity.

Keywords: planning; modularity; refurbishment

INTRODUCTION

While environmental requirements on new construction become increasingly stringent, attention is increasingly shifting to the relative benefits of prolonging the service life and improving the performance of existing built environment through refurbishment. The organisations that own existing structures and infrastructure are however faced by considerable complexity in realising refurbishment projects and programmes. The refurbishment of existing structures is a complex challenge due to the scale, uncertainty in interaction with the existing structures, and constraints in coordination with the existing occupants, users, or operators (Davies and Brady 2000; Kemmer 2018; Pikas *et al.,* 2021). Platform thinking, the design of a modular production system, has been discussed as a potential solution to the outlined challenges in construction (Jones *et al.,* 2022), since technology platforms have a long history in product-based industries applying standardisation, modularisation, and configuration to increase efficiency and streamline processes, while maintaining a necessary degree of flexibility (Meyer and Lehnerd 1997; Robertson and Ulrich

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1998). However, the transfer of these concepts to a project-based industry, like construction, has been more challenging (Thuesen, 2012). As Aksenova and Oti-Sarpong (2024: 230) write: "the achievement of this goal on a large scale has remained elusive for at least three decades". Although the concept has broadened more recently to include more dimensions of modularity, the focus is often on product standardisation and a "kits of parts" approach, which may overlook other potentially useful forms of modularity such as process, organisation, knowledge or socio-technical (Aksenova and Oti-Sarpong 2024: 239; Campagnolo and Camuffo, 2010; Thuesen, 2012).

This paper studies the constraints associated with a major national railway renewal programme and explores further potential for modularity in a context characterised by both a high degree of repetition, but also uncertainty and variability in product and process. The renewal projects are analysed using a Design Structure Matrix (DSM) approach (Browning 2001; Eppinger and Browning 2012) to understand the internal relationship between each activity and to propose a potential form of modularity. The proposed form of modularity is assessed against the criteria of Cohesion and Coupling, which is used to evaluate the quality of proposed modules (Stevens *et al.,* 1974). This study is guided by the research question: How can modules be defined in major refurbishment programmes? The findings indicate firstly that the most apparent form of modularity is the time and location where the work is agreed to take place (called track “possession” in the rail context). Often in refurbishment, there is a negotiation with existing users, tenants or operators when and where the work may take place, creating a fixed spatial and temporal boundary for work activities. This proposed form of modularity shows relatively high functional and sequential Cohesion. The analysis of Coupling primarily shows the main relationship between modules as a significant transfer of material, equipment and people between the modules. Other than this physical transfer, the Coupling of the modules is relatively loose and dictated by the rules which govern the time and location of track possessions. Finally, this paper proposes a conceptual model for the definition of modularity in a refurbishment context where the activity is defined through interaction with the existing physical asset, and the time-location is negotiated through interaction with the user, tenant or operator. This definition process is refined iteratively by assessing the quality of the module against the criteria of Cohesion and Coupling. This model provides a contribution to the design of modules with the inclusion of socio-technical constraints during the project. While the socio-technical dimension commonly exists in determining the nature of the product ("what" is to be produced), it is less common to apply constraints on how the production process is carried out ("when-where"). This paper explores how socio-technical constraints influence product and process modularity in refurbishment projects.

Background

Platform thinking and the definition of modules

Platform thinking is "the process of identifying and exploiting the shared logic and structure in a firm's activities" (Sawhney 1998: 1), essentially the design process of the platform, defining the form of modularity employed firstly through design of the module itself and the interfaces between the modules (Meyer and Lehnerd, 1997). The design of modules requires an understanding of the critical constraints in production, but also the degree of standardisation versus customisation required from the output (Schmidt and Foss, 2023) and a decision as to which core elements will remain consistent and which peripheral elements may be variable (Gawer, 2014).

This core-periphery model enables the creation of 'economies of repetition', which can include repetition of components, processes, knowledge, and organisational structures (Davies and Brady 2000: 931). In this way, product platforms enable "highly differentiated products to be delivered to the market without consuming excessive resources" (Robertson and Ulrich 1998: 20). While the use of product platforms was "more or less unknown in the project-based construction industry" (Thuesen and Hvam 2011: 340), there has been a significant increase in research in this area throughout the past decade, particularly connected to industrialised construction (Larsson *et al.,* 2014; Pikas *et al.,* 2021).

Quality of modularity - Cohesion and Coupling

The concepts of Cohesion and Coupling, originally developed in software engineering, are applied in the assessment of quality of modularity in software development (Stevens *et al.,* 1974). Cohesion describes a close logical relationship between the components of the module, where the logical internal composition gives the benefit of the ability to transpose the module as a unit, giving flexibility and adaptability. Coupling describes the strength of relationship between the modules, whereby a weak relationship (or loose coupling) results in an improved flexibility and ability to transpose the modules in the overall structure, whereas a strong relationship (or tight coupling) results in reduced ability to change the structure of the modules and the increased dependence between modules means that a change in one module is likely to impact other modules, increasing the complexity of the overall system. Therefore, a highly flexible and adaptable modular system is characterised by high Cohesion and low (or loose) Coupling. Sub-categories for Cohesion and Coupling are summarised in Stevens *et al. (*1974), although some translation is required from the software context to the physical construction context.

Refurbishment

While the terms are often applied interchangeably, this paper applies the term 'refurbishment' generally to cover 'renovation' or 'renewal', which is the process of returning to a current standard of quality, and 'retrofitting', which is the process of fitting a new functionality that was not originally present at the time of creation. Refurbishment projects are often characterised by high uncertainty, variable and labour-intensive production systems (Neve *et al.,* 2022; Kemmer 2018; Sahlberg, Lehtovaara and Seppänen 2021). Consequently, refurbishment projects result in various types of waste, including rework, onsite disruptions and waiting time, additionally affecting schedules, costs and productivity negatively (Neve *et al.,* 2022). The main differences between refurbishment compared to building new are firstly specialised skills, such as selective demolition, knowledge about hazardous materials, preservation and conservation, and structural changes (Kemmer 2018). Secondly, refurbishment typically involves great uncertainty due to lack of information transparency on the condition of the asset including as-built information, potentially leading to changes, rework or design iterations throughout the refurbishment process. Finally, there are typically constraints on the time and location or work: refurbishment activities often need to negotiate access with tenants or operators to perform work at a certain time and location (Ho and Fischer 2009). Therefore, there is a combination of specialised skills represented by variability in different types of work and specialised disciplines, uncertainty in the condition of the physical asset and rigid constraints which dictate how the asset can be accessed.

METHOD

The renewal programme was chosen as a representative case that was large and repetitive enough to justify the design of a modular platform structure in the context of refurbishment. While rail is a context with specific characteristics (Chapman, 2016), it has been chosen as it is considered representative of a large scale and long duration refurbishment programme. The project documents were analysed using the Design Structure Matrix method to understand the internal dependencies in the project process that set the constraints for the form of modularity. The validity of interpretation was confirmed through triangulation (Miles *et al.,* 2020: 293) by presentation and discussion of the results with relevant members of the organisation.

Empirical Context

To acquire insights into large scale refurbishment, this paper takes a national railway infrastructure renewal programme as a case study. This programme is 'semi-permanent' in nature with a rolling planning horizon which comprises multiple concurrent projects under development and execution. The programme is subject of an ongoing standardisation initiative in the organisation which seeks to leverage similarities between the renewal projects, which contain similar types of activities, such as replacement of railway components such as sleepers and the introduction of new functionality, such as electrification and new signalling systems (and should therefore be referred to as a 'refurbishment' programme according to the definition above, but the paper retains 'renewal' as translated). However, the projects face considerable variability in the volume of each type of activity required in each location, the site conditions, and the parties involved in each project, since each project is procured separately.

Data Collection and Analysis Process

The study uses empirical data collected through review of project documents, which were analysed and the findings validated with relevant actors in the organisation. Project data was collected from six renewal projects executed or planned for execution between 2022 and 2026, with one project analysed in detail using Design Structure Matrix (Browning 2001; Eppinger and Browning 2012). The project data includes the process for project development and design which is applied to all projects, the project construction plans, design plans and drawings, specifications and quantities.



Figure 1: Analysis process

The project documents were firstly analysed using the Design Structure Matrix (DSM) method to assess for internal dependencies between related activities and the potential for process modularity (Eppinger and Browning 2012). The first DSM was constructed from listing each of the 703 activities in the standardised project development process and the 1087 activities in the construction plan on the vertical and horizontal axes creating a 1790x1790 matrix (see Figure 2). Activity outputs are assigned to columns and inputs are assigned to rows, meaning that an output from an earlier to a later activity is marked in the lower left half (below the diagonal), and an output from a later to an earlier activity will be marked in the upper left half (above the diagonal) (Browning 2001). The first DSM analysis led to the proposal of "track

possessions" as an important constraint in the definition of modules. The proposed modules were then analysed against the concepts of Cohesion and Coupling using a project Time-Location plan to assess the quality of the modularity (Stevens *et al.,* 1974). Finally, following an interview with members of the owner organisation, the Team Lead for Construction Planning was asked to fill out another DSM which describes the dependencies between different types of activities (see Figure 4). The notation large 'X' meaning "always before" and large 'Y' meaning "always after", the small 'x' and 'y' mean "usually before" and "usually after" respectively, and '---' means "no relationship". This notation was applied to introduce the possibility for strong, weak and absent sequential relationships.

FINDINGS

Step 1: Analysis of project development and construction processes using DSM

The DSM analysis of the project development and construction process demonstrated firstly a strong interdependence between the development of the design and iterative collection of physical information about the site, secondly an iterative approval of the project development through verification of interfaces with adjacent projects and traffic planning, thirdly a clear boundary in the activities of the technical disciplines in the track "possessions", which define the time and location that the track is closed to operation so that activities may be performed.

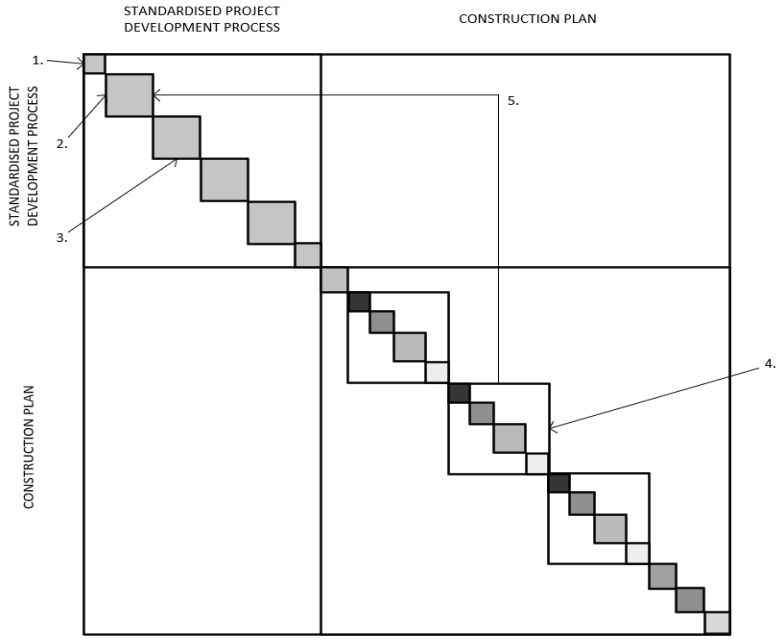


Figure 2: Schematic representation of Design Structure Matrix (DSM) analysis of the combined development and construction processes (full analysis printed on 2x A0 pages)

The following observations are labelled on Figure 2:

1. Preliminary step of collecting all available data regarding the project site, specification of the necessary additional surveys and investigations including ballast borings (to determine condition of ballast)
2. In the next phase, the site information including geotechnical investigations are incorporated into design. A virtual and physical site walk through is performed to reduce uncertainty about the condition of the site. An initial check is made to confirm interfaces between each discipline and confirmation of sufficient space on site.

3. As the project develops, there is iterative confirmation with traffic planning of the time available, interfaces with adjacent projects, rail safety, land ownership and adjacent property, access routes at the end of each stage to be approved before moving to next design stage.
4. Track possessions contain similar disciplines, but different volumes of each activity in each area. Total length of the possession is defined by the duration of the longest activity (plus buffer) in negotiation with traffic planning for the time available for track possession.
5. Potential iterative loops where the construction conditions do not match those assumed during design can cause rework and delay (examples could be unexpected soil conditions, or activities taking longer than expected).

Although the project is not intentionally organised in modules, the DSM analysis demonstrates that the modules could potentially be defined by the time and location of the track possessions (also called "stages"), due to the clear temporal and physical boundaries created by the possessions. Having defined potential modularity according to the track possessions, the proposed modules were reviewed with members of the construction planning department in the organisation and the quality of modularity was assessed according to the principles of Cohesion and Coupling.

Step 2: Analysis of time-location plan for Coupling

An analysis was made of the time-location (TILOS) plan to understand the constraints which define the relative placement of the modules and the relationship between the modules, which defines the degree of Coupling. The analysis should also give an understanding of whether there is Cohesion within the modules, or whether the modules are coincidental or temporal, and thereby only defined by the coexistence in time and location.

Figure 3 presents a schematic representation of the layout of track possessions and location from a real project, with stations labelled A-D on the x-axis and time on the y-axis from approximately February to September. The project starts with a series of night closures spread over several weeks and labelled “Stage 0”. Stages 1, 4 and 9 are total (both track) closures which coincide with Easter, Ascension and Summer holidays respectively. Stages 2, 3 and 5 are single track (“LS” Left Side) closures and Stages 6, 7, 8 and 10 and single track (“RS” Right Side) closures. It is worth noting variability due firstly to the timing of the closures, since the total closures are timed to coincide with major holiday periods, and secondly due to the requirement that some activities (such as bridge works) need to be performed during a total closure, whereas others can be performed during a single-track closure (with reduced speed of operation in the adjacent track).

Finally, some activities may not complete during one Stage, requiring multiple Stages to complete the activity. Figure 3 demonstrates the necessary variability in timing and location of the modules, due to the objective of minimising disturbance to operation through timing of the possessions.

Examples from other contexts, where it is possible to make a total closure for the full duration of the project clearly dramatically changes the constraints in construction planning. Considering the different types of possession, there are roughly three different types; nights, total closure and single closure, where there are activities which are more suited to certain possessions. However, the types of activity do not determine the arrangement of the possessions, apart from Preparatory Work, which must be placed first.

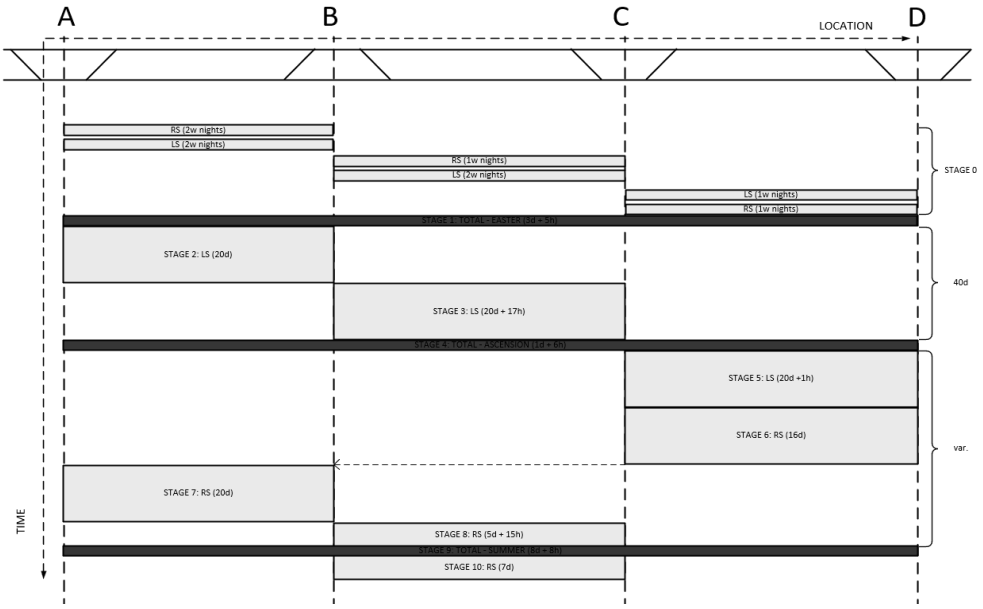


Figure 3: Schematic representation of the layout of track possessions on a single project spread out between four stations

When considering Coupling between the modules, it is possible to see that there is a significant transfer of materials, equipment and people from one stage to the next. This may be the most significant factor determining the relative placement of the modules, other than the rules that govern the time and location of track possessions negotiated with traffic planning and train operators.

Step 3: Analysis of activities within module for Cohesion

Next, the activities within each of the modules were studied. This analysis found that there was relatively high repetition of the types of activity in each module, but with variability in the volume and location of each activity. To understand the degree of Cohesion between the activities, the types of activity were put into a Design Structure Matrix format (see Figure 4) and members of the owner organisation were asked to describe the typical sequential relationship between the activities.

	PREPARATORY WORK	EARTHWORKS	DRAINAGE	TRACK_MANUAL	TRACK_MACHINE	ELECTRICAL (CATENARY)	ELECTRICAL (HIGH VOLTAGE)	BRIDGES AND STRUCTURES	SIGNALS
PREPARATORY WORK		X	X	X	X	X	X	X	X
EARTHWORKS	Y		x	x	x	X	X	---	X
DRAINAGE	Y	y		x	X	x	X	---	X
TRACK_MANUAL	Y	y	y		x	x	X	---	X
TRACK_MACHINE	Y	y	Y	y		x	x	---	X
ELECTRICAL (CATENARY)	Y	Y	y	y	y		x	---	X
ELECTRICAL (HIGH VOLTAGE)	Y	Y	Y	Y	Y	y		---	X
BRIDGES AND STRUCTURES	Y	---	--- -	---	---	---	---		X
SIGNALS	Y	Y	Y	Y	Y	Y	Y	Y	

Figure 4: Dependency between different activities within a track possession "module"

This analysis shows that the sequential and functional cohesion is high since all the activities relate to the renewal of a particular stretch of railway and there is a relatively

clear ideal sequence for the execution of the activities. However, it is also possible to see that some activities have a clear distinction from the others. Almost by definition, the Preparatory Works need to be performed in advance of all other activities. Further, the Signal works typically need to be performed after all the other activities, due to sensitivity of signalling systems to changes in the track infrastructure. The Bridges and Structures work only has a relationship to the Preparatory and Signalling works, raising an interesting question of the cohesive 'fit' between this and the other activities in the module.

DISCUSSION

Returning to the research question, the objective of the paper is to determine an approach to the definition of modularity in refurbishment programmes. While the focus of the analysis is at the project level, it is worth noting that the scale and repetition within and between projects must be significant enough to justify the effort of creating a modular platform architecture. Therefore, the form of modularity proposed must be valid for a series of similar, albeit variable, projects. The findings present how projects are currently shaped firstly by the types of activities deemed necessary for the renewal and secondly by the track possession agreed with the rail service operators to perform the work. The current approach to forming projects therefore is to match the activities to the available duration of track possession. However as observed in the sample of projects, because of the variability in types and volumes of activities and the timing of track possessions, the construction plans for the renewal projects are consequently very different. The analysis presented a boundary defined by the time and location of the track possessions, which supports defining the possessions as the primary form of module. This proposed form of modularity was analysed against the concepts of Cohesion and Coupling (Stevens *et al.,* 1974), which found a relatively high functional and sequential cohesion within the modules but also identified some activities within the modules which were relatively independent, with low cohesion with the other activities. The analysis of Coupling found a significant connection in the form of the movement of equipment and people between modules. While this transfer of equipment, materials and people between modules is necessary, it can be simplified by arranging the modules to reduce as far as possible the amount of movement. The proposed form of modularity could be further improved by critically assessing the types of activities which are placed together in the same possession (thereby improving cohesion), and by considering continuity between adjacent possessions (thereby improving coupling). A modular approach marks a distinctly different approach to that traditionally used to form projects. Whereas the traditional approach seeks a high utilisation in terms of the volume of activities planned within the available time, the modular approach seeks to increase the cohesion between activities within modules and create either a loose coupling, or at least a smooth transition between modules. The optimisation lost in the traditional approach is thereby regained through improved efficiency of execution of modules.

Theoretical Implications

Refurbishment concerns the transformation from an existing state into desired future state, therefore it is important to understand the constraints that are associated with the existing state, which may be physical uncertainties, lack of documentation and other historical factors (such as unknown soil conditions and utilities, hazardous materials, temporal movement such as creep/settlement), or socio-technical constraints (such as negotiated agreements on the time, duration and location of track possessions). The

project analysis demonstrates that these complex constraints determine the form of modularity that is achievable in the context. The modules are defined iteratively by the product and process (what) and the socio-technical dimension (when-where) through interaction with the physical asset and through negotiation with the existing owner, tenant or operator.

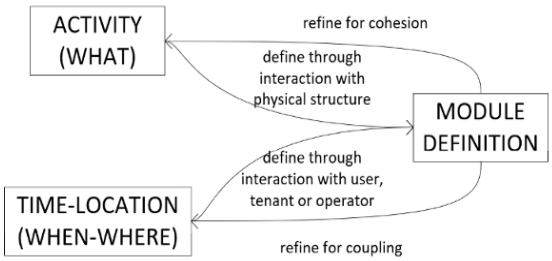


Figure 5: Process of module development

Figure 5 shows the iterative process of module definition, which takes input from physical interaction with the asset and socio-technical interaction with the asset users, but also how the module is refined bearing in mind the degree of cohesion and coupling. Crucially, by balancing the activity with time-location and refining the degree of Cohesion, it is possible to challenge the composition of the project, whether in the activities or in the constraints that define the time and location.

CONCLUSION

This paper studies the definition of modularity in the context of a major refurbishment programme in the product, process, and socio-technical dimensions using the Design Structure Matrix method. The findings show firstly the iterative definition of the extent of the activity through interaction with the physical asset, and secondly the negotiation of the time and location of the activity with the existing users, tenants or operators. In the focal case, this paper posits a form of modularity delimited by the spatial and temporal boundary of the track possessions. Further the paper recommends that the structure of the modularity is progressively refined to improve the functional cohesion within the module, which is mostly related to the composition of different activities, and the coupling which is primarily the physical transfer of materials, equipment and people between modules. An important limitation of this finding is that the "rules" determining the time and location of work activities can vary depending on the context, from the relatively rigid rules presented in the analysis, to other contexts, where the constraints may be quite different.

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LAW

A LEGAL SCOPING REVIEW OF UK LAW GOVERNING GREEN BUILDING

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Green building presents distinct legal challenges as sustainability objectives are embedded within construction law, regulatory frameworks, and planning regimes. This paper maps the current legal landscape governing green building in the UK through a doctrinal scoping review of statutes, judicial decisions, and regulatory initiatives. Targeted legal searches were conducted using Westlaw UK, LexisLibrary, and UK government repositories, focusing on laws and cases directly influencing sustainable construction practices. The analysis reveals three key findings: first, legal obligations for energy efficiency and operational carbon are well established, but statutory mandates for embodied carbon assessment remain absent; second, significant jurisdictional divergence exists between devolved administrations, creating complexity for cross-border compliance; and third, recent case law, including R (Finch) v Surrey County Council, demonstrates a judicial shift toward enforcing climate accountability through planning law. The paper highlights the emerging trend toward lifecycle-based carbon regulation and calls for harmonisation of sustainability standards across the UK. Future research could assess how legal fragmentation impacts enforcement outcomes and the effectiveness of climate-aligned construction law.

Keywords: green building law; sustainability governance; UK construction law; legal frameworks

INTRODUCTION

For the purposes of this review, green building (GB) encompasses the use of environmentally sustainable materials, technologies, and construction methods to minimise carbon emissions across a building's lifecycle. As legal and regulatory frameworks evolve to align with national and international climate objectives, the construction industry faces new compliance challenges, particularly in relation to contractual obligations, planning requirements, and sustainability standards (Mohammadi, 2016; Darabpour *et al.,* 2022).

The increasing integration of sustainability commitments into construction law has led to more stringent regulatory requirements, particularly as the UK strengthens its climate policies (Gibbs and O'Neill, 2014). The Climate Change Act 2008 and the Building Regulations 2010 (as amended) establish legal obligations concerning energy efficiency, carbon reduction, and environmental performance. However, green building law introduces unique legal risks, diverging significantly from traditional construction regulation (Guan *et al.,* 2019; Shi *et al.,* 2015). These risks include

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Dickson, D (2025) A Legal Scoping Review of UK Law Governing Green Building, *In*: Thomson, C and Neilson, C J (Eds) Proceedings of the 41st Annual ARCOM Conference, 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 535-544.

uncertainties in statutory interpretation, increased potential for contractual disputes, and heightened liability exposure for non-compliance (Yaman, 2022). Understanding these challenges is therefore essential to ensuring regulatory adherence, managing risk, and supporting the delivery of sustainable construction outcomes.

This paper presents a legal scoping review of the UK frameworks governing green building, focusing on both statutory developments and judicial decisions. The review maps key legislation, regulatory instruments, and case law that define the legal obligations surrounding sustainable construction across the UK's devolved jurisdictions. In doing so, it addresses the complexity of current legal provisions, highlights gaps, particularly around embodied carbon regulation, and contributes to a clearer understanding of how legal mechanisms are evolving to support net-zero targets in the built environment.

METHOD

The review employs a doctrinal scoping review methodology, which systematically identifies, categorises, and synthesizes primary legal sources relevant to green building in the UK. This method is appropriate for interrogating legislative developments, judicial reasoning, and regulatory interpretations across jurisdictions (Hutchinson and Duncan, 2012; Aryal, 2024). The purpose of the scoping review is to map the evolving legal landscape and assess how statutory and judicial instruments address sustainability in construction.

Review Questions

The review was guided by the following questions:

RQ1: What statutory laws and policies currently govern sustainable construction practices in the UK?

RQ2: How have UK courts interpreted and expanded legal obligations relating to green building and environmental performance?

Transparency and Replicability:

A full list of statutes and cases reviewed is available in the supplementary table (Table 1). The review protocol adhered to academic standards for legal doctrinal research and transparent evidence mapping, enabling replication and extension in future comparative studies.

Databases Used

The research was conducted using three legal research databases:

6. Westlaw UK: selected for its comprehensive database of UK case law, statutes, and legal commentaries. Westlaw's tools, such as KeyCite, were used to validate case law and trace judicial interpretations.
7. LexisLibrary UK: Chosen for its extensive collection of legal precedents, statutory law, and Halsbury's Law of England, providing a broader perspective on UK legal principles and commentary.
8. Big Data for Law (UK Legislation repository)

These databases provide authoritative access to primary legal sources and secondary literature, making essential tools for examining the regulatory framework governing green building.

Search Strategy

A targeted search strategy was implemented, combining general keyword queries with precise legal database searches. This was supported by cross-referencing UK Parliamentary repositories (legislation.gov.uk) to verify the inclusion of both widely recognised statutes and lesser-known regulations critical to green building governance. Searches combined Boolean operators and legal terminology across statutes, case law, and secondary sources using the following keywords: "green building", "sustainability", "carbon regulation", "building regulations", "embodied carbon", "emissions", "planning law", "environmental impact assessment"

Inclusion Criteria

UK jurisdiction (including devolved administrations)

Statutory law, regulations, or case law directly affecting construction sustainability

Published post-2000, with particular focus on developments from 2010 onwards

Exclusion Criteria

Generic environmental law unrelated to construction

International treaties not incorporated into UK law

Policy papers or non-binding guidance unless cited in judgments

Statutory Framework for Green Building Governance in the UK

This section responds to RQ1 by identifying the key statutory frameworks that define legal obligations for green building across the UK's devolved jurisdictions. It highlights national and regional laws governing carbon emissions, building safety, and sustainability standards.

The statutory law governing green building in the UK is fragmented across different devolved administrations, leading to variations in planning regulations, enforcement mechanisms, and sustainability targets (McManus, 2021). While primary legislation, such as the Climate Change Act 2008, establishes binding carbon reduction commitments, the implementation of sustainability policies varies between England, Scotland, Wales, and Northern Ireland (Moore and Moore, 2024). Moore and Moore (2024) is cited selectively to provide cross-jurisdictional legal commentary, used in conjunction with statutory and case law sources to highlight enforcement divergence. This review identifies the statutory basis for building regulations, planning law, climate obligations and environmental governance. It also highlights key legal precedents and regulatory divergences across the devolved nations, particularly in relation to the emerging legislative shift towards whole-life carbon assessment requirements for embodied carbon in England and Wales (Foster and Green, 2019).

England and Wales: The Building Act 1984, Building Regulations 2010, and Proposed Carbon Assessment Legislation

The Building Act 1984 serves as the primary statute governing building regulations in England and Wales, empowering the Secretary of State to introduce secondary regulations that establish technical standards for construction (Dworkin *et al.,* 2022). The Building Regulations 2010 (as amended) provide statutory requirements for sustainable construction, including, structural integrity, fire safety, ventilation, and energy efficiency.

Recent amendments to this framework illustrate the evolving nature of building regulations, particularly in relation to safety and sustainability:

- The Building Safety Act 2022 (BSA 2022) introduced enhanced regulatory oversight for high-risk buildings, following post-Grenfell reforms (Moore and Moore, 2024).
- The extension of the limitation period for defective premises claims from 6 year to 30 years, under Section 135 of the BSA 2022, was judicially affirmed in BDW Trading Ltd v Ardmore Construction Ltd[2].

Currently, Part L of the Building Regulations focuses only on operational carbon, ignoring emissions from material extraction, transportation, and construction processes (UKGBC, 2025). Therefore, a critical legislative gap remains in the mandatory assessment of embodied carbon emissions in construction (UKGBC, 2025).

The Carbon Emissions (Buildings) Bill

The Carbon Emissions (Buildings) Bill, currently at the Second reading stage in Parliament, due to take place Friday 11th July 2025 (UK Parliament) proposes mandatory whole-life carbon assessments for embodied carbon in new developments in England and Wales that meet the criteria. The Bill seeks to:

- Amend the Building Act 1984 to require whole life carbon assessments at the planning and construction stage
- Introduce a statutory carbon reporting framework, aligning with BS EN 15978 standards on whole life carbon calculation
- Enable local authorities to impose carbon performance conditions as part of planning consents (House of Commons, 2023).

If enacted, this legislation would mark a significant shift towards lifecycle sustainability regulation, addressing longstanding criticisms of the narrow scope of current energy efficiency standards (Foster and Green, 2019), and provide a statutory foundation for lifecycle-based regulation, responding to sustainability concerns identified in RQ1.

Scotland: The Building (Scotland) Act 2003 and the Scottish Technical Standards

Scotland's building regulations framework is governed by the Building (Scotland) Act 2003, which mandates compliance with the Scottish Building Standards Regulations. Unlike England and Wales, Scotland enforces:

- Stricter energy efficiency requirements, aligning with its net-zero target by 2045 (Climate Change (Scotland) Act 2009).
- Tiered sustainability standards under Section 7, allowing local authorities to enforce higher performance thresholds beyond minimum statutory requirements (McCarthy, 2020).

Spence (2023) notes how the Building (Scotland) Amendment Regulations 2022 introduced significant changes to the Building (Scotland) Act 2003, primarily to enhance fire safety following the Grenfell Tower fire. Key amendments such as material bans, technical standards, operational changes and liability periods are all like the Building Safety Act 2022 but are based on the Scottish construction practices and building types (Kelly, 2022).

[2] [2024] EWHC 3235 (TCC)

Northern Ireland and Wales: Comparative Enforcement Challenges

Northern Ireland's Building Regulations (Northern Ireland) 2012 closely resemble those in England and Wales but suffer from weaker enforcement due to the absence of an Approved Inspector system, leaving compliance solely to local councils (Moore and Moore, 2024). The legal disparity between Northern Ireland and England and Wales concerning building safety and limitation periods for defective premises claims, focussing on the case of Ulster Garden Villages Ltd v Farrans (Construction) Ltd[3] that highlights the differences.

Wales has devolved building control powers but largely follows English standards (Moore and Moore, 2024), with notable exceptions in carbon reduction target set by the Environment (Wales) Act 2016.

Climate Change Law and Environmental Planning

The Climate Change Act 2008 was hailed a groundbreaking legislative milestone by Fankhauser (2013) and remains the most significant piece of climate legislation in the UK, establishing legally binding net-zero commitments by 2050. This was highlighted in the case of R (on the application of Friends of the Earth Ltd and Others) v Heathrow Airport Ltd[4], where the Supreme Court ruled that the UK's commitments under the Climate Change Act 2008 take precedence, over the Paris Agreement (In UK case law, "R" stands for Regina or Rex, denoting a case brought by the Crown, typically in the context of judicial review). White and Case LLP (2021) discuss the case and inform that government policies and planning decisions must align with UK climate law rather than relying on non-incorporated international treaties.

The Town and Planning Act 1990 remains the primary governing land-use regulation in England and Wales. However, judicial interpretation has expanded its sustainability remit:

- In R (Finch on behalf of the Weald Action Group) v Surrey County Council and Others[5], the Supreme Court ruled that Scope 3 emissions must be assessed in Environmental Impact Assessments (EIAs), reinforcing carbon accountability in planning decisions (McCarthy, 2024).

These cases illustrate a growing judicial tendency to enforce climate-conscious interpretations of planning law, even in the absence of explicit statutory mandates.

Judicial Decisions Shaping Green Building Governance

This section addresses RQ2 by examining how judicial decisions have expanded or clarified legal obligations related to green building, particularly in planning, contract, and real estate law.

The legal basis surrounding green building governance is continuously shaped by judicial decisions that interpret and refine regulatory obligations, contractual responsibilities, and environmental compliance standards (Fisher, Lange, and Scotford, 2019). This section summarises key cases that have influenced the governance of sustainability in construction, planning, and real estate, offering insights into the evolving relationship between environmental objectives and legal accountability. The cases discussed establish critical principles on the enforceability of sustainability commitments, the role of environmental impact assessments (EIAs),

[3] [2024] NIKB 15
[4] [2020] UKSC 52
[5] [2024] UKSC 20

the implications of green building standards in contractual disputes, and the growing significance of green leases.

Environmental Impact Assessments and Climate Commitments

EIAs are crucial tools for evaluating the sustainability of development projects (Glasson, J. Therivel, R. and Chadwick, A. 2019). Recent case law highlights their expanding scope, particularly regarding the inclusion of greenhouse gas (GHG) emissions and cumulative environmental impacts.

In R (on the application of Finch on behalf of the Weald Action Group) v Surrey County Council and Others, the Supreme Court ruled that planning authorities must consider downstream (Scope 3) emissions in EIAs when these emissions are a foreseeable consequence of the project. The judgement reinforced that EIAs are procedural mechanisms to ensure informed decision-making and public participation, rather than merely tools for mitigation. This ruling establishes that emissions generated beyond the immediate site of a project must be factored into environmental assessments, a principle with potential implications for other high-emission industries such as transport and manufacturing.

Similarly, in R (on the application of Spurrier and Others) v Secretary of State for Transport[6], the court examined whether the EIA for Heathrow Airport expansion adequately assessed cumulative carbon emissions. While the claim was dismissed, the ruling emphasized that EIAs must account for cumulative environmental effects, though the level of detail required remains within the discretion of decision-makers.

The intersection of international climate agreements and domestic planning law was explored in R (on the application of Friends of the Earth Ltd and Others) v Heathrow Airport Ltd. Here, the Supreme Court clarified that the Paris Agreement does not automatically impose binding legal obligations under UK law unless explicitly incorporated into domestic legislation. However, the court acknowledged that broader sustainability commitments remain relevant within the existing legal framework, reinforcing the idea that climate considerations are increasingly influencing planning decisions.

Sustainability in Contractual and Commercial Disputes

As sustainability targets become embedded in contractual agreements, disputes over green building performance, energy efficiency, and environmental standards are becoming more prevalent (Haggett, and Smith, 2020). Courts have upheld the enforceability of sustainability commitments, particularly where these are clearly defined within contracts.

In MT Højgaard A/S v E.ON Climate and Renewables UK Robin Rigg East Ltd[7], the Supreme Court ruled that a contractor must meet specified performance guarantees, even if the work complies with general industry standards. While this case did not directly involve sustainable materials, it has significant implications for their use in construction. Contractors utilising innovative green technologies must ensure they meet contractual performance criteria, reinforcing the legal expectation that sustainability objectives should not compromise functionality or durability.

[6] [2019] EWHC 1070 (Admin)
[7] [2017] UKSC 59

Enforceability of Green Leases and Sustainability Certifications

Green Lease contracts that impose sustainability obligations on landlords and tenants, are becoming an essential tool for promoting environmental responsibility in commercial real estate. Courts have increasingly upheld their enforceability, demonstrating that sustainability clauses are binding obligations rather than aspirational commitments. A dispute arose in Canary Wharf (BP4) T1 Ltd v European Medicines Agency[8], where the court held that a landlord's failure to maintain BREEAM certification breached the lease agreement. However, instead of termination, the tenant was awarded damages. These ruling highlights that while sustainability clauses are enforceable, remedies for breaches may vary depending on the circumstances. Beyond leasing, sustainability certification obligations have also been upheld in construction contracts to achieve sustainability certification. In Saint-Gobain Building Distribution Ltd v Hillmead Joinery (Swindon) Ltd[9], the court ruled that supplying non-compliant timber breached contractual warranties, preventing the project from achieving its required sustainability certification. This case demonstrates that sustainability certifications such as BREEAM are more than aspirational goals, they are binding contractual obligations with significant legal and financial implications.

Local Planning Policies and Environmental Performance Standards

Judicial decisions have also reinforced the importance of aligning national planning approvals with local sustainability policies.

FINDINGS

The statutory landscape for green building is fragmented across the UK, as summarised in Table 1 which provides an overview of statutory laws regulating green building across the UK and highlights key legislative instruments and their relevance to sustainable construction, carbon reduction, and environmental governance.

Table 1: Key Statutory Law Governing Green Building in the UK

Legislation	Jurisdiction	Key Provisions	Relevance to GB
Climate Change Act 2008	UK-Wide	Establishes legally binding net-zero target by 2050; sets carbon budgets	Provides overarching statutory framework for sustainability and emissions reduction
Building Act 1984	England and Wales	Primary legislation governing building regulations; enables secondary regulations (e.g., Building Regulations 2010)	Regulates construction standards, including sustainability provisions (e.g., energy efficiency under Part L)
Building Regulations 2010 (as amended)	England and Wales	Establishes technical standards for energy efficiency, ventilation, and sustainable materials	Directly regulates green building design, operational carbon reduction, and construction methods
Carbon Emissions (Buildings) Bill (Proposed)	England and Wales (pending)	Proposes mandatory whole-life carbon assessments and statutory carbon reporting	Would mark a significant shift towards lifecycle carbon regulation in construction
Building (Scotland) Act 2009	Scotland	Governs building standards through the Scottish Technical Standards	Enforces stricter energy efficiency requirements and higher sustainability benchmarks
Climate Change (Scotland) Act 2009	Scotland	Sets net-zero target for 2045 (five years ahead of UK-wide target)	Drives higher green building and energy efficiency requirements
Environment (Wales) Act 2016	Wales	Establishes carbon budgeting and biodiversity net gain (BNG) requirements	Integrates sustainability into planning and development policies
Building Regulations (Northern Ireland) 2012	Northern Ireland	Like England and Wales but without Approved Inspector system	Enforces energy efficiency standards but faces enforcement challenges
Climate Change Act (Northern Ireland) 2022	Northern Ireland	Establishes net-zero target for 2050 with sectoral considerations	Aligns Northern Ireland with UK climate law but allows flexibility for high-emission industries (e.g., agriculture)

[8] [2019] EWHC 335 (Ch)
[9] [2015] EWHC 1924 (TCC)

The table illustrates several critical themes, including regulatory fragmentation, emerging legislative trends, and the growing role of carbon reporting in construction law.

CONCLUSION

This paper has demonstrated that green building law in the UK is a rapidly evolving area of construction and environmental law, shaped by statutory developments, judicial interpretation, and contractual obligations. As the UK strives to meet its net-zero commitments under the Climate Change Act 2008, the legal landscape governing sustainable construction has become increasingly complex, with heightened regulatory requirements, growing contractual risks, and evolving case law clarifications (Fankhauser, 2013; McCarthy, 2024). It has answered RQ1 by identifying the key statutory laws that currently govern sustainable construction across the UK's devolved jurisdictions.

A key finding is that statutory law provides a fragmented yet developing regulatory structure for green building (Moore and Moore, 2024). While primary legislation such as the Building Act 1984 and the Building Regulations 2010 establish baseline construction standards in England and Wales, regulatory approaches vary across the devolved thresholds, including tiered energy efficiency standards (McCarthy, 2020), whereas Northern Ireland's regulatory framework faces enforcement challenges due to the absence of an Approved Inspector system (Moore and Moore, 2024). This divergence creates legal uncertainty, particularly for developers and contractors operating across multiple jurisdictions (Kelly, 2022; Moore and Moore, 2024).

The absence of mandatory whole-life embodied carbon assessments in current UK building regulations represents a critical legislative gap (UKGBC, 2025). Currently, Part L of the Building Regulations only addresses operational carbon, neglecting emissions from material extraction, transportation, and construction processes (UKGBC, 2025). The Carbon Emissions (Buildings) Bill, currently under parliamentary review, seeks to address this issue by introducing statutory carbon reporting obligations and requiring whole-life carbon assessments for new developments of certain criteria (House of Commons, 2023). If enacted, this legislation would mark a major shift in the UK's sustainability regulation, potentially aligning construction law with broader climate targets, if adopted by all devolved governments.

Beyond statutory law, judicial decisions play a vital role in shaping the legal obligations surrounding green building. Courts have expanded the interpretation of sustainability obligations, particularly in planning and environmental impact assessments. The Supreme Court's ruling in R (Finch) v Surrey County Council has expanded the scope of EIAs by confirming that Scope 3 emissions must be accounted for in planning approvals (McCarthy, 2024). Similarly, R (Friends of the Earth Ltd) v Heathrow Airport Ltd reaffirmed that UK climate law takes precedence over non-incorporated international agreements such as the Paris Agreement, ensuring that government planning decisions align with domestic legal commitments (White and Case LLP, 2021). In response to RQ2, the review examined how UK courts have interpreted and extended legal obligations through recent case law.

This review has highlighted that UK green building law remains fragmented, with regional disparities in enforcement, compliance, and sustainability targets (Moore and

Moore, 2024). The ongoing evolution of statutory frameworks and judicial interpretations indicates a trend towards greater legal accountability for environmental performance in construction. Future research could further analyse the effectiveness of these regulations across the UK, comparing enforcement mechanisms and sustainability outcomes to identify the most robust legal approaches for ensuring compliance and reducing carbon emissions in the built environment.

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OFFSITE CONSTRUCTION

INDUSTRIAL HOUSING AS EUROPEAN CRISIS RESPONSE

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The EU has understood that the crisis of affordable housing needs to be addressed by a pan-EU policy on affordable sustainable housing. The European Economic and Social Committee and a new commissioner for housing are two salient initiatives. The policy reads "measures to reduce building costs, increase skills of the labour force, raise productivity and environmental performance...." (the EU-commissions mandate). So industrial production of low-cost housing should receive renewed interest. Sweden encompasses a considerable volume of newly built affordable sustainable wooden modular housing. But can this industrial complex be exported? The contribution adopts a technological innovation system approach to an industrial complex. Here the Swedish modular housing industry, its manufacturing companies and the finance. A feasibility study of expanding Swedish production to Denmark is used as empirical material. The result of the desk study show, that while technologies are available, the financial backbone is not. The Swedish housing industry is in a dire crisis, even if a temporary issue, whereas the need for local production throughout Europe is prevailing and should be supported with public measures to be feasible.

Keywords: industrialisation; housing; Sweden; technology innovation system

INTRODUCTION

The EU have appointed a commissioner for affordable housing and made important policy suggestions asking for "measures to reduce building costs, increase skills of the labour force, raise productivity and environmental performance of construction" (the EU-commissions mandate 2024).

On this background industrial production methods for low-cost housing should receive renewed interest. One of the countries with the most volume in affordable sustainable housing is Sweden. But can the industrial complex behind the extensive production of modular wooden houses be exported to other countries? And what conditions need to be in place? Also mainly ruling out that transporting the finished modules from Swedish factories to the rest of Europe would be an option as it hardly complies with climate concerns.

Moreover, an interest in possible import of an (successful) industrial complex is a recurrent thinking model in national and regional innovation policies, making the study of possible transfer relevant for other possible development of the construction sector.

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Modular construction, which is the focus here, is an innovative construction method where the building is manufactured as prefabricated modules in a factory before being transported to the construction site and assembled (therefore also often labelled “off-site construction”, Dowsett *et al.,* 2019, Grenzfurtner and Gronalt 2021, Johnsson and Lennartsson 2012, Meiling 2009). This approach is said to enable faster construction processes, less material consumption and waste, and often higher construction quality, as the elements are produced under controlled conditions. Modular construction is also expected to support sustainability through efficient use of resources and energy.

To answer the research question, the "technological innovation system" (TIS) approach is adopted (Carlsson and Stankiewicz 1991, Jacobsson and Bergek 2011). It is and approach that has been used in technology and innovation policy context since the 1990ties. TIS is often conceptualised as a set of elements, including technologies, actors, networks and institutions, which actively contribute to the development of a particular technology field (e.g., a specific technical knowledge field or a product and its applications). It is thus very directly addressing the issue of possible export of an industrial complex.

The empirical material stem from an extensive desk study of primary material from Swedish manufacturers of prefab housing, with a focus on multistory appartment buildings. Contributions from a series of other actors in the technological innovation system was included. Interviews were carried out with a few selected key players, in an informal fashion.

The contribution is built in a traditional manner: After the introduction has established the main research question, the method section develops the responding research design, including choice of Technological Innovation System as theory and desk research as empirical approach. Then follows the theory, the meso level Technological Innovation System, which seven main dimensions of understanding of an industrial complex. A description of the Swedish modular wooden housing industry is then presented before the analysis scrutinises the TIS aspects of this industry. Finally, the paper reaches the conclusion that responds to the main research question.

METHOD

The research question raised here is asking for a meso to macro scope theory that embraces industrial development of an extended set of companies. It was chosen to mobilise Technological Innovation Systems (TIS) as this is focused on industrial dynamics more than the university role or regulation (as would be the case in triple helix or multilevel perspective (Geels 2011, Köhler *et al.,* 2019). TIS is a very mature conceptual framework used in several studies of meso-level innovation systems, supporting policy development, since Carlsson and Stankiewicz (1991) seminal paper. Proposals for improving the TIS framework has been many, here it has been chosen mostly to involve more structural dimensions such as proposed by Bergek *et al. (*2015).

The analysis made here is drawing on a previous study made in 2023- 2024, thus revisiting the material in an abductive manner (Dubois and Gadde 2002, 2014).

The empirical material stem from an extensive desk study of primary material from Swedish manufacturers of prefab or industrial housing, with a focus on multistory products. This involved 18 manufacturers selected to cover the variety in size, production and products. This can be compared to the members of the respective

industry association for industrial housing, which counts 120 members with more than five employees and totalling around 6000 employees. Material from the national public housing association, other major costumers and university research was also included. Interviews were carried out with a few selected key players, in an informal fashion.

For the analysis a further selection of five major players was done: Boklok, Derome, Lindbäcks bygg, Moelven and Vida Bygg based on their important positioning in the sector. In the first desk research, operations management studies and innovation systems research were the main guiding for search, study and analysis of material. In this second iteration a more direct use of TIS factors were use to extract point from the desk study.

Most of the written material used for the desk study is in Swedish. It has been chosen not to reference this material.

It is a limitation that it is maintained, yet not corrobated that shipment of modular housing elements from Sweden abroad should be ruled out since transporting the finished modules from Swedish factories to the rest of Europe would not be a sustainable option. Moreover, it is a limitation that a narrow focus on the Swedish status is done. Similar industries in other countries were not systematically covered, although foreign owned corporations operating in Sweden were included (such as Moelven and VIDA). Also, a range of international studies on industrial housing has not been used. Some of these are similar studies to this one, but it can be noted that a body of international studies adopt a narrower interpretation of operations management, focusing on the production process, which is deemed less relevant here.

Conceptual Framework

A technological innovation system is defined as "a dynamic network of agents interacting in a specific economic/industrial area under a specific institutional infrastructure and involved in the generation, diffusion, and utilisation of technology" (Carlsson and Stankiewicz 1991:93).

The technological innovation system (TIS) is thus conceptualised as a set of interrelated elements, including technologies, actors, networks and institutions, which actively contribute to the development of a particular technology field (a specific technical knowledge area or a product and its applications) (Bergek *et al.,* 2008c; Markard and Truffer, 2008). The TIS perspective emphasizes systemic interdependencies between these elements, which give rise to synergies, such as collective assets on which the different actors can draw but which they could not produce if they worked in isolation. TIS proposes seven functions crucial for the development of and industry complex (the TIS, Jacobsson and Bergek 2011). These are Entrepreneurial activities, Knowledge development, Knowledge diffusion, Guidance of the direction of search, Market formation, Resource mobilisation and Legitimacy.

This "classical" middle level transition theory features some important limits that need to be conceptualised differently in four distinct manners: First TIS implicitly and explicitly operate with different levels of aggregation. The idea of levels risks producing illusions on separate worlds with different dynamics. Second at the outset the TIS encompassed a relatively high number of recognised dynamics in innovation systems development. Something that can be seen as a necessary response to the complexity of transition. As the theories have matured, more dynamics have been added (Jacobsson and Bergek 2011, Bergek *et al.,* 2015). Third even if (human)

agency and materiality is recognised, it remains unclear what the distinct contribution of agency is. There are also other elements of (human) agency but when it comes to role of materiality TIS assume after all that humans manipulate materiality into technologies and products but disregards that opposite dynamic from hybrid associations of human and non-human elements (Latour 1993). This leads to the fourth limitation, that despite the intention of understanding dynamics in TIS, the framework tend to merely describe various elements in a static descriptive manner. Fifth there is a tendency to view innovation system development as a modification of a linear process and focus on singular change. The question occurs, what happens once the technological innovation system is established? In other terms, TIS theory lack meta cycle concepts.

Bergek *et al. (*2015) propose the adding of geography and politics to the already existing central placing of "technology" and "sector" to corrobate the TIS analysis with a stronger context analysis.

Summarising: Development of a technological innovation system is here understood through the seven functions; entrepreneurial activities, knowledge development, knowledge diffusion, guidance of the search, market formation, resource mobilisation and legitimacy. supplemented with geography and politics.

Empirical Material

The Swedish modular wood industry has undergone significant development. In 2020, a market share of 20% of the housing construction market was reached with more than 100 manufacturers (Steinhardt *et al.,* 2020). Between 1994 and 2015, around 11,000 apartments were built in approximately 190 construction projects in multi-storey wooden buildings in Sweden. During the same period, it is estimated that a maximum of 1,000 apartments were built in neighbouring Denmark, typically in buildings with a maximum of two floors. From 2015-2020, Swedish industrial modular wood production experienced a significant increase in the construction of apartment buildings in wood, while 2021-2025 has been characterised by the housing crisis in Sweden. 1994 is a landmark year for apartment buildings in wood. For more than 100 years, it was forbidden to build apartment buildings with a vertical supporting wooden frame. Until 1994, it was not permitted to build houses with a load-bearing structure of wood of more than two floors. In connection with Sweden's accession to the EU (EC), the regulatory framework was changed throughout Europe. The ban on using wood in buildings higher than two floors was then removed and replaced by functional requirements. All buildings, regardless of construction, must meet the same requirements for function and safety. In 1997, the first Boklok wooden house was ready for occupancy. This had been preceded by four years of development in a collaboration between Skanska and IKEA. In the first years, only two-story houses were built. At the same time, Lindbäcks experimented with building apartment buildings and over three main trials, they came up with building in wood and in a factory.

In 2007, production of NCC's large wooden module initiative "Komplett" began. The building system was well thought out in every way and business development included agreements with several municipalities and NCC's own property developers. The factory was located close to Stockholm, the largest market in Sweden, in Hallstahammer, approximately 130 km from the capital. The factory contained several machines and a single robot. The development work, including establishing a company, developing a building system, making a prototype, etc., started in 2003. A

guiding principle was that "everything that can be made in a factory should be made in a factory". However, wet rooms and concrete stairs were purchased ready-made. The factory had its own concrete production with its own concrete recipe, where it only took 2.5 days from casting to the elements leaving the factory. At that time, ordinary concrete had a drying time of four weeks. Production was planned to be order-driven, but before starting, six months of production had been secured. The factory also had its own rolling mill. Sheets delivered in rolls were cut to size and run through the rolling mill to be bent into steel sheet roofs and joists. A CNC robot then welded the parts together to form roof and floor joists. However, by the autumn of 2007, it was

Figure 1: Lindbäcks building Stockholm (source Lindbäcks)



already difficult to get enough orders in and by Christmas a deficit of more than SEK 300 million had been built up. The sale was made on the premise that it could be produced at half the price, but at the beginning the production was more expensive than what NCC could normally produce. There was an ambition to reduce the number of building parts to 3,000 instead of the usual more than 100,000, but this did not happen quickly enough. In the sales phase, there was a fear of scaring customers away and quite a few options were therefore accepted. NCC Komplett succeeded in building approximately 300 apartments in 16 apartment buildings (up to 8 floors) in the Stockholm area (Eskilstuna, Nyköping as well as Beckomberga, Ursvik, Järfälla and

Table 1: Main manufacturing players. 1 SEK = 0,0781 £

	Corporate turnover	Factory turnover	Factory employees
Derome	6,5 bill.	2,37 bill.	1750
Moelven	14,4 bill.	1,7 bill.	500
Boklok	157bill.	360mio.	300
Lindbäcks	-	1,7 bill.	98
Vidabygg	58bill.	122mio.	6500

Råcksta). It would have required several large investments of millions to mature the business concept, but NCC's top management got cold feet and stopped the project. The factory in Hallstahammar was closed in May 2008. NCC had invested more than a billion in the project. 2018 saw a historically high level of activity in the Swedish construction industry and the modular house building timber industry. Several major investments followed during this period: Lindbäcks inaugurated their new factory in 2017, Setra, Södra and Boklok in the following years. Boklok was inaugurated in

February 2023, just before the housing crisis hit. Martinssons Byggsystem, on the other hand, was out earlier, inaugurating a new factory in 2017 and thus immediately benefited from the high housing construction activity in the following years.

ANALYSIS

The Swedish timber industry has a very long history and timber production is an integral part of Swedish business and its sectors. This has had a major impact on the progress of modular apartment building production. The approximately 100 industrial producers can be divided into two groups: the advanced and the more traditional. The latter can be briefly characterised as having brought together industrial joinery and building trades under one roof. The advanced have a much broader set of activities often organising their production in lines with a series of machines. The construction markets in Sweden are characterised by many sub-markets, large variations in material prices, different technologies.

The technological innovation system of modular wooden house building is here understood through the seven functions: entrepreneurial activities, knowledge development, knowledge diffusion, guidance of the search, market formation, resource mobilisation and legitimacy. supplemented with geography and politics.

Entrepreneurial activities

By 2024 entrepreneurial activities in the industry complex is predominantly situated in the small manufacturer segment (the joinery workshops), which on the other hand mostly rely on traditional manual production methods. However, viewed over the period from 1994, where the present development commenced, then Skanska and NNC initiatives stands out. Skanska allied with IKEA and conceptualised the BOKLOK products, which has been a success despite present challenges. NCCs highly ambitious concept “Komplett” on the other hand was closed down. As Skanska prevailed their entrepreneurial initiative stabilised the emerging technological innovation system.

Knowledge development

As the factories grew from 2000 and onward, they came to represent important practice-based knowledge about industrial housing production. This knowledge development became far more systematically documented than previously generation parallel to manufacturing's development during scientific management in the 1950ties. The period also features a formation of a particular labour market group specialised in industrialised housing production. Moreover, specific technologies get developed in a smaller group of large modular house manufacturers, drawing on technology from the adjacent woodworking industry, such as machines for handling wall size wood panels.

Knowledge diffusion

The knowledge diffusion following the establishment of a TIS back in the 1990ties follows first and foremost from companies and professionals that over the years diffuse from company to company and gradually broaden the knowledge base. There are also examples of knowledge institutions, i.e., universities collaborating with the companies and diffusing knowledge through publications and education. Two manufacturers stand out in this respect in relying on close collaboration with university academics. But most of the industry follows a more practitioners-oriented path.

Guidance of the search
The most important guidance of the search came from a cluster of large companies whereof most were embedded in the Swedish wood working industry and therefore possessed necessary capital for an expansion into industrial modular housing. Once in this field fewer companies (Lindbäcks and Boklok) took leading roles. Their search for growth of their respective business led to two characteristically different model of industrial modular housing, in brief a craftsman-based customer oriented and a more industrial manufacturing of standard products.

Market formation
Where wooden single-family houses have a long study and hardly is need of any market formation. The multi storage modular industry-s market formation started cautiously offering two story variants selling them to associations of citizens, in so-called tenant owned associations, a collective form of ownership common in Sweden. Through selling in small volumes (of for example a row house district to these customers, the companies became able to expand into larger projects of multistorey apartment building. The market was secured by public housing companies demanding affordable housing counter to the early small projects, where the price parameter was relaxed. The market was further corroborated by large scale purchasing agreement running over a long time, stabilising the order pull for the manufacturers.

Resource Mobilisation
The early resource mobilisation was secured mostly through existing wood industry companies expanding into the modular house production. Some of these companies are multinational giants, but the resource mobilisation spans also to the small manufacturers, which often emerged from contractors or joinery workshops. The challenge of mobilising resources are very different for these segments and a large group of the manufacturers never grow beyond the status as SMEs in the period from 1994 to 2025.

Legitimacy
Wooden houses carry a legitimacy in a Swedish context due to its deeply embedded traditional use. This might go against issues of moisture, rot and fire risks, but is nevertheless merely viewed as a natural prolongation of a tradition. The companies can rest with habitually mentioned that they guarantee against these issues. The legitimacy was further extended when sustainability became a more valued issue. Thus, identification with sustainability, a narrative of wood as equal to a sustainable world strengthen the TIS. The low fire risk is maintained as marketing argument, even if public statistics rank modern multi-story modular wooden housing as equally safe/risky as other modern (recent) buildings.

Summarising, the classical TIS framework provide several explanations for the strengths and weaknesses of the modular industrial housebuilding industrial complex. And systematically point to factors in need to be taken into consideration ins a possible transfer, imports effort. Nevertheless, some remarkable absences in the analysis became clear, once contextualised the industry analysis into Sweden in the year 2023, namely the role of large capitals and the housing crises.

But first a brief reflection on Bergek *et al. (*2015) proposals for a stronger conceptualisation of structural elements. Two aspects largely overlap; “technology” and “sector”, while geography and politics extends the analysis. When it comes to geography the closeness to raw material and Sweden’s wood industry as adjacent, the fifth largest exporter of timber, are prevalent elements. “Politics” is here played out on

several levels of the public bodies in Sweden. Several of the factories receive active support from local municipalities, the association of municipalities and region makes a large deal with standard purchasing through a frame contract and the Swedish government support the industry complex with innovation funding.

But once contextualising the industry analysis into Sweden in the year 2023, the two aspects of large capitals and the housing crises comes to the fore.

Moving from a heated market for housing in 2018, by 2023 the market has plummeted. This proliferated several large capitals in the industry's recent investments in new manufacturing facilities. Management was now facing a dilemma: should they keep their personnel and insist on the longer-term aspect of the investment in multistory modular wood housing, OR should they reduce costs in a classical way, close factory units and dismiss personnel. Most of the manufacturers chose the latter strategy, despite their size and capital capacity. The consequences summitted when Skanska sold their factory in Gullringen in February 2025. This factory represented a recent Skanska investment of some 50mio euros in machinery and capacity. Skanska chose nevertheless to first reduce personnel and secondly to sell the factory. Skanska is now customer of the reduced production from the factory.

Figure 2: Bokloks factory (source Boklok)



It thus becomes clear once enlarging the TIS analysis to encompass macro-economic aspects that these can be crucial for the development of a TIS. This goes beyond market formation as large structural forces impact on the development of the industry complex.

DISCUSSION

We have so far focused on one of the countries with the most volume in affordable sustainable housing, Sweden. This is to establish a basis for raising the question whether an industrial complex with extensive production of modular wooden houses be exported to other countries? Given the EU policy of affordable house and more practically given that transporting the finished modules from Swedish factories to the rest of Europe hardly complies with climate concerns.

In favour of such a policy, establishing production of modular wooden housing to offer affordable housing in the countries of Europe stands that the technology and production method is well known and transferable. Many other factors of the TIS are equally so. The Swedish close access to raw material and forestry knowledge is possibly on aspect that more difficult to transfer. When it comes to finance, then the recent crisis in the Swedish housing market have illustrated that more robust solutions than those provided by large single capitals is needed. A joint public private financing would be a possibility, where linking the long-term public interest in sustainability with the long-term production.

Another visible and transferable success factor are the organised purchase by semi-public Swedish clients, which point organised long term frame agreements might be very important.

Despite the Bergek *et al. (*2015) expansion of the TIS framework of understanding it is in this analysis from Sweden 2024 apparent that the framework disregards the macroeconomic ups and downs. The transfer and introduction to the European nations therefore needs either to dismantle such macroeconomic influence or provide a type of protection against it.

CONCLUSIONS

This contribution asks whether the Swedish industrial complex of modular wooden housing can be exported? And what element need to be taken into concern?

A technological innovation system approach to an industrial complex was adopted. Here the Swedish modular housing industry complex, focusing on its manufacturing companies and including the financial side of the technological innovation system.

The result show, that while technologies are available and well developed, the financial backbone is very important for any import. So, a receiver country would need to have a well-developed financial structure, be it private, public or a combination. The Swedish modular industrial housing industry does not at present have a financial backbone it can offer as part of an exportation on pure private marked basis. The Swedish housing industry in general is in a dire crisis, even if a temporary issue, whereas the need for local production throughout Europe is prevailing and should be supported with public measures to be feasible.

The Dimensions of Technological Innovations Systems: Entrepreneurial activities, knowledge development, knowledge diffusion, guidance of the search, market formation. resource mobilisation and legitimacy all proved useful to establish a comprehensive overview of many of the central features of the Swedish industrial housebuilder complex. Nevertheless, they were not sufficient for answering to our research question as overall structural features hit in. And the lack of full understanding of dynamic in the framework of Technological Innovations Systems stands out as a major limitation.

If EU wants to mitigate the European wide crisis of affordable housing it needs to address this by a pan-EU policy on affordable sustainable housing. But the establishment of industrial complexes need to be carefully prepared in each member country.

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POLICY PURPOSE AND EFFECT ON THE USE OF MODERN METHODS OF CONSTRUCTION IN THE ENGLISH HOUSE BUILDING SECTOR

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Policymakers regularly cite Modern Methods of Construction (MMC) as a favoured method to improve productivity and quality of new houses, but the perception of many within, and associated to, the sector is that despite policy directions, the house building sector in general continues to be resistant to its widespread use. Whilst previous studies have considered aspects of the use of MMC within the house building sector, the disconnect between policy creators, and those affected by it, as to its purpose and effect remains under-researched. The aim of this paper therefore is to investigate and explore the purpose and effect of policy on use of MMC in the English house building sector. An exploratory critical review of literature relevant to policy, MMC and house building in England identified key policy areas connected to MMC use. Findings reveal four principal policy purpose clusters influencing MMC use in the sector: 'pipeline predictability', 'regulations and guidelines', 'commercial market', and 'robustness'. The work aspires to facilitate greater clarity for policymakers and the sector in relation to the effect of policy and the use of MMC for house building in England.

Keywords: houses;; house building; MMC; policy; policymakers

INTRODUCTION

Concluding the September 2024 parliamentary debate (Hansard 2024) on the House of Lords Built Environment Committee report (Lords Built Environment Committee 2024), Baroness Taylor (for the Ministry Housing, Communities and Local Government (MHCLG)) concluded that, "Innovation has revolutionised so many sectors and transformed the way we live, with incredible gains in productivity and living standards, yet much of the housebuilding industry continues to build in the same way it has for hundreds of years". Previously these comments may have been associated with the wider building sector (Egan 1998), now more commonly directed at house building alone - perceived by many as the last to modernise. Policymakers in England (Commons Built Environment Committee 2019; Homes England 2023; Lords Built Environment Committee 2024) regularly cite MMC as a favoured approach to improve productivity and quality of new houses, but based on the perception of many within and associated to the sector there is a question over why,

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despite policy directions, the house building sector continues to be resistant to its use (Farmer 2016; De'ath and Farmer 2020). Given the apparent disconnect and lack of clarity, the research seeks to answer the question, what are the policy areas, and principal purpose, that are thought to influence the use of MMC in English house building?

Delimitations

This section sets out the scope, reasons behind, and the focus for the paper's research. Housing, planning policy and associated legislation has been a devolved function since the 1998 Acts (Devolution of powers to Scotland, Wales and Northern Ireland 2013), which left the UK government with responsibility for England alone. As such, data is relevant for England rather than the UK unless otherwise stated. Whilst a 'house' may generally be understood, it is often legally defined by what it isn't (Morton 2022), so for the purposes of this research, it is a permanent residential property (within the scope of General Permitted Development Order (GPDO) C3) (Litchfields 2021), not divided horizontally but used as a single residence with the building assessed as a single entity for the purposes of Council Tax, regardless of whether it is detached, semi-detached, or of terraced construction. Houses remain the most populus type of homes built each year in England (approx. 75% (ONS 2023)), whilst house builders as a sub-sector remain distinct from general contractors (Pan and Goodier 2012), concentrating on land acquisition and building houses, rather than constructing other building types. The top 20 English house builders by output are responsible for approximately 75% of those houses constructed each year (Gardiner 2021). Several publications have sought to establish the taxonomy (Ayinla *et al.,* 2020; Vásquez-Hernández *et al.,* 2025), history (O'Neill and Organ 2016) and wider understanding (Green 2024) of non-traditional building methods. Given the context of the research however, focused on policy in England, the paper has chosen to define MMC in the terms of the UK government's seven categories (MHCLG 2019) (Figure 1) albeit limited to categories 1-5, which are deemed by many (Lords Built Environment Committee 2024) to be more appropriate. Whilst the history of offsite construction is extensive, the literature researched stems from 1997 onwards, being the year that Rethinking Construction (Egan 1998) was commissioned, and the current policy debate on MMC reignited (Matthews 2024).

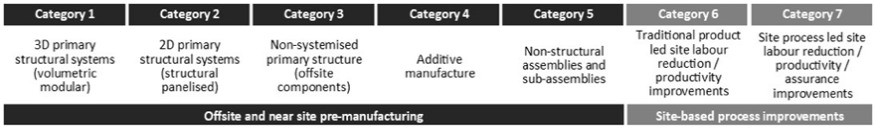


Figure 1: Modern methods of construction definition framework (MHCLG, 2019)

METHODS

An exploratory research method was selected through a systematic selection (Figure 2) of relevant literature on the subject. The effects of policy on the use of MMC in house building appear to be under-researched from the Scopus keyword search, but through the process described and with inclusion of reference papers from government, policy think tanks and professional bodies, 60 papers over the last 25 years in total formed the basis of the review. The review of the literature identified data, facts, and arguments relevant to MMC and house building, and enabled the broad categorisation of policy areas that had, or had the potential, to influence its use. In places the literature referenced specific policy instruments, rather than policy areas, so part of the review process involved interpretation of arguments in the context of the

probable policy areas intended, grouped into four principal clusters to establish common links, themes, and purpose.

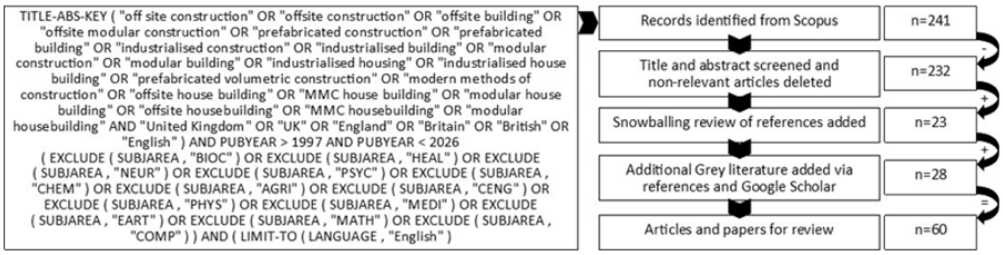


Figure 2: Process for selecting papers for review

Exploratory Critical Literature Review

There may be a broad appreciation of policy as a concept, however it remains challenging to agree a common definition (Cairney 2015), its general scope, or the categorisation and use of policy instruments (Salamon 2002) to shape and direct policy to achieve its desired outcome. Whilst many perceive it in terms of government direction in the form of public policy, it also covers those strategies and plans in the private, Not for Profit (NFP) and Non-Governmental Organisations (NGO) sectors. However, for the purpose of this research, areas are deemed to be capable of being categorised if they can be seen as directing objectives or strategy through the lens of being financial, regulatory and non-regulatory policies. The inherent variability in descriptions and labels (Bryman 2016) used in the reviewed literature, required an iterative approach to common descriptions to identifying and create policy areas, and then clusters, with sometimes interchangeable references to both policy and instruments. The review explored ways to identify and categorise policy references, whether through the lens of explicit or implicit direction, or potentially use of similes such as Carrots, Sticks and Sermons (Bemelmans-Videc *et al.,* 1998), to reflect the sometimes more subtle approach that can be used by policymakers.

Identifying Policy Areas

Throughout the review process, policies and policy areas referenced in relation to influencing the use of MMC in the house building sector were identified and described, to identify a comprehensive list of 25 policy areas (Figure 3). The review occasionally interpreted the author's implied intent and focus as indicating that a policy area had, or would have, an effect, even though a particular policy or instrument was not always explicitly identified in the literature, and whilst some, such as Agapiou (2019) restricted policy to the areas of planning, regulation, funding, insurance and warranties, however, many of the legal and contractual issues identified could also be deemed to be the product of policy.

The absence of specific literature through the search, and the use of snowballing to find additional papers through reference searches (Figure 2), suggests a research gap in connections between policy, MMC and house building, with no papers fully addressing the research question. The review also identified the lack of data in assessing the use of MMC, its effect on house building, nor a framework to gauge its long-term robustness, with 30% of the papers citing data's absence as a detriment to the understanding of MMC use within the sector. Using the approach taken by Bemelmans-Videc *et al. (*1998), the policy areas were grouped into clusters by their overall purpose and approach to influencing the use of MMC in house building, resulting in 25 policy areas within four distinct but interlinked clusters:

A. Policies that enable ‘pipeline predictability’ for house builders in England (7)

B. Policies that create the ‘regulations and guidelines’ that house builders work to (7)

C. Policies that shape the ‘commercial market’ that house builders work within (6)

D. Policies that embed the ‘robustness’ of the house builders’ approach over time (5)

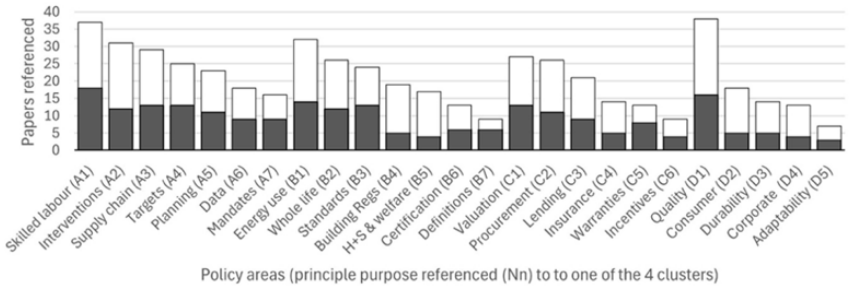


Figure 3: Policy areas and overall purpose cluster referenced within reviewed literature

Pipeline Predictability

The traditional house building business model (Farmer 2016) has evolved to accommodate the stop-start demand and economic cycle, with the capacity to instantly change development on any given site (Lang *et al.,* 2016). This approach is considered unsuited to the manufacturing processes used in MMC, particularly those in categories 1 and 2 (Figure 1), with papers referring to the effect that a predictable pipeline (Make UK Modular 2023) would have on MMC use in house construction. The papers make varied references to absent or poor data(A6) collection across several areas, which is reflected in a wider debate about the Office for National Statistics (ONS), and others’ ability to collect relevant and high-quality data (Hudson 2025). The lack of reliable data has, and will continue to have, a detrimental effect on decision making around MMC use, and house building in general.

With the partial exception of the creation of a skilled workforce, all items in this cluster were within the field of public policy, with the focus on the government’s capacity to act or lead. The papers’ discussion on the need for skilled labour(A1) focussed on the role of bodies such as CITB to improve training, skills and knowledge about MMC (Farmer 2016), but also acknowledged that government could lead through direction or legislation (Hill 2019). Whilst the unpredictability of the planning(A5) system was cited by 38% of the articles as having a detrimental effect on MMC use, there was an acknowledgment by some that this was not a unique problem for the sector (Peters *et al.,* 2023), but a problem in its totality, albeit the current permission led approach had partly led to the traditional house builder business model (Payne and Serin 2023), and without significant changes (RTPI 2023), the system to some degree would continue to encourage the use of non-MMC systems.

The remaining four policy areas identified in the papers relate to the effects on MMC use following general and specific government interventions(A2) - whilst sometimes less precisely defined in articles, such intervention referenced the general funding for social housing, research, land release, and financial backing for high capital investment requirements linked to MMC production (De’ath and Farmer 2020), with the latter, specifically generating conflicting comments on the effectiveness of Homes England (Lords Built Environment Committee 2024).

The government’s ongoing housing targets(A4) were seen as potentially a key driver for innovation in construction, but also regularly used as a driver for MMC use (Peters

et al., 2023)- the targets themselves were seen as influencing the need for MMC (on the basis that the house building sector was currently capacity limited). The capability to promote MMC use via mandates(A7) (funding through Homes England, but previously through the Housing Corporation) was seen by many to be potentially highly effective (Chakravarti and Cowley 2024), but the non-stipulation of categories 1 and 2, for the measure being based on pre-manufactured values (PMV) instead was criticised (Lords Built Environment Committee 2024), for allowing too much content from lower categories to be used. The suggestion that pipeline predictability though the application of targets(A4), the use of mandates(A7) and government intervention(A2) to support capital intensive manufacturers would also lead to the creation of a stable supply chain(A3), which was deemed as essential for government (house building supply), as it was for MMC contractors (Alhawamdeh and Lee 2024), particularly following a number of supply chain failures, harming the potential for future investment in the sub-sector (Saad *et al.,* 2024).

Regulations and Guidelines

The capacity to direct, control and influence the building sector through regulatory means is long established, whether by statutory instruments (The Construction (Design and Management) Regulations, 2015), creation of specific standards (DLUHC 2023) and bodies (such as BSI), or compliance frameworks (Vagtholm *et al.,* 2023). Whilst not strictly part of the formal regulatory framework, the MHCLG definitions(B7) framework (2019) was cited by several papers as an essential part of future support for MMC use in housing, whether through clearer direction in targets, or linked to future standards, with the latter believed to have a significant effect. The effect that building regulations(B4) may have on the use of MMC is described in 40% of the literature, but more recently in the context of the current regulations not being responsive (Commons Built Environment Committee 2019) to the systems being adopted, and as a barrier to greater use. In a similar context, the capacity and requirement to measure and assess the whole life(B2) of the building, particularly through embodied carbon use (Daniel *et al.,* 2024), is referenced as a potential policy change that would have a significant effect, although the evidence that all MMC systems would benefit is not proven (O'Hegarty *et al.,* 2025). The perceived benefits of MMC systems (Goodier and Pan 2010) in relation to satisfying policies directed to reduce energy use(B1), and the drive towards zero-carbon use through the adoption of the Future Homes Standard (DLUHC 2023) are cited to have had a significant effect on MMC use by house builders (Make UK Modular 2023) through the application of offsite systems. Whilst the establishment of recognised standards(B3) (Price *et al.,* 2019) for MMC systems seen as essential, particularly in relation to certification, warranties, and insurance (Agapiou 2019), the introduction of standardised components is more contentious. Many authors recognise that a kit-of-parts approach may produce more consistent adoption of MMC systems in house building (Kennedy *et al.,* 2023), particularly in relation to supply chain stability, whilst many manufacturers remain wary of regulation that stymies innovation (Make UK Modular 2023).

Likewise, the capacity to provide certification(B6) for components and systems seen as a significant step in creating more opportunities (Alhawamdeh and Lee 2024) for MMC use by removing perceived barriers, particularly in relation to warranties, insurers, and lenders. Legislation in relation to health, safety and welfare(B5) on construction sites isn't necessarily new or targeted specifically at contractors using

MMC but has been seen as a potential driver for many contractors in its adoption (Pan *et al.,* 2008), particularly to avoid working at height (such as using pre-finished roofs).

Commercial Market

Traditional house builders are long established, know their sector well, use proven traditional approaches to construction, finely adjusted to the financial and regulatory systems they work within (Pan and Goodier 2012). All of which can potentially result in a commercial market highly resistive to innovative approaches, referred to by Saad *et al. (*2024) as 'innovation negativism'. The early adoption of an MMC system approach is recognised as key to successful procurement(C2) during the design and building stages (Farmer 2016). Existing commercial frameworks and legal contracts were designed around traditional building approaches, with milestones based on commercial stages that don't necessarily suit MMC systems (Thompson 2021). Acknowledging the barriers that exist in traditional professional and commercial contracts, whilst actively promoting alternative routes, will have a significant influence on procurement practice (Agapiou 2019).

Likewise, the ongoing question about the issue of warranties(C5) for MMC constructed houses was referenced as a significant barrier to wider adoption. The policy approach taken by relevant bodies such as NHBC to new systems is either an attack on innovation (Make UK Modular 2023), or an appropriate management of under researched risk (Green 2022). This has resulted in the creation of the Build Offsite Property Assurance Scheme (bopas.org) by the MMC sector, to issue accreditation for MMC systems. The issuing of warranties impacts two further areas that derive predominately from private sector policy making: the insurance(C4) of the finished houses, along with cover for the manufacturers and developers within the sector; and the decision by banks to agree competitive lending(C3) to the individuals (Agapiou 2019). The risk-averse policy approach by commercial companies to both is seen to have a clear effect on the decision for individual to purchase homes using MMC, but also on the decision to lend to, or invest in, businesses that use or manufacture MMC systems, particularly after the ongoing spate of announcements and insolvencies within the sub-sector (Saad *et al.,* 2024).

The final two policy areas identified within this cluster relate to appreciation of the construction valuation(C1) linked to using MMC systems, and the associated incentives that government could use to support the use of MMC to alleviate the barriers and challenges highlighted elsewhere. The policy approach to the first of these concerns the estimates used within the RICS Red Book, which do not allow for higher capital costs associated with houses constructed using MMC, nor make allowance for the lower maintenance and running costs that some believe result from MMC use (Lords Built Environment Committee 2024). A position cited in relation to grant funding for affordable housing (Chakravarti and Cowley 2024), with the acknowledgment that MMC construction costs will become more compatible with traditional systems once the market expands, matures, and stabilises.

The government's role in encouraging and supporting a changing market towards MMC systems achieved through a more targeted use of incentives(C6) via taxation and grants. The analogy to recent policy towards electric cars, whether via grants (used to discount the purchase price of the car, and the installation of home charging points) or taxation (lower BIC rates for company cars, and road tax duty) suggests that a similar approach to those using MMC systems could, if wished, have a significant

effect on developers (grants for capital investment) or purchasers (discounts on Stamp Duty or through Council Tax) (Peters *et al.,* 2023).

Robustness

The capacity for MMC systems to be holistically robust over time may have a more significant effect on its adoption now than in previous decades. Several papers recounted the earlier drivers and problems associated with offsite use in England over the past century (O'Neill and Organ 2016), and whilst the current taxonomy for MMC may be novel, the principles are not, which may suggest that the sustainability of the approach is yet to be comprehensively proven to consumers or the corporate bodies that invest in it.

The durability(D3) of the systems against traditional methods, especially for organisations that remain the long-term owners of the properties (Kempton and Syms 2009). Homes England's investment in the AHP for 25% MMC use will need to be tracked to assess the condition and value of the homes over time which is certainly of interest to Registered Social Landlords (RSL), and their approach to data collection and sharing through the sector will be critical (Chakravarti and Cowley 2024). In addition, the quality(D1) of various systems assessed and recorded over time is discussed in many papers, but without specific policies cited, to establish which methods generate fewer defects on handover compared to traditional approaches and whether maintenance costs are lower over time (Kempton 2009) - however the assumption that a focus on quality is an obvious benefit from using MMC systems is not evidenced. Whilst the policy towards adaptability(D5) requires elements to be designed into new houses (Building Regulations Part M, and Lifetime Homes Standard), the capacity for future changes to be made to MMC systems may not be clear (Penny 2024), particularly within category 1 and 2 (Figure 1).

Corporate(D4) organisations require significant assurance that investments are justified, but with limited relevant data available in relation to MMC and ESG (Environmental, Social and Governance) policies (Alhawamdeh and Lee 2024), the effect may be to rely instead on headlines of past insolvencies and withdrawals from the sector, rather than data-driven evidence. Finally the need to gauge consumer(D2) support for future MMC systems (Alhawamdeh and Lee 2024) is critical given past reputational problems (O'Neill and Organ 2016), and whilst potentially assessable through surveys of tenants in social housing, or purchases made of private houses, there is currently no differentiation made within the ONS data of how houses are built in England to allow for independent analysis of consumer preferences.

CONCLUSION

Observations are made regarding the research limitations together with an indication of the policy areas that may currently, and potentially will have in the future, the greatest effect on the use of MMC in house building in England, followed by a recommendation for further research. Firstly, the lack of specific literature on policy in relation to MMC use is perhaps surprising and suggests that there is a significant research gap, particularly in relation to the white literature, which tended to be evenly published over the past 25 years, and as such not always referencing more recent data or developments, whilst the grey literature, often authored by think tanks or trade bodies, can have an inbuilt bias. Secondly, the references to policy areas within the literature tend to be implied, not always reflective of policy practice or able to quantify the scale of influence, so requiring clarity around taxonomy and purpose. Lastly, the reference to poor data around house building, MMC use, and consumer

perception is of concern both from a commercial but also government perspective, leading to potentially poor decision and policy making.

To a degree the policy purpose four clusters identified (pipeline predictability, commercial market, regulations and guidelines, and robustness) have the potential to operate in synergy to influence the use of MMC, given that they seek to create a predictable pipeline for houses, constructed within a receptive commercial market, to appropriate regulations and guidelines, and embedding the robustness of the house building approach over time. The literature suggests that policies that create predictability in house building, will have the greatest effect on MMC, in particular its capacity to supplement the current market limited by the supply of skilled labour, whilst those directed at robustness, are seen as the least likely to influence its use, albeit the regularly cited assumption that a drive towards higher quality standards will naturally benefit MMC systems isn't convincingly evidenced. The discussion about supply chain stability may potentially lead to more active government interventions and incentivisation, along with greater standardisation, a drive towards net zero, and the use of whole life costing for determining value - all of which may well have a greater influence in the future, especially if housing targets remain a key policy objective of this government. The research has identified 25 policy areas, within four principal policy purpose clusters that have, and may have in the future, an effect on the use of MMC in English house building. However, the research limitations identified above, suggest that further research of the sector's relevant stakeholders would gain a greater insight into the perception around, and experience of, specific policy and its effect in practice on the sector, helping to determine which of the 25 policy areas, or four clusters, are the most influential, and why.

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ADVANCING OFFSITE CONSTRUCTION PRACTICES: A SYSTEMATIC LITERATURE REVIEW OF POTENTIAL CHALLENGES TO ADDRESS IRELAND'S SOCIAL HOUSING CRISIS

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The Offsite Construction (OSC) industry has positioned itself as a solution to address global housing issues, including Irelands current social housing crisis, through reduced time, cost, and waste, while promoting sustainability. This research investigates potential challenges associated with adopting OSC, which may address Irelands social housing crisis. A systematic literature review (SLR) is conducted using a structured Boolean search across academic journals in Scopus, published between the years 2005 and 2025. The review synthesized global insights into five themes: economic constraints, regulatory barriers, industry limitations, digital technology barriers and cultural resistance, providing a structured framework, offering a holistic understanding of challenges specific to the Irish construction context. Challenges identified include end-user scepticism regarding OSC quality and cost-effectiveness, cultural resistance to new methods, and the absence of a standardised evaluation tools, regulatory fragmentation, and supply chain inefficiencies. This research offers policymakers, industry practitioners and end-users' valuable guidance to proactively address these barriers. The contribution is to identify the challenges associated with implemented OSC to the social housing crisis in Ireland.

Keywords: Affordable housing; housing for all; modular construction; social housing; sustainability

INTRODUCTION

Currently, Ireland is dealing with a significant social housing problem. In 2021, a total of 20,903 new homes were completed, including private, cost-rental, and social housing units (GeoDirectory, 2022). Of these, only 9,169 were social homes (Department of Housing, Local Government and Heritage, 2023), despite 61,880 households qualifying for social homes during the same period (Housing Agency, 2022). This highlights an ever-growing gap between housing supply and social housing demand that urgently needs to be addressed. Recent data further stresses this urgency, as of November 2024, the Housing Agency's Summary of Social Housing

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Assessment (SSHA) reported that 59,941 households were officially qualified and waiting for social housing, a 1.9% increase from previous years (Housing Agency, 2025). One-adult households made up over 60% of the waiting list, and homelessness-driven need rose from 13.5% to 14.7% year on year, reflecting deepening pressures. Additionally, the Irish Council for Social Housing (ICSH) 2024 Activity Report notes that Approved Housing Bodies (AHB) delivered 4,385 social homes and 1,213 cost rental homes in 2024, accounting for 41% of long-term social housing output, yet falling short of targets. The Department of Housing's Q3 2024 Construction Status Report shows over 48,600 new-build social homes in the pipeline across nearly 2,900 schemes, but this alone has not been enough to close the gap. Most strikingly, an Irish Times report from April 2025 confirmed that the Irish government missed its 2024 social housing delivery target by nearly 20%, falling short by around 1,800 units (Irish Times, 2025). The Irish construction industry has struggled to meet the demand for social housing due to inefficiencies such as, but not limited to, labour shortages, and rising material costs.

The offsite construction (OSC) industry has potentially positioned itself as a solution to address the shortage of social housing in Ireland. OSC is described as the process where building components are manufactured and preassembled off-site in a factory setting before being installed in their ultimate position onsite (Hairstans, 2014). OSC methods have garnered attention due to their potential to expedite the delivery of high-quality, cost-effective and energy-efficient housing units and to ensure quality control, cut out weather-related problems and decrease construction time, waste, and onsite accidents (Jaillon and Poon, 2008). OSC covers a wide range of construction practices, including modular construction, panelised systems, and hybrid methods (Blismas *et al.,* 2006; Pan., 2007). These approaches allow for most construction activities to be carried out in controlled factory environments, leveraging advantages such as improved construction speed, quality, and environmental performance (Blismas, *et al.,* 2006; Pan, *et al.,* 2007; Ayinla, *et al.,* 2019). Modular construction has been used to form the scope of this paper, although the broad term “modular construction” is sometimes used interchangeably with other terms based on overlapping offsite/onsite principles. In the construction industry, modular buildings can be described as the end-product of modular construction (Lim, *et al.,* 2022). Offsite factories typically pre-assemble components into three types of prefabricated structures: 1D single elements, 2D panelised systems and 3D volumetric systems or units (Lim, *et al.,* 2022). To clarify, while the term modular construction is used as an umbrella term in this paper, the review focused specifically on literature concerning 2D panelised and 3D volumetric modular systems The purpose of this research is to provide an insight on what factors could potentially be perceived as challenges to the advancements in OSC practices, which are hindering its ability to alleviate some of the pressures of the social housing crisis in Ireland. In the context of this study, the term challenges refer to any factor contributing to OSC being overlooked in favour of traditional construction methods.

To achieve this aim, this paper conducts a systematic literature review (SLR). Whilst the authors acknowledge the existence of studies on challenges to the adoption of OSC; the value of this SLR is that it consolidates and synthesizes the findings from a wide range of sources into a comprehensive, structured framework, offering a holistic understanding of challenges specific to the Irish construction context. The outcome of this review is an extensive list of challenges, identified by academia, which can provide valuable guidance for policymakers, industry practitioners and end-users.

Note, the findings of this research cannot be conclusive in terms of what OSC users believe to be challenges, as these factors have been derived by authors and not directly from industry. This paper aims to answer the research question what are the challenges hindering the adoption of OSC in Ireland's social housing sector? Answering this question may better position OSC as a solution to addressing the social housing crisis in Ireland.

METHOD

A Systematic Literature Review (SLR) is a well-known method for synthesising exiting research in a structured manner (Okoli and Schabram, 2015). It differs from traditional reviews as it applies a structured, transparent, and replicable approach, reducing bias and ensuring an in-depth analysis of relevant research (Boell and Cecez-Kecmanovic, 2015). The gathering of findings can reveal research gaps; thus, SLR's can provide a foundation for future studies (Palmatier, *et al.,* 2018). In this study, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 are followed to ensure clarity and reliability in the review process (Page, *et al.,* 2021). PRISMA is recognised as a standardised approach to identifying, screening, and selecting relevant studies (Page, *et al.,* 2021). The Boolean search technique is used to refine and target the gathering of academic papers and articles. This technique is critical for converting the research topic into a precise query string, facilitating the effective search across the chosen academic databases. This method was chosen due to its efficient way of examining fragmented and emerging areas of research such as OSC, where structured review of peer-reviewed literature can support the development of a clear thematic understanding. The application of inclusion and exclusion criteria also allowed the study to remain focused on the literature directly relevant to the research topic, improving the relevance of the overall findings to Irish policy and practice. See Figure 1 as to how PRISMA was incorporated for this SLR.

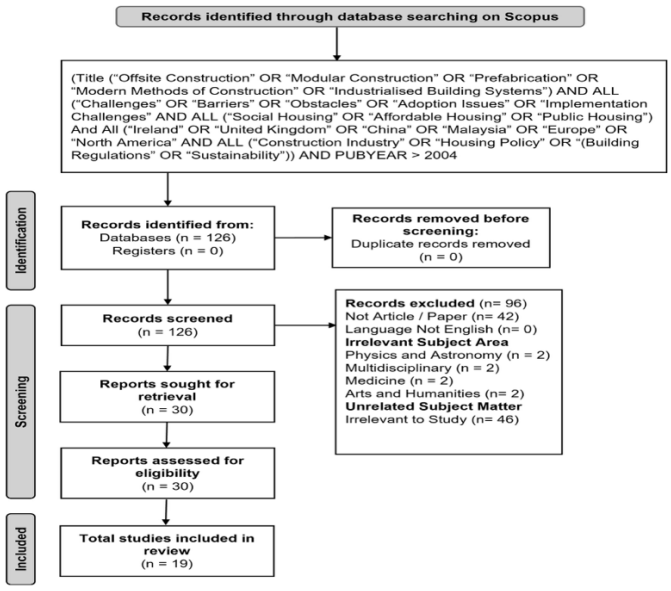


Figure 1: PRISMA flow diagram

STRUCTURED LITERATURE REVIEW

This section presents the challenges that are hindering OSC adoption in Irelands social housing sector. The sample consists solely of publications published in academic journals in Scopus in the library of the researcher's institution. This article search

produces 126 articles, which were further screened based on inclusion and exclusion criteria, resulting in 19 eligible articles published between 2005 and 2025. On reviewing the full text documents, 46 challenges are catalogued and presented in Table 1. These findings are categorised into five key themes: Economic Constraints, Regulatory Barriers, Industry Limitations, Digital Technology Barriers and Cultural Resistance All key themes, potential challenges and corresponding authors are listed in Table 1. Each theme is then developed and discussed, outlining the challenges recognised by authors from the literature.

Economic Constraints

A major challenge presented in the literature is the high initial investment required for OSC particularly in the construction of production facilities and logistical infrastructure. Rahman (2014) stated that the significant initial expense in the adoption of Modern Methods of Construction continues to be a barrier inhibiting smaller contractors, especially when financial incentives are not available. The finding is consistent with research conducted by Agapiou (2022), who highlighted similar reluctancy from UK housing associations, due to the initial capital requirements often overshadowing the potential long-term savings. Pan, *et al. (*2007) further reinforced this by highlighting that UK housebuilders often perceive financial risks and uncertainties in OSC, limiting its widespread adoption. Misconceptions relating to the life cycle costs and return on investment of OSC also creates a significant economic challenge. Despite the known benefits of OSC, such as reduced material waste and faster construction timelines, stakeholders in the housing industry tend to ignore these long-term benefits (Ayinla, *et al.,* 2019). In a similar argument, Tam, *et al. (*2007) acknowledges that miscalculations and biases towards traditional construction methods exist because of short-term economic assessments, limiting wider adoption of OSC. Transportation and logistics have also positioned themselves as an additional economic concern, particularly in the context of Ireland potentially due to its dispersed rural and suburban populations. According to Mao, *et al. (*2016), logistics costs have an impact on modular construction implementation, with remote manufacturing locations increasing total project expenses. Such concerns are potentially relevant in Ireland, where limited rural transport infrastructure and regulatory constraints on transporting large modular components further complicate logistics; thus, potentially increasing overall project cost.

Regulatory Barriers

Ireland's current regulatory environment provides potential challenges for OSC implementation, due to the lack of standardised guidelines. As noted by Lee *et al. (*2019) there is a need for regulatory frameworks to be tailored specifically to OSC to streamline approvals and the overall construction process. This is consistent with the findings of Jiang, *et al. (*2018), who highlighted the lack of OSC specific building regulations in regions like Ireland, leads to project delays, increased compliance uncertainty and reduced investor confidence in the construction practice. The development of well-defined OSC regulations in countries such as Singapore and China could be seen to increase the adoption rates, providing a clear pathway for modular construction approvals (Xu, *et al.,* 2020). Lim, *et al. (*2022) highlighted the significant importance of planning and regulatory approvals for successful modular construction implementation, emphasising that fragmented approval processes negatively affect project timelines and cost effectiveness. Public procurement policies in Ireland, potentially further increase regulatory barriers, favouring traditional

construction methods with lower initial associated costs. According to Blismas, *et al. (*2006) procurement practices which prioritise initial tender price over long-term value or sustainability are found to hinder OSC adoption, as modular methods often have higher initial costs despite substantial long-term economic and environmental benefits. As a result, procurement change is potentially critical to promoting OSC use across Ireland's social housing initiatives.

Industry Limitations

The fragmented nature of Ireland's construction industry potentially restricts OSC scalability. According to Gan, *et al. (*2017), the effectiveness of modular construction depends heavily on a well-integrated supply chain. The findings highlight how fragmented and poorly integrated supply chains increase the likelihood of delays, reduce cost-effectiveness, and result in quality inconsistencies. In Ireland, where construction supply chains remain traditionally structured, there is a potential need for restructuring to create integrated and collaborative supply chain networks and communication streams, as successfully demonstrated by China's centralised modular construction industry (Zhang and Skitmore, 2012). Workforce skills shortages present as another potential challenge within the literature, as the shift towards OSC requires specialised skills not typically developed through traditional trades and general traditional construction labour (Shahzad, 2016). While this presents a potential barrier, OSC's safer and more controlled work environment may help attract new entrants to the industry. Awodele, *et al. (*2023) conducted a study on modular construction in the Nigerian context which demonstrates that a lack of training and awareness in relation to OSC methodologies severely restrict workforce adaptability. Addressing this skill gap through targeted training programmes and university-industry partnerships could potentially fast track the widespread adoption of OSC in Ireland's social housing sector.

Digital Technology Barriers

Digital technology barriers also present themselves as a potential challenge for OSC in Ireland. Modular construction is often criticised for its limited flexibility and customisation selections, this is a perception that is shared across many stakeholders across markets (Olawumi, *et al.,* 2018). As noted by Ali, *et al. (*2023) OSC requires early design stage finalisation and limited scope for onsite design changes. This lack of flexibility could potentially struggle to align effectively with the varied and ever-changing needs typical of Ireland's social housing sector. Adopting and further advancement of digital technologies such as Building Information Modelling (BIM), could potentially address these concerns, facilitating greater customisation and flexibility within modular projects (Najjar, *et al.,* 2023). Additionally, integration challenges associated with BIM and modular construction have emerged as a notable technology barrier, especially in regions new to the process of construction digitalisation. Research conducted by Ibem and Uwakonye, (2018) investigated inhibiting factors of BIM adoption within modular construction projects in Nigeria, discovering that the digital divide and resistance to new technologies limit the seamless implementation of digital processes. Similar technology adoption challenges may be expected in the Irish construction industry, reinforcing the need for focused investment in technology infrastructure and education.

Cultural Resistance

Cultural resistance is among one of the most persistent barriers hindering OSC adoption. Negative perceptions regarding modular housing quality, durability and

resale value remain widespread among public and private stakeholders. Research by Agapiou, (2022) and a comparative analysis by Xu, *et al. (*2020) of modular construction practices in China, Hong Kong and Singapore indicate strong cultural resistance to OSC, which stems from misconceptions about the quality of modular methods in comparison to traditional construction methods. Jaillon and Poon, (2008) identified major cultural and stakeholder resistance in adopting prefabricated construction methods, mainly due to the perceived lower quality and lack of awareness of modular construction techniques compared to traditional construction methods. This cultural bias is relevant within the Irish context, where historical failures of prefabricated housing initiatives continue to potentially impact public perception negatively. Additionally, cultural resistance is influenced by industry inertia, defined as a strong preference towards traditional construction methods, which plays a critical role on overall cultural resistance. Construction professionals have been described to frequently oppose the idea of implementing new methods due to uncertainty, potential disruption to existing workflows and concerns over job displacement (Mao, *et al.,* 2016). Such cultural resistance could potentially prove challenging in Ireland, where the construction industry remains dominated by well-established traditional construction methods.

Future Research

While this review provides a comprehensive synthesis of the potential challenges to OSC adoption in Irelands social housing sector, further research is required to build on these findings. Industry engagement is recommended to validate and prioritise the identified challenges through interviews, focus groups, or workshops with practitioners, policymakers, and housing associations, Comprehensive research examining how international regions have addressed similar challenges cold also yield valuable policy and practice insights. In addition, future research could explore project management capabilities necessary to support OSC implementation at scale. Ginigaddara *et al. (*2024) propose a conceptual framework that consolidates various capability dimensions such as strategic alignment, process integration, and digital readiness, into a coherent model for offsite delivery.

Applying or adapting this framework within the Irish context may offer a structured approach to evaluating organisational and institutional readiness for OSC. This would be particularly valuable in addressing capability gaps among local authorities, approved housing bodies, and contractors, thereby improving the effectiveness and scalability of OSC led housing programmes. Notably the concept of Generative Design (GD) did not feature within the scope of the reviewed literature, suggesting a potential gap in current academic discourse regarding its potential application in modular construction for social housing. GD employs computational algorithms to generate and evaluate multiple design options-based om constraints such as spatial efficiency., constructability, and cost (Wei *et al.,* 2022). As modular housing continues to evolve, future research should investigate the applicability of GD in the Irish context, particularly to overcome the perceived limitations of standardisation in offsite methods. Exploring the integration of GD alongside established digital tools like BIM could enhance design flexibility and optimise outcomes in social housing projects.

Table 1: OSC Challenges and corresponding literature

Theme	OSC Challenge	Rahman (2014)	Agapiou (2022	Pan et al., (2007)	Ayinla et al., (2019)	Tam et al., (2007)	Mao et al., (2016)	Lee et al., (2019)	Jiang et al., (2018)	Xu et al., (2020)	Lim et al., (2022)	Blismas et al., (2006)	Gan et al., (2017)	Zhang & Skitmore (2012)	Awodele et al., (2023)	Olawumi & Chan (2018)	Ali et al. (2023)	Najjar et al., (2023)	Ibem & Uwakonye (2018)	Jaillon & Poon (2008)
Economic Constraints	High initial investment cost	x	x	x																
	Financial and funding limitations		x																	
	Unclear return on investment		x	x	x	x														
	Short term cost focus	x	x	x	x	x						x								
	Logistics and transport difficulties						x													
	Fluctuating market demand for OSC			x	x	x	x			x		x	x	x				x		
	Shortage of OSC suppliers			x		x	x								x					x
Regulatory Barriers	Lack of OSC specific building codes	x	x		x			x	x	x	x	x			x	x				
	Complex and lengthy approval process							x	x	x	x									
	Inconsistent planning regulations				x			x	x	x	x	x	x		x					
	Lack of government incentives for OSC	x	x				x	x				x				x		x	x	
	Regulatory uncertainty	x		x			x	x	x		x			x	x	x	x	x	x	
	Limited public sector experience with OSC	x	x								x				x	x	x			
	Public procurement prioritises lowest cost	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x
Industry Limitations	Fragmented supply chain					x	x				x		x	x						
	Lack of collaboration between stakeholders	x		x	x	x	x			x	x	x	x	x	x	x	x	x	x	x
	Lack of skilled workforce		x				x					x	x	x	x					
	Insufficient industry orientated training and education														x					
	Site access limitations						x													
	Quality control issues in prefabrication	x	x		x	x		x	x			x	x		x	x	x	x	x	
	Poor customisation for local needs		x	x	x			x	x	x	x						x			x
	Inflexibility of OSC design							x	x	x	x					x	x			x
	Lack of OSC related educational programmes				x											x				
	Lack of case studies						x					x							x	
	Limited capacity of factories			x	x		x					x	x	x			x			x
Digital technology Barriers	Limited use of BIM									x	x					x	x	x	x	
	High cost of BIM implementation		x							x	x					x	x	x	x	
	Limited integration of BIM with OSC	x				x		x	x	x	x	x			x	x	x	x	x	x
	High cost of BIM implementation		x							x	x					x	x	x	x	
	Limited BIM expertise																x			
	Lack of BIM training									x	x				x	x	x	x	x	
	Fragmented digital construction systems	x			x		x		x				x	x		x				x
	Resistance to adopting digital tools			x						x	x					x	x	x	x	
	Limited flexibility in modular design	x			x	x	x	x	x	x	x	x	x	x		x	x	x	x	x
Cultural Resistance	Resistance to digitalisation		x	x			x			x						x			x	x
	Negative perception of OSC quality	x	x	x	x	x				x				x						x
	Negative perception of OSC durability	x	x							x										x
	Public resistance due to past failures of OSC		x	x			x			x	x	x	x	x						x
	Lack of knowledge among public clients	x	x	x	x	x	x	x			x	x	x	x	x					x
	Cultural inertia favouring traditional methods		x				x													x
	Fear of job displacement		x																	

CONCLUSIONS

International experiences offer valuable lessons for advancing OSC in Ireland. In the UK, government-backed policies have supported growth despite supply chain and cost challenges (Goodier and Gibb, 2007). China's industrial investment and Malaysia's prefabrication mandates show the importance of aligning policy and industry (Arif and Egbu, 2010; Badir *et al.,* 2002). In North America, market demand in the U.S. and a sustainability focus on Canada illustrates economic and environmental factors can drive the adoption of modular housing (Azman *et al.,* 2010; Kamali and Hewage, 2017). The Irish construction industry has struggled to meet the demand for social housing in Ireland. The offsite construction industry has positioned itself as a potential solution to address this shortage. Subsequently, the aim of this paper is to identify an exhaustive list of potential challenges, limiting the adoption of OSC practices, the results of which can be taken forward to industry, for validation. To achieve this aim, a comprehensive catalogue of challenges is identified, using an SLR as the underlying method, synthesising the findings of 19 journal articles. This results in 46 potential challenges to the adoption of OSC to address the social housing crisis in Ireland, which are grouped into five themes: economic constraints, regulatory barriers, industry limitations, digital technology barriers, and cultural resistance. Potential challenges include, end-user scepticism regarding OSC quality and cost-effectiveness, cultural resistance to new methods, and the absence of a standardised evaluation tools, regulatory fragmentation, and supply chain inefficiencies. This

research offers policymakers, industry practitioners and end-users' valuable guidance to proactively address these barriers.

This study contributes at a local level by providing an exhaustive list of potential challenges which inhibit the OSC industry to consider, when addressing the social housing crisis in Ireland. At a broader level, this promotes potential research, in both OSC and social housing development in Ireland, ultimately progressing the agenda in support for the government's Housing for All policy. This research addresses an important gap in existing knowledge, where industry and academia are now provided with a catalogue of challenges to take to industry to promote dialogue and subsequent validation. Secondly, the structured identification of challenges presents policymakers, industry professionals, and stakeholders within the Irish construction sector with a targeted framework to begin addressing these challenges proactively. However, this study is not without limitations. The SLR is confined to academic journal articles within a specific database and keywords, potentially limiting the comprehensiveness of the study.

To extend this research further, it is recommended that the identified challenges are validated through direct consultation with Irish construction industry professionals, including architects, engineers, housing policymakers and modular construction specialists. Such engagement could confirm the practical relevance of the challenges, identify additional context-specific factors not covered in the academic literature and refine the understanding of OSC adoption within Ireland. Future research might also broaden the SLR criteria by including additional keywords, databases and sources such as industry reports, case studies and interviews with industry professionals, enhancing the depth and applicability of the findings; however, this is beyond the scope of this SLR.

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NO MORE CURSORY SUMMARIES: RETHINKING LITERATURE REVIEWS IN CONSTRUCTION MANAGEMENT

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Literature reviews are an ideal starting point for scholarly research in construction management. However, when conducting and presenting them, researchers should carefully consider what these reviews are intended to deliver. Are they meant as standalone contributions to knowledge or merely as catalogues of summaries for internal use during initial research phases? To examine this, we (ironically) analyse literature reviews published during the past two decades of the ARCOM conference. Our analysis of intended purposes, methods and outcomes reveals that the role of review articles is frequently reduced to cursory summaries of thematically loosely coupled domains. Few critically engage with existing knowledge, and many fail to generate novel insights. Drawing on the philosophical tenet of mereology, we illustrate that assembling fragmented pieces of knowledge into summaries results in a whole with limited value. We argue that literature reviews derive significance when their components collectively serve distinct functions, such as exposing controversial positions, challenging assumptions, and bridging research fields. By reframing literature reviews as composite objects, we aim to trigger debates on the forms and necessity of literature reviews within our community.

Keywords: literature review; classification; integration; synthesis; mereology

INTRODUCTION

Reviewing the literature is an indispensable scholarly task that enables researchers to connect their work with the cumulative body of knowledge around a specific topic and develop theoretical points of departure for their research (Snyder, 2019). Literature helps explore schools of thought on a phenomenon and understand important concepts, relations and narratives. Scrutinising the body of knowledge is often part of a larger research endeavour by a research team. Such review activities then culminate in definitions, concepts, frameworks, and methodologies supporting data collection and analysis, for instance, case studies and surveys (Kraus *et al.,* 2024).

Almost all research projects begin with literature scavenging activities with the primary intention of laying the conceptual and theoretical groundwork for the empirical part that follows. These activities educate and prepare the research team to conduct a study that aligns with ongoing scientific debates rather than presenting a

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scholarly contribution of its own. Later, they often form the basis of the theoretical sections of research papers, establishing the points of departure and framing the empirical findings.

The literature review, however, is also a distinct piece of research aimed at synthesising the work in a mature research field or providing the theoretical foundation for emerging topics, often published as standalone studies. Following review studies in medicine in the early days, the literature review has also inspired management scholars to assimilate, compare, and contrast previous findings, ultimately shaping new hypotheses, extracting previously unobserved patterns, or offering new theoretical perspectives (Barry *et al.,* 2022). They provide new disciplinary understandings to the academic community on their own. Once published, such novel scientific knowledge may substantially impact the discourses and domain's research agenda. Several review approaches have been developed and adopted across most fields, including social and management sciences to produce comprehensive, integrative, reflective and critical scientific outcomes (Kraus *et al.,* 2024; Simsek *et al.,* 2025).

Essentially, literature reviews as a first activity in a research project (i.e., to familiarise the research team with the domain knowledge) do not serve the same purpose as conducting research based on literature review methods. The former is an internal activity conducted by, and primarily for, the research team, while the latter is a comprehensive data collection and analysis activity by itself. Further, the former typically finds its way as a background section at the start of every empirical research paper. In contrast, the latter is published less frequently, especially in domains with consolidated knowledge. In short, the former primarily focuses on *educating* the researcher, and the latter focuses on *knowledge production*.

The ARCOM conference proceedings include an increasing number of literature reviews. Since the first digital proceedings appeared in the ARCOM CM Abstracts database (in 2011), the indexed and working papers database has resulted in 114 entries. Many of those are scientometric and systematic reviews recently published (Oti-Sarpong and Glass, 2024). This relatively high number of reviews is published in the small yet diverse field of Construction Management (CM). While one might expect that literature reviews are rare, the number of published reviews in our community is rising. This may be explained by the prominent 'first paper should be a review' paradigm, where particularly early-career researchers are motivated to present their research projects at a conference. Such projects often start with literature reviews. The popularity of fast-and-frugal review methods, such as systematic and bibliometric reviews, may further exacerbate this tendency.

We are certainly in favour of ARCOM being the platform for early-career researchers to present their work and get connected with our community. However, we also believe it is necessary to critically engage with the questions of what research, and especially a literature review, needs to deliver to be valuable for the construction management research community. Can they be legitimately presented as standalone knowledge contributions, or are they merely authors' catalogues of summaries necessary to form a mental model of a specific research niche? This question fuelled our aspiration to critically reflect on how existing reviews contribute to the CM research domain.

By doing so, we adopt the ontological notions of mereology, a branch of metaphysics which addresses the conditions under which multiple parts form a distinct whole

object (Inwagen, 1990, p. 30). In the case of literature reviews, this can be reinterpreted as: When do reviewed pieces of literature combine into a coherent chunk of new knowledge? We discuss two perspectives (viz., the universalist and teleological), which guided us toward the study objective of examining the content and purposes of published literature reviews. Specifically, we conducted a content analysis of the intended purposes, the methods used, and the outcomes of reviews published in the online ARCOM CM Abstracts database.

Two observations stood out. First, while literature reviews often aim for integration and classification, these efforts are rarely fully realised, leaving reviews as loosely or universally connected collections rather than cohesive wholes. Second, the presentation of the findings is often fragmented, with minimal syntheses and discussions that hide the value of the review for the wider academic field and, thus, offer limited novel insights. From a mereological perspective, reviews often fail to fulfil clear functions, which is deemed necessary to be considered as whole distinct (new) objects.

In the remainder of the paper, we briefly introduce how we selected and analysed the reviews. Next, we discuss the most striking insights, and finally, we provide remarks to spark further discussion on review papers in the CM research community.

Characterising and Analysing Reviews

Literature reviews seek to collect, combine, or contrast existing perspectives and pieces of knowledge - e.g., concepts, constructs, frameworks, and methodologies (Kunish *et al.,* 2023). However, how and when do these separate pieces cumulate into a distinctively new and meaningful whole? Mereology stems from metaphysics and centralises the Special Composition Question. This question examines the properties and shapes of material objects, by asking: "under which conditions, exactly, do a collection of materials compose something? (Van Inwagen, 1990 p.30). Or, put differently, what distinguishes a heap of parts from distinct whole objects?

From the *universalist* perspective of mereology, one may argue that any collection of parts forms a composite object (i.e., a whole), no matter how distant or different their shapes are. Not only does this include commonly recognised distinctive composite objects such as shoes, kings and cabbages but also more imaginary ones such as 'pairs of top-halfs of kings' (Bowers, 2019) and the object 'my nose and the Eiffel Tower' (Hirsch, 2002, p. 60). Building on similar reasoning, Rose and Schaffer (2017) discuss the perspectives of contact and fastening, for which it is sufficient to fasten or let components make contact for composition to take place, forming a whole.

However, many mereologists reject these perspectives as too permissive, arguing that they allow any arbitrary collection of parts to qualify as a unified entity (Bowers, 2019). Conversely, the *teleological* perspective argues that a more coherent answer to the special composition question requires composite objects to contain parts that jointly fulfil a commonly recognised function beyond the sum of its parts (Bowers, 2019; Rose and Schaffer, 2017). These objects are goal-directed, meaning their components integrate to serve a novel, specific purpose.

Following the teleological perspective, we build on Bowers (2019) by arguing that a literature review must articulate a clear purpose or overarching rationale and, as a composite object, integrate knowledge to serve a distinct function—differentiating itself from a mere compilation of prior works. Thus, we contend that a review must be more than a loose collection of fragmented 'knowledge pieces.'

We examined the stated purposes and categorised the outcomes of published literature reviews in the CM domain to analyse their function. Using the ARCOM CM Abstracts database, we collected all digitally available review papers, including proceedings (2011-present) and working papers (2017-present). A title search, along with screening abstracts and research methods sections, yielded 205 studies, of which 114 reviews relied solely on literature as their data source. We then conducted a full-text analysis to extract trends and tendencies within these 114 reviews.

We categorised each paper based on its purpose, method, and synthesis. Specifically, we classified the type of research identified, the objectives stated at the beginning of each paper, the methods used to collect and analyse the reviewed literature, and the main results, including the claimed knowledge contribution.

After extracting these elements, we coded the intended purposes. Specifically, we classified the intended purposes of each paper using the eight legitimate purposes of literature reviews defined by Kunisch *et al. (*2024): classifying, representing, problematising, configuring, aggregating, integrating, interpreting, and explaining. *'Classifying'* reviews aim to conceptually unravel a domain by mapping and allocating constructs into (sub)categories. *'Representing'* focuses on creating an overview of large, complex research fields into easier-to-understand pieces and visualisations. *'Problematising'* synthesizes the literature to describe better rivalling schools of thought, omissions in published work, or other conceptual contradictions, often leading to novel research questions or agendas. *'Configuring'* identifies and compares complex patterns of causally significant conditions across cases to refine theories about how and why outcomes emerge differently. *'Aggregating'* reviews combine standardised data from multiple studies to identify relationships and estimate effects, often through meta-analysis, providing evidence for decision-making. *'Integrating'* synthesizes insights from previously disconnected domains or paradigms to arrive at new frameworks, bridge theoretical gaps, or initiate dialogue across traditions or fields. *'Interpreting'* reviews foster a deeper understanding of concepts, fields, or theories by engaging with the meanings embedded in qualitative findings, thereby allowing for richer theoretical insights. Finally, *'explaining'* reveals underlying patterns, mechanisms, or causal links, allowing for constructing models or theories that clarify why phenomena occur and under what specific conditions or circumstances.

Once we classified the intended purpose of each review, we assessed whether its outcomes aligned with that purpose. This allowed us to determine the degree of synthesis achieved and whether the review formed a cohesive whole or remained a fragmented compilation. Finally, we reflected on the claimed contributions from a mereological perspective. The next sections discuss the insights from our analysis.

Reviewing ARCOM Reviews

Table 1 provides a quantitative summary of the stated and achieved purposes of the reviewed ARCOM literature reviews (columns 1-2), and states whether papers described the literature collection and analysis methods (columns 3-4). The following sections build on these findings, detailing the reviews' purposes, methods used, and synthesis of the findings.

Purpose

From all 114 reviewed papers, purposes were only explicitly formulated in 103 cases. Considering the eight purposes outlined by Kunisch *et al. (*2023), published ARCOM

literature reviews exhibit a slight variation in their initial framing. Table 1 presents an overview of the number of papers, allocated to the most closely related purposes within the eight categories. Notably, most papers focus on objectives related to integrating or classifying the existing literature, whereas no papers aimed to configure, one to aggregate, three to interpret and four to explain. The five most frequently occurring purposes are elaborated below.

Table 1: Overview of purposes and methodological reporting in reviewed ARCOM papers

Purpose	Reviews stating this as the purpose	Reviews achieving this purpose	Reviews describing literature collection	Reviews describing literature analysis
Integrating	48	27	24	17
Classifying	25	14	16	6
Problematising	13	10	7	4
Representing	9	6	7	3
Explaining	4	2	4	2
Interpreting	3	2	0	0
Aggregating	1	1	1	-
Configuring	0	-	-	-
Unspecified	11	-	7	3
TOTAL	114	62*	66	35

**** of the 62 that achieved their purpose, 12 can be considered whole following universalist ontology, 23 fitting the fastenist perspective and 27 a teleological.***

The purpose of 48 of the reviewed studies relates to the integration of literature. For example, one study aimed "to systematically and critically evaluate the arguments and counterarguments about disaster, crisis and emergency to date, […] to relate concepts and relevant arguments in order to advance and synthesize knowledge" (Al-Dahash, Thayaparan and Kulatunga, 2016). Such work involves integrating concepts from theoretical streams or discourses, which aligns with Kunisch *et al. (*2023). These integrations can result in new analytical frameworks and assumptions about empirical phenomena.

The second example of integration we identified involved applying a theoretical concept (such as circularity, innovation, or capabilities) to a specific theme or disciplinary topic within construction management tasks (e.g., cost assessment, knowledge sharing, or health and safety). While characterised as integration, this purpose may be on the verge of what may be called a literature study, since it relates concepts but lacks further ambitions for adding novel insights based on this confrontation between reviewed concepts.

Classification-related purposes appear as the second-most frequent category, appearing in 25 papers and manifesting in various forms. A typical example fitting the classification purpose is formulated with the following goal: "The current study aims to undertake a systematic literature review (SLR) to answer the review question of: 'what are the best practices which encourage the diversion of DW (demolition waste, red.) from landfill to promote RLSC (reverse logistics supply chain, red.) in the construction industry?' " (Wijewickrama *et al.,* 2020).

Similarly, other common classification purposes are to identify and cluster factors (success and barriers) that contribute to effective offsite prefabrication, list different lean construction practices, develop classifications of social value in the context of digitalisation, classify the application types of virtual reality tools for construction safety training; characterise different cost modelling approaches; define knowledge management strategies; assess types of circular supply and sustainable construction methods; and, provide an overview of barriers in dispute resolution methods. Generally, the classification papers share the aim of providing a comprehensive overview of the diversity of existing factors, concepts, and definitions.

While 26 studies purport other purposes such as problematising, explaining and representing, a striking number of 11 papers do not articulate their purposes clearly. Some formulated an ambiguous goal with a structure resembling the following: "This study aims to review 'X' in CM literature." In these phrases, X could be any term or phenomenon, like BIM, circularity, or construction safety. These formulations do not evidence the ambition to add specific novel insights to literature or theory. Such papers seem to align with the first type of review discussed in the introduction. These are primarily executed as starting points for further research - and follow the structures of reviews for internal use.

Declared methods

The ability to achieve the stated purpose depends on whether the research team has selected a suitable method for the review. We analysed the details that the research method sections in the various papers provided on how the review was executed in relation to the stated purpose. For each of these purposes, the third and fourth columns in Table 1 indicate how many review articles presented information on data collection and analysis.

The numbers reveal that the details of the review approach in the reviewed papers vary significantly. Around half (66) of all review articles provided details on the steps taken to collect relevant literature. These papers provide, for example, search engine names and queries, as well as inclusion and exclusion criteria and the process of narrowing down from initially screened to reviewed papers. Literature search strategies are often described in recent papers that employ a systematic literature review (SLR), typically through the popular PRISMA method. Of these, surprisingly, only 35 explain their literature analysis and synthesis procedures. This subset includes SLR papers as well as descriptions of narrative and critical review approaches. From the above, it can be derived that from 47 articles, the methodological description is either absent or too limited and just condensed into a brief mention of classifier keywords such as bibliometric, systematic, critical, or narrative analysis. In this category, we also include papers where the methodology did not support the claimed purpose (e.g., when the claimed purpose required an empirical or mixed method approach rather than solely a literature review).

Further, to culminate into a valid synthesis, review papers should address the 'data analysis step'. In other words, they ought to explain how the authors extracted meaning from papers, derived conceptual definitions, or distinguished various constructs from different studies. While the criteria that support the analysis process need to be expanded, studies describing this are limited. Only 35 explained whether or how theoretical elements from the different reviewed papers were integrated, aggregated, compared, or contrasted. This may imply that not all studies thoughtfully selected an appropriate method for their formulated purpose.

Remarkably, the deployed seem to have methods converged (while the type of purposes did not alter). In the early proceedings analysed (2010-2017) most reviews are approached as narrative reviews. In such studies, literature was selected in a less transparent way to support the development of a compelling theoretical claim. Throughout the years 2017-2024, however, many reviews employed systematic or scientometric approaches for collecting and analysing literature. In recent years, systematic and scientometric review approaches have gained dominance. Notably, we found these methods are also applied to review studies whose purposes might be better served by alternative approaches, such as critical or narrative reviews.

Synthesis

While very fact that reviewed studies were presented at ARCOM indicates they have merit for conferencing, a closer analysis of their results sections reveals that these contributions do not always constitute distinctly new knowledge. While having value for the researchers themselves - e.g., in bringing together selected literature related to grand thematic concepts like circularity, innovation, and net-zero leadership - such efforts did not often add a deeper layer of analysis to this.

Specifically, only a subset of the papers identified as reviews appeared to achieve its intended purpose of classifying (14 out of 25) and integrating (27 out of 48). A critical look at what has been classified and integrated shows that this execution is often focused on summarising the outcomes of a structured search process - for example, by providing different definitions for concepts - without engaging in or relating them in-depth. Such papers summarise literature but offer merely a kaleidoscopic catalogue of concepts and definitions.

Further, only 62 fulfilled the initially outlined purpose, meaning 52 papers did not. Of those that met their purpose, 12 contained summaries and descriptions of theoretical constructs. Why and how these constructs were selected, presented, and clustered were explained minimally. Mereologically, these studies qualify as papers fitting the universalist ontology as they do not serve one of the scientific review purposes in Kunish *et al. (*2023). Furthermore, 23 of these papers aimed to combine two or more domains, fields, or perspectives. In such studies, different disciplinary fields, societal themes, or life cycle stages are reviewed in conjunction. For example, such papers present leadership, BIM, GIS, circularity, and sustainability within the contexts of offsite manufacturing, digital innovation, or infrastructure maintenance. Instead of integrating, however, these studies discussed the concepts sequentially, with only a minimal explanation of why (not necessarily how) the theoretical elements related to one another. This ultimately means that papers with the purpose of integration did not achieve their function and merely resembled a cursory piece. These studies, at best, fit a contact or fastest mereology. In literature, both the universalist and contact/fastenist perspectives are considered not tenable and too permissive. We posit they should seldom be published as stand-alone academic contributions.

Papers that successfully synthesized findings into new insights primarily served the purpose of classification, with only a few integrating, problematising, explaining, or representing literature. In the discussion sections of reviewed papers, adequate synthesis occurs, for example, by integrating previous studies into an analytical framework - such as combining career development models with circularity assessment models - and by identifying tensions or gaps between two streams of literature - such as those related to dimensions of circularity. However, many of the reviewed discussions failed to synthesize the reviewed literature into new insights

beyond those already covered by existing works. Whether these papers exceed the status of a mere literature summary is debatable. This, in turn, raises questions about their contribution to CM knowledge, i.e., beyond what could be achieved through a quick search and summarising effort.

In essence, the analysis of purpose, methods, and synthesis shows gaps between the front and end sections of the various papers. Most studies (1) present purposes that suggest new insights through the review, but many of them still (2) fall short in realising these purposes since their outcomes did not reintegrate the reviewed work within the theoretical debates which they build upon. These points highlight the importance of a literature review being a coherent whole rather than a loose collection of theoretical elements. Below, we further discuss what this could mean for the practices of literature reviews in CM research, and ARCOM specifically.

The Future of Reviews in CM

We started this paper with the question: Can literature reviews for ARCOM be legitimately presented as standalone knowledge contributions? Or: Are they merely authors' catalogues of summaries and mental models, useful only as a starting point for their subsequent empirical study? Our findings imply that a fair share of the papers misses a critical engagement with the literature and previous knowledge. Reviews were frequently reduced to summaries of thematically loosely coupled domains. Even when ambitious purposes or aims were formulated - such as developing frameworks or critical examinations of domains - many did not or only partly succeed in achieving those.

Concluding this, we build further on the point made by Oti-Sarpong and Glass (2024), who issued a "provocation to the field and supporters of scientometric reviews to reconsider the value that such exercises contribute to the [CM] domain" (p. 297). Considering that the purposes of reviews should reach beyond such kaleidoscopic pieces of knowledge, critical reconsiderations are needed on the types of review papers that should be pursued, executed, and accepted for ARCOM.

Mereology (cf. Simons, 2000; Bowers, 2019) may provide grounds for such critical reconsiderations. This domain in metaphysics examines when a set of parts forms a distinct composite whole and proposes a range of answers. From the universalist perspective, all parts can always form a whole with any other, irrespective of their position and utility. From the connect or fastenist ontology, parts must at least be placed or fixed together to form a whole. However, from a teleological ontology, parts only form a whole if they fulfil a function beyond the sum of its parts. Considering the part-whole relationship in literature reviews from a teleological ontology, we argue that a literature review is not merely an assemblage of prior studies but must serve a distinct function that cannot be achieved without it (Kunisch *et al.,* 2023). Viewed this way, reviewed papers act as integral parts whose collective synthesis contributes to a meaningful whole. In CM research, this implies that reviews should go beyond curating existing knowledge to generate novel insights by structuring and interpreting literature in ways that advance understanding.

By reframing literature reviews as composite objects, the value of a review lies not only in its composition but also in its emergent function - generating new insights and enhancing the academic system's capacity to grow. Thus, a good review paper is a purposeful, integrative, and synthesising endeavour that connects, clarifies, and advances scholarly understanding.

To avoid literature becoming mere cursory summaries or ill-structured connections between explored definitions and concepts, we first argue that CM scholars, before starting to write a review paper, need to consider the intertwinement between the purpose of the review and available review methods. From all approaches out there, each has specific traits. For example, bibliometric reviews should not be conducted on a sample of a few dozen papers since this does not provide comprehensive, statistical and representative results. Yet, such a volume of papers may still be analysed in, for example, a deep and qualitative critical review approach. Second, we encourage providing transparency in the reported research steps, not only regarding the literature search but also the process of analysing papers and reaching synthesis. This includes providing details about how the content of the various papers has been discriminated, compared, and related, as well as how these culminated in novel insights during the review process.

While our analysis may support the assertion that the current ARCOM paper format does not lend itself to comprehensive and rigorous literature reviews, this does not imply that literature reviews are unsuitable for the ARCOM community. The current format inherently prioritises conciseness over detail, a constraint not exclusive to literature reviews but also applies to empirical studies, which cannot be presented in extensive detail. Both literature reviews and empirical papers should offer submissions with intriguing, controversial, or debatable findings that ignite interest and stimulate discussion during the conference. At a minimum, these papers should briefly outline review methods and may present only a selection of the review outcomes. This leaves room for the most interesting component of the review: the final synthesis.

Apart from these challenges in publishing reviews as ARCOM proceedings, we observe another tendency that may explain the lack of reviews that, in a structured and methodologically justified manner, synthesize existing knowledge and generate novel insights. In many groups and universities, it has almost become a rite of passage, particularly for early-career researchers, to begin their research work by executing and, preferably, publishing a literature review. This 'first-paper-should-be-a-review-paper' paradigm results in situations where the review becomes a necessary, quick check-box activity rather than a distinct and complex piece of research aimed at finding new theoretical or conceptual insights. To change this practice, established structures and constraints that many PhD trajectories are often forced into may need to be reconsidered.

Another reflection on the proliferation of 'fast cursory review practices' is the rise of quick, comprehensive generative AI applications that have the potential to support or even replace much of the traditionally labour-intensive work involved in collecting and analysing scientific papers. These technologies could benefit 'internal reviews,' which often serve as catalogues of summaries and mental models primarily intended to aid scholars in further data collection and analysis. While we do not advocate for replacing human labour with machines, we argue that human effort could be refocused on the more intellectually demanding step: synthesis. By shifting attention to synthesis, there is more potential for producing novel contributions that are truly impactful and relevant to the broader field of CM.

Finally, we acknowledge the limitations of the reflection process. Our research drew on the ARCOM CM Abstracts database, which only represents a limited (and arguably non-representative) portion of the existing literature reviews in CM.

Therefore, our tentative conclusions might carry less weight than those in esteemed scientific journals. This paper itself is far from an exemplary piece in a textbook on literature review practices; several of our critics and implications may also be relevant to our paper. Nevertheless, we hope to spark the debate on the role and approaches to reviewing papers in the ARCOM community.

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PEDAGOGIC RESEARCH

NAVIGATING BIAS IN APPRENTICESHIP RESEARCH: A REFLECTIVE CASE STUDY

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Researcher bias can significantly impact the validity and reliability of studies, particularly when the researcher has a particular interest in the subject. This paper uses a doctoral research project on apprenticeship completion in Ireland's built environment sector as a methodological case study to examine how bias and subjectivity were identified and mitigated. Given the researcher's active role in the field, the potential for bias is heightened, making it essential to address this challenge. Drawing on reflexive practices, including journaling and visual mapping of positionality, the paper explores how bias awareness was developed and addressed. While these strategies will be essential in future stages of apprenticeship research, the aim of this study is to highlight the necessity of these measures in mitigating bias and ensuring objective findings. By offering practical tools for identifying and mitigating bias, the study contributes to growing calls for reflexive, values-aware approaches in education research and provides guidance for future apprenticeship studies.

Keywords: Apprenticeship completion; built environment; researcher bias; vocational education; training

INTRODUCTION

Apprenticeships play a crucial role in developing essential skills within the further and higher education sector, serving as a bridge between theoretical knowledge and practical, hands-on experience. To participate, apprentices must be employed under a formal contract, with at least 50% of their training occurring in the workplace to ensure direct engagement with real-world tasks (Generation Apprenticeship, 2020). Out of the 79 apprenticeship programmes available in Ireland, eight are dedicated to the built environment sector, covering trades such as brick and stone laying, carpentry and joinery, electrical work, painting and decorating, plastering, plumbing, stonecutting and masonry, and wood manufacturing and finishing. These programmes typically span at least four years and follow a seven-phase, standards-based training model, which systematically alternates between workplace learning and structured off-the-job instruction (O'Connor, 2006). Beyond individual skill development, apprenticeships contribute significantly to workforce sustainability, economic growth, and industry innovation by ensuring a steady supply of skilled professionals.

This paper uses a doctoral research project from the University of Limerick which focused on apprenticeship completion in the built environment in Ireland as a methodological case study to explore how insider bias and subjectivity were actively

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acknowledged and mitigated throughout the research process. Rather than reporting on substantive findings of that doctoral study, the paper reflects critically on the design, conduct, and interpretation of research undertaken by an insider-practitioner.

Few studies explore the positionality of researchers who are themselves insiders to the apprenticeship ecosystem. Insider researchers like those who study contexts in which they are professionally embedded, bring unique perspectives but also face challenges in maintaining analytical distance.

Insider Research, Positionality and Reflexivity

Insider research occurs within a group or organisation to which the researcher belongs. Merton (1972) defines an insider as someone with prior intimate knowledge of a community, though "community" extends beyond just organisations, and such knowledge doesn't always require direct membership. In contrast, outsider research involves studying a setting and people unfamiliar to the researcher, a perspective traditionally celebrated in academic literature.

Many researchers do not always explicitly acknowledge their own positionality. Greene (2014) underscores the value of reflective and reflexive practices in insider research, emphasising their role in navigating data collection and analysis to achieve deeper introspection and authenticity. These practices enable researchers to minimise bias, enhance ethical integrity, and ensure the trustworthiness of their data. A key strategy involves maintaining a research journal, documenting reflexive thoughts, methodological adjustments, and any emerging biases that may influence findings.

Reflective approaches, particularly in education, have gained prominence through professional doctorate programs such as the Ed.D., which encourage practitioner inquiry within institutions (Hellawell, 2006). These programmes value the integration of professional experience with research practice, reinforcing the need for rigorous and ethical engagement with positionality. This broader context informs the current study, emphasising rigorous methodologies that address researcher bias and positionality in apprenticeship research.

Researcher Background

With nearly 30 years in further education and training, including nine in apprenticeships, the researcher brings extensive experience and established industry relationships. This insider perspective provides access to key apprenticeship datasets and direct engagement with companies and apprentices. Such privileged access allows for more in-depth data collection and a nuanced understanding of workplace dynamics, which external researchers may struggle to obtain. However, it also presents challenges, such as potential conflicts between professional duties and research responsibilities. Striking a balance between these roles requires careful ethical consideration and transparency in research practices. While insider status grants unique access to participants and data, it also necessitates rigorous self-awareness to avoid reinforcing pre-existing assumptions. Furthermore, it evaluates various strategies designed to mitigate the effects of bias, ensuring that research outcomes remain objective, credible, and valuable to the wider academic and professional community.

Adding complexity, the researcher is also an apprentice, currently pursuing a Principal Engineer Doctorate apprenticeship. This lived experience offers first-hand insight into the academic and practical challenges apprentices face. Unlike detached

observational studies, this research is embedded within the system it evaluates; thus, rigorous reflexive strategies are essential to mitigate bias.

Despite these challenges, the insider role offers a unique lens that external researchers may lack. The ability to engage deeply with the subject matter allows for a nuanced understanding of the apprenticeship system. This deep engagement can be leveraged to uncover underlying systemic issues that might be overlooked in traditional research approaches. By adopting reflexive practices, such as critical self-examination and transparent methodological choices, the study ensures a more balanced and rigorous approach.

Research Problem

Researcher bias occurs when a researcher's personal beliefs, values, or expectations distort the study's results or interpretations. Researcher bias may present itself in multiple forms: (1) professional role bias, stemming from the researcher's position within the education and training sector, which may shape interactions with participants; (2) personal experience bias, as the researcher is an apprentice herself, potentially influencing interpretations based on lived experience and that relationship with her clients; and (3) researcher bias, due to developing methodologies in research and interpreting results. Each of these biases introduces challenges in maintaining neutrality, requiring proactive mitigation strategies.

As described by Buetow and Zawaly (2022), researcher bias represents a predisposition to think in a specific manner, which can either obscure or illuminate efforts to address research questions. Unlike traditional research where the researcher is fully external, this study involves deep professional and personal immersion in the subject matter. This positioning presents both advantages such as access to rich, firsthand insights and challenges, particularly in maintaining objectivity. Without careful management, bias could impact data collection (e.g., how questions are framed), participant responses (e.g., social desirability bias due to the researcher's professional role), and analysis (e.g., subconscious preference for findings that align with personal experience or opinion).

This paper aims to critically examine how researcher bias and positionality can be identified, visualised, and mitigated in insider-practitioner research. Framed within a doctoral case study focused on apprenticeship completion in the built environment in Ireland, the paper reflects on the methodological processes involved in conducting research from within a system the researcher actively participates in. Rather than reporting empirical findings, it explores how methodological rigour and reflexive strategies were used to manage the complexities of dual researcher roles.

The following research objectives guide this investigation:

1. How can potential biases within this research stemming from the researcher's various perspectives be effectively visualised?

2. What modifications can be made to the research methodology to reduce the impact of insider bias?

METHOD

This paper adopts a reflexive, first-person methodological approach to critically explore and manage insider bias in a doctoral research study on apprenticeship completion in the Irish built environment sector. The aim is not to present the substantive findings of that study, but to use its design and conduct as a

methodological case study to examine the challenges and strategies involved when the researcher occupies multiple insider roles.

The original doctoral study employed semi-structured interviews, documentary analysis, and descriptive statistics to investigate factors influencing apprenticeship completion. The researcher's role as both a professional in the further education and training sector and a doctoral apprentice necessitated particular attention to positionality, bias, and ethical complexity throughout the research process.

A key innovation in the methodological design was the creation of a data visualisation tool, a Venn diagram mapping the researcher's overlapping roles (professional, researcher and personal). This visual model served as both a planning and reflective device. It made visible the multiple identities shaping the researcher's perspective and helped anticipate where role conflicts or biases could emerge during data collection and interpretation. The diagram evolved alongside the research, capturing the dynamic nature of researcher positionality over time.

RESULTS

This section presents two key methodological outcomes of the study. First, a visual model was developed to illustrate the intersecting sources of potential researcher bias arising from multiple insider roles. Second, a series of methodological modifications were implemented to reduce the influence of such bias, thereby enhancing the credibility and trustworthiness of the research process.

Creating a Bias Visualisation Model

To conceptualise the overlapping roles held by the researcher, a Venn diagram was adapted from the logical set theory introduced by John Venn (1880). Using overlapping circles, he illustrated how to visualise logical relations, with each region representing unique or shared elements between sets (Venn 1880).

Figure 1 maps the interplay between three intersecting domains: professional, researcher and personal. One circle representing the researcher's position as an insider in the apprenticeship system, emphasising knowledge, established relationships, and access to data. The second circle represents the role as a researcher, focused on objectivity, academic integrity, and the application of rigorous methodologies. The third circle concerns the personal experience as being an apprentice and passion for this subject. The central intersection symbolises the depth of understanding afforded by an insider-practitioner perspective, but also underscores the potential for bias when professional, academic, and personal interests converge. This model served as a reflective tool throughout the research process to support awareness of positionality and its implications for study design and interpretation.

Modifications to the Methodology to Reduce the Impact of Insider Bias

Throughout this research, the researcher has employed various methodologies, which have been documented in peer-reviewed papers and publications (McMahon *et al.,* 2022; Ryan *et al.,* 2022; McMahon *et al.,* 2023; O Neill *et al.,* 2023). A series of methodological strategies were integrated into the study to address and mitigate the influence of researcher bias. Table 1 summarises these strategies, outlining the specific methods used and the corresponding bias-reduction techniques.

Taken together, these practices reflect a deliberate effort to uphold academic rigour while acknowledging the unique complexities of insider-practitioner research. These practices reflect a deliberate effort to uphold academic rigour while managing the

complexities of insider-practitioner research. Engaging critically with positionality and bias was not always easy.

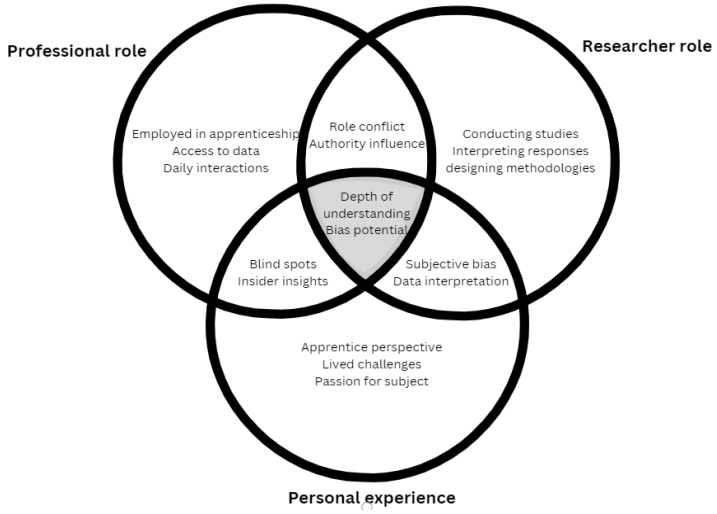


Figure 1: Venn diagram visualising professional and researcher roles along with personal experience.

During one focus group, I became aware of anticipating responses based on apprentices' company types—expecting more measured views from those in semi-state firms and more critical ones from others. This highlighted how my assumptions could shape interpretation. Additionally, I noticed feelings of frustration arising as apprentices discussed their wages. Knowing that other apprentices in lower-paying companies accepted their conditions without complaint, I had to consciously check my emotional response to avoid allowing it to bias the analysis. These experiences reinforced the importance of maintaining self-awareness and reflexive journaling to document and mitigate such moments of insider bias.

DISCUSSION

This study offers a critical methodological reflection on managing researcher bias within insider-practitioner research, using a case study on apprenticeship completion in the Irish built environment sector.

This paper contributes to bridging that gap by developing and applying a bias visualisation model and incorporating rigorous reflexive techniques across the research process. This study echoes the call by Eitzel (2023) for more reflexive, values-oriented approaches to research, particularly in applied fields. Just as Eitzel uses autoethnography to examine how personal values shape modelling practices, this paper deploys visual and methodological tools to explore how insider status and positionality influence educational research design.

In insider-practitioner research, boundaries between these roles are often blurred, making objectivity difficult to define, let alone achieve. The visual model presented here is not merely illustrative but diagnostic, offering a structured mechanism for reflecting on where and how bias may manifest and served as a continuous reminder to the researcher to challenge their assumptions and minimise unconscious bias . Recognising bias alone is insufficient; action must follow. This study implemented several methodological adaptations, including pretesting, triangulation, and exploratory piloting, which echo best practices in mitigating insider influence.

Table 1: Overview of bias- reduction methods employed in doctoral study

Methodology	Bias Reduction Strategy
Literature Review	A comprehensive review of diverse sources (e.g. government reports, journal articles, publicly available data) helped expose the researcher to multiple perspectives, reducing personal bias by broadening the knowledge base. This also helped identify biases in previous studies, guiding more objective methodology.
Reflective Journal	Reflexive techniques including a reflective journal and peer debriefing were employed to counteract these risks, such as unconscious bias, over-identification with participants, and challenges in maintaining a neutral perspective.
Exploratory Study	A smaller exploratory ex post facto study was employed using just 60 participants to help direct the larger study of 225 participants, allowing for the identification of potential biases, and testing of analysis. This preliminary phase also provided valuable insights for ensuring more accurate and reliable data collection in the main study.
Ex Post Facto Research	This approach relies on secondary data analysis, meaning the researcher does not manipulate variables or conditions. This reduces the risk of researcher-induced bias because the researcher cannot influence the data, ensuring a more objective examination of causal relationships based on real-world evidence.
Pretesting Questionnaires	Pretesting of online questionnaires with professional and academic colleagues helped identify any ambiguous, leading, or biased questions. Feedback from pretest participants refined question wording and structure, ensuring clarity, neutrality, and reliable data collection.
Focus Groups	Focus groups encouraged interaction between participants, which allowed for a diversity of perspectives on apprenticeship completion. The researcher actively monitored group dynamics to ensure all voices were heard and no single participant dominated the conversation, reducing bias from group interactions.

These practices not only improved the clarity and neutrality of data collection tools but also encouraged a more pluralistic understanding of apprenticeship completion, incorporating perspectives from both apprentices and educators. This study not only examines how to minimise bias but also contributes to the broader discussion on balancing subjectivity and credibility in apprenticeship and other research.

Drawing on Van Maanen's (2011) concept of "confessional tales" in ethnography, this paper acknowledges the deeply personal nature of insider research. While this study does not fully adopt the confessional tale genre—which involves overt self-disclosure and narrative intimacy—it shares the core aim of reflexively examining the researcher's positionality and the emotional and ethical challenges encountered in the field. Incorporating Van Maanen's insights encourages transparency about the researcher's experiences, highlighting how insider status shapes both data collection and interpretation, and reinforces the importance of reflexivity in mitigating bias.

Peer review was not just a dissemination strategy but a methodological safeguard. The researcher published multiple studies from the doctoral study that underwent double-blind peer review, reducing the risk of personal influence by subjecting findings to external scrutiny. This independent validation strengthened the study's credibility and objectivity.

CONCLUSION

This study highlights the critical importance of recognising and addressing bias in research, particularly when the researcher has a dual role as both an industry professional and an academic. Heightened awareness of potential biases allowed for the implementation of proactive measures to enhance validity and reliability at each research stage. Recognising that complete objectivity is unattainable, this research instead prioritised transparency, self-awareness, and methodological rigor to maintain credibility. By acknowledging conflicts of interest and adopting rigorous, transparent methodologies, this study ensures a more objective examination of apprenticeship completion.

Beyond identifying bias, this research contributes to the broader discussion on methodological rigor in apprenticeship studies. Employing strategies such as reflexivity, structured self-reflection, and peer review reinforces the credibility of findings. It highlights the importance of researcher positionality, showing how background, experience, and professional role can influence research outcomes. Additionally, it emphasizes the need for transparency, reflexivity, and rigorous methodological design to ensure credible and trustworthy research.

Moving forward, continued efforts to refine methodologies, diversify research samples, and incorporate longitudinal studies will further strengthen the validity of apprenticeship research. By maintaining transparency and rigor, future studies can provide evidence-based insights that inform policy and enhance apprenticeship success within the built environment sector.

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EXAMINING THE PERCEPTION OF QUANTITY SURVEYING STUDENTS DURING MEASUREMENT OF CONSTRUCTION WORKS WORKSHOP SESSIONS

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Quantity surveyors are important professionals who deal with the cost aspect of the construction industry. Their training involves modules such as the measurement of construction works. Some students encounter various challenges in learning the measurement process; hence, workshop sessions were introduced to enhance students' learning. This study aims to understand the effectiveness of these workshop sessions on students' learning experiences. A UK university offering Quantity surveying courses was used for this study to have in-depth analyses. Quantitative and qualitative methods were used to access data. Statistical and thematic analyses were used to analyse the data. The study established that measurement workshop sessions were a pivotal tool in students' learning, and instructors play an essential role. However, the study identified challenges such as an insufficient inclusive learning environment and a large class size. The study established that these sessions could be improved by introducing measurement software, more drawings, a small class size, and an inclusive learning space. This study will help improve institutions' measurement modules and curriculum that train Quantity surveyors.

Keywords: construction; measurement workshop; pedagogy; quantity surveying

INTRODUCTION

Measurement of construction works is a module in the Quantity Surveying and Commercial Management courses at both undergraduate and postgraduate levels. This module estimates construction project costs by utilising construction technology/processes to produce construction costs. Issues related to the success of this module have been identified, they include the fragmenting of teaching and learning in the curriculum (Williams *et al.,* 2010), inadequate skills development, inadequate teaching and learning resources, unqualified teachers, and a dearth of linkages in different educational levels (Razali *et al.,* 2024a). Ostrowski *et al.,* 2011 and Tunji-olayeni *et al.,* 2021 categorised these issues into; process (inadequate understanding of the sequential process), calculations (issues with numerical calculations, technology (inadequate understanding of the building process), rulings (inadequate understanding of the specialist paper), standard method of measurement (inadequate understanding of the utilisation of the rule books) and speed (speed of

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teaching and learning either too fast or too slow). Based on the perspective of teaching a model postulated that measurement students would achieve quality learning and higher success rates, when the lecturers possess four tenets, namely, the characteristics of the teacher, course content, delivery strategy, and assessment methods (Gurmu and Mahmood 2021).

From the learning perspective, the measurement of construction works is a core module in QS educational training. However, some students encounter various problems while learning these modules (Tunji-olayeni *et al.,* 2021). The contributing factors to the difficulty in learning measurement by students include insufficient prior knowledge of construction technology, insufficient learning resources, and inappropriate teaching style (Gurmu and Mahmood 2020).

Measurement modules are perceived as complex because they require prior knowledge of Construction and Mathematics (Gurmu and Mahmood, 2020) and the intense calculations involved in the different stages of calculating each construction section of work (Ostrowski, 2011); there are more records of students failing measurement modules compared to other QS modules (Gurmu and Mahmood, 2020). Several authors have established that an inefficient learning process could contribute to producing incompetent QS graduates (Adekunle *et al.,* 2019; Hanapi and Nordin, 2014).

Measurement workshop sessions were introduced to improve learning efficiency and passing rates (Lee, 2013). These sessions are platforms where students have practical experience of what they were taught in class. A tutor is assigned to guide the process and provide students with practice drawings and workshop tasks, in some institutions, logbooks are used to assess students. This process has improved students' measurement skills and passing rates. While the use of measurement workshop sessions is pivotal in QS curricula, few studies have critically evaluated these sessions through the lens of the students (Gurmu *et al.,* 2020), more so, limited studies have acknowledged the use of workshop sessions for effective learning and more can be done to address the pedagogical issues associated with teaching measurement (Razali *et al.,* 2024). Therefore, this study advances by identifying the pedagogical and operational challenges that students experience during measurement workshop sessions and proposes ways of improvement.

MATERIALS AND METHODS

The methodology outlined the strategy used to achieve the study's objective. The philosophy, approach, strategy, choice, time horizon, and techniques were used for this study (Saunders *et al.,* 2009). Excel was used to carry out both quantitative and qualitative analyses.

Methodology: Interpretivism as the research philosophy was applied for this study to explore the learning experiences of QS students during measurement workshop sessions. The focus is to understand the perception and experiences of individuals within a particular context (Saunders *et al.,* 2009). An inductive research approach was used for this study to explore the learning experience of QS students for the qualitative analysis, however, a deductive approach with pre-defined hypothesis was used for the quantitative analyses. This study collected data to generate theories. A mixed method was used for this study; the qualitative research method explored the subjective experiences and in-depth insights of QS students' experiences. This approach explores complex feelings, opinions, and perspectives (Saunders *et al.,*

2009). A case study research strategy was employed to focus on a specific set of students in a university with experience in measurement workshop sessions. This strategy encourages in-depth exploration of students' experiences, context, and interaction in a particular setting.

Semi-structured interviews and questionnaires were conducted with a 5 sample of students to explore their experiences, feelings, and thoughts about the measurement workshop sessions. The questions asked in the interview focused on the student's perception of the importance of the workshop sessions to aid their learning, their faced challenges, their impact on their theoretical knowledge, and what they thought could improve their learning experience during the workshop sessions. The interview provided a rich narrative about personal learning experiences. The interview participants were selected using purposive sampling, targeting year 4 and 5 students who have experienced at least two measurement workshop sessions. These students were chosen based on their firsthand experience with these sessions, the sample size was 5, this is established as sufficient as suggested by Braun and Clarke, 2013; Morgan *et al.,* 2002.

The data from interviews were analysed using content and thematic analyses. This involves coding to identify patterns, themes, and recurring issues in the experiences of students. The data was transcribed, initial codes were generated, themes were identified and reviewed, and finally, a thematic map was produced. Due to the qualitative nature of the data collection process, the findings may be subjective and will be based on the student's perception. Efforts will be put in place to reduce this by triangulation and the use of a sufficient number of respondents. The relatively small sample size for interviews could limit the generalisation of the findings. However, this study seeks an in-depth understanding rather than a broad generalisation.

For the Quantitative analysis, data was acquired from 23 respondents using random sampling techniques. The questionnaires were used to access additional views of QS students during the measurement workshop session. A random sampling technique was used to achieve this, and it is a sufficient method of representing a large population size (Hossan *et al.,* 2023). The quantitative approach validated the result of the qualitative analysis by using inferential statistics, this was done to have a comprehensive understanding of the data acquired. Z-test and Chi-square test were used to analyse the quantitative data (Akingbade and Bello 2018) and the formulas are shown in equations 1 and 2, respectively.

Z-test was used to compare two proportions specifically: improvement and challenges in measurement workshops.

$$Z=\frac{P_1-P_2}{\sqrt{(p(1-p))\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}} \quad \text{eqn 1}$$

Where P1 and P2 are proportions from samples 1 and 2 respectively and n1 and n2 are sizes of samples 1 and 2 respectively.

The chi-square test was used to determine significant differences between observed and expected frequencies particularly; the improvement required, and challenges faced in measurement workshop sessions, respectively.

$$X2 = \sum \frac{(O_i-E_i)^2}{E_i} \quad \text{eqn 2}$$

Where Oi is the observed frequency, Ei is the expected frequency, and ∑ is the sum of the overall categories.

RESULT AND DISCUSSION

We conducted interviews with five Quantity Surveying (QS) students. All had reached the penultimate or final year of university study at a UK university, and each had completed a semester of measurements of building works workshop sessions and others had completed Advanced measurement workshop sessions. The sample included three males and two females, all ranging in age from 21 to 24. To maintain anonymity, all participants will be referred to as QSS01 to QSS05.

Thematic findings: The thematic analysis revealed five key themes and some sub-themes in Figure 1 that capture the perceptions of QS students during measurement workshops. The five main themes included Workshop structure and environment, Skills development, Challenges and support, Engagement and learning preferences, and Assessment and feedback.

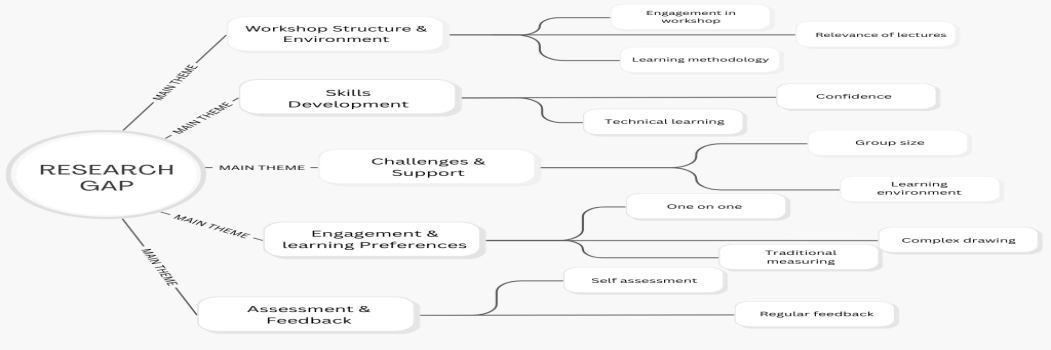


Figure 1: Thematic Map of Main Themes and Subthemes

Theme 1. Workshop Structure and Environment: The participants' encounter with the measurement workshops, including the teaching methods and organisation of the workshop process, certainly shaped their learning experiences. Three sub-themes were identified: relevance of lectures, engaging in workshop sessions, and teaching methodology:

Sub-theme 1a: Relevance of lectures: One participant stated that lectures are tailored to match the workshop activities. Students seemed to perform better when lectures offered appropriate measurement guidance as building blocks to the more complex tasks awaiting them before the workshop sessions.

> 'We work on applying the knowledge that we acquired during the lecture, in a practical sense, to get a sense of what the exam would be like.' (QSS01).

Sub-theme 1b: Engagement in the workshop: Both content delivery and session dynamics influenced engagement. Some participants reported that they engaged more during workshop sessions than during lectures because the content was presented in manageable chunks.

> 'I found the lecture is always quite informational, but the workshops are a bit more practical and engaging because we solve practical questions which help me to engage more with what happened during the lectures.' (QSS05). This study established that students preferred hands-on learning and interactive learning.

Sub-theme 1c: Learning Methodology: Some participants thought about the various workshop instructional techniques, such as guided training, drilling, and teaching in small groups.

> 'I preferred the smaller groups as they allowed for better engagement and made learning easy for me.' (QSS02)

Lectures are an effective strategy in higher education learning; however, it requires adapting to the dynamic needs and expectations of students (Hotarenko *et al.,* 2024). Since measurement involves complex calculations and processes, it is pertinent that the lecture content is elaborate and sizeable for better student assimilation. Adequate preparation, presentation, and application are essential in measurement lectures for better assimilation by students (Razali *et al.,* 2024b). This learning process is relevant; however, the process of delivery also matters and could lead to achieving a positive or negative outcome (Loughlin and Lindsay, 2023).

Theme 2. Skills development: Theme 2 captures the skills students gain or develop during the workshop. The subthemes under this were confidence and technical learning.

Sub-theme 2a: Confidence: The workshop context, especially regarding opportunities for practice and role-playing, helped students gain readiness beyond assessment, fostering enhanced professional preparedness.

> 'I think they're almost more side by side with the lectures, but they are very beneficial, give you a bit more confidence in the ability to do a certain measurement or subject.' (QSS01).

Sub-theme 2b: Technical Learning: Some participants emphasized the importance of going through real-life scenarios, which not only contextually framed the teaching but also helped reinforce the skills being taught at a theoretical level through their application.

> 'I applied the skills I learnt in measurement during my internship, and I saved the company £500,000 by identifying errors in measurement for a large-scale window installation.' (QSS02). 'Measurement skills are highly relevant to the work I am doing and I applied them to my work'(QSS03).

The main idea of the workshop is to improve skills development in measurement, this can be achieved by developing a good curriculum and efficient technical learning environment in turn improving the employability of QS graduates, these skills are important to sustain the QS profession (Mohammad and Abd Hafizd, 2021).

Theme 3. Challenges and Support: This theme encompasses the barriers that students faced during the workshops alongside the enabling factors that shaped their learning. The two sub-themes that stand out are group size and learning environment.

Sub-theme 3a: Group Size: One participant highlighted concerns about the number of students per workshop. A large group size restricted the opportunity for individualised attention and feedback from the tutors.

> 'Larger groups in workshop sessions created difficulties such as overcrowding, distractions and reduced individual interaction with the instructor.' (QSS01).

Sub-theme 3b: Learning Environment: The physical and pedagogical environment also served to construct the learning experience.

> 'I would say probably the lecturers, just because they are willing to answer all questions… they just stopped to make sure everyone is on the same page like they wouldn't continue until people just gave them a little bit of an indication as to what they were thinking.' (QSS04).

A conducive environment was a positive factor for measurement learning (Tunji-Olayeni, *et al.,* 2021). Smaller group size is an essential requirement for better learning (Razali *et al.,* 2024). The study found that the block that had smaller workshop sizes performed better than those that had larger class sizes, there was a

20% improvement in grades achieved. This could be attributed to a better understanding of the module via one-on-one engagement in workshop sessions and a better understanding of the complex measurement topics due to a better workshop environment (Tunji-olayeni *et al.,* 2021). However, some students might indicate affirmation that they understood the lecture and fail the exams afterward and other students are shy of asking questions in front of their peers (Razali *et al.,* 2024). These were addressed during workshop sessions as one-on-one explanations from the tutors were provided.

Theme 4. Engagement and Learning Preferences: Theme 4 analyses ways in which students interacted with the content of the workshop and their preferred methods of learning. Three sub-themes emerged: one-on-one, complex drawing, and traditional measuring.

Sub-theme 4a: One-on-One: The one-on-one verbal instructions offered by tutors during workshops were considered extremely useful for maintaining attention, understanding concepts, and enhancing learning during the classes.

> 'I enjoyed the one-on-one tutor interaction.' (QSS03)

Sub-theme 4b: Complex Drawing: One participant argued that sophisticated drawing should be used during the measurement workshop to reduce some of the frustration associated with understanding drawing.

> 'I would prefer more complex drawings used during workshop sessions.' (QSS02)

Sub-theme 4c: Traditional Measurement: One participant preferred the traditional methods of hand measurement. He regarded these methods as crucial to understanding measurement and measurement logic.

> 'I would keep the traditional measurement process because it allows students to understand the background history and first principles of QS.' (QSS01).

Most QS students are kinaesthetic learners (Kamarazaly *et al.,* 2020) therefore a clear workshop setup is essential in learning measurement with a clear framework of rules and procedures, this will make the time allocated for the session more productive, especially when one-on-one interaction is required vis a vis class size (Razali, 2024). Furthermore, adequate study drawings are significant in the effective learning of measurement (Tunji-Olayeni *et al.,* 2021). However, utilising complex drawings will be beneficial to brilliant students or apprentices. Nevertheless, care must be taken when having a combined class of experienced, non-experienced, and students with diverse learning abilities.

Complex drawings could be provided to support fast learners and apprentices as additional learning materials. Traditional measurement is essential in measurement even with the advent of technology/software because traditional knowledge is still required when using QS software (Soon *et al.,* 2023; McDonnell, 2010). However, this does not stop the use of digital tools to improve measurement workshop sessions because the construction industry is dynamic and requires the use of contemporary technology to stay relevant (Mohammad and Abd Hafidz, 2021).

Theme 5. Assessment and Feedback: This theme summarises learners' views on the impact assessment and feedback had on their learning and self-efficacy during the workshops. The two identified sub-themes were self-assessment and regular feedback.

Sub-theme 5a: Self-assessment: One participant mentioned self-evaluating to be "on the right track" by comparing their work to peers or model solutions provided.

> 'I like the self-assessment through comparing answers with friends, and extra guidance by the tutor' (QSS04).

Sub-theme 5b: Regular Feedback: Some participants pointed out that regular feedback or comments the tutor provides greatly increase their learning and confidence, especially when preparing for summative evaluations.

> 'I appreciated the regular feedback after workshops, which helped me in identifying errors in calculations and improved my understanding of measurement.' (QSS02)

> 'I love the constant One-on-one feedback from tutors.' (QSS03).

Feedback is essential in measurement learning and it helps students to understand their flaws and where to improve (Kamardeen, 2015). Interaction with tutors and peers can improve their learning process (Yap *et al.,* 2022). However, this must be closely monitored as students can copy from peers and sometimes become free riders especially when group activities are involved (Razali *et al.,* 2024a).

Statistical Analyses: Based on the statistical analyses, 70% of respondents were male, 30% of respondents were females, and 96% of respondents had attended more than one measurement workshop session. 78% of the respondents believe that the measurement workshop session has improved their measurement skills.

These figures outline the disparity between the number of genders in QS modules, even though, the analyses did not reveal any difference between male and female perceptions of the importance of workshop sessions which was also the case in a previous study (Preszler, 2009). Figure 2 shows that 43% of the respondents had an average understanding of the measurement of construction works before attending the workshop sessions, while 33% had poor construction background knowledge. This could be attributed to more apprentice students in the module who have some QS work experience. Inferential statistics were conducted for further analysis, and the results are shown in Table 1.

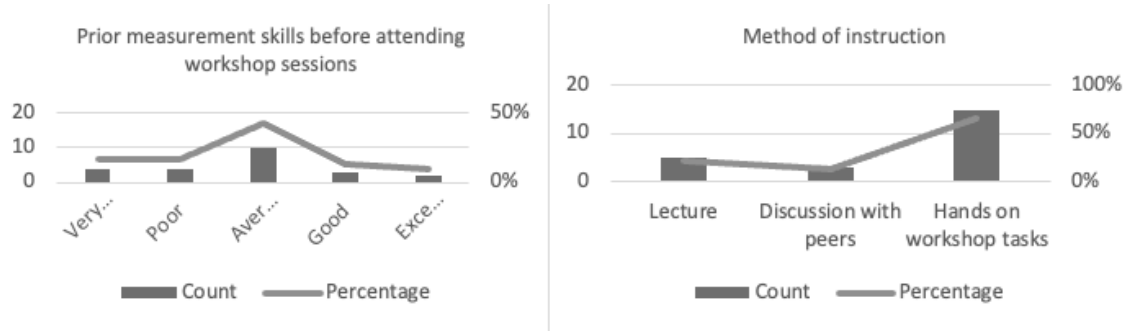


Figure 2: Prior Measurement Skills and Method of Instruction for Measurement

The statistical analyses in Figure 2 also established that interaction with peers (13%) was not as important as the hands-on experience (65%) during the workshop sessions, which was contrary to a previous study for a science module (Preszler *et al.,* 2009). This establishes the kinaesthetic nature of QS learners (Ooi and Loo 2025) and buttresses the need for sustaining measurement workshop sessions. Even though the class size had more frequencies in terms of importance in Figure 3. The Z-test and Chi-square test were conducted to assess the significance of the preferences.

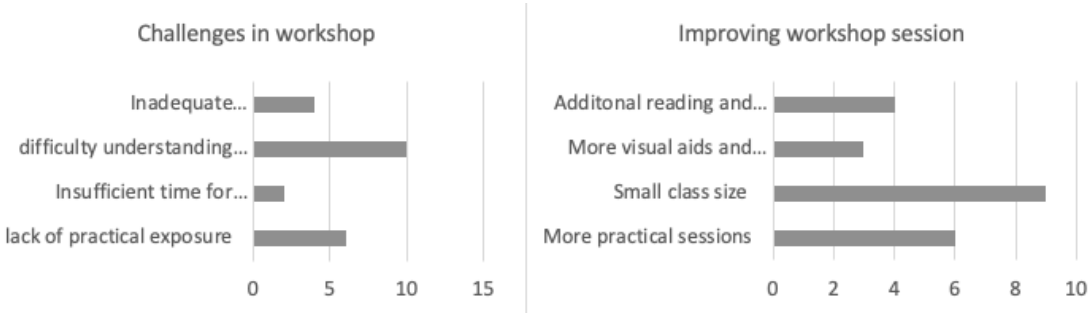


Figure 3: Challenges and improvements in measurement workshop session

This study established that all improvements should be utilised in the measurement workshop session and should be done collectively without prioritising one over the other. This supports the assertions of previous studies based on the learning environment and materials (Crafford and Frick, 2023).

Table 1: Inferential Analyses of Measurement Workshop sessions

Questions	Test Type	Statistics	P-value	Conclusion
Improvement in workshop sessions	Z-test (2 props)	0.95	0.17	Not significant
	Chi-square test	3.82	0.28	Not significant
Challenges in workshop sessions	Z-test (props	1.26	0.10	Not significant
	Chi-square test	6.36	0.095	Not significant
Prior Measurement skills before attending a measurement workshop session	Z-test (props	1.92	0.027	Significant
	Chi-square test	8.53	0.07	Not significant
Recommending workshop sessions to others.	Z-test (props	2.65	0.004	Significant
	Chi-square test	3.52	0.06	Not significant.

The analysis also wanted to understand the impact of prior measurement learning on students' comprehension, the response distribution indicated that the Z-test (1.92) and Chi-square test (8.53) suggested that the majority of students had an average understanding of the measurement concept before their workshop session and the majority of the students entered the workshop sessions with neither a strong nor very poor understanding of measurement. This reinforces the need for foundational instruction and skill-building in earlier levels before starting measurement modules (Kamardeen, 2015). The inferential analysis established that students appreciated the workshop session and would recommend to others (z-test and chi-square test of 2.65 and 3.52, respectively). This shows a positive impact on the participants and should be broadly implemented within QS curricula across the globe. Continuous improvement of pedagogical processes is relevant in the QS curricula (Razali *et al.,* 2024b)

CONCLUSION AND RECOMMENDATION

Based on the analyses conducted the most frequent themes were workshop engagement and effective practical learning. Instructors play a significant role in the student's understanding and learning experience during measurement workshop sessions. This study established the importance of a practical hands-on process and the use of software. This study believes that a combination of various teaching and learning methods is needed for the successful implementation of measurement

modules, this could include advanced technology, innovative assessment, and the use of real-world exercises. Also, careful monitoring and all-inclusive implementation of workshop processes are needed to improve the workshop sessions. Further study could be conducted to assess the perspectives of lecturers during measurement workshop sessions.

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SHAPING SUSTAINABILITY MINDS IN CONSTRUCTION EDUCATION: UNVEILING THE IMPACT OF THE ERASMUS+ SUSTAINABUILD COURSE

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Integrating sustainability into higher education is vital to addressing global challenges, especially given the construction sector's role in carbon emissions and resource depletion. However, a gap persists between theoretical concepts and practical applications in education. This article evaluates the design, implementation, and impact of the SUSTAINABUILD Erasmus+ course, which involves institutions from Belgium, Denmark, Finland, and Spain, to equip students with the skills to design adaptable buildings through a hybrid course model. A mixed-methods approach was used, combining student surveys and educator feedback to assess the course's effectiveness in enhancing knowledge, teamwork, and sustainability competencies. Results indicate improved student understanding of sustainable construction and developing soft skills such as teamwork, intercultural communication, and reflective thinking. The international nature of the course increased the effectiveness of student learning. Educators praised the course's structure but suggested increasing interactivity and reflective practices. The study highlights the course's potential to prepare professionals for sustainability challenges. Future iterations will expand its reach, refining content to increase impact.

Keywords: construction pedagogy; sustainability education; interdisciplinary collaboration; course evaluation; Erasmus+

INTRODUCTION

The construction industry's significant impact on global carbon emissions underscores the need to embed sustainability in education (Wieser *et al.,* 2019). Higher education is crucial in driving sustainable development and effectively preparing future generations to tackle sustainability challenges (Abo-Khalil 2024). Sustainability integration in education is vital for addressing the construction industry's environmental, economic, and social challenges (Murray and Cotgrave 2007). To meet the increasing demands for sustainability, students' knowledge, skills, and competencies are crucial (Opoku and Guthrie 2018). However, despite recognising sustainability's importance, its implementation in academia remains under-

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implemented, with many initiatives failing to be effectively applied in practice. This indicates challenges in translating theory into practice (Gade *et al.,* 2022). According to Bond *et al. (*2010), integrating knowledge through information sharing, opinion exchange, and collaborative data construction forms the foundation of interdisciplinarity and transdisciplinary learning. This fosters a shared understanding of key sustainability concepts (Bond *et al.,* 2010).

Caiado *et al. (*2018) argue that collaborative and digitised education fosters innovation in sustainable development, requiring a shift in practices to empower students to think critically and develop skills beyond traditional teaching models (Caiado *et al.,* 2018). In response to these challenges, the SUSTAINABUILD hybrid course, as part of the broader SUSTAINABUILD Erasmus+ project, aims to foster interdisciplinary expertise, sustainable practices and pedagogical strategies within construction education. By involving higher educational and research institutions from Belgium, Denmark, Finland, and Spain, the course equips future construction professionals with the skills and knowledge to address environmental, economic, and social complexities (Sustainabuild 2024). Achieving sustainability goals requires coordinated efforts to monitor and measure progress (Schmidt-Traub *et al.,* 2017), with actions from governments, the private sector, and society (United Nations, 2015).

Evaluation of Educational Courses

Evaluating educational courses ensures alignment with institutional goals, industry needs, and Sustainable Development Goals (SDGs). Evaluation frameworks assess learning outcomes and their long-term effects on professional and societal advancements. They are essential for measuring the impact on learners and professional outcomes, such as the Kirkpatrick Model (2006), providing a structured approach to evaluating educational programs, focusing on immediate learning outcomes, behavioural changes, and long-term results, making it particularly useful for assessing sustainability initiatives (Kirkpatrick and Kirkpatrick 2006).

Effective evaluations require alignment between course design, teaching methods, and learning outcomes to ensure content and delivery foster critical competencies. This includes quantitative approaches, like pre- and post-assessments, and qualitative tools, like focus groups and interviews (Coffey and Atkinson 1996). This article assesses the effectiveness of the SUSTAINABUILD course on students' knowledge and skills in sustainable construction, examining its impact, development, implementation strategies, and measurable outcomes. It highlights how the course bridges the gap between theoretical knowledge and practical application while disseminating findings to academia and industry stakeholders. Through these efforts, the course aims to contribute to global best practices in sustainability education, preparing a generation of professionals capable of addressing environmental and social challenges.

Course Features and Pedagogical Principles

The SUSTAINABUILD Erasmus+ hybrid course was designed with key pedagogical principles to enhance interdisciplinary collaboration, providing students in construction engineering educational programmes with theoretical and practical knowledge and competencies in sustainable construction:

1. The course included two main components. A theoretical part covering sustainable construction topics such as circularity, regenerative buildings, materials, and energy efficiency, and a practical module based on the Bracops Hospital case, where students

applied sustainability principles to real-world design challenges. This approach ensured both understanding and practical application.

2. The course's hybrid model combines asynchronous learning (3 weeks) for foundational knowledge with synchronous online collaborative work (2 weeks), fostering interdisciplinary teamwork and international collaboration.

3. The international nature of the course through digital mobility allows students from various institutions to collaborate on international projects. This international approach provides insights into sustainability as a complex global system of interrelated issues. Sustainability was explored holistically, covering ecological, social, and, to a lesser extent, economic aspects.

4. The course emphasized hard skills like technical knowledge of sustainable construction, energy-efficient design, and material selection, as well as soft skills such as enhancing awareness, critical and reflective thinking, problem-solving, teamwork, intercultural communication skills, and time management while engaging with diverse cultural and professional perspectives. Educators conducted three workshops to define and develop these hard and soft skills, reinforcing the practical application of sustainability in the construction industry.

5. The student's learning process followed a structured cycle: explore, analyse, synthesize/propose, communicate, and reflect, informed by Kolb's experiential learning cycle (2017). This approach is ideal for courses with practical components as it stresses the value of reflective learning and real-world application, aligning with the course implementation phase and allowing students to evaluate their learning processes, enabling continuous improvement (Kolb and Kolb 2017). Kolb's theory underpins the SUSTAINABUILD course by emphasising learning through real-world, hands-on experiences. Students engage in sustainable design challenges (concrete experience), reflect on the environmental and social impact of their work (reflective observation), develop innovative, sustainable solutions (abstract conceptualisation), and test or present their ideas in authentic contexts (active experimentation). This cyclical process mirrors the course's goal to empower learners to think critically, act responsibly, and build solutions contributing to a more sustainable future.

Theoretical Frameworks

The impact of the course on students' learning was assessed according to Kirkpatrick's four-level evaluation model, including reaction, learning, behaviour, and results (2006), to measure its success in terms of learning outcomes and long-term influence on students' professional behaviours (Kirkpatrick and Kirkpatrick 2006). It helped to understand how well the course met its objectives and its contribution to addressing sustainability challenges in the construction industry as follows:

Reaction (satisfaction): Students' perception of the course (e.g., satisfaction, interest). Learning (knowledge and skill acquisition): Assessing students' learning (e.g., understanding sustainability topics and whether they felt increased knowledge). Behaviour (application of learning): Analyse whether students can apply what they learned and provide feedback on whether the course developed sustainability skills. Results (impact on future actions): Assessing the broader impact of the course on students' future actions. e.g., responses as "I recommend this course to others".

To analyse educators' course evaluation, the Delta plus analytical framework (Davenport and Harris 2007; Bishop 2024) helped to assess the alterations between expected outcomes and actual results. It identifies key areas of course improvement,

strengths, and gaps, allowing for a deeper understanding of its impact. The evaluation process was structured and data-driven, offering insights into the strengths and improvement areas in the course. This approach provided a balanced view of the course's effectiveness and a foundation for continuous improvement, helping the course better meet its educational goals in future iterations. The course expected outcomes were defined based on objectives, pedagogical principles, and learning goals, outlining the skills and knowledge students should gain, as well as the effectiveness of the course delivery (hybrid structure, online collaboration, etc.).

Educator feedback was collected via an online focus group, highlighting views on theory-practice balance, sustainability integration, and the course's hybrid format. Educators shared insights on student engagement, teamwork, and course structure. The delta refers to analysing differences and to the gap between expected outcomes and feedback, highlighting areas of success or challenge. For example, while students gained technical knowledge, some needed support in soft skills as teamwork or intercultural communication. Identifying alterations helped to recognise improvement areas. The plus analysis refers to the course's successful aspects, such as international collaboration and the holistic approach to sustainability, identifying elements for future iterations. According to reflection and actions, the delta plus analysis informed actions to refine the course, as modifying content, adding interactive components, or improving delivery methods. Educators may have suggested further training for students in reflective thinking or practical sustainability applications.

Tuckman's team development model (1965) guided assessing SUSTAINABUILD's course teamwork and collaboration, outlining five stages teams typically progress through: Forming, storming, norming, performing, and adjourning (Tuckman 1965). This model illustrates the natural progression of group dynamics, from initial introductions and conflicts to high performance and disbandment, offering valuable insights into student collaboration and showing how students and educators navigate group work, overcome challenges, and foster effective partnerships.

METHOD

This study employed a mixed-methods approach to evaluate the effectiveness of the SUSTAINABUILD course in fostering sustainability competencies and cross-institutional collaboration. Data were collected via an online student survey (Groves *et al.,* 2011) and an educator focus group workshop. Combining qualitative and quantitative data allowed for a comprehensive assessment of the course's impact on student learning, engagement, teamwork, and broader pedagogical outcomes. For students, an online survey questionnaire was sent to 73 participants in January 2024, following their course completion from November to December 2023. The survey included 53 multiple-choice and Likert-scale questions (Likert 1932) to measure perceived learning outcomes, satisfaction, and collaborative experiences. To ensure validity and clarity, the survey was pre-tested by colleagues to confirm alignment with the course objectives. The survey achieved a response rate of 61%, providing a substantial sample for evaluating student engagement.

Course Design and Implementation Approach

The SUSTAINABUILD course was developed and implemented, guided by the ADDIE Model (Zulkifli *et al.,* 2018), to ensure effective course delivery, consisting of five elements: Analyse, design, develop, implement, and evaluate. In the Analysis phase, we identified the key sustainability skills needed for addressing challenges in

the construction industry. This involved workshops with industry professionals to define the necessary knowledge in sustainable construction, energy-efficient design, and materials, as well as practical skills for real-world application. Based on these insights, we set clear course objectives aligned with sustainability goals. The hybrid course was developed in the Design phase to include theoretical and practical components. The theoretical content provided foundational knowledge, while the practical module facilitated hands-on, collaborative learning. These components were designed to ensure that students would learn and apply theoretical concepts in real-life projects, promoting interdisciplinary teamwork. Educators from all four institutions taught the theoretical part and supervised and evaluated students in the practical part, supported by inspirational guest lectures.

The Development phase focused on creating the course materials. This included producing presentations, videos, and interactive tasks, ensuring students were engaged and applied key concepts in the practical workshops. In the practical part of the course, students worked with a case, Joseph Bracops Hospital in Belgium, designed by Archipelago Architects, who introduced the case and task requirements to students, focusing on circular and adaptable building design (Scialpi and Declercq 2023). Students had to solve several tasks related to the case and integrate and reflect on new, innovative, circular, and adaptable solutions. The Implementation phase involved the course delivery to students through Blackboard Training and Development Manager, ensuring that the online collaborative workshops and practical modules ran smoothly. Integrating digital mobility allowed students from different institutions to collaborate across borders on sustainability-focused projects, enhancing their learning experience and fostering global collaboration. Finally, in the assessment and evaluation phase, we collected feedback from both students and educators to assess the effectiveness of the course. It provided valuable insights into strengths and improvements. Based on this input, we refined the course content and structure for future iterations, ensuring it remained relevant and effective in meeting the construction industry's learning objectives and sustainability challenges.

Theoretical Frameworks for Course Evaluation

Educator feedback was gathered through an online focus group after the course concluded. This qualitative approach provided valuable insights into the course's effectiveness and the dynamics of cross-institutional collaboration. Educators reflected on course content, delivery methods, and student engagement, while identifying potential improvement areas. In total, twelve educators—from the four participating institutions—were involved in delivering and supervising the course, of whom six took part in the focus group workshop, which took 90 minutes.

Two key theoretical frameworks informed the evaluation approach. Kirkpatrick's four-level evaluation model (Kirkpatrick and Kirkpatrick 2006) guided the analysis of student data, assessing the course's impact across reaction, learning, behaviour, and results. This framework was particularly suitable for evaluating sustainability education initiatives, as it captures immediate learning outcomes and long-term behavioural changes in professional practice. The Plus-Delta analytical framework (Davenport and Harris 2007); (Bishop 2024) was applied to educator feedback to complement this. This framework identifies strengths (plus) and areas for improvement (delta), offering a structured, data-driven assessment of the course's implementation and cross-institutional collaboration.

Tuckman's team development model (1965) was used to assess teamwork development, observe and analyse how student teams progressed through the forming, storming, norming, performing, and adjourning stages, providing insights into group dynamics and collaborative learning processes through the course (Tuckman 1965). Fifteen interdisciplinary student teams were formed, consisting of 4-6 students.

FINDINGS AND DISCUSSION

Students' evaluation of the SUSTAINABUILD course

Survey results revealed high student engagement and satisfaction with the course structure and content. Topics such as circularity, construction materials, and energy usage were rated highly relevant and interesting. These responses indicate that the theoretical and practical components were well-received. Notably, 73% of students strongly agreed that the theoretical part provided a solid foundation for the practical project, suggesting coherence and alignment in course design. Students expressed appreciation for the international and interdisciplinary nature of the course, which enriched their learning experience and fostered cross-cultural collaboration.

Regarding perceived complexity of course topics, most students rated the course content as easy to moderately easy, suggesting that the materials were appropriately pitched for the target cohort. However, specific topics, particularly eco-design, biodiversity and water efficiency, were perceived as more challenging, indicating areas where further emphasis might be needed. This highlights areas that may benefit from improved instructional scaffolding or enhanced practical integration to make their relevance more tangible. These findings suggest that while core sustainability topics were effectively communicated, certain niche areas require clearer framing or additional context to support comprehension.

Considering students' knowledge acquisition and skills development, students reported significant learning outcomes across both knowledge and skills. 73% indicated they had gained new insights into sustainable construction, and 66% noted a better understanding of the Sustainable Development Goals (SDGs) within a construction context. Topics like circularity, energy usage, and material efficiency received particularly high learning value and clarity ratings, indicating effective knowledge transfer and alignment with student expectations. Results support the emphasis on industry-relevant content, aligning with the findings of Murray and Cotgrave (2007), who stress the importance of aligning course content with industry needs to improve learning outcomes. The Bracops Hospital case provided students valuable experiential learning opportunities to apply sustainability concepts in a collaborative, real-world setting. This hands-on learning experience reflects Kolb's (2017) theory that experiential learning fosters deeper understanding through reflection and application. The course emphasized hard skills (sustainable methodologies) and soft skills (teamwork, communication, time management). Students found the practical case beneficial, with significant learning outcomes for applying sustainability knowledge.

Measuring students' behaviour, ability to apply what they have learned in real-life situations, and confidence, students reported feeling more confident applying what they learned, particularly in circularity and energy usage. The practical project allowed students to engage directly with real-world sustainability challenges, increasing their ability to apply knowledge in practice. These findings confirm the views of Abo-Khalil (2024), who emphasizes the importance of preparing students to

address complex sustainability challenges in professional settings. Results showed that students found the practical case most interesting, and many appreciated the flexible course materials and the lack of language barrier during international collaborations. This suggests that students could implement theoretical knowledge in a practical context and collaborate effectively across international teams.

The survey results indicate that the course positively impacted students' understanding and implementation of sustainable construction practices. 85% of students rated the course as excellent or good, and 78% reported that it significantly improved their ability to understand and apply sustainability principles in their future careers. Interest in key topics was particularly high. 92% expressed strong interest in circularity, construction materials, and energy, indicating these will likely influence their professional practice. While 68% found the SDGs and eco-design topics valuable, 34% suggested they could benefit from more focused content or clearer practical applications to increase their relevance and impact. Overall, the course effectively prepared students to apply sustainability principles, though topics like SDGs and eco-design could be enhanced to increase their practical applicability.

Educators' evaluation of the SUSTAINABUILD course

Key feedback from educators provided valuable insights into various aspects of the course. Educators discussed several dimensions of the course, including its content, delivery methods, student engagement, and how well it addressed the learning objectives. Educators highlighted that the variety of teaching methods used was appreciated, as it offered a diverse approach to learning. They also recognised the relevance and applicability of the course content to real-world sustainability issues in construction, which helped ensure the course's practical value. Additionally, the flexibility of the course structure was seen as a strength, as it allowed different institutions to adapt the content delivery to meet their specific needs. However, there were concerns regarding the interactive elements of the course, with some educators noting a need for greater student engagement, particularly in the online learning environment. This feedback is consistent with the recommendations of Opoku and Guthrie (2018), who argue that effective sustainability education requires active student involvement to foster deeper learning and engagement.

The delta analysis identifies areas for improvement, revealing differences between the course's intended outcomes and educators' perceptions. A key area for enhancement was interactivity. While the course was well-received, educators suggested adding more interactive elements like real-time discussions and hands-on projects to boost engagement. The timing was also a concern, with some educators feeling the time for both theoretical and practical components, especially practical sessions, was insufficient. Extending these would allow for a deeper exploration of sustainability concepts, aligning with Gade et al.'s observations (2022), who note that sustainability education often struggles to provide sufficient time to fully apply theoretical concepts in practical scenarios. Cross-institutional collaboration posed challenges due to differences in approach. UCN (Denmark) and SAMK (Finland) followed a more procedural method, while PXL (Belgium) and CTCON (Spain) were more flexible, making it difficult to manage the course's collaborative aspects.

The Plus (+) aspect of the framework highlights the strengths and positive feedback provided by educators. One key strength was the variety of teaching methods employed in the course. Educators appreciated the use of diverse approaches, including theoretical lectures, online discussions, and the integration of real-world

projects, contributing to a richer and more engaging learning experience. Another significant outcome was the high student motivation. Many students found the course an eye-opener and valued the opportunity to collaborate with peers from different countries. This international teamwork effectively motivated students to engage deeply with sustainability in construction. Educators praised the course's collaborative approach, encouraging students to work with peers from different cultural and academic backgrounds. This exposure to diverse perspectives enriched the learning experience and fostered important cross-cultural communication and teamwork skills. Finally, the course's design flexibility was recognised as a significant strength. The ability of institutions to adapt the curriculum based on local needs and priorities allowed for a broader audience to benefit from the course, ensuring its relevance and effectiveness across different educational contexts.

Based on the educator's feedback, it is evident that while the SUSTAINABUILD course had several strengths, certain areas require improvement. To address these, educators suggested several actions can be taken. First, increasing interactivity in future iterations of the course would be beneficial. Incorporating more interactive elements like live case studies, role-playing exercises, and student-led discussions would help boost engagement and deepen learning. Additionally, educators suggested that extending the course's practical component could provide students more time to engage in hands-on activities and further explore sustainability issues. This would allow more opportunities for feedback and reflection without feeling rushed. Also, an important area for improvement is the harmonisation of cross-institutional approaches. To improve consistency across participating institutions, aligning the course structure and expectations more closely would be helpful. This could involve standardising certain course delivery aspects while allowing flexibility to adapt to local needs. Enhancing collaboration among partner institutions could bridge cultural and procedural differences, and regular planning sessions, ensuring that all partners understand their roles and expected outcomes, could improve communication and ensure smoother collaboration in the course.

Teamwork was central to the SUSTAINABUILD course, as students were placed in interdisciplinary teams in the forming stage, where they learned about the course objectives and roles. These teams, consisting of students with varying English proficiency and backgrounds, initially hesitated to use English. However, this diversity enhanced group dynamics and fostered camaraderie. Educators from all partner institutions supervised the groups, promoting English skills and enriching the course's international dimension. As roles became clearer during the norming stage, teams collaborated more effectively, especially in online workshops that required clear communication and constructive feedback. The remote nature of the work required clear communication strategies, helping students articulate ideas and provide feedback. By the performing stage, teams efficiently tackled real-world problems, demonstrating the application of sustainable construction principles. Despite language barriers, collaboration was strong, though some students felt that the lack of face-to-face interaction limited deeper engagement. In the adjourning stage, students reflected on teamwork, sharing insights for future improvement, with surveys showing increased satisfaction and cooperation.

Cross-institutional collaboration, a core feature of the SUSTAINABUILD course, brought challenges and strengths. Differences in teaching cultures—structured versus flexible approaches—sometimes caused inconsistencies. Logistical challenges, such as coordinating across time zones and institutional schedules, also posed obstacles.

Language barriers occasionally limited participation and required extra support, while varied digital platforms posed challenges for online collaboration. However, early planning and consistent communication helped align expectations and foster a shared vision for sustainability education. The hybrid course model's flexibility enabled local adaptation within a common framework, and exposure to diverse cultural and professional perspectives enriched collaboration and strengthened intercultural skills.

CONCLUSION

The SUSTAINABUILD Erasmus+ course effectively shaped sustainability-minded professionals in the construction sector by combining theoretical learning with practical application. The hybrid course model promoted interdisciplinary and international collaboration, allowing students in construction education to develop key hard and soft skills competencies, aligning with the SDGS. Results revealed positive outcomes in student engagement, teamwork and learning, particularly in topics like circularity, energy usage, and construction materials. Educators praised the variety of teaching methods, including lectures, online discussions, and real-world projects. The course's effectiveness was assessed using the Plus Delta framework and Kirkpatrick's evaluation model. The Plus Delta framework identified strengths such as international collaboration and real-world applications but noted the need for greater interactivity. Kirkpatrick's model confirmed high student satisfaction, improved knowledge, and increased confidence in applying sustainability concepts. Improvements can include enhancing online interactivity, extending practical sessions, and better integrating topics like eco-design and SDGs. Addressing challenges like unequal participation and cultural differences will strengthen the collaborative nature of the course. The course offers a replicable model for embedding sustainability in higher education, preparing students to tackle sustainable construction challenges.

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INNOVATIVE PEDAGOGIES IN CONSTRUCTION PROJECT MANAGEMENT EDUCATION: INTEGRATING ACTIVE BLENDED LEARNING, TECHNOLOGY AND AUTHENTIC APPLICATIONS

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This study examines innovative pedagogical teaching strategies in MSc. Construction Project Management (CPM) education, focusing on active blended learning (ABL), advanced classroom technologies, and real-world applications. Drawing on a mixed-methods research design including surveys, interviews, focus groups, classroom observations, and industry consultations, the research explores how ABL enhances flexibility, interactivity, and student engagement, ultimately improving knowledge retention and professional readiness. The student co-creation, where learners actively contribute to shaping course content and activities, fosters a sense of ownership, creativity, and alignment with both academic goals and industry expectations. Using real-world applications, interactive role-plays, industry cases, and technology-driven simulations, which cultivate critical thinking, leadership, and a deeper understanding of complex project dynamics. The existing ABL and experiential learning literature provides limited insight into its mechanisms and effectiveness in CPM education. Preliminary findings, based on data from 24 postgraduate students, suggest that ABL, integrated with block-teaching, technology, authentic assessment, and student-driven learning, bridges the gap between theory and practice, offering a robust framework for curriculum innovation. This study recommends scaling these strategies to foster a more sustainable, collaborative, and industry-aligned CPM education.

Keywords: Active blended learning; authentic assessment; construction project management education; innovative pedagogies; student co-creation

INTRODUCTION

Engineering and Construction Management curricula in post-secondary institutions provide the perfect forum for integrating new and advanced pedagogies, specifically in project control subject (Alborz, *et al.,* 2024). Katende, E. (2023) recommend that institutions strengthen project management instruction by adopting blended learning, emphasising critical thinking, prioritising continuous assessment, and student-centric approach. By learning and harnessing the power of AI and new technologies, organisations can streamline project workflows, improve collaboration, and achieve greater efficiency and effectiveness in project delivery (Shamim, 2024). University of Portsmouth is recognised as one of the best universities in the UK for quality of teaching and student experience, with a gold rating in the national Teaching

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Sepehri, M, Ayhan, M, Samuel, D and Allinson, M (2025) Innovative Pedagogies in Construction Project Management Education: Integrating Active Blended Learning, Technology and Authentic Applications, *In*: Thomson, C and Neilson, C J (Eds) Proceedings of the 41st Annual ARCOM Conference, 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 617-626.

Excellence Framework (TEF). The university launched its modern London campus in Walthamstow, UK in September 2023, offering career-focused courses, flexible learning, state-of-the-art facilities that support cutting-edge pedagogical innovations. Its features implemented and studied here enhance the student learning experience:

Active Blended Learning and Co-creation: It entails active participation, multi-media, belonging and purpose, student co-creation and commitment in the learning process.

Focused or Block teaching: The student learning is compressed in 4 weeks of classes with 2 weeks of catch-up and assessment, when students study one module at a time.

Authentic and Experiential: This approach allows the students to explore, discuss, and meaningfully construct concepts in contexts that involve real-world problems.

Technology in Classroom: It provides various tools and online platforms to enhance the learning, while to engage students in unique, innovative, and equitable experience.

Learners' Performance: Focus is to commit knowledge to long-term, not immediate, application, and performance which leads to better retention and future employability.

LITERATURE REVIEW

Construction Project Management (CPM) education is facing significant challenges in aligning academic content with rapidly evolving industry needs. Individuals entering building and construction industries must consistently update and adapt their skillset to sustain their relevance and employability in this fast-changing environment (Emmitt, 2016). Graduates often encounter gaps between theoretical knowledge and practical industry competencies, which hinders their immediate employability (Wu *et al.,* 2018). This directly relates to the primary research aim of this paper, which is investigating the effectiveness of ABL, technology integration, and student co-creation strategies to enhance student engagement and industry readiness.

ABL combines face-to-face instruction with digital learning methods, creating a flexible and interactive educational experience. Armellini and Padilla Rodriguez (2021) articulate a comprehensive framework for implementing ABL, emphasising careful pedagogical design, clear learning outcomes, and structured interactions. Vodovozov *et al. (*2022) further substantiate this by showing how ABL significantly boosts student engagement, particularly at the postgraduate level, due to the flexibility and relevance of online and face-to-face activities. These studies support adopting structured ABL models such as flipped classrooms, peer-assisted learning, and interactive discussions to enhance student engagement.

Despite its advantages, student acceptance of ABL can be variable, heavily influenced by perceived relevance, assessment clarity, and instructor engagement. Lomer and Palmer (2023) and Armellini *et al. (*2021) both highlight that students prefer blended learning activities when explicitly linked to assessments and when face-to-face interactions enrich online experiences. Their findings underline the critical importance of clear pedagogical intent and communication to foster positive student perceptions, emphasising the need for clearly articulated active learning tasks that are meaningfully integrated into assessments.

Integrating advanced technologies such as Artificial Intelligence (AI) and Building Information Modelling (BIM) significantly enrich CPM education. Muhie and Woldie (2020) propose a comprehensive AI integration framework emphasising intelligent tutoring systems, adaptive learning environments, and personal student experiences. On the other hand, Park *et al. (*2023) illustrate practical challenges faced

by educators in adopting AI-driven instructional methods, suggesting substantial faculty training to optimise technology benefits. In this research, we treat AI as an emerging component within the broader objective of technological enhancement, particularly as it relates to personalised learning, adaptive assessment, and digital construction tools.

Authentic assessments, directly linked to real-world challenges, significantly enhance students' industry readiness and deeper cognitive engagement. Merrill (2002) and Chickering and Gamson (1987) provide foundational support, highlighting principles such as problem-centred instruction, active learning, immediate feedback, and the integration of learning into practical contexts. El Sadik and Al Abdulmonem (2021) further validate this approach by demonstrating how flipped classrooms significantly enhance higher-order cognitive outcomes. These studies underpin the importance of shifting from traditional exams to competency-based, industry-relevant assessment practices, including portfolio-based and scenario-based tasks.

Student involvement in curriculum design effectively bridges academia-industry gaps by aligning course content with professional aspirations and industry expectations. Zarandi *et al. (*2024) detail various successful student co-creation strategies such as advisory panels, elective provision, and industry-integrated project learning that significantly enhance students' satisfaction and employability. Dickinson *et al. (*2022) further highlight the unique benefits of involving industry practitioners ('pracademics') in curriculum development, enhancing practical relevance and student engagement. These insights directly support structured student co-creation approaches, including collaborative curricular workshops and student-designed assessment scenarios.

Effective pedagogical strategies in CPM education depend heavily on the authenticity and professional credibility of educators. Kreber (2010) argues convincingly that educators who authentically engage students through genuine dialogue, critical reflection, and real-world relevance profoundly influence student engagement and learning outcomes. Dickinson *et al. (*2022) reinforce this perspective, demonstrating how practitioners transitioning into academia significantly improve curriculum authenticity and student motivation. This aligns with stressing industry collaboration through mentorship programs, live projects, and guest lecturers (industry educators).

Finally, for innovative pedagogical strategies and technological tools to be effectively sustained, scalability and institutional support are crucial. Armellini and Padilla Rodriguez (2021) and Margolis *et al. (*2017) underline the necessity of scalable digital platforms, robust institutional backing, and faculty development to sustain blended learning innovations. These issues emphasize the importance of developing sustainable, scalable digital learning platforms and continuous training initiatives. In conclusion, the reviewed literature comprehensively supports the research aim and objectives, providing robust theoretical grounding and practical guidance for implementing ABL, technology integration, student co-creation, authentic assessments, and sustainable institutional frameworks in CPM education.

METHOD

The newly established campus provided an ideal environment for experimenting with innovative pedagogical approaches and emerging technologies, fostering a highly interactive and student-centred learning experience. The study leveraged this setting to explore how ABL, technology integration, and student co-creation influence postgraduate education, particularly in Construction Project Management (CPM). The

first two cohorts of MSc. Construction Project Management students at the London campus were participants in the study after completing three or four modules, ensuring they had substantial exposure to the ABL framework. The study employed a mixed-methods approach, combining both qualitative and quantitative data collection to provide a comprehensive understanding of ABL's impact.

Objectives

The study aimed to investigate the effectiveness of ABL in postgraduate CPM education. Specifically, it sought to:

- Evaluate the impact of ABL on student engagement, knowledge retention, and active participation.
- Assess how technology integration enhances the learning experience and facilitates collaboration.
- Explore the role of student co-creation in fostering critical thinking and problem-solving skills.
- Determine the extent to which ABL improves industry readiness by bridging the gap between academic learning and professional practice.

Data collection

9. Surveys and Questionnaires: Students completed structured surveys to assess their perceptions of ABL, engagement levels, knowledge retention, and preparedness for industry challenges.
10. Focus Groups and Interviews: Small-group discussions and in-depth interviews were conducted to capture students' experiences, insights, and reflections on the effectiveness of various pedagogical strategies.
11. Academic Performance Analysis: Students' coursework, assessments, and overall academic performance were analyzed to measure the effectiveness of ABL and technology-enhanced learning.
12. Classroom Observations: Lectures, workshops, and collaborative sessions were observed to evaluate student participation, interaction, and co-creation activities aligned with higher levels of Bloom's Taxonomy.
13. Industry Feedback: Future potential employers and industry professionals were consulted to assess whether students demonstrated improved industry readiness and practical competencies as a result of the ABL approach.

FINDINGS

By employing the above multi-faceted research methodology, the study provides valuable insights into the pedagogical innovations that can enhance postgraduate education, ensuring students develop the skills and competencies needed for success in the construction industry.

To assess student preferences and engagement with ABL, an initial survey was conducted among MSc. Construction Project Management (CPM) students. The survey aimed to determine the effectiveness of ABL in postgraduate education and gauge students' receptiveness to this innovative approach, particularly in contrast to their prior experiences with traditional learning methods. The survey targeted a current cohort of 27 international postgraduate CPM students, all of whom had prior exposure to conventional, lecture-based education. A total of 24 students responded, yielding an 89% response rate. The survey employed a structured, multiple-choice questionnaire designed to capture quantitative insights into student preferences,

engagement levels, and perceptions of the ABL framework. Additionally, open-ended questions were included to gather qualitative feedback on individual experiences and expectations. The survey will be applied to the future cohorts.

Figure 1: Rank the reasons for your ABL preference



Figure 2: Evaluate the following statements using the Likert scale



Figure 3: Which transferrable skills did you gain with ABL?

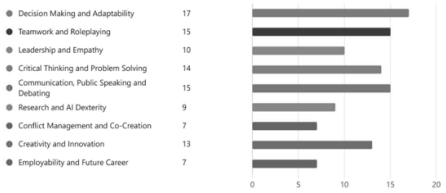


Figure 4: Do you recommend ABL approach to future CPM cohorts?



Survey outcomes

Preliminary results reinforced the effectiveness of ABL in postgraduate education. Key findings include:

- Strong Preference for ABL: A significant majority of students (95%) expressed a preference for ABL over traditional lecture-based learning, citing increased engagement and improved understanding of complex concepts.
- Increased Student Participation: 82% of respondents reported feeling more actively involved in discussions, group activities, and problem-solving exercises compared to their previous educational experiences.
- Positive Impact of Technology Integration: 75% of students found that the use of digital tools, online collaboration platforms, and interactive content enhanced their learning experience.
- Higher Knowledge Retention: 79% of students agreed that ABL facilitated deeper learning and better retention of course material, particularly through practical application and experiential learning.

- Improved Industry Readiness: Most students felt the real-world applicability of ABL methodologies, such as case studies and project-based learning, better prepared them for professional roles in construction management.

The survey results validate the effectiveness of ABL in postgraduate education, demonstrating its capacity to enhance engagement, knowledge retention, and industry readiness. The overwhelmingly positive response from students underscores the need for continued refinement and expansion of ABL methodologies in higher education. Future studies will explore longitudinal impacts and further optimise the integration of technology and student co-creation in learning environments.

Focus group

Six CPM students along with two tutors participated in a focus group discussion. The meeting focused on the effectiveness of ABL and its impact on student performance. We reviewed the value of student engagement and co-creation, group activities, and blending classroom technologies such as Vevox, Padlet, Montimeter, Moodle, Teams, H5P. The students also collaborated on the solutions for challenges that arise in using ABL, like student absences, diverse backgrounds and various prior level of education.

Participants highlighted the benefits of ABL, such as improved problem-solving skills, better work-life balance, and increased student engagement. However, challenges were noted, including the need for better integration of AI, addressing group dynamics, and ensuring all students are engaged. Suggestions included using digital tools for more vivid presentations, providing printed notes, and stricter attendance policies. The discussion also emphasized the importance of authentic teaching methods and industry visits to enhance learning outcomes. A summary of points raised in the meeting and a sample of actual quotes are below:

- How ABL and student engagement helps students learn better.
- Students share insights on how ABL helps them better learn and perform.
- The effectiveness of different teaching methods, such as traditional vs. ABL, asynchronous vs. synchronous, online vs. in-person.
- Interactive teaching methods over passive listening.
- Classroom setup and group dynamics, for participation and engagement.
- Group work is challenging when some individuals do not contribute equally.
- Using technology and real-world examples to enhance learning.

All participant confirmed the effectiveness of ABL. “ABL approach promotes critical thinking more than traditional teaching. It improves problem solving skills and we're doing the research, trying to solve the problems which the tutor shows in the class.” In fact, the students enjoyed the ABL class approach and found it very rewarding.

Majority of students appreciated the teaching approach and class pedagogy. One participant noted, “Block teaching is the better way and learning technology like YouTube and eBooks is useful. It helps work life balance This allows you to do more things outside of the university, and you still have time to focus on your studies.”

Participants valued the classroom group activities, one stated, “I personally, when someone's just talking, I really get tired. In this kind of teaching I'm involved, and my mind is focused more on the things that happens in the classroom. My background is not from the Construction Management, but I learn from my groupmates.”

Some participants, on the other hand, argued the challenges and shortcomings of working on groups. A person stated, “Being in a group make some people do nothing

and put much pressure on others. We decide member one must do something and member two must do something else. It is great for every person to be involved."

The students welcomed the real-world application. One student commented, "We have industry visits, the industry educators come, and we do case studies. While doing all these industry-oriented activities, we know more about the industry, and what exactly is needed. Everything is unique for me, compared to back in my country."

The students were pleased with the class and course setup. One individual stated, "The class sizes are small, and interaction is more, with one-to-one interaction. If we have questions, we just ask. That's what we want here. I prefer to study in groups. I prefer block teaching. I can learn better from this type of course structure."

Participants praised the integration of digital tools, with one student noting that, "Using technology in classroom is good. Without it is back to the basics, books and articles. Using YouTube to show, for example, scaffolding helps our understanding." The participants appreciated the digital tools and technology used in the classroom.

DISCUSSION

ABL is increasingly recognised as a transformative approach in higher education institutions across the UK and globally. Despite its growing adoption, a fundamental question remains: under what mechanisms and conditions does ABL yield a more significant impact on learners' performance? This question requires an understanding of the mediating factors that enhance the ABL effectiveness in real-world education.

Our research includes an existing literature review, thematic analysis of focus groups, and observations during module delivery at the London campus, three key mediating factors were identified. These factors serve to amplify the effects of ABL and student co-creation, leading to improved engagement, knowledge retention and employability.

Proposed model

The initial model suggests the mechanisms through which ABL enhances learners' performance. As in Figure 5, 3 primary mediating factors influence the ABL impact:

Focused Schedule: By structuring the curriculum to focus on a single module at any given time, students can immerse themselves fully in the subject matter. The dedicated approach minimises cognitive overload, allowing learners to develop a deeper understanding of core concepts while effectively managing summative assessments.

Authentic and Experiential Exercises and Assessment: The integration of real-world scenarios, industry-relevant projects, and experiential learning activities provides students with a practical foundation. These foster critical thinking and problem-solving skills, ensuring that students not only grasp theoretical concepts but also gain the necessary competencies for future employability and professional success.

Classroom Technology for Effective Blended Learning: Leveraging interactive digital tools and online learning platforms enhances the flexibility and accessibility of blended learning. Whether in face-to-face or online environments, technology enables active engagement, seamless collaboration, and an adaptive learning experience tailored to individual needs.

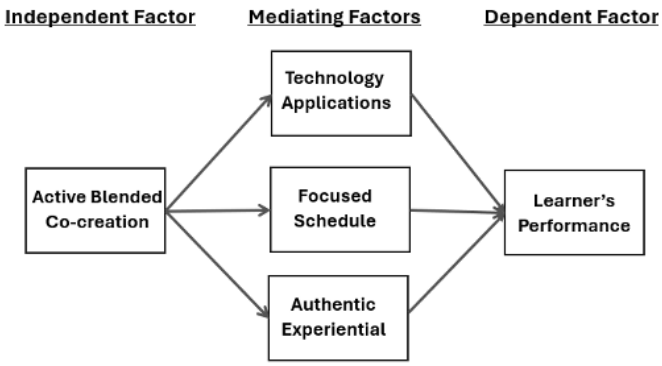


Figure 5: The proposed model considering initial findings

Further research is required to quantitatively refine and validate the proposed model, along with its associated hypotheses, using empirical data and statistical analysis. While a formal quantitative validation is not yet done, we carried out a preliminary qualitative validation through in-depth discussions with domain experts. These experts included several tutors and former main campus students, whose insights provided valuable feedback on the model's relevance, coherence, and potential applicability.

Challenges and limitations

Despite the valuable insights derived from this study, several challenges and limitations must be acknowledged. One key limitation is the scope of data collection. The research primarily relies on a survey and a focus group of students at MSc. CPM, which may not fully capture the variability present in different geographic or industry-specific contexts. Future studies could benefit from broader, multi-regional datasets to enhance generalisability.

Another challenge is methodological constraints. While thematic analysis provides a robust framework for analysis, it has inherent limitations in capturing dynamic, real-time interactions and contextual nuances. For instance, qualitative data may be subject to interpretation biases, whereas quantitative models might oversimplify complex relationships. A mixed-methods approach integrating both could provide a more holistic perspective.

Additionally, technological and practical barriers remain significant. The adoption of innovative pedagogies such as ABL faces hurdles such as high implementation costs, interoperability issues, and resistance from stakeholders. Many organisations still struggle with integrating innovative solutions into legacy systems, leading to suboptimal adoption rates. Addressing these barriers requires collaborative efforts between industry practitioners, policymakers, and researchers.

Finally, regulatory and ethical considerations present further challenges. Data privacy concerns, compliance with industry standards, and ethical implications related to technology-based learning and AI-driven assessments must be carefully navigated. As regulations evolve, ongoing research is necessary to ensure that solutions align with legal and ethical frameworks.

Future research

Building upon the findings of this study: several promising avenues for future research emerge. By addressing these research gaps, future studies can build on the foundations laid by this paper, driving further innovation and impact in the field.

Longitudinal Studies and Big Data Integration: Future research could explore long-term trends by conducting longitudinal studies that track the evolution of learner's performance over time, using big data analytics and machine learning capabilities.

Expanding and validating the model: The preliminary model in Figure 5 may be extended to include more factors, including moderating and mediating variables. Quantitative tools may be used to obtain and analyse data to validate the model.

Cross-Sectoral and Global Comparative Studies: Expanding the research to different sectors and global regions for comparative insights of contextual factors. Exploring best practices across industries to refine strategies and identify universal solutions.

Advanced Technological Applications: Emerging technologies such as AI, digital construction, and digital twins hold significant potential in current limitations. A particular focus on their scalability and integration into existing systems is valuable.

Policy and Governance Frameworks: Research into regulatory frameworks and governance mechanisms is crucial to ensure ethical and sustainable implementation. The policies impact new technologies, legal challenges, and industry compliance.

Human-Centric and Behavioural Insights: Investigating the human factors influencing adoption of stakeholder perceptions, resistance to change, and behavioural dynamics. Behavioural psychology studies provide valuable insights in optimising engagement.

CONCLUSIONS

ABL has become a fundamental approach in many UK university courses, offering a dynamic and interactive learning experience that enhances student engagement, knowledge retention, and overall academic performance. This study aimed to explore the mechanisms and pedagogical strategies that can further optimise ABL, combined with innovative pedagogies and class technology, in postgraduate CPM education.

The University of Portsmouth's London campus integrated ABL, focused teaching, authentic and experiential learning, and innovative technology applications to create a more immersive and effective learning environment. Preliminary findings suggest that these elements serve as key mediators in amplifying the positive impact of ABL on student outcomes. By fostering critical thinking, practical application of knowledge, and digital fluency, this approach not only improves academic performance but also enhances students' employability prospects in an increasingly competitive job market.

Future research should probe deeper into long-term student outcomes, the scalability of this approach across diverse disciplines, and the role of emerging technologies in further refining ABL. As higher education continues to evolve, institutions must remain adaptive, leveraging innovative pedagogical models to meet the needs of modern learners and prepare them for success in the ever-changing global landscape.

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PERFORMANCE

DECIPHERING FRAMEWORKS FOR WORK BREAKDOWN STRUCTURE DEVELOPMENT IN COMPLEX CONSTRUCTION PROJECTS: A SYSTEMATIC LITERATURE REVIEW

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The increasing scale and multidisciplinary nature of complex projects such as data centres or hospitals have amplified the need for structured, encompassing, and effective Work Breakdown Structures (WBS) to ensure successful project delivery. The aim of this research is to conduct a systematic literature review to identify existing WBS development frameworks. Specifically, the study seeks to 1) categorise available guidance, and 2) explore the frameworks for cohesion and applicability. The research method investigates findings from initially fifty-three publications and narrows to thirty-three using online databases, that focus on WBS development and implementation on construction projects. The investigation concludes the available literature falls into three main categories: international standards, project specific, and project management guidance. The findings reveal that standards lack depth for complex projects, while tools like artificial neural networks are narrow in scope and complex to implement. Project management guidance emphasizes scope clarity, however, fail to outline methods in which to develop a WBS for construction and iterative tasks, highlighting fragmented literature and gaps in WBS frameworks, emphasising the need for robust methodologies adaptable to complex projects.

Keywords: buildability; construction planning; contracting; productivity; project management; stakeholders; standardisation

INTRODUCTION

"The art of simplicity is a puzzle of complexity." (Wittgenstein *et al.,* 2003). The dynamics of the construction industry have often been regarded as complex, uncertain and continuous change (Gondia *et al.,* 2019). Although definitions vary, the term complex project is generally characterised as one that involved numerous interrelated components and stakeholders, high levels of uncertainty, and evolving conditions that challenge conventional planning and execution (Baccarini 1996; Mok *et al.,* 2015; Gondia *et al.,* 2019). While these publishing's differ to a degree, a level of commonality is achieved in that a complex project is one that has a high degree of

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McElwee, A, Spillane, J P and Bradley, J G (2025) Deciphering Frameworks for Work Breakdown Structure Development in Complex Construction Projects: A Systematic Literature Review, *In*: Thomson, C and Neilson, C J (Eds) Proceedings of the 41st Annual ARCOM Conference, 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 629-638.

technical and operational uncertainty, contains numerous interdependent tasks and systems, will experience diverse stakeholder interests and coordination challenges, and the project conditions are ever evolving. The term "complex" can be defined as "involving a lot of different but related parts" (Matthews 2014). Haas (2007) notes that it is difficult to fully define what a complex project is as most construction projects carry elements of complexity, however, projects in sectors such as data centres, hospitals, large infrastructure, and tunnelling tend to experience an amplified degree of complexity (Sharifzadeh *et al.,* 2011). This heightened complexity necessitates advanced planning tools and methodologies to ensure successful delivery. One such essential tool is the Work Breakdown Structure (WBS), which deconstructs the overall project scope into manageable work packages and tasks. The management, identification and inclusion of scope on a construction project enables project managers to react to schedule, budget, and/or quality under-performances by allocating additional or reassigned resources in response (Cerezo-Narváez *et al.,* 2020). However, while simplistic in theory, approximately 52% of projects fail to fully incorporate the works in the planning stage resulting in the execution of unforeseen activities (Elton 2018). Inadequate scope management often stems from insufficient planning at different project stages. This typically arises from vague or incomplete scope definitions, incomplete documentation, and a lack of clear communication regarding project boundaries. Consequently, frequent changes occur in the project's scope, which can disrupt schedules, inflate costs, compromise quality, and elevate risks, a phenomenon commonly referred to as “scope creep" (Ajmal *et al.,* 2022). The WBS not only forms the backbone of the baseline schedule, cost estimation, and risk management but also serves as a critical reference for performance tracking throughout the project lifecycle (Siami-Irdemoosa *et al.,* 2015; Sharon and Dori 2015). The WBS is a hierarchical decomposition of the total scope of work to be executed on the project, that fulfils the project objectives by organising the scope in an executable format (PMI 2019). However, given the importance of a WBS, the availability of frameworks appears to be confined to either project specific, or overly simplistic examples that are not easily applied to projects of a more complex nature (Cerezo-Narváez *et al.,* 2020).

International standards such as MIL-STD-881C, IEEE Std 1233, ISO 21500, and Practice Standard for Work Breakdown Structures have historically provided guidance for the development of the WBS. These standards offer a framework for consistency and a common language for project decomposition and reporting. Yet, while they supply a solid foundation, it is one of simplicity in terms of project type, and often lacks the flexibility and depth required to address the unique challenges posed by complex, multidisciplinary projects (Dod 2011; IEEE 1998; ISO 2012; PMI 2019).

In response to these limitations, several project-specific frameworks have emerged, incorporating advanced computational techniques and knowledge-based systems to automate or enhance the WBS development process. For instance, early research by Siami-Irdemoosa *et al. (*2015) demonstrated the feasibility of using neural networks to recognise patterns in complex construction projects, while more recent studies in modular construction have utilised ontology-based mapping and knowledge graph approaches to enrich work package formation (Li *et al.,* 2022). Despite their promise, these approaches are often limited in scope or require significant computational resources, which hinders their widespread applicability across diverse project environments.

Conventional project management guidance, on the other hand, underscores the importance of clear scope definition and hierarchical decomposition. Researchers such as Sharon and Dori (2015) and Cerezo-Narváez *et al. (*2020) have advanced conceptual models that integrate both product and project perspectives to facilitate coherent planning. However, these models frequently fall short of providing systematic methods for developing a WBS that can effectively accommodate the iterative and evolving nature of complex projects.

The motivation for undertaking this research stems from the continuing prolongation of construction projects, with 56% (Haass and Guzman 2020) to 85% (Gurgun *et al.,* 2024) of projects repeatedly failing to achieve the intended milestones, and 52% failing to identify the entirety of the scope involved with the project objectives (Elton 2018), with no evident research on the role the WBS plays. Therefore, this research is a pilot-study as it will look to explore if the existing literature presents cohesive frameworks that are applicable to complex construction projects (Kistin and Silverstein 2015).

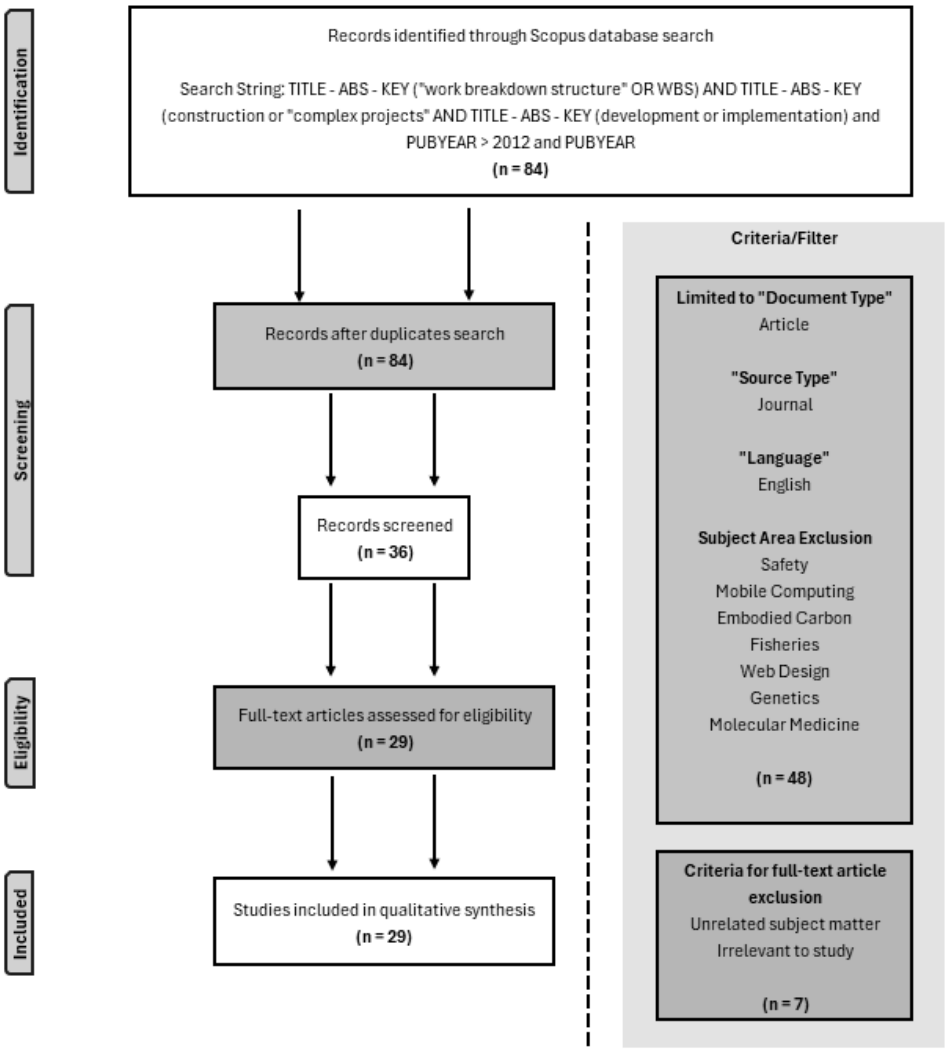
Construction projects are becoming increasingly multi-disciplinary, involving numerous interrelated components and stakeholders, with higher levels of uncertainty, and are continuously evolving. While these challenges impact construction broadly, projects such as data centre are constantly faced with the need to compress timelines for rapid delivery to meet increasing global digital infrastructure demands, while projects such as hospitals or large infrastructure works are experiencing escalating costs and extended delivery timeframes that are consistently in the public eye (The Irish Times 2023). Building on these considerations, this study aims to address key research questions regarding WBS development and the key factors influencing their development. Through this investigation, the research contributes to the continuous collaboration aiming to enhance construction planning practices, offering the much-needed exploration into the frameworks available for WBS development available to practitioners.

METHOD

A systematic literature review (SLR) is conducted to form the basis for new research, identify gaps and provide summary evidence of existing scholarly works and international standards. An SLR uses specific methods to produce reliable and valid results, by closely reading coding within the literature to identify themes, concepts, and narratives that help explain the intellectual structure and evolution of a research field (Parsons *et al.,* 2009). The outcome of the SLR is to provide a combination of results retrieved from multiple studies relating to an assessable topic for the purpose of evaluating the strength of the results and summarising evidence from practice (Whittemore and Knafl 2005; Crossan and Apaydin 2010; Tranfield *et al.,* 2003). To explore the development of a WBS for complex projects and fulfil the aim of the paper, it is first necessary to confirm whether the current literature is adaptable to projects of a multidisciplinary nature. Searches are undertaken through Scopus, which is a database of scientific literature, and the researcher's institution Library which expanded the search to standards and other types. This was then further refined using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) on the application of WBS frameworks on complex construction projects. The PRISMA methodology (Moher *et al.,* 2009) was used to assemble an evidence base using the scholarly works and international standards. This article research yielded eighty-four documents, which were further limited to those relevant according to the

specific inclusion and exclusion criteria. The inclusion criteria comprised all papers and standards pertaining WBS development with the exclusion of those not associated with the construction industry and unrelated to the subject matter. Finally, twenty-five articles and four standards, totalling twenty-nine, were included because of the PRISMA. A publication year of 1977 was selected as it appears to be the initiation of WBS frameworks, however, most of the relevant literature is from 2010 onwards when the inclusion criteria is applied.

Figure 1: PRISMA flowchart for Scopus search (Source: Author)



LITERATURE REVIEW

Siami-Irdemoosa *et al. (*2015) notes there are a limited number of published studies that provide the methodologies or tools required to develop a WBS that is appropriate for projects outside of the construction of apartments and boiler manufacturing, and as such are not suitable for construction projects that are complex, uncertain, and undergo constant change (Gondia *et al.,* 2019). By critically evaluating these approaches, the literature review will seek to uncover effective strategies and highlight any existing limitations that may hinder industry wide adoption of WBS development frameworks. While project management has been in existence for quite some time, it wasn't until 1996 that an attempt to document and standardise accepted project

management information and practices was made, triggering the development of further internation standards (Tang *et al.,* 2018).

International Standards

Various international standards have been developed to guide the creation of a WBS, yet many of these frameworks fall short when applied to complex projects. ISO 21500 (2012) emphasizes the need for a clear project scope, defining objectives, deliverables, requirements, boundaries, and presents the WBS as a hierarchical framework to decompose work into manageable work packages. However, the standard stops short of providing a detailed methodology for constructing a WBS. Similarly, the guidelines offered by PMI (2019) focus on decomposition, relationship building, and quality control, however, as Cerezo-Narváez *et al. (*2020) notes, the examples of manufacturing a bicycle or organising a pert are overly simplistic and do not easily translate to the complexity of large-scale or complex projects. CSI (2024) discusses the use of the WBS to categorise project specifications yet does not outline a hierarchical method to decompose scope of projects of any type. Bentley (2010) outlines the Product Breakdown Structure (PBS) used in PRINCE2 as a comparable model. The PBS is broken into simple, intermediate, and external products; however, it is simply described as a hierarchal decomposition with no framework for development and is only applicable to product manufacturing in a controlled environment. IEEE (1998) offers extensive guidance for documenting system requirements and emphasizes traceability between high-level requirements and detailed work packages to avoid scope creep, but its focus is on system documentation rather than providing a formal WBS development process. Dod (2011) developed a standard tailored for defence projects defining a product-orientated WBS, as opposed to a task orientated approach, typically structured into three levels for defence systems, or five to six levels for construction projects. This product focus means that the WBS is organised around the system and its deliverable components, ensuring that each element represents a part of the final product, however, PMI (2019) indicates the WBS for construction project should be deliverable orientated. The standard is specific to focused defence product types such as aircrafts, ground vehicles, and space systems. However, the standard offers little in the way of applying a hierarchical methodology to all project types, rather it outlines the WBS to be used for these product types.

The internation standard available for WBS development focus on the clear definition of scope and discuss the use of a hierarchical decomposition. However, the standards often lack granularity and adaptability to complex projects that contain multidisciplinary scopes.

Project Specific Frameworks

While there are many frameworks for the development of a WBS, there are none adaptable to projects of a complex nature (Siami-Irdemoosa *et al.,* 2015). However, while no WBS is easily adapted to another project, the intent of a framework is to apply a project, regardless of complexity (PMI 2017). Additionally, Norman *et al. (*2008) outlines that conflicting and a poor understanding of scoping methodologies often lead to oversimplified frameworks that do not capture the full complexity or scope of projects. Lee *et al. (*1998) developed a framework for apartment construction, which employs case-based reasoning and constraint-based techniques to rapidly generate project plans using historical data. While this approach enables quick plan generation, it is developed using data from previous projects which offers no

guarantee of accuracy or detailed scope delineation. Other studies have also employed the case-based approach using historical data for boiler installation and pre-fabrication (Dzeng and Tommelein 1997; Xie *et al.,* 2023).

Sharifzadeh *et al. (*2011) applied the use of artificial neural networks in tunnelling projects, demonstrating their application to process key parameters, such as excavation features, ground conditions, project durations, to generate an initial WBS framework that can be further refined in the planning process. Siami-Irdemoosa *et al. (*2015) also incorporated the use of artificial neural networks for underground construction. This employs a feed-forward network with back-propagation learning algorithms. However, both studies noted the complexity of incorporating the neural networks and highlighted it may not be practical to apply to the majority of, if any, construction projects. Rivanda *et al. (*2021) discusses the use of a WBS framework for the repairs of ships to improve the accuracy of completion and avoid schedule delays. Like the case-studies, the framework is not adaptable to other project types and depends on the accuracy and scope completeness of previous projects. Other studies have discussed the development of a WBS for ship building projects, however, are more orientated to aligning with the Construction Breakdown Structure (CBS) (Lee 2014; Steele 1977).

Project Management Guidance

PMI (2017) outlines that for a project to set out attainable deliverables, it is vital the project scope is appropriately decomposed in a WBS, thereby translating high-level objectives into actionable tasks. Zhang *et al. (*2009) outlines the automation of construction progress using a 3D model, by developing a suitable WBS to outline sensible work packages for progressing throughout the project lifecycle. The approach outlined three main criteria for WBS selection, namely that of work section, floor level, and type of components to outline the work packages to be progressed. However, this is hinged on the 3D model being complete at an early stage, which is unlikely given the number of stakeholders involved Cerezo-Narváez *et al. (*2020), and the necessity of the WBS to be established early in the planning stage PMI (2019). Although this method streamlines progress costing, it offers limited support for identifying specific disciplines and aligning the WBS with the overall construction schedule.

Similarly, PMI (2019) outlines principles for hierarchical decomposition, scope management, and work package creation. The standard outlines the importance of the 100% rule where the entirety of the scope is identified, which is then decomposed. The standard provides examples such as a small house and bicycle assembly. Furthermore, while the examples provided are useful for smaller or more straightforward projects, they lack the depth needed to address the complex nature of more advanced undertakings and lacks granularity. Additionally, Norman *et al. (*2008) discusses a similar approach regarding the creation of work packages by breaking down the scope into smaller and more manageable components, which is essential for effective cost estimation, scheduling, and resource allocation. The method is applied in practice by guiding project managers to define all elements of a project, ensuring that each of the components is clearly defined. However, despite the common acknowledgement of decomposing scope to improve the overall project planning, the guidance does not expand into frameworks that are applicable to for use on complex projects to accurately ensure all scope is identified and decomposed within the WBS.

Developing Adaptable Frameworks

When examining existing WBS frameworks in isolation, it becomes evident that none are entirely suitable for complex construction projects. Project-specific frameworks, including those using neural networks for tunnelling (Sharifzadeh *et al.,* 2011) and case-based reasoning for apartment construction (Lee *et al.,* 1998), offer innovative methods tailored to specific contexts. However, their narrow focus and computational demands make them impractical for broader application. Similarly, project management guidance, like PMI's hierarchical decomposition approach (PMI, 2017), and international standards, such as ISO 21500 (2012) and PMI guidelines (2019), emphasize structured scope definition, hierarchical decomposition, and work package creation, however, these are often too simplistic for the iterative and multifaceted nature of complex projects.

As indicated at the onset, a WBS must present a clear definition of the scope (Ajmal *et al.,* 2022; Siami-Irdemoosa *et al.,* 2015; Sharon and Dori 2015), adaptability to various project types (Sharifzadeh *et al.,* 2011; Lee *et al.,* 1998; Dzeng and Tommelein 1997; Xie *et al.,* 2023), and a structured approach for decomposition (PMI 2017; PMI 2019; Zhang *et al.,* 2009; Lee 2014; Steele 1977). Simply put, a deliverable orientated, hierarchically decomposed WBS containing 100% of the scope (Brotherton *et al.,* 2008). While existing frameworks exhibit some of these features independently, individually they fail to combine them into a cohesive approach. Moreover, although these sources acknowledge the importance of principles such as full scope inclusion or structured decomposition, they stop short of offering practical mechanisms or guidance for how to implement these in the context of complex, evolving project environments.

This fragmentation across the literature suggests that while various frameworks address individual elements of WBS development, none offer a complete or integrated solution suitable for complex projects. However, when viewed collectively, some conceptual overlap emerges. Figure 2 illustrates two Venn diagrams. The left illustrates conceptual overlap across international standards, project-specific frameworks, and project management guidance, with shared emphasis on core principles such as 100% scope, hierarchical decomposition, and adaptability. In contrast, the right illustrates the gap and lack of integrated tools or methods to deliver these principles, highlighting a gap in practical guidance and cohesion across the literature.

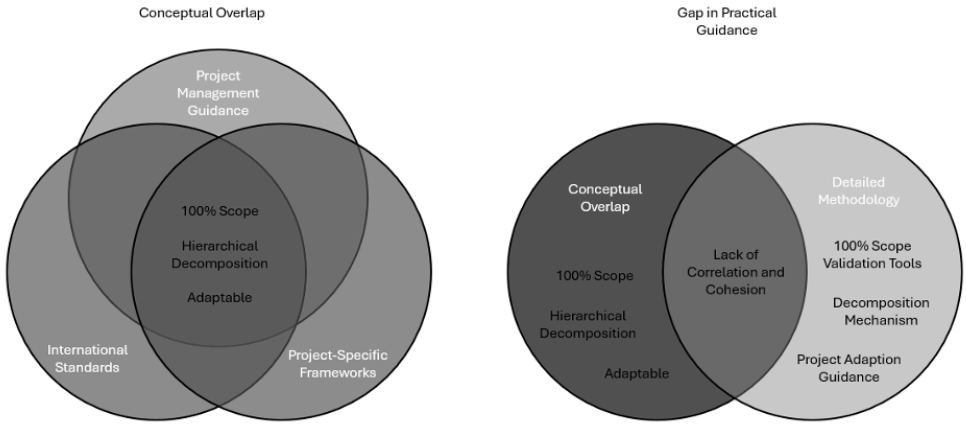
CONCLUSION

As the built environment continues to evolve, and projects become more complex with 52% of projects fail to accurately capture the project scope (Elton 2018), and 56% (Haass and Guzman 2020) to 85% (Gurgun *et al.,* 2024) of projects repeatedly failing to achieve the intended milestones the need for inclusive and adaptable WBS frameworks is becoming increasingly vital. Therefore, this paper sought to explore the frameworks available and analyse their applicability to complex construction projects.

The analysis reveals that while international standards provide a solid foundational framework through clear scope definition and hierarchical decomposition, they often lack the granularity and adaptability required for complex projects. Additionally, project specific frameworks, including those leveraging artificial neural networks and ontology-based mapping, offer innovative solutions for automating and enhancing

WBS creation. However, these approaches tend to be narrow in scope and computationally intensive, limiting their broader applicability.

Figure 2: Venn diagram of concept vs detailed methodology (Source: Author)



In contrast, traditional project management guidance emphasizes the importance of clear scope definition and systematic decomposition, however, fall short in providing detailed, iterative methodologies. While there is an availability of guidance for WBS development, there is little in terms of frameworks that can be applied to projects of a different or more complex nature. Furthermore, aside from highlighting the need to detail and encapsulate the entirety of the scope and decompose, the guidance available does not provide users with procedural steps in which to apply. Additionally, many of the frameworks available are of a significant age, and do not appear to be incorporated into current research or construction projects regularly.

This paper contributes to the current body of knowledge, by establishing the current lack of detailed and adaptable WBS development frameworks, identifying the need for further research and subsequent development of such frameworks. Additionally, the analysis of relatable strengths each category of framework provides does allow for a potential foundation or platform that may allow for future development. Further research into the process of scope definition and decomposition for projects of differing levels of complexity and multi-disciplinary involvement will stem from this study. Future study and in-depth analysis are required to determine the specific nature of WBS development frameworks for implementation on complex construction projects.

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TOWARDS AN OPTIMISED TAXONOMY OF ERRORS IN CONSTRUCTION: A CONCEPTUAL FRAMEWORK FOR CATEGORISATION

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Construction errors remain a persistent barrier to quality, efficiency, and sustainability. A well-structured taxonomy of errors is crucial for systematically identifying, categorising, and managing these issues to reduce their impact and drive improvement. This study conducts a comparative analysis of existing categorisation frameworks, evaluating their design approaches, classification dimensions - i.e., error type (e.g., architectural, structural, mechanical and electrical), root causes (e.g., design, materials, workmanship) and lifecycle stages (e.g., construction, post-construction) - as well as practical applicability. By building on the strengths of existing frameworks, such as coverage of lifecycle stages and categorisation flexibility, and addressing weaknesses including limited standardisation and lack of digital integration, the research synthesizes these insights to propose an optimised taxonomy. The proposed taxonomy adopts a hybrid top-down and bottom-up approach, combining literature/expert-driven categorisation with data-driven enrichment. This multi-category structure supports standardisation, adaptability and scalability to AI-driven error management. By addressing gaps in current frameworks, it can contribute to advancing error documentation and management and promoting sustainable practices to foster continuous quality improvement.

Keywords: categorisations; defects; errors; quality; rework

INTRODUCTION

The construction sector has often been condemned for its failure to deliver quality, and this has led to major interventions from professional bodies, which have issued codes of practice for managing quality to help the industry improve its performance record (Chartered Institute of Building (CIOB), 2019). Similar efforts have been undertaken by multi-disciplinary groups of industry experts, such as the Get It Right Initiative (GIRI) (2025) which aims to improve quality by eliminating construction errors.

The lack of a universally utilised terminology to refer to construction errors is one of the many barriers to their prevention, with GIRI (2016) associating "errors" with

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actions, or the lack thereof, that result in rework, and the closely related term of "defect" referring to failure to meet project requirements at handover.

With projects being highly complex endeavours linked to large volumes of information, the construction industry has historically sought to adopt classification systems to manage their complexity (Royano *et al.,* 2023). Although efforts to create construction error classification systems and taxonomies have been reported (Chong, 2005; Love *et al.,* 2014; Rahimin *et al.,* 2024), a comprehensive and widely adopted classification framework or taxonomy that captures varied error types across the project life cycle and uses multiple categorisation criteria is yet to be developed.

This paper aims to contribute to the existing body of knowledge by proposing an optimised construction error taxonomy that can aid error detection and prevention. The objectives of the paper are to: (1) identify and critically review the relevant literature, focusing specifically on factors hindering construction error categorisation; (2) appraise proposed classification systems and perform a comparative analysis of the approaches adopted in these; (3) synthesize the strengths of existing taxonomies and address their limitations to conceptualise an optimised taxonomy; and (4) outline directions for the integration of the proposed taxonomy with novel digital methodologies.

REVIEW OF RELATED LITERATURE

Errors in construction have long been recognised as a significant challenge, leading to cost overruns, project delays, and compromised quality (Forcada *et al.,* 2014; Love *et al.,* 2004; Matthews *et al.,* 2023; Rahimin *et al.,* 2024). The absence of a universally accepted taxonomy for construction errors hinders the ability to systematically track, analyse, and mitigate these issues (Burati *et al.,* 1992; Love *et al.,* 2016).

Various researchers have sought to classify errors based on their origins, manifestations, and impact on construction projects (Asadi *et al.,* 2021; Jingmond and Agren, 2014). However, inconsistencies in terminology, scope, and classification schemes have resulted in fragmented frameworks, limiting their applicability across different contexts (Matthews *et al.,* 2023).

Terminology and Definitions

A major challenge in construction error classification is terminological inconsistency, which complicates efforts to standardise taxonomies across different studies and industry practices. Definitions of errors range from non-conformances and deviations from specifications to failures in workmanship and material applications (Burati *et al.,* 1992; Rahimin, 2024). Love and Smith (2018) highlight that terms such as "quality deviation," "non-conformance," "defect," and "error" have been used interchangeably, creating confusion in error classification and reporting. Similarly, the Get It Right Initiative (2016) underscores that identical types of errors may be labelled differently depending on contractor preferences, project stages, or organisational structures, further complicating comparative analysis.

Error Occurrence Across Lifecycle Stages

Compounding this issue is the lack of consistency in defining lifecycle stages of errors. Some studies classify errors based on project stages, such as pre-construction, construction, and post-construction (Jingmond and Agren, 2014). The design stage is particularly critical, as errors at this stage tend to have cascading effects throughout the project lifecycle. Research suggests that nearly 50% of errors originate from this

stage, including miscalculations, inadequate specifications, and poor coordination between consultants (Burati *et al.,* 1992). The Get It Right Initiative (2016) highlights that rushed procurement processes and the absence of detailed design reviews contribute to construction-stage errors. Love and Smith (2018) also explored the influence of procurement on errors/rework. They applied a systems-thinking approach, using causal mapping and forensic analysis of project records to explain how procurement inefficiencies and contract structures contribute to recurring errors. Aljassmi and Han (2013) further argue that incomplete or inaccurate design documentation forces contractors to make on-site adjustments, increasing error occurrence and the likelihood of costly rework.

During the construction stage, additional errors may arise due to workmanship deficiencies, material mishandling, and deviations from design specifications. Studies estimate that 40% of total construction errors arise at this stage, with factors such as inadequate site supervision and skill shortages being major contributors (Chong, 2005). Ahzahar *et al. (*2011) highlight that improper material handling and poor storage conditions exacerbate construction errors, particularly in reinforced concrete and façade systems.

Latent defects are defined as those that remain undetected at the time of handover but emerge during the occupancy/operational stage, often within the defects liability period (DLP) (Chong, 2005; Rahimin *et al.,* 2024). Hassan *et al. (*2011) reported that many architectural defects identified during the DLP were attributable to errors originating in earlier project stages. According to the Get It Right Initiative (2016), 30% of construction defects are latent. Forcada *et al. (*2014) highlight that inconsistencies in defect classification can lead to disagreements between clients and contractors over rectification obligations and timelines. The Royal Institution of Chartered Surveyors (RICS) (2024) also notes that contractual disputes often arise due to ambiguous defect classifications, particularly in cases where responsibility is contested.

Data Capture and Management

Data capture inconsistencies further complicate construction error classification. Accurate data collection is essential for tracking errors, understanding patterns, and supporting effective decision-making. However, Love *et al. (*2016) criticise the over-reliance on survey-based methodologies, which often result in subjective error classifications that lack robustness. Hwang *et al. (*2009) identify fragmentation in data ownership as a key barrier, with error records being stored across different platforms and business units.

Moreover, error data is frequently documented in disparate repositories, including site logs, non-conformance reports, site instructions, and punch lists, making it challenging to assess the actual costs and long-term consequences of errors (Get It Right Initiative (GIRI), 2016; Love *et al.,* 2016; Matthews *et al.,* 2023). GIRI notes that companies often use isolated error tracking systems, preventing seamless integration of data across projects and departments. Aljassmi and Han (2013) emphasize that misclassification of error data between site inspections, project reports, and subcontractor records leads to incomplete datasets, undermining efforts to conduct trend analysis and predictive error management. Matthews *et al. (*2023) highlight that unstructured documentation hampers more sophisticated approaches such as AI-based classification systems, as machine learning models require consistent and structured data formats to function effectively.

Classification, Taxonomy and Ontology

Establishing a clear distinction between classification, taxonomy, and ontology is fundamental to developing a standardised construction error framework. Classification involves grouping errors into predefined categories, often based on industry standards or historical trends (El-Diraby, 2005). Taxonomy expands on classification by introducing hierarchical structures, allowing errors to be organised into different levels based on attributes such as cause, severity, and lifecycle stages (El-Diraby, 2005). Ontology, in contrast, offers a formalised knowledge representation, defining semantic relationships between different error types to enable digital interoperability across platforms (Matthews *et al.,* 2023).

Taxonomy Development Approaches

Various methodologies have been employed to develop construction error taxonomies, broadly falling into two categories: top-down and bottom-up approaches. While this distinction is most often emphasized in ontology development, it is equally useful for understanding how taxonomies are derived—whether through the modelling of high-level concepts (top-down), or empirical/data-driven modelling (bottom-up) (Matthews *et al.,* 2023).

Top-down taxonomies are generally developed through synthesis of literature/expert-informed categorisation. They often reflect an effort to impose order and consistency across contexts, based on theory or industry best practice (Matthews *et al.,* 2023). For example, Burati *et al. (*1992) proposed a hierarchical classification system dividing errors into design, construction, and operational categories based on the analysis of multiple projects.

Likewise, Rahimin *et al. (*2024) developed a taxonomy of eleven error types—including workmanship, design, material, and documentation—by conducting a systematic literature review of 18 published studies. Since their categories are drawn from patterns across secondary sources rather than raw data, their method also reflects a top-down orientation.

Hassan *et al. (*2011) and Chong (2005) also developed classification frameworks through synthesis of existing literature and practitioner experience without applying formal data-driven techniques. These frameworks include five and six major error categories, respectively. As Matthews *et al. (*2023) note, deriving categories from literature and expert input is a defining trait of top-down approaches.

In contrast, bottom-up methodologies rely on empirical data and analytical techniques to allow categories to emerge from the observed characteristics of construction errors. These approaches offer greater adaptability and responsiveness to real-world trends, particularly when used with structured datasets and modern computational tools (Matthews *et al.,* 2023).

Matthews *et al. (*2023) exemplify this approach by analysing more than 1,900 non-conformance records from live infrastructure projects using machine learning and topic modelling techniques. Their taxonomy incorporates dimensions such as severity, impact, and consequence, derived from patterns found in actual project data. Unlike pre-defined concepts, their classification framework evolves based on the content and frequency of reported issues, reflecting the strengths of bottom-up methodologies in identifying emerging patterns and enabling real-time refinement.

Asadi *et al. (*2021) also adopt a bottom-up strategy, integrating historical data, probabilistic modelling, and risk metrics to support predictive classification of construction errors. Their approach emphasizes the value of data analytics for forecasting and mitigation, moving beyond static classification into dynamic risk management.

Forcada *et al. (*2014) present a bottom-up classification developed specifically for construction defects, based on the analysis of 3,647 defect records across 68 residential buildings, categorised by location, building element, subcontractor, and defect type. This data-driven structure illustrates how large empirical datasets can inform taxonomy development tailored to residential construction contexts.

COMPARATIVE ANALYSIS

This section presents a comparative analysis to evaluate these taxonomies and synthesize their strengths into an optimised framework for error classification in construction projects. The final selection included only those studies that provided comprehensive and applicable frameworks for construction error classification. Each taxonomy was assessed based on the following key criteria:

1. Method - Whether the taxonomy adopts a top-down (literature/expert-driven) or bottom-up (data-driven) approach.
2. Categorisation Approach - Whether the classification system is hierarchical, matrix-based, or ontology-driven, and how it structures error categories.
3. Data Integration - The ability of the taxonomy to integrate with Building Information Modelling (BIM), AI-driven error analysis, and other digital construction platforms.
4. Lifecycle Coverage - The extent to which the classification accounts for errors across design, construction, and post-construction stages.
5. Standardisation - The degree of alignment with standards e.g., BS 8541-2 (British Standards Institute (BSI), 2011) or ISO 9000:2015 (International Organisation for Standardisation (ISO), 2015) or other recognised frameworks.
6. Flexibility and Scalability - The adaptability of the taxonomy to different project types, evolving construction technologies, and cross-disciplinary applications.

Each taxonomy was systematically reviewed based on these criteria to identify strengths, limitations, and gaps in existing frameworks. This structured comparison enabled the identification of patterns in how construction errors are classified, highlighting areas for refinement and improvement. The outcomes of this analysis are summarised in Table 1.

The reviewed taxonomies reveal distinct strategic orientations, shaped by their underlying methodologies, intended applications, and capacity to accommodate digital workflows and evolving project demands. Earlier top-down models, such as those proposed by Burati *et al. (*1992) present structured classifications grounded in theoretical frameworks. While they contribute to clarity and consistency in error grouping, their limited adaptability and lack of integration with digital tools restrict their relevance in increasingly data-intensive project environments. These models tend to rely on predefined categories, making them less responsive to evolving construction practices or emerging error types.

In contrast, bottom-up approaches, including the one by Asadi *et al. (*2021) demonstrate a shift toward dynamic and data-driven classification. Matthews *et al.*

*(*2023) leverage structured project data to develop an ontology-based taxonomy capable of real-time refinement, while Asadi *et al.,* focus on predictive modelling to anticipate error risks. These methods offer high scalability and are well-positioned for integration with AI and BIM systems. However, their effectiveness depends heavily on the availability and quality of structured datasets—an ongoing challenge in practice.

Table 1: Comparison of construction error taxonomies

Study	Method	Categorisation Approach	Data Integration	Lifecycle Coverage	Standardisation	Flexibility and Scalability
Burati *et al.,* (1992)	Top-down	Hierarchical (phase-based)	Not integrated with digital tools	Full lifecycle	Not aligned with standards	Low (fixed categories)
Chong (2005)	Top-down	Categorical (expert-defined)	Not integrated with digital tools	Full lifecycle	Not aligned with standards	Low (context-specific)
Hassan *et al.,* (2011)	Top-down	Categorical (practice-informed)	Structured system, no AI or BIM	Full lifecycle	Partially aligned (quality control)	Low (rigid framework)
Forcada *et al.,* (2014)	Bottom-up	Empirical (attribute-based)	Structured for statistical systems	Construction and early post-construction	Not aligned with standards	Moderate (context adaptable)
Asadi *et al.,* (2021)	Bottom-up	Predictive (data-driven)	Integrated with ML tools	Full lifecycle	Not formally aligned	High (data-driven adaptation)
Matthews *et al.,* (2023)	Bottom-up	Ontology-based (data-driven)	Integrated with AI/BIM	Full lifecycle	Aligned with ISO/BIM standards	High (real-time flexibility)
Rahimin *et al.,* (2024)	Top-down	Thematic (literature-derived)	Partially structured, maintenance-linked	Full lifecycle	Not formally aligned	Moderate (scalable taxonomy)

Taxonomies like Hassan *et al. (*2011) and Rahimin *et al. (*2024) reflect a middle ground. Though methodologically top-down, they synthesize a broad spectrum of error types and show potential for practical application. Yet, without systematic integration of empirical data or analytical tools, these models remain static and less suited for digital environments. Similarly, Chong (2005), through a workshop-based framework, and Forcada *et al. (*2014), through defect data from residential buildings, offer grounded yet relatively constrained classification systems—useful within specific contexts but not easily generalisable across project types or scalable to high-volume data applications.

Optimised Taxonomy

To address the limitations of existing construction error classification systems, this study proposes a hybrid taxonomy, with a dual-layer structure which is illustrated in the schema in Figure 1. This integrates concept-related structuring with data-informed enrichment. The numbering system used in the schema, indicates the literature source(s) from which each category was derived.

The first layer follows the top-down structure, drawing on reviewed studies that classify construction errors through structured literature synthesis. Five core categories were identified: error type, cause category, lifecycle stage, discipline, and work package. While the first four categories are directly derived from the literature, the fifth, work package, has been added to the taxonomy, which is conceptualised and proposed to enhance semantic consistency and alignment with digital delivery standards. The work package category structure is informed by Uniclass 2015 (National Building Specification (NBS), 2025), which organises construction scope into tables including systems, products and elements/functions.

The second layer follows a bottom-up enrichment process grounded in project-generated data. Construction error patterns can be extracted from large empirical datasets including documentary records such as error logs, non-conformance reports etc. This layer incorporates four categories: building part, building location, error consequence, and frequency. A fifth category—project metadata—has been added as part of the conceptualised model to support predictive modelling across diverse project contexts. Project value, programme duration, project complexity, procurement method and contract type have been included in the structure of the project metadata category, as they have influence on errors (Love and Smith, 2018). Their inclusion in the conceptualised taxonomy can also significantly enhance the performance of machine learning models, such as Graph Neural Networks (Scarselli *et al.,* 2009) by enabling cross-project similarity detection and inference. This layer ensures the taxonomy remains responsive to emerging trends and scalable for data-driven implementation.

The proposed taxonomy shows the vertical hierarchy of the concept-related layer (top-down), the data-driven layer (bottom-up) and the recursive data enrichment loop that can continuously refine the taxonomy. Together, all these components constitute an optimised taxonomy that begins with clarity and structure and progresses dynamically toward adaptive learning and predictive intelligence.

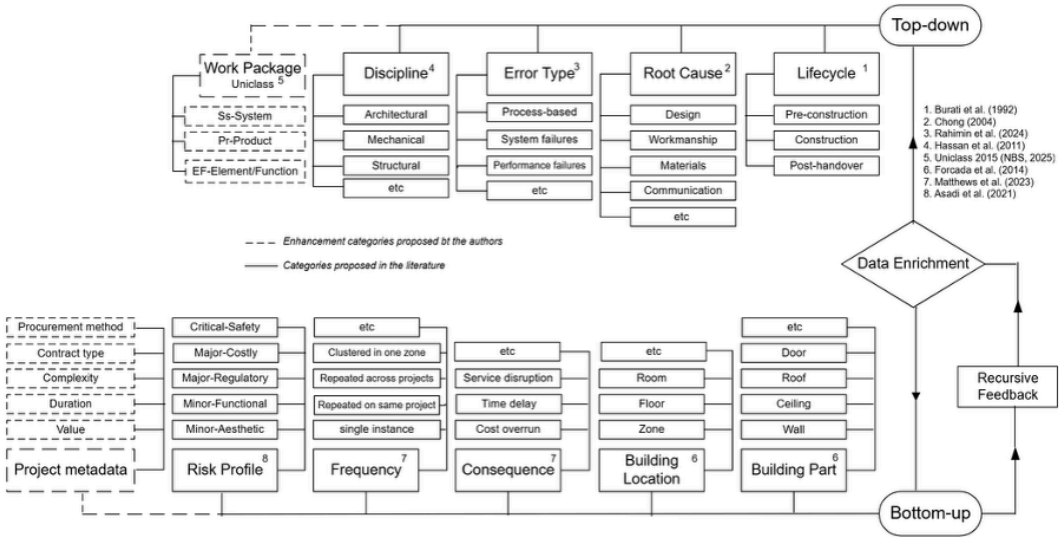


Figure 1: Conceptualised optimised hybrid taxonomy of construction errors

CONCLUSIONS

This paper has examined the persistent challenge of construction errors through a critical review and comparative analysis of existing classification frameworks, revealing both the value and limitations of current top-down and bottom-up approaches. While existing taxonomies offer structure or adaptability, few succeed in combining both—leaving a gap in how errors are understood, tracked, and used to inform future practice.

To address this, the study proposed an optimised hybrid taxonomy that combines literature/expert-driven categorisation with data-driven enrichment. Structured categories such as error type, cause category, lifecycle stage, discipline, and work package provide standardisation and interoperability. These are complemented by bottom-up categories such as building element, building location, error consequence, frequency, and project metadata.

The proposed taxonomy contributes to both academic research and industry practice. It bridges rigid predefined structures with adaptive learning models, offering a scalable foundation for AI-enabled error management. It can support more consistent error documentation, predictive quality control, and improved coordination across the project lifecycle. As construction becomes increasingly digitised, the taxonomy provides a foundation for smarter categorisation, interpretation, and quality management.

Responsibility and accountability for construction errors is a complex subject influenced by a range of factors, including collaborative or non-collaborative procurement methods, contractual arrangements etc. As it is outside of the scope of this study— the paper remained neutral on this topic. Future research can explore how the responsibility of different contractual parties can intersect with taxonomies, offering further insights for industry practice and project governance.

Further research can investigate how the taxonomy can be integrated and utilised with other digital platforms (e.g., BIM) to drive further operational efficiencies. Additionally, subsequent studies can focus on field validation to assess the practical applicability of the proposed taxonomy using large datasets from real-world construction projects. Field validation can be carried out either by conventional data processing methods or intelligent data analysis leveraging AI and machine learning models.

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STAKEHOLDER SALIENCE IN MANAGING INTRAGROUP CONFLICTS IN AUSTRALIAN CONSTRUCTION PROJECTS

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Managing intragroup conflicts is essential in construction projects to mitigate their negative effects while retaining positive effects. Stakeholder engagement plays a significant role in conflict management and existing studies have overlooked the stakeholder salience when analysing its influence on managing conflicts in construction projects. Thus, this study investigates the nature of intragroup conflicts and the salient stakeholders in managing them. The data was collected from a questionnaire survey of 103 project stakeholders in the Australian construction industry. The findings revealed that despite intragroup conflicts are not prevalent, certain causes such as different opinions between stakeholders, issues with designs and schemes, personality clashes, and issues created by other stakeholders still contribute to intragroup conflicts in construction projects. It further identified that the client, architect, project manager, engineers and main contractor as the stakeholders with the highest salience values in both causing and managing conflicts. These findings will be useful for construction project stakeholders to proactively identify potential conflicts and salient stakeholders connected with conflicts and assist them in making well-informed decisions in conflict management.

Keywords: construction projects; intragroup conflicts; conflict management; project stakeholders; stakeholder salience

INTRODUCTION

A construction project is a collaborative venture where the construction project team is formed by involving members from different organisations with expertise in their professions, which can often lead to conflicts (Senaratne and Udawatta 2013). Conflicts can occur at different levels, such as within and between individuals, teams, different levels of an organisation and organisations (Deutsch 2005). Accordingly, they can be categorised as intrapersonal conflicts, interpersonal conflicts, Intragroup Conflicts (IC), intergroup conflicts, intra-organisational conflicts and inter-organisational conflicts (Hussein and Al-Mamary 2019). Various scholars have considered IC as the type of conflict available in teams and when researching conflicts

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Senarath, N B, Udawatta, N, Karunasena, G and Shooshtarian, S (2025) Stakeholder Salience in Managing Intragroup Conflicts in Australian Construction Projects, *In*: Thomson, C and Neilson, C J (Eds) Proceedings of the 41st Annual ARCOM Conference, 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 648-657.

in construction projects, researchers have considered IC (Senaratne and Udawatta 2013; Senaratne *et al.,* 2013). Intragroup conflicts in construction project teams occur when an individual in the team works differently to obtain a different goal than the others because it consists of different stakeholders with diverse perspectives (Hussein and Al-Mamary 2019). The prevailing literature suggests that IC can be categorised as Relationship Conflicts (RC), Task Conflicts (TC) and Process Conflicts (PC). The interpersonal incompatibilities between the team members cause RC, including hostility, tension and frustration, whereas TC occur due to the disagreements between the members regarding the views and ideas of the content of performing a task (Jehn 1995) and PC occur due to the disagreements on the process a task should be performed (Hussein and Al-Mamary 2019). These IC in construction projects can lead to either productive or non-productive results with positive or negative impacts on project outcomes (Wu *et al.,* 2023). Thus, effective Intragroup Conflict Management (ICM) is essential to reduce the effects of negative outcomes while enhancing positive outcomes (Femi 2014).

The conflicts and their management are regularly connected with the processes that include Stakeholder Engagement (SE), and continuous addressing of conflicts and readdressing is a mandatory part of SE as they may occur at any stage in the process (Conallin *et al.,* 2017). Stakeholder Engagement process identifies and incorporates the requirements, concerns and values into the decision-making process, securing their involvement and commitment of stakeholders to reduce differences and hostility among them (Khalilzadeh *et al.,* 2023). Thus, it implies that SE plays an essential part in the success of a project and the conflict assessment for all stakeholders is a crucial part of any SE approach that should be conducted during the primary stakeholder mapping stage in projects (Conallin *et al.,* 2017). The stakeholder theory focuses on distinguishing the stakeholder concept and grouping stakeholders that present an understanding of individual stakeholder interactions (Andriof and Waddock 2017). General SE theory also emphasizes that it is essential to initially analyse the characteristics of the stakeholders and classify them as per their level of interest, power and attitude towards the project to successfully engage the stakeholders throughout the construction project life cycle (Bal *et al.,* 2013). Various methods such as power/interest/impact/influence grids, stakeholder cube, salience model, directions of influence and prioritisation can be used to represent data of stakeholders' characteristics and group them (Project Management Institute, 2017). However, Yu *et al. (*2019) emphasized that stakeholder salience is capable of measuring stakeholder attributes and numerically evaluating the effect capabilities of stakeholders built on empirical information assembled from representatives of each group of stakeholders. Mitchell *et al. (*1997)'s stakeholder salience model is one of the most used models to quantify stakeholders and it analyses and maps out the stakeholders based on the power, urgency, and legitimacy of the stakeholders. The ability to control resources, create reliance and support the interests of other stakeholders is referred to as their power, appropriateness of a stakeholder's actions within a socially constructed system is referred to as legitimacy, while urgency refers to the degree of attention required for stakeholders' claims (Bahadorestani *et al.,* 2020). According to the authors, these attributes play a major role in determining the importance of the stakeholders and their impact on the project. Salience refers to the degree which stakeholders' claims are prioritised (Kapiriri and Razavi 2021). Centred on the allocation of these three attributes of salience, decision-makers can decide the stakeholders who may have a major impact on the project (Yang *et al.,* 2010). Accordingly, the stakeholders with high salience will have an interest in and knowledge of conflict issues and solutions as

well. As per the prominence of the stakeholders, Mitchell *et al. (*1997) introduced three main stakeholder groups as latent, expectant and definitive. Latent stakeholders have low salience and possess only one attribute (power-dormant, legitimacy - discretionary and urgency-demanding). Expectant stakeholders who possess two attributes with moderate salience (power and legitimacy - dominant, legitimacy and urgency - dependent and power and urgency - dangerous). Definitive stakeholders who possess all three attributes with high salience. Despite the emphasis on the importance of SE in ICM, SE itself is an insufficiently studied area in the implementation and the theoretical and conceptual foundation of ICM (Collinge 2020). Specifically, there is a lack of investigation focused on identifying and prioritising the salient stakeholders, which represent the initial stage of the SE process, based on their salience based on power, urgency and legitimacy considering IC. Along with stakeholder salience, identification of issues is an important element in the first stage of SE (Krick *et al.,* 2005). Identification of IC is an under investigated aspect specifically in Australian construction projects as it provides deeper insights into the dynamics of decision-making and collaboration of the stakeholders (Senarath *et al.,* 2025). Addressing both gaps is equally important to understand how IC types and stakeholders' impact directly to each other. Therefore, this study aims to comprehensively investigate the nature of IC in Australian construction projects and the salient stakeholders in terms of who causes the IC and manages the IC.

METHOD

A quantitative research design was used to investigate the nature of IC available and the salience of the stakeholders in terms of causing and managing IC. A questionnaire survey was conducted to collect the relevant data in this research as it is less expensive, saves time, human and financial resources, and offers greater anonymity (Kumar 2011). Key internal stakeholders in construction projects were selected as the target population for the questionnaire to avoid bias in the opinions. Furthermore, they are connected to construction projects by agreements, unlike the external stakeholders (Chinyio and Olomolaiye 2010).

The participants were first asked about their demographic information (Designation, work experience in the industry and organisation type). Then, their opinions were sought regarding IC in terms of RC, TC and PC and the salience of stakeholders for causing and managing IC in terms of power, legitimacy and urgency. The responses were measured using a 5-point Likert scale (ranging from 1- strongly disagree, 2 - somewhat disagree, 3 - neither agree nor disagree, 4 - somewhat agree, 5 - strongly agree). A total of 103 responses were collected and included in the data analysis. The IBM SPSS statistical software was used to analyse the data. Quantitative data analysis methods range from developing simple tables or graphs that display the frequency of occurrence, using statistics to facilitate comparisons, complex statistical modelling and establishing statistical correlations between variables (Saunders *et al.,* 2019). Descriptive statistics such as the mean and standard deviation of variables, and inferential analysis using one-way Analysis of Variance (ANOVA) and stakeholder salience model were used to analyse the data.

FINDINGS AND DISCUSSION

Demographic information of the respondents

The demographic information of the participants is presented in Table 1 below.

Table 1: Demographic information of the respondents

Experience in the construction industry (years)	Percentage (%)	Designation type	Percentage (%)	Organisation type	Percentage (%)
0 - 5	23.33	Project Manager	15.00	Client	15.83
6 - 10	28.33	Architect	9.17	Main Contractor	30.83
11 - 15	22.50	Engineer	35.83	Consultant	34.17
16 - 20	8.33	Contract Administrator	14.17	Subcontractor	9.17
More than 20	17.50	Quantity Surveyor	20.00	Project Manager	5.83
		Facilities Manager	5.83	Other	4.17

Reliability and normality of the data

First, Cronbach's Alpha was conducted to test the reliability of the dataset. Cronbach's Alpha values were observed as 0.832 (RC), 0.874 (TC), 0.851 (PC), 0.824 (power of stakeholders in causing IC), 0.864 (legitimacy of stakeholders in causing IC), 0.899 (urgency of stakeholders in causing IC), 0.885 (power of stakeholders in managing IC), 0.904 (legitimacy of stakeholders in managing IC) and 0.900 (urgency of stakeholders in managing IC). The acceptable values of Cronbach's Alpha, range from 0.70 to 0.95 (Tavakol and Dennick 2011). Therefore, the obtained values indicate the reliability of the data set. Thereafter, the normality of the data set was checked before determining the analysis method by using Skewness and Kurtosis tests. Absolute values of skewness and kurtosis less than 1.0 are considered as slight nonnormality, between 1.0 and about 2.3 as moderate nonnormality and beyond 2.3 as severe nonnormality (Lei and Lomax 2005). According to the analysed data, the skewness and kurtosis values are less than 1, thus can be considered as the data is normally distributed.

Nature of intragroup conflicts in Australian construction projects

Table 2 presents the nature of IC in construction projects by considering descriptive statistics of the three IC types and one-way Analysis of Variance (ANOVA) of IC considering the designation and organisation type of the participants. As presented in Table 2, at the construction project level, certain RC types and TC types have significance values greater than 3.00. Accordingly, issues formed by other stakeholders (mean value = 3.29), differences in opinions (mean value = 3.28), issues regarding design and construction schemes (mean value = 3.18) and personality clashes (mean value = 3.01) have a significant impact on construction project teams in terms of IC. Under RC, stakeholders believe that mainly the problems created by stakeholders for others and personality clashes have the highest potential of forming IC, while under TC, conflicts regarding the designs and schemes and differences in opinions mainly foster IC. However, though the overall mean values characterise the likelihood of only a few IC, it is necessary to analyse the mean values of IC across different designations and organisation types to understand the nature of IC accurately because the opinion may vary based on the role the participants have. Therefore, a one-way ANOVA test was conducted for three IC types considering the designation and organisation of the participants.

As shown in Table 2, there is no significant difference in the opinion of different organisations as the significant values are greater than 0.05. In terms of designation type, all the significant values are greater than 0.05 except for TC4. Thus, statistically, it can be concluded that there is no difference in the views of stakeholders in Australian construction project teams from different designations except for TC4. As there are differences in opinions about TC4, post-hoc testing was conducted to

identify the groups with different views. However, upon conducting the post-hoc test, the results indicate that none of the pairwise comparisons bear a significant p-value. Thus, it can be concluded that there is no significant difference between different designation types for the TC4 as well.

Table 2: Descriptive statistics and results of one-way ANOVA of IC as per designation and organisation

IC type	Mean value	Std. deviation	Asymp. Sig. (Desg)	Asymp. Sig (Org)
The other project stakeholders often create problems for your party (RC1)	3.29	0.982	0.903	0.120
There are many personality clashes between your party and other project stakeholders (RC2)	3.01	1.000	0.534	0.198
There are many disputes between your party and the other project stakeholders (RC3)	2.94	0.981	0.167	0.533
The other project stakeholders often withhold information necessary for the attainment of your party's tasks (RC4)	2.65	1.128	0.451	0.967
There is significant personal friction between your party and the other project stakeholders (RC5)	2.48	1.020	0.162	0.053
There is significant tension between your party and the other project stakeholders (RC6)	2.58	1.066	0.287	0.083
There is much emotional conflict between your party and the other project stakeholders (RC7)	2.25	1.063	0.640	0.115
There is much conflict about ideas for the project design and construction scheme (TC1)	3.18	1.004	0.075	0.898
There are always significant conflicts about ideas for project goal setting (TC2)	2.80	1.058	0.061	0.418
There are significant conflicts about the task between your party and the other project stakeholders (TC3)	2.85	0.993	0.389	0.465
There are a lot of different opinions between your party and the other project stakeholders (TC4)	3.28	1.100	0.012	0.974
The other project stakeholders often disagree about opinions regarding the work being undertaken (TC5)	2.81	1.040	0.368	0.657
The other project stakeholders often have disagreements about the tasks of the project you are working on (TC6)	2.66	0.983	0.241	0.931
The other project stakeholders often have conflicting opinions about the tasks of the project you are working on (TC7)	2.68	0.997	0.139	0.833
The other project stakeholders often do not assist your party in accomplishing your tasks (PC1)	2.48	1.012	0.543	0.291
Your party often does not assist the other project stakeholders in accomplishing their tasks (PC2)	2.04	0.920	0.245	0.067
There is not much cooperation between your party and the other stakeholders (PC3)	2.18	1.004	0.542	0.751
There are many disagreements about who should do what during project execution (PC4)	2.38	1.093	0.718	0.699
There is much conflict between your party and the other project stakeholders about task responsibilities (PC5)	2.42	1.149	0.734	0.805
Your party often disagrees on resource allocation during project execution (PC6)	2.65	1.105	0.116	0.705

The salience of the stakeholders in terms of causing and managing intragroup conflicts

Projects consist of different stakeholders with conflicting interests trying to achieve their own goals irrespective of the available resources (Bahadorestani *et al.,* 2020), which may cause IC. Thus, stakeholders should be well-engaged, whereas the salient stakeholders should be first identified. The stakeholder salience model provides an inclusive analysis considering the significant attributes of stakeholders (Kapiriri and Razavi 2021). Accordingly, the stakeholders are categorised as per their possession of

the attributes, namely power, urgency and legitimacy, and the most salient stakeholders possess all three attributes (Poplawska *et al.,* 2015). Therefore, the salience of the stakeholders in terms of causing and managing IC in Australian construction projects was investigated and mapped to determine the salience dynamics and their interactions. The respondents were asked to evaluate the power, urgency and legitimacy of each stakeholder in causing and managing IC. As per the results, this study presents how the three attributes of salience relate to causing and managing IC and the salience of individual stakeholders.

To formulate an indicator of stakeholder salience, Guerci and Shani (2013) followed by combining the values for power, urgency and legitimacy for each stakeholder. The salience for each stakeholder was calculated by averaging together the values of three attributes based on the findings by Agle *et al. (*1999:520) which denotes "stakeholder attributes of power, legitimacy and urgency are individually and cumulatively related to stakeholder salience across all groups". The following equation was adopted by Guerci and Shani (2013) to calculate the stakeholder salience.

$$i = 1, 2, \ldots\ldots, 12 \qquad K = 1, 2, \ldots\ldots\ldots 103$$

$$Si = \frac{\sum_{k=1}^{103} Sik}{103} \qquad Sik = \frac{Pik + Lik + Uik}{3}$$

[i = stakeholder types, k = number of responses, Si = Salience of stakeholder i, Sik = Salience of stakeholder i for response k, Pik = Power of stakeholder i for response k, Lik = Legitimacy of stakeholder i for response k, Uik = Urgency of stakeholder i for response k]

Accordingly, this study has calculated the salience of the stakeholders in terms of IC causing and managing by using the above equation, and the results are presented in Table 3. The stakeholders are arranged in descending order for both causing and managing IC and P, L, U and S denote power, legitimacy, urgency and salience, respectively. Using a 1-5 Likert scale, the results depict that every stakeholder has salience mean values greater than 3.0 for causing and managing IC. However, the client, project manager and main contractor have a mean salience score above 4.0, which indicates their high involvement in IC in construction projects.

Table 3: Salience of the Stakeholders in terms of causing and managing IC

Stakeholder Type	Causing intragroup conflicts				Stakeholder Type	Managing intragroup conflicts			
	P	L	U	S		P	L	U	S
Client	4.44	4.14	4.31	4.29	Project manager	4.28	4.22	4.24	4.25
Project manager	4.19	4.15	4.17	4.17	Client	4.22	4.22	4.28	4.24
Main contractor	4.10	3.91	4.10	4.04	Main contractor	4.05	3.97	4.07	4.03
Architect	3.99	4.03	3.82	3.95	Architect	3.91	3.92	3.90	3.91
Engineers	3.69	3.80	3.73	3.74	Engineers	3.74	3.71	3.79	3.74
Quantity surveyor	3.52	3.61	3.50	3.55	Quantity surveyor	3.60	3.66	3.56	3.61
End user	3.51	3.50	3.45	3.49	Facility manager	3.49	3.45	3.47	3.47
Sustainable consultant	3.48	3.54	3.35	3.46	Sustainable consultant	3.42	3.43	3.31	3.39
Facility manager	3.39	3.49	3.37	3.41	Sub-contractors	3.33	3.35	3.44	3.37
Building surveyor	3.28	3.42	3.17	3.29	Building surveyor	3.28	3.36	3.31	3.32
Sub-contractors	3.14	3.32	3.40	3.28	End user	3.23	3.23	3.26	3.24
Suppliers	3.05	3.15	3.19	3.13	Suppliers	3.10	3.13	3.18	3.14

Furthermore, the client, project manager, architect, engineers, and main contractor can be identified as the most salient stakeholders in the top 5 considering both causing and

managing IC. However, the client has the highest salience in causing IC, while the project manager has the highest salience in managing IC. Quantity surveyor, facility manager, sustainable consultant, sub-contractors, end user and building surveyor have moderate salience, with suppliers having the lowest salience.

Moreover, Guerci and Shani (2013) classified the stakeholders according to Mitchell et al.'s (1997) salience model by using the terms that, when the stakeholders are assigned an attribute value that exceeds the overall average, they are considered to belong to a particular class and they are considered to tendentially belong to a particular class when the assigned value is above average value minus half a point. The following equations were adopted from their study to categorise the stakeholders into groups as per the salience model.

$$C\ (average) = \frac{(\sum_{i=1}^{12}(Pi+Li+Ui))}{3\times12} \quad Pi = \frac{(\sum_{k=1}^{103}(Pik))}{103}, Li = \frac{(\sum_{k=1}^{103}(Lik))}{103}, Ui = \frac{(\sum_{k=1}^{103}(Uik))}{103}$$

[C(average)=how much a characteristic is attributed to a stakeholder on average, Pi = Power of stakeholder i, Li=Legitimacy of stakeholder i, Ui=Urgency of stakeholder i]

C(average) value was calculated as 3.65 for causing IC and 3.64 for managing IC. According to Guerci and Shani (2013), if Pi, Li, Ui are higher than C(average), the stakeholder has high power, urgency and legitimacy. However, if the values are less than C(average) minus 0.5 (3.15 - causing IC, 3.14 - managing IC), the stakeholders are considered to have no power, urgency and legitimacy. If the values are in between, they are considered quite powerful, legitimate and urgent. According to the data in Table 3, it is evident that the client, architect, project manager, engineers and main contractor have higher values than c(average) for both conflict causing and management. Thus, they can be categorised under definitive stakeholder group. In terms of causing IC, sustainable consultant, facility manager, quantity surveyor, building surveyor and end user have values between 3.15 to 3.65 for all three attributes. Therefore, it can be inferred that they tendentially belong to definitive stakeholder group as well. However, even though sub-contractors hold values between 3.15 to 3.65 for legitimacy and urgency, the value for power is less than 3.15. Hence, Subcontractors can be categorised under dependent stakeholder group. As for suppliers, the stakeholder group only has high value for urgency. Thus, the suppliers can be categorised as demanding stakeholder. However, in terms of managing IC, it can be identified that sub-contractors can be categorised under definitive stakeholder group and that suppliers group remains the same.

According to the definitions of power, legitimacy and urgency by Bahadorestani *et al. (*2020), in terms of causing conflicts, stakeholders have the power to impose their decisions on the project, can pressure the team for their urgent demands and if their legitimate claims are ignored, it may cause them to oppose actions causing conflicts. This suggests that in Australian construction projects, the client, architect, project manager, engineers, and main contractor, being the definitive stakeholders with the highest salience values of all, exercise more significant influence on IC because of their power, legitimacy and urgency in decision-making processes. Similarly, the project manager, client, architect, engineers, and main contractor possess the highest values for power, urgency and legitimacy, and thus can be considered as the ones playing the most critical roles in managing IC. According to the definition put forward by Bahadorestani *et al. (*2020), the three stakeholder salience attributes, these stakeholders have the power to intervene when a conflict occurs to manage it by being involved in the decision-making process, allocating resources, and ensuring all

stakeholders that their interests are considered and valued. Thus, it is essential to keep them informed and involve in the decision-making process, treat their concerns respectfully and address the urgent concerns preventing further escalation. Thus, the results imply that the needs and concerns of all stakeholders should be prioritised to manage IC and especially, the ones with the highest salience should be well managed and engaged. Interestingly, despite the data of IC concluded the likelihood of only several IC types, the stakeholders in construction projects identify specific stakeholders who cause more conflicts in projects as well as who manage the conflicts the most. Thus, arguably, it is evident that proper consideration should be given to enhanced stakeholder management and engagement to manage potential IC.

CONCLUSIONS

Intragroup conflicts are inevitable in construction project teams causing constructive and destructive outcomes. Therefore, they should be managed in a manner to retain the positive effects while reducing the negative effects. To do so, a comprehensive idea should be obtained regarding the nature of conflicts available and the prominent stakeholders in causing and managing them. This research aimed to investigate the nature of IC in Australian construction projects and the salience of the stakeholders in causing and managing IC considering power, urgency and legitimacy attributes. The findings revealed that despite the likelihood of IC seeming comparatively less in the projects, certain causes such as different opinions between stakeholders, issues with designs and schemes, personality clashes, and issues created by other stakeholders can originate IC in the Australian context. Stakeholder engagement plays a crucial role in managing IC and the first stage of the SE process is to identify key stakeholders. Despite previous authors investigated hindrances to SE, strategies to enhance SE, and developed a framework by ranking the conflicting interests between stakeholders to facilitate sustainable SE, no significant study has been conducted to fulfil the first and foremost step of SE to identify salient stakeholders considering IC. This research fulfilled this gap. Accordingly, the client, architect, project manager, engineers and main contractor were identified as the salient stakeholders in terms of causing and managing IC. Overall, this study contributes to knowledge and practice by exploring the prevalent IC in Australian construction project teams, enabling them to identify the issues that may cause IC beforehand and address them proactively while preventing their recurrence. By identifying the salient stakeholders, the project team members can be further cautious while engaging the stakeholders in decision-making processes, giving priority to their concerns and allocating resources accordingly. However, further research is required to investigate the interrelationships between each IC type in more depth, specific strategies that can be implemented in construction project teams for ICM and how the SE process can be further incorporated to manage IC.

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TRUST, CONTROL AND PERFORMANCE IN INTERNATIONAL JOINT VENTURES: AN ASSESSMENT OF THEIR PRACTICAL IMPLICATIONS

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Despite the extensive literature devoted to trust, control and performance in International Joint Ventures, most of the existing studies only explore these variables individually or in pairs. This work intends to highlight the importance of simultaneously analysing trust levels, control mechanisms and resulting performance in International Joint Ventures and, additionally, to provide construction companies with a related framework that helps them make decisions before and during their participation in these alliances. After a comprehensive literature review, findings from previous studies are consolidated into a novel approach that explains the dynamics between trust, control and performance in practice, and proposes guidelines for construction organisations participating in International Joint Ventures. The study shows the intricate cause-effect relationships between trust, control and performance in International Joint Ventures, indicating that every change or alteration, planned or not, in any of these variables will inevitably have an impact (direct or indirect) on the other two. Consequently, it is mandatory that parent companies know what kind of analysis to perform and courses of actions to follow at the different stages in the life of these alliances.

Keywords - International Joint Venture; trust; control; performance

INTRODUCTION

In the last few decades construction companies around the world have been engaging in International Joint Ventures (IJV) to deliver large-scale, complex engineering projects (Walker and Johannes, 2003). An IJV can be defined as an alliance between organisations that involves the creation of a new legal entity managed and controlled by two or more partners of different nationalities (Shenkar and Zeira, 1987). Among the benefits associated with entering these kinds of strategic alliances are the access to new markets, size and scope capabilities' improvement, and risk reduction (Tetteh *et al.,* 2023). Regrettably, the proliferation and popularity of IJVs has not kept these partnerships free from significant dissatisfaction in their operations (Boersma *et al.,* 2003). Diverse problems have been reported, with a high level of discontent among parent companies (Geringer and Hebert, 1991) as well as appalling rates of dissolution (Camara *et al.,* 2013) without consensus on their root causes (Yan and Gray, 1994).

The underlying objective of this study is to shed a new light on some of the success and failure factors of IJVs, to help construction companies make the right decisions about the formation and management of these kinds of alliances. Namely, the research aims at exploring the dynamic interactions between trust, control and

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performance in IJVs and, subsequently, operationalising the conclusions of such evaluation. Although there have been a myriad of studies exploring these variables individually or in pairs, the originality of this work resides in the introduction of an overarching framework analysing these three elements concomitantly and providing practical guidelines for IJV partners. The research methodology consists of the conduction of an encompassing literature review, the generation of a comprehensive theoretical framework and the creation of a new model whose application and usefulness will be validated in future studies.

Theoretical Framework

Definition of Trust, Control and Performance

Inter-partner trust can be defined as the expectation that a party can be relied on to keep to agreements, perform its role competently and behave honourably even where no promises or performance guarantees have been made (Boersma *et al.,* 2003). From this definition, it can be clearly elicited that there are three dimensions or features the partners of an alliance should demonstrate to be deemed trustworthy. The first dimension is called "integrity" or "promissory-based trust" and involves following the intentions that had beforehand been declared through either written or oral agreements, to build reliability or predictability (Mohr, 2004). The second dimension is called "benevolence" or "good-will trust" and encompasses "influence receptiveness", which includes the behavioural changes to accommodate the wishes of the other partner (Smith and Barclay, 1997); and "forbearance', which entails that a partner acts with cooperation refraining from deceiving its counterparts (Parkhe, 1993). The final dimension is referred to as "competence" and consists in demonstrating and applying the capabilities and resources that are expected from each partner to achieve the IJV goals (Wicks *et al.,* 1999).

Control can be defined as the system established to influence the members and departments of an organisation to behave in ways that are conducive toward the achievement of its goals (Yan and Gray, 1994). The different potential control mechanisms in IJVs are countless but there are a handful of them that are present in almost every alliance, such as the nomination of directors and top managers, contracts between partners and with external parties, policies and procedures governing the IJV's functions, goal's setting, and performance evaluation (Camara *et al.,* 2013; Mohr, 2004). Control mechanisms can be grouped into formal or contract centred and informal or relationship centered, the former being predictable, regular and explicit (such as contracts or procedures) and the latter being uncertain, ambiguous and based on values and culture (such as informal communication) (Inkpen and Curral, 2004). There are several intertwined factors affecting the level and kind of control that each of the parents exert on IJVs' operations; including the voting rights; equity distribution, which might be, but is not necessarily always proportional to the voting rights; bargaining power; and origin and culture (Yan and Gray, 1994).

Performance has been described as the ability of an organisation to achieve its goals by using its resources in an effective and efficient fashion (Daft, 2007). As a concept that is relative to objectives, its meaning has a special nuance in the specific cases of IJVs, as these organisations pursue not only the goals of the alliance itself, but also those of each member (Yan and Gray, 1994). There are two main groups of instruments that are used to measure performance in IJVs (Dikmen and Triki, 2010). The first group is constituted by objective measurements; which, in turn, encompass financial indicators, such as profitability, stock market value and returns on assets; and

non-financial indicators, such as sales volume, longevity and stability (Beamish and Luptom, 2009). Subjective measurements, which form the second group of performance indicators, consist of the partners' general satisfaction and their impression of the level of attainment of objectives (Camara *et al.,* 2013). These kinds of measures are usually obtained through interviews and are extremely helpful to assess the performance from the "partners" perspective, even more when their underlying goals differ from the alliance's ones and/or are difficult to measure (Beamish and Lupton, 2009; Geringer and Hebert, 1991).

Cause-Effect Relationships Between Trust, Control and Performance

Despite their intricate and controversial relationship (Das and Teng, 1998), the strongest and most relevant link between trust and control consists in the negative causation between the former, as an independent variable, and the latter, as a dependent one (Philippart, 2005). It is consistently asserted in the literature that when IJV's partners perceive each other as trustworthy, they are less likely to impose further controls (Larson, 1992). Conversely, when the degree of trust between the partners is scarce, they tend to adopt stronger control mechanisms (Van der Meer-Kooistra and Kamminga, 2015). The significant influence that trust wields on control mechanisms in IJVs has also specifically been highlighted in the construction sector's literature (see Ho *et al.,* 2009; Zhao *et al.,* 2013).

The relationship between trust and control is dynamic and potentially fluctuating throughout the life of the IJV (Hsieh and Rodrigues, 2014). At the beginning, there is normally no basis for trust other than public information and, therefore, partners must exert control through formal contractual mechanisms to create structural assurance effects (McKnight *et al.,* 1998). As interactions increase, partners will have the opportunity to mutually evaluate their integrity, benevolence and competence thereby further shaping their level of trust in one another (Boersma *et al.,* 2003). In turn, this re-evaluation will allow them to decide whether they can relax formal controls and rely more on relational and informal mechanisms, or they must reinforce and make more rigid the existing control instruments (Hsieh and Rodrigues, 2014).

The importance of understanding the relationship between control and performance in IJVs has been emphasized in the literature specific to the construction sector (see Lin and Ho, 2013; Tetteh *et al.,* 2022). The interaction between these two variables in these kinds of alliances is highly complex and its analysis has provided conflicting and ambiguous results (Geringer and Hebert, 1989). More specifically, there is an intense controversy on the direction of this relationship, with little agreement on whether their causation is positive or negative (Mantecon *et al.,* 2016).

The first school of thought states that a desired performance requires parent firms to build effective control systems and to allocate appropriate supervising powers so as to effectively transfer their firm specific advantages to the joint venture, thereby endorsing a positive cause-effect relationship between control and performance (Liu *et al.,* 2014). The alternative paradigm supports the possibility of a potential negative causation between control and performance, as autonomy from parents has been identified as a strong contributor to the latter, meaning that excessively rigid monitoring systems could have a negative impact on it (Robledo, 1998; Van der Meer-Kooistra and Kamminga, 2015). Moreover, control tools are costly and then their inordinate utilisation would directly affect profitability and, consequently, performance (Lu and Hebert, 2005).

There are several factors whose incorporation may shed some light on this debate, including the kind of control applied, the distribution of equity, and the criteria to assign control (Mantecon *et al.,* 2006). Firstly, the control mechanisms causing adverse effects on performance are mainly the formal ones and, consequently, informal controls would be more likely to favourably contribute to the achievement of goals (Robledo, 1998). Secondly, an asymmetric control distribution is more prone to harming performance than a symmetric one as, even when it might help the dominant partner achieve its goals (Liu *et al.,* 2014), it would constrain other partners' ability to attain theirs, thereby promoting their opportunistic behaviour in areas where control is lenient (Blodgett, 1991). Thirdly, the criteria utilised to allocate control are also relevant, with alliances dividing it based on the functional expertise of partners achieving better performance than their average counterparts (Beamish and Luptom, 2009).

The relationship between trust and performance, which has also been subject of research in the construction industry's literature (see Myers, 1990; Sridharan, 1995), seems to be less labyrinthine than the two previously investigated. The most tangible causation between these two concepts is the positive effect of the former on the latter (Costa and Silva *et al.,* 2012) via reducing uncertainty about the partners intentions and behaviour, which in turn reinforces cooperation, improves communication and minimises conflicts (Ertug *et al.,* 2013).

The first mediating variable between trust and performance is cooperation, as high levels of trust create and favour frequent interaction and mutual understanding (Ali and Khalid, 2017); thereby promoting discretion, facilitating delegation, fostering autonomy and streamlining decision making (Das and Teng, 1998). The second mediator is improved communication or information sharing (Beamish and Luptom, 2009); which will generate, inevitably, a positive effect on the performance of the IJV (Hsie and Rodrigues, 2014). Lastly, trust also contributes to performance through reducing the likelihood and intensity of conflicts between partners, as difficulties and problems such as power disputes or low profitability are more easily overcome in a trusting partnership (Boersma *et al.,* 2003).

It is relevant to note that the causation between trust and performance is of mutual nature, meaning that the successes or failures of an alliance may also have an influence on the degree of trust between the partners (Inkpen and Curral, 2004). More specifically, the systematic achievement of IJV's goals will most probably increase the willingness of partners to rely on each other, above all if they are going through difficulties individually (Van der Meer-Kooistra, 2015). On the contrary, when an IJV is failing to achieve their goals or having unsatisfactory results, tension could grow between the partners and negatively affect the levels of integrity, benevolence and competence perceived from the others (Hsieh and Rodrigues, 2014).

Practical Implications of Trust, Control and Performance

Description of the interactions of trust, control and performance in practice
In the previous section, the cause-effect relationships between trust, control and performance were studied from a theoretical viewpoint. In the current section, a comprehensive framework depicting the three precedingly analyzed variables and their respective links is introduced through Figure 1.

The assessment of trust in potential allies normally emerges from the intention of an organisation of creating a partnership to pursue its agenda, situation represented by arrow 1 in Figure 1. For instance, if a corporation sets the goal of introducing its

services in a foreign jurisdiction, it may start to consider the possibility of partnering with a local company to gain access to that specific market. Another example would be a scenario in which a contractor has the ambition of being hired by a public institution but is suffering the limitation of missing certain indispensable knowledge and expertise to execute the required work.

In the cases where a partner is perceived as trustworthy by the rest of the members of an alliance, there is a lower necessity of applying preventive measures against potential risks and, therefore, a smaller inclination to impose strict control mechanisms (Larson, 1992; Philippart, 2005). In Figure 1, this is illustrated through arrow 2, which shows a negative cause-effect relationship between trust and control. For example, if partners in the IJV believed that one of the other ones had the intention of having its employees occupying several key managerial positions to gain power, they might include a clause in the formation agreement limiting this possibility.

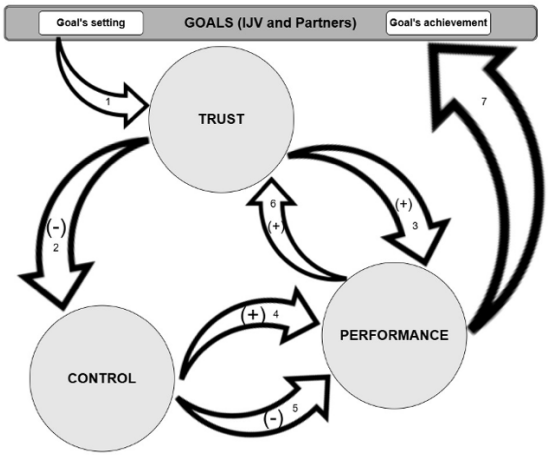


Figure 1: Trust, control and performance in IJVs

The positive effect of trust on performance, which is symbolised by arrow 3 in Figure 1, can be accounted for by an increase in levels of cooperation and communication (Ertug *et al.,* 2013). If partners deem their alliance counterpart benevolent, integrous and competent, they will most likely be willing to openly share information and eagerly receive its proposals, which will result in an enhanced level of performance (Costa and Silva *et al.,* 2012). For instance, if one of the partners assigns its most reputable employees to a specific activity inside the IJV, it is highly probable that the other partners will follow suit, thereby creating a team with superior chances of success.

The adoption of control mechanisms is supposed to have a positive impact on the IJV's performance, as depicted by arrow 4 in Figure 1. In theory, the existence of rules, instructions and indicators designed by specialists with pertinent knowledge and background, positively contributes to the accomplishment of objectives (Liu *et al.,* 2014). For example, the fact that the IJV's management control department closely and frequently monitors budget compliance by the different areas creates a stronger sense of responsibility, thereby keeping the costs of the organisation under control.

Notwithstanding the mentioned positive effects of control on performance, arrow 5 in Figure 1 indicates the presence of a potential opposite impact. Namely, the adoption of strong monitoring mechanisms from parent companies reduces the leeway to manoeuvre or level of autonomy of the IJV management, which may obstruct the

timely completion of activities (Van der Meer-Kooistra and Kamminga, 2015). Furthermore, as previously stated, control is not cost-free, so its increased intensity affects profit margins adversely (Lu and Hebert, 2005). For instance, if partners decided to implement a procedure with multiple, unnecessary steps to approve payments, additional costs would be generated. First, personnel and approvers would spend time performing non-value adding activities and, second, it would make meeting payment deadlines more challenging, which might undermine the relationship with suppliers and, consequently, reduce future negotiation's power.

Apart from being positively affected by high levels of trust, as indicated by arrow 3 and described above, performance has a similar impact on trust, completing a reciprocal causation (Inkpen and Curral, 2004; Rousseau *et al.,* 1998). This intuitive, direct effect of performance on trust is represented by arrow 6 in Figure 1 and explained by the fact that good results stemming from collaborative work inexorably increases the esteem among partners. Put it differently, the poorer the performance, the weaker the feelings of benevolence, competence and integrity between the members of the IJV. For example, if one of a contractor's partners with expertise in a specific area failed to submit a deliverable to their client and that generated an economic penalisation, the other partners might doubt its competence to meet future similar requirements.

Finally, arrow 7 of Figure 1 represents the contribution of performance toward the achievement of goals, which derives from the own definition of performance provided above.

Guidelines for partners throughout the IJV's life cycle

After having explored in detail the interactions among trust, control and performance, it is possible to analyse their practical implications, which might help parent companies not only during normal operations once the IJV has been established, but also during the pathways toward its formation. With this purpose, Figure 2, which is based on relationships elucidated in previous sections, presents a highly simplified model introducing a procedure that aims at providing general guidance to organisations planning on participating in an IJV.

The left side of Figure 2 shows the different stages happening before and during the formation of an IJV. Step "a" represents the emergence of the plan to create an IJV, which is normally devised by one of the future members of the alliance. The reasons for this kind of initiative may be of very diverse nature; including economical, technical or expansionist, just to cite a few.

In response to this need, the company leading the project will conduct a search and identify potential partners, as displayed in step "b". The criteria to select possible IJV partners will depend on the goal that is driving the initiative of creating an alliance. For instance, if the reason were to access a foreign market, the potential partners would be organisations providing a similar service in that specific target market.

Once the candidates have been shortlisted, the organisation must appraise their level of trustworthiness, as indicated in step "c". At this incipient stage in the development of the partnership, the sole sources of information about the probable members are their overall reputation, their financial stability (in the case of public companies), the previous interactions with them or their employees and, in the best-case scenario, some superficial information on their strategic goals.

Based on this trust assessment, the initiating company must decide on the course of action to follow. If the perceived levels of trustworthiness of pre-selected partners were unreasonable low, the organisation should discard the possibility of forming a partnership with them and return to step "b", thereby selecting other candidates for evaluation. This is justified by the fact that, as stated in previous sections, lack of trust would cause a significant level of uncertainty, which, in turn, would preclude harmony and connection between the partners from developing and, eventually, negatively affect performance. Differently, if the levels of trust in likely partners were adequate, the organisation could initiate the conversations with them.

During the negotiation stage, represented in step "d", the company and the potential partners disclose their goals and can confirm the preliminary impressions of one another. At this point, the company must decide whether it is going to move on with the partnership agreement and, if this is not the case, resume the search of other potential candidates, going back to step "b". If the decision is to create the IJV instead, the company moves into the phase of formation of the IJV, which is represented by step "e".

The formation stage entails the application of the first control mechanisms, such as the nomination of authorities, the signature of the constitution contract with the most general clauses to rule the alliance, and the implementation of some informal control instruments such as unofficial communications or casual meetings. At this early point in the life of the IJV, the objective is to exert a moderate level of control, given its bidirectional (positive and negative) cause-effect relationship with performance previously analysed.

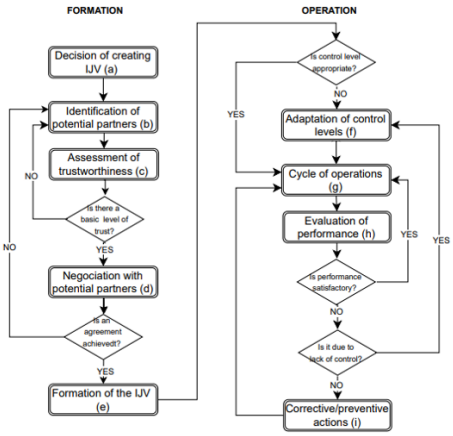


Figure 2: Guidelines for IJV's potential members

The right side of Figure 2 describes the stages occurring during the normal course of operations of the IJV's. After the formation of the alliance, the partners will have more elements to reevaluate the level of trust between them, as they will have interacted during the negotiation and the signature of the main constitution contract. Based on this new evaluation, the parent organisations must reassess the current levels of control.

If it is determined that the ongoing control instruments are appropriate for that "updated" level of trust the IJV can initiate its cycle of operations, which is represented by step "g". However, if the degree of control is considered too low or too high, it must be adjusted as indicated in step "f", as neither scenario would be desirable. In the cases when control mechanisms are considered insufficient, stricter measures must be applied, such as the enforcement of new policies and procedures,

the reduction of the term of goals, or the addition of job positions to monitor compliance. Conversely, if control mechanisms are deemed excessive and then have to be lessened, the opposite measures would be pertinent.

Once a full cycle of operations has elapsed, it will be time to measure the performance, as shown in step "h". The main objective of the performance evaluation is to ascertain whether the goals formerly set up have been achieved, for both the alliance and the individual partners. As described above, there are diverse measures that can be used for this purpose; including financial indicators, such as percentage of profits on sales, return on assets or costs per units produced; non-financial measures, such as number of new clients or rate of accidents; and subjective measures, such as open questionnaires with partner's representatives.

If the outcome of the performance evaluation is satisfactory, the partners can continue and move to the new cycle of operations by returning to step "g". Conversely, if the conclusion is that the performance has been defective, an additional analysis is required to determine the root cause of the problems encountered. If the reason for the poor performance were an inadequate level of control, the following step would be its adaptation, activity that has already been described as step "f". Differently, a meagre performance with suitable control mechanisms in place would signify that the IJV must implement other corrective and preventive actions (step "i"), because the difficulties found during the performance evaluation would not be related to the nature, amount or intensity of control tools being used.

CONCLUSIONS

Despite all the evident advantages of partnerships, construction companies aspiring to embark on an IJV need to carefully consider a couple of variables whose importance is often underestimated: Trust and control. The level of trust in potential partners is an essential factor at the time of evaluating the possibility of entering an international alliance given its powerful positive impact on performance. Additionally, trust has the capacity to lower the necessity of control mechanisms, which further contributes to performance through cost reduction. Control is also relevant due to its bidirectional effect on performance and, therefore, parent companies should be well versed in the different control mechanisms available and know when to utilise them.

The framework presented in Figures 1 and 2, intends to introduce guidelines to help organisations analyse these key variables in a systematic way at the different stages of the life cycle of the partnership. It provides directions on when to evaluate the levels of trust, control and performance, and what kind of decisions should be made as a result. The usefulness and applicability of the model hereby proposed need to be demonstrated in practice, which opens an important avenue for future research by the application of action methods (Eden and Huxman, 1996). Another relevant line of research stemming from this work would be related to finding more objective methods to measure the existing amount of trust between partners and more precise techniques to determine the optimal levels of control in these kinds of alliances.

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CRITICAL SUCCESS FACTORS MAY BE "SUFFICIENT" BUT ARE THEY "NECESSARY" FOR PROJECT PERFORMANCE OR SUCCESS? A PRELIMINARY ANALYSIS OF THEORY-METHOD MISFIT

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Construction and project management research is replete with theoretical statements that suggest that certain factors or conditions are "necessary" for an outcome to occur. This is most pronounced in "critical success factors" (CSFs) studies. Two theoretical causation perspectives are however prominent in organisation and management research: "sufficiency" and "necessity", with different and varying theoretical, analytical, practical and managerial implications. Sufficiency connotes that a factor or condition has the likelihood or probability to produce an outcome while necessity connotes that an outcome cannot occur without a particular factor or condition. Preliminary analysis of CSFs studies raises a fundamental question of theory-method misfit, where CSFs researchers often theoretically invoke "necessity", test for "sufficiency" and conclude that "necessity exists or is confirmed". Necessity Conditions Analysis (NCA) is introduced as the appropriate data analysis approach for studies that specify/invoke necessity theoretically, such as the case in CSFs studies. NCA is illustrated with a dataset from Hong Kong, demonstrating its viability. Reanalysing past CSFs data using NCA could determine if CSFs are indeed critical or necessary, rather than sufficient.

Keywords: causality; critical success factors; necessity; necessity conditions analysis; project performance; project success; sufficiency

INTRODUCTION

Construction and project management research is replete with theoretical statements that suggest that certain factors or conditions are "necessary" for an outcome to occur. These statements are commonly made when developing hypotheses (e.g., in the introduction, literature review or theory development sections) or when evaluating theoretical or practical implications of the empirical results (e.g., in the discussion or conclusion sections) (Dul, 2016). This is most pronounced in "critical success factors" (CSFs) studies which often invoke the notion that a set of factors are "critical" for project performance or success (Gunathilaka *et al.,* 2013, Dul *et al.,* 2010, Dul *et al.,* 2020). Dul (2020) asserts that "critical' in this context "means that the factor must be present for success and there will be guaranteed failure if the factor

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is absent" (6). In other words, these factors are necessary for project success. Ranjan and Bhatnagar (2008) define CSFs in "necessary condition" terms explicitly when they define CSFs as "a business term for an element which is necessary for an organisation or project to achieve its mission" (7). Indeed, Dul *et al. (*2010) earlier asserted that "an important synonym for necessary is 'critical' such as in 'critical success factors (CSFs)" (1174). "Necessity" is however one of two valid theoretical causation perspectives prominent in organisation and management research, the other being "sufficiency". Sufficiency connotes that a factor or condition X is has the likelihood or probability to produce an outcome Y or that "X causes Y" (i.e., ''If X, then Y'') (Dul, 2016) while necessity connotes that Y cannot occur without X (i.e., ''No Y without X'') (Dul, 2016). Applied to CSFs studies, it raises the question whether CSFs researchers theoretically invoke "sufficiency" or "necessity" or even both? This distinction is important because the two perspectives have different and varying theoretical, analytical, practical and managerial implications. Yet, scholars have confused and employed the same traditional regression-based data analysis approaches (e.g., correlation, regression, structural equation modelling-SEM) for testing hypotheses that specify sufficiency and/or necessity even though these methods only focus on the average or additive effect of factors on the outcome i.e., sufficiency (Dul, 2020).

It is contended here, drawing on recent analytical developments that, there is a theory-method misfit in CSFs studies where researchers invoke theoretical necessary statements, apply traditional data analyses approaches appropriate for testing sufficiency and yet conclude the existence of necessity, an exception being Solaimani and Swaak (2023) who recently applied Necessity Conditions Analysis (NCA) to the study of CSFs of artificial intelligence adoption. The only other study employing NCA in the construction and project management domain being Tuuli and van Rhee (2021). The inappropriateness of prior methods for testing necessity has become apparent following the advent of Dul (2016) NCA method, which enables the identification of necessary determinants that may prevent an outcome from occurring (i.e., "constraints" or "bottlenecks"). Without the necessary condition, there is guaranteed failure, which cannot be compensated by other determinants of the outcome (Tuuli and van Rhee (2021). This logic and its related methodology are fundamentally different from the traditional sufficiency-based logic and methodology. Hitherto, researchers were unaware of the importance, special characteristics, and required methodology of the necessity approach (Dul, 2016). This paper therefore addresses the key question: do CSFs connote sufficient or necessary and is there a theory-method misfit in CSFs studies?

The remainder of this paper is structured as follows. First, a brief overview of two theoretical perspectives on causality is provided, distinguishing necessity causality from probabilistic sufficiency causality. This is followed by an overview of the CSFs concept, demonstrating that the notion of CSFs is synonymous with a necessity logic. Next, the research approach is detailed, a systematic review of CSFs studies and analysis of necessity statements and, the logic and methodology of NCA. Preliminary findings of the systematic review provide illustrative evidence of a theory-method misfit situation in CSFs research where researchers theoretically invoke "necessity", test for "sufficiency" and conclude that "necessity exists or is confirmed". NCA is illustrated with a Hong Kong dataset, leading to a call for CSFs researchers to consider applying NCA to reanalyse their data to truly determine if CSFs are indeed critical or necessary, rather than sufficient.

LITERATURE REVIEW

Theoretical Perspectives on Causality

The philosophy of causation has a long history. According to the 18th-century Scottish philosopher David Hume (1777) "We may define a cause to be an object, followed by another, and where all the objects, like the first, are followed by objects, like the second. Or in other words, where, if the first had not been, the second never had existed." The first sentence of the above quote reflects the common understanding of causality: sufficiency, i.e., X is sufficient for Y or that ''If X, then Y'' (Dul, 2016) or "If X, then probably/likely Y" (Dul, 2024a). The second part of the quoted sentence reflects necessity causality, i.e., X is necessary for Y or that ''No Y without X'' (Dul, 2016) or "if not X then not Y" (Dul, 2024a). Although scholars have confused necessity and sufficiency perspectives of causality for long, the two are totally different (Chung, 1969, Goertz and Starr, 2003, Dul, 2016). This confusion is even evident in Hume (1777) quote above when he uses the words "Or in other words" between his two statements that denote different causality, which could be inferred to mean the two parts of the sentence are equivalent or interchangeable (Marques, 2011).

As Dul (2016) explains, a necessary cause allows an outcome to exist i.e., without the necessary cause, the outcome will not exist. Therefore, a necessary cause is a constraint, a barrier, an obstacle, a bottleneck that must be managed to allow a desired outcome to exist. On the other hand, a sufficient cause makes it more likely or probably that the cause produces the outcome (Dul, 2016). Until recently however, analytical approaches were non-existent for testing hypotheses or theoretical statements that invoke the necessity or criticality of determinants or factors to various outcomes. This lacuna resulted in researchers invoking necessity theoretically, applying sufficiency approaches analytically and concluding that necessity is confirmed, resulting in a theory-method misfit. Yet, the managerial implications for sufficiency and necessity are also substantively different: while the identification of sufficient factors suggests that managers should invest in these factors as to (on average, though not in all situations) increase the outcome, identification of a necessary factor(s) requires managers to ensure a minimally required level for that factor(s) or else the outcome will not occur (in any situation) (van der Valk *et al.,* 2016, Tuuli and van Rhee, 2021).

The Concept of Critical Success Factors (CSFs)

Project success or performance remains an important and illusive phenomenon of interest for organisations and academics alike, as we continue to grapple with what it means in different context, it's attributes/criteria/dimensions and measurement as well as the contributing factors to success (success factors/critical success factors) (Ika and Pinto, 2022). The notion of success factors in project studies dates to Rubin and Seelig (1967) and their study of experience as a factor in the selection and performance of project managers. This has triggered decades of research by scholars to identify and explain variables that are considered "critical" for predicting and achieving various aspects of project success or performance (Amies *et al.,* 2024). In defining CSFs, a primer by Rockart (1979), states that CSFs are the "limited number of areas in which results, if they are satisfactory, will ensure successful competitive performance for the organisation. They are the few key areas where things must go right for the business to flourish." Bullen and Rockart (1981) also define CSFs as the "few key areas of activity in which favourable results are absolutely necessary for a

particular manager to reach his goals". A necessity logic is therefore central to the notion of CSFs. As Erling *et al. (*2006) notes, if CSFs "are not present or taken into consideration, problems will be experienced which may act as barriers to success". Indeed, Dul (2020) was explicit when he stated that "when the desirable outcome is formulated as 'success', the necessary condition is sometimes called a 'critical success factor', or 'key success factor'" (6). Yet, analytical methods hitherto have not been available for CSFs researchers to truly determine "criticality" of factors, until Dul (2016). Instead, CSFs researchers have often employed traditional variants of the general linear model (e.g., correlation or regression, SEM, etc) or other ranking/weighting methods (e.g., severity/relative importance index, AHP, mean ranking/weighting and standard deviation, factor analysis and principal component analysis, multi-criteria ranking, T-test, ANOVA, qualitative assessment, etc) to determine or confirm criticality of success factors, resulting in theory-method misfit.

METHODS

Systematic Review

A systematic review was conducted employing the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines (Page *et al.,* 2021). Two databases, Web of Science and SCOPUS, considered the most influential digital databases for scientific research globally were employed. The search for relevant CSFs journal papers was restricted to 24 leading journals in construction and project management including: Built Environment Project and Asset Management, Construction Innovation, Construction Management and Economics, Engineering, Construction and Architectural Management, International Journal of Construction Management, International Journal of Project Management, Journal of Construction Engineering and Management, Journal of Management in Engineering, Journal of Modern Project Management, Journal of Project Management, Project Management Journal, etc. The search adopted a syntax based on a combination of keywords and Boolean operators related to the focus area of "critical success factors": ("critical success factor*" OR "success factor*") AND ("project success" OR "project performance" OR "project failure" OR "project outcome*"). The search was performed within the article titles, abstract and keywords in the two databases selected.

The Inclusion Criteria comprised: (a) The concept of "critical success factors" or "success factors" is the central focus of the paper and explicitly mentioned or synonyms referencing the criticality of factors explicitly mentioned, (b) A focus on an impact of factors on aspect of project failure/success/performance/outcomes is the objective or one of the objectives of paper, (c) The study is empirical (i.e., involving qualitative or quantitative data collection and analysis and outcome parameters or factors are reported), and (d) The paper is published in one of the 24 leading construction and project management journals between 2010 and 2024. A total of 1,465 publications were identified by inputting the search syntax in both databases, with 579 from Scopus and 886 from Web of Science. After removing duplicates, 1,024 publications remained and after employing the inclusion criteria above fully and screening the titles, abstracts and keywords, 278 publications remained. The 278 papers are being read individually (process ongoing), searching for "necessary" statements. Such statements are typically made in papers when developing hypotheses (e.g., in the introduction, literature review or theory development sections) or when evaluating theoretical or practical/managerial consequences/implications of

the empirical results (e.g., in the discussion or conclusion sections). Dul *et al. (*2010) provides several alternative formulations of "necessary" statements as either enablers or constraints and these were adapted for the search as synonyms of "necessary" statements in the selected journal papers to determine if a theory-method misfit exists.

Necessary Condition Analysis (NCA)

NCA is a data analytic tool for testing hypotheses or statements that connote necessity of various determinants (e.g., success factors, CSFs) to various outcomes (e.g., project performance, project success). NCA allows two elements of criticality to be examined, 'in kind' criticality (i.e., 'is X necessary for Y?' or similar), and 'in degree' criticality (i.e., 'what level of X is necessary for a certain level of Y?') (Dul, 2024a, Dul, 2016, Dul, 2020). NCA analysis is conducted by first producing an XY scatter plot of the data and drawing ceiling lines that separate the area with, and the area without cases. Two types of ceiling lines are drawn: CE-FDH, a stepwise linear line and CR-FDH, a straight trend line. NCA results are interpreted by calculating two parameters: effect size (d) and significance level (p) (Ding and Kuvaas, 2025). NCA 'in kind' criticality is determined through the effect size (d) which is calculated by dividing the area of the space above the ceiling line (i.e., CR-FDH or CE-FDH) without observations (i.e., area of the blank zone called ceiling zone) by the total area of the space that can contain observations given the minimum and maximum values of the condition and the outcome (i.e., scope), producing a parameter (d) that represents how much the necessary condition constrains the outcome (Dul *et al.,* 2023). The effect size can be valued as important or not, depending on the context and can range between $0 \leq d \leq 1$, with effect size $0 < d < 0.1$ representing a 'small effect' size, $0.1 \leq d < 0.3$ representing a 'medium effect' size, $0.3 \leq d < 0.5$ representing a 'large effect' size and $d \geq 0.5$ representing a 'very large effect' size (Dul, 2016). On the other hand, NCA 'in degree' criticality on the other had is determined through "bottleneck" analysis, which assess what level of a factor is necessary for a certain level of an outcome (Dul, 2016).

RESULTS AND DISCUSSION

Analysis of Necessity Statements in CSFs

As found similarly by Dul (2016) in his analysis of papers in a leading organisational science journal (i.e., Academy of Management Journal), the preliminary analysis of "necessary" statements in part of the 278 publications so far shows that CSFs researchers tend to adhere to the following consistent theory-method sequence, symptomatic of theory-method misfit: (a) A theoretical "necessary" statement is made in the "Introduction", or "Theory" or "Literature Review" section; (b) This statement is sometimes reformulated as a traditional hypothesis with specified/unspecified ''positive association'' (or similar) between the determinant and outcome (i.e., mostly without specifying that the determinant is considered as "necessary" for the outcome); (c) The obtained observational data are analysed using traditional variants of the general linear model (e.g., correlation or regression, SEM, etc) or other ranking/weighting methods (e.g., severity/relative importance index, AHP, mean ranking/weighting and standard deviation, factor analysis and principal component analysis, multi-criteria ranking, T-test, ANOVA, qualitative assessment, etc); and (d) If the hypothesis is supported (e.g., a positive association found between determinant and effect) or factors are identified through some ranking or factor analysis, the results are interpreted as support of or confirmation that the factors are "necessary" or "critical" for the outcome. Three papers are presented here as illustrative examples of

the pattern of approaches adopted by CSFs researchers as identified form the 278 papers so far. First, Abas *et al. (*2022) studied CSFs in construction supply chains and stated in the Introduction section that "the flow of raw material, information, and cash flow are critical risk factors for project success" (2258). Using Kendall's coefficient and severity index/relative importance index they found support and concluded in the Discussion section that "Communication with a severity index of 93.23% is the most critical success factor……. a successful supply chain in construction projects is not possible without effective communication" (2263). In another example, Ali *et al. (*2024) studied CSFs for modular construction adoption and stated in the Literature Review section that "CSFs are factors that should be given continuous attention and commitment to guarantee the success of the MC in residential projects" (1315). Subsequently, they reformulated this in several hypotheses as "There is a significant relationship and a positive effect between Modular Construction Adoption (MCA)……" (1316) and several CSFs which they tested and confirmed using Structural Equation Modelling (SEM). They then concluded in the Discussion section that "Regardless of the type of project, MC projects' success necessitates the services, skills, and understanding of a variety of participants" (1321). In yet another example, Ikuabe *et al. (*2024) studied CSFs influencing the failure of joint ventures and claimed in the Literature Review that "A critical determinant of successful delivery of construction projects is the regular cash flow……." (1681).

Using one sample t-test, exploratory factor analysis and confirmatory factor analysis and claimed in the Conclusion section that "Based on these findings, it is essential that the right financial framework is put in place for the unhindered delivery of construction projects with the deployment of JV" (1691). They further assert that "The outcome of this study would aid in propagating the necessary success measures for the actualisation of a formidable JV in the delivery of construction projects in developing countries" (1691). These examples are not unique in the CSFs studies in the construction and project management domain but demonstrate a pattern of CSFs researchers inducing necessity in theory, employing sufficiency analytical tools and drawing necessity conclusions, resulting in a theory-method misfit. The exception however is Solaimani and Swaak (2023), who studied CSFs in multi-stage adoption of artificial intelligence. They assert in the Introduction section that "studies on CSFs help IS/IT professionals wisely allocate their resources to those aspects that matter the most in achieving a higher level of technology adoption, given their level of maturity" (2). Using a Cross-sectional survey and employing NCA (the first know application of NCA in CSFs in this domain), they assess the necessity of seven factors to AI adoption. All but one factor was found to be necessary for AI adoption. They assert appropriately in the Discussion section that "The results evidence that performance expectancy is the most critical factor for firms to embark on an AI journey…." (11).

Illustration of NCA with Hong Kong Dataset

To illustrate NCA, data is drawn from a Hong Kong study that examined the notion from organisational behaviour literature that behaviour is a function of one's ability (A), motivation (M) and opportunity (O) (Appelbaum *et al.,* 2000, Blumberg and Pringle, 1982). The primary question addressed here to illustrate NCA is whether like CSFs, ability (A), motivation (M) and opportunity (O) are necessary or critical for behaviour to occur. An effective sample size of 380 responses is obtained from a questionnaire survey of 115 teams working in projects in Hong Kong as client, contractor or consultant teams. For NCA studies Dul (2024c) notes that for a

quantitative study "a sample size of 180 …… will probably have enough power to detect a necessary condition when it exists…." Dul (2024c, 10).

Five variables are measured: Ability to perform, motivation to perform, opportunity to perform, task performance and contextual performance. Following guidelines by Dul (2016) and explained earlier, NCA analysis is performed in R version 4.0.2 (Dul, 2024b) by producing an XY scatter plot of the data and drawing CE-FDH and CR-FDH ceiling lines. The NCA parameters (i.e., effect size (d), accuracy, ceiling zone and scope) are then calculated and the significance level (p) of the effect size assessed to determine NCA 'in kind' criticality or necessity (i.e., 'are the AMO factors necessary for task and contextual behaviours?') (see Table 1). NCA 'in degree' criticality or necessity (i.e., 'what levels of AMO factors is necessary for a certain level of task and contextual behaviours?') is also determined by conducting 'bottleneck' analyses (see Tables 2). For more details on how to perform NCA, see Dul (2020), Dul *et al. (*2020) and Dul *et al. (*2023). The scatterplots all show empty spaces in the upper left corner (i.e., ceiling zones) above the space with observations, suggesting the possible presence of necessary conditions. This is corroborated by the effect size results in Table 1, showing that ability ($d = .16$, $p < 0.01$), motivation ($d = .13$, $p < 0.01$), and opportunity ($d = .16$, $p < 0.01$) are moderately necessary (i.e., $0.1 \leq d < 0.3$, medium effect) for contextual performance and weakly necessary (i.e., $0 < d < 0.1$, small effect) for ability ($d = .08$, $p < 0.01$) and opportunity ($d = .06$, $p < 0.01$) and moderately necessary (i.e., $0.1 \leq d < 0.3$, medium effect) for motivation ($d = .11$, $p < 0.01$) for task performance (Dul, 2016).

Table 1: Necessary Condition Analysis (NCA) Parameters

Independent variable	Method	Contextual Performance				Task Performance			
		Effect Size (d)	Accuracy (%)	Ceiling Zone (area)	Scope (area)	Effect Size (d)	Accuracy (%)	Ceiling Zone (area)	Scope (area)
Ability	CE-FDH	.18***	100	2.76	14.93	.11***	100	1.54	14.25
	CR-FDH	.16***	98.4	2.33	14.93	.08***	99.5	1.17	14.25
Motivation	CE-FDH	.15***	100	2.11	13.75	.15**	100	1.91	13.12
	CR-FDH	.13***	99.7	1.85	13.75	.11***	99.5	1.41	13.12
Opportunity	CE-FDH	.15***	100	2.30	15.72	.08***	100	1.17	15.00
	CR-FDH	.11***	99.5	1.76	15.72	.06***	99.2	0.93	15.00

*p < 0.10; **p < 0.05; ***p < 0.01

The bottleneck analysis results in Tables 2 specify the threshold levels of the three conditions that are necessary for reaching a certain desired level of task and contextual performance. These threshold levels are expressed as percentages of the observed range of values (van der Valk *et al.,* 2016). For contextual performance, none of the AMO factors are necessary to reach 20% of contextual performance. However, for a contextual performance level of 50%, an employee needs at least 14.5% of ability, and at least 12.8% of motivation but opportunity is still not necessary to attain this level of contextual performance. However, for instance, for a level of 80% of contextual performance or above, one needs at least 29.5% of ability, 30.4% of motivation and 27.4% of opportunity. Similarly, for task performance levels of up to 10%, none of the AMO factors is necessary. For a task performance level of 50% an employee needs at least 3.6% of ability and 10.2% of motivation, but still opportunity is not necessary to attain this level of task performance. However, for instance, for a level

of 80% of task performance or above, one needs at least 18.7% of ability, 19.6% of motivation and 10.6% of opportunity. Overall, therefore, the results show that ability, motivation, and opportunity are necessary for higher levels of task and contextual performance.

While the relationships between the AMO factors and performance variables could have been determined by employing multiple regression or SEM analysis, such an analysis may only spot determinants (i.e., AMO factors) that (on average) contribute to the outcome (i.e., task and contextual performance), i.e., sufficiency. If the goal is to just determine the relationship or the probability/likelihood that the AMO factors produce performance variables (i.e., sufficiency), then employing multiple regression or SEM analysis is the appropriate approach. On the other hand, if the goal is to determine if the AMO factors are necessary or critical for performance, then NCA is the appropriate approach as NCA may spot necessary (critical) determinants that prevent an outcome from occurring (constraints or bottlenecks). When bottlenecks are present (in the form of absence of certain levels of AMO factors) as shown in the results above, performance will not improve by increasing the values of other determinants which are not necessary (e.g., determinants with large regression coefficients) unless the bottleneck is taken away first (e.g., by increasing the value of the critical or necessary determinant).

Table 2: Bottleneck Analysis (%) (NN = Not Necessary)

Outcome	Contextual performance			Task performance		
	Ability	Motivation	Opportunity	Ability	Motivation	Opportunity
0	NN	NN	NN	NN	NN	NN
10	NN	NN	NN	NN	NN	NN
20	NN	NN	NN	NN	0.8	NN
30	4.5	1.1	NN	NN	4.0	NN
40	9.5	7.0	NN	NN	7.1	NN
50	14.5	12.8	NN	3.6	10.2	NN
60	19.5	18.7	NN	8.6	13.4	NN
70	24.5	24.5	8.9	13.6	16.5	NN
80	29.5	30.4	27.4	18.7	19.6	10.6
90	34.5	36.2	45.9	23.7	22.8	29.6
100	39.5	42.1	64.4	28.7	25.9	48.6

CONCLUSIONS

Due to hitherto unavailable and/or lack of awareness of appropriate analytical methods such as NCA, CSFs researchers have adopted research approaches that exposed CSFs research to a theory-method misfit. It is important to emphasize that the authors of the CSFs papers illustrated here were pursuing relevant research questions, unfortunately, the data analytic tools that were available were not developed to address the types of questions they sought to answer, until now. Consequently, the authors were restricted to using traditional analytical tools. But by using traditional analytic methods and drawing necessity conclusions, a theory-method misfit is evident. This paper however has demonstrated the viability of NCA in CSFs studies and illustrated this new analytical tool with a Hong Kong sample. CSFs researchers are encouraged to employ this tool in future research. Researchers could also benefit by reanalysing their previous CSFs studies data using NCA to determine if the conclusions they drew from traditional sufficiency analysis remain

valid. There is also a growing trend of research in management science combining NCA with traditional analytical tools to address both sufficiency and necessity questions/hypotheses, thereby complementing each other and providing a more holistic picture of causality in their studies. Note however that NCA like other methods of analysis is not immune to problematic theory, variable measurement errors, or research design problems, see Dul (2016) for more details and see Dul (2020), Dul *et al. (*2020) and Dul *et al. (*2023) for further details on employing NCA in appropriate research studies.

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AGGREGATED ANNUAL PROFIT ANALYSIS METHOD: A BENEFICIAL CLIENT TOOL FOR ASSESSING CONSTRUCTION CONTRACTOR FINANCIAL PERFORMANCE RISK

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Using aggregated annual profit analysis methods (AAPAM), over a study period, helps overcome limitations with evaluating traditional averages or medians of builders and construction contractors' annual profit results. Accounting standards permit contractors to include projects' estimated variation claim outcomes in profit statements. As project results may be years from finalisation, a contractor's true financial position is unknown. AAPAM as a tool to help overcome this limitation is justified for clients' use in a detailed study of 33 contractors listed on the Australian Securities Exchange, for a minimum four years, over 2010-2019 (i.e., outside COVID). Aggregated annual real profit (after tax, abnormals, outside equity interests) findings varied (median 1.7%, average 1.4%) from traditional average-of-annual-result considerations (median 1.5%, average -1.2%). Thirty percent of these contractors returned poorer aggregate profit results than their averaged-annual values. Three of the seven contractors who failed during the study period had lower aggregate profits compared to their average-annual values. Plotting respective aggregated profit results backwards in time shows AAPAM is an essential prequalification tool for non-accountants to better assess contractors' financial performance and potential-failure risk.

Keywords: Australian Securities Exchange; benchmarking; governance; insolvency; tendering

INTRODUCTION

Publicly listed civil engineering construction and general building contractors (contractors) operate under strict governance controls (Australian Securities Exchange (ASX) 2019). Delivering sustained profit results over an extended operational period, within fluctuating business and market conditions, indicates a contractor is meeting its governance objectives (including non-financial matters like reputational growth, customer satisfaction, employee performance, and process quality (Deng and Smyth 2014; Tripathi *et al.,* 2019)) and provides potential clients with a degree of comfort about the contractor's viability. However, given the permitted accounting standard vagaries including recognition of estimated financial outcomes from unresolved project variation claim disputes (Yee and Cheah 2006), evaluation of annual report

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financials does not always represent a reliable picture of a contractor's real financial position. The question arises as to what other options are available to clients, especially those with limited accounting knowledge, when assessing a contractor's financial security during a tender evaluation.

Applying aggregated annual profit analysis methods (AAPAM), over a longer study period, helps overcome these limitations. To demonstrate AAPAM's use, a longitudinal analysis of 33 purposive sampled ASX listed Australian contractors' aggregate profit results over a 10-year period (2010-2019) is compared against their individual annual results and evaluated.

LITERATURE REVIEW

Governance and Disclosure

Listed public companies must make risk management disclosures in their annual reports as part of their corporate governance obligations (ASX 2019). Jia et al.'s (2016) analysis of ASX100 companies' 2010-2012 annual reports found many provided qualitative 'boiler plate' disclosures over consecutive years with non-time-specific information. They argued this practice is to avoid negative consequences of disclosure, or not re-evaluating past annual report text in periods without regulatory change. In contrast, Linsley and Shrives' (2006) UK study found, while monetary risk exposure statements were uncommon, companies exhibited a willingness to disclose limited forward-looking positive or negative risk information. Real disclosures provide competitors with potentially sensitive information (Scantlebury and Alleyne 2015). Consequently, it remains difficult to adequately assess a company's real risk profile. This research addresses this gap, in the context of the financial performance of Australian construction companies.

Financial Performance Studies

Notwithstanding annual reporting requirements, contractors focus on project performance measures (Hegazy and Hegazy 2012). In contrast, business outcomes' studies include investment suitability (Balatbat *et al.,* 2010); performance indicator development (Hegazy and Hegazy 2012); global event implications (Thangaraj and Chan 2012); prediction models (Jin *et al.,* 2013); aandstrategy and structure impacts (Deng and Smyth 2014) on contractors' business finances and profits. There is no consensus on how to evaluate contractors' financial performance (Jin *et al.,* 2013). Study timeframes range from two to 10 years, with some requiring contractors to be operational for the full duration (Deng and Smyth 2014) while others have not (Akintoye and Skitmore 1991; Yee and Cheah 2006). Fundamental analysis of a variety of financial ratios, sourced from appropriate financial databases, is common (Hegazy and Hegazy 2012). Where a study focus was primarily on profitability (Yee and Cheah 2006), net profit after tax (NPAT) expressed as a percentage of operating revenue is a common consideration (Balatbat *et al.,* 2010). Other profitability parameters may include return on assets (ROA) and return on equity (ROE) (Deng and Smyth 2014).

Despite sustained profitability performances indicating ability to increase revenue while controlling costs, given their project-based businesses, contractors' organisational performances receive comparatively little research (Deng and Smyth 2014). Representative business performance studies with civil engineering contractors include UK 1980-1987 (Akintoye and Skitmore 1991); USA, Europe and Japan 1997-2001 (Cheah *et al.,* 2004); International 1997-2003 (Yee and Cheah 2006);

International 1984-2003 (Devinney *et al.,* 2010); aandUK 2002-2011 (Deng and Smyth 2014). Balatbat *et al. (*2010) analysed 30 ASX listed contractors (all within Global Industry Classification Standards (GICS) 'Capital Goods') over 1998-2007, primarily for their investment potential. Eighteen were classified as civil, and the balance property construction companies. Resource-sector infrastructure contractors were excluded. Thangaraj and Chan's (2012) 2006-2010 study of 36 publicly listed and private companies only included eight building contractors. None of those operated in the resource construction sector, notwithstanding its importance to the Australian economy.

Direct comparisons between studies are not easy due to variations in: management distortion or manipulation of results through abnormal items (Cheah *et al.,* 2004); understating profitability to reduce tax obligations or other revenue recognition practices (e.g., estimated future variation claim successes) permitted under applicable accounting rules (Yee and Cheah 2006); and, holding cash on balance sheets (Devinney *et al.,* 2010). Given construction's cyclical nature and that finalisation of variation claims may be prolonged, clients would gain with longer study durations that smooth out short-term fluctuations (Yee and Cheah 2006). Management faces challenges to balance short and long-term performance (Deng and Smyth 2014), though most measures focus on shorter-term performance (Yip *et al.,* 2009). Short-term profit results made be impacted by deliberate low-tender (suicide bidding) strategies (Coggins *et al.,* 2016), to secure opportunities via variation claims to recover a position, that subsequently prove to be unsuccessful.

Under Australia's Corporations Act 2001, directors face severe penalties if they allow their company to trade while insolvent, i.e., cannot pay debts when due. Consequently, directors usually place the company into 'voluntary administration' (VA) before reaching insolvency. Contractor failures are time-dependent, with actual 'failure' not being immediately apparent. Financial distress, leading to insolvency or VA, often only becomes apparent in a contractor's final two years, when the failure process is virtually complete (Alaka *et al.,* 2016). This research provides clients, and contractors concerned with their own governance, with an earlier failure risk detection tool.

METHOD

A longitudinal study of annual financial reports of 33 purposive sampled ASX listed contractors provides an opportunity to assess effective business processes, applying at the large-contractor end of the Australian based market. The following sub-sections describe sample selection; financial parameters considered; and rationale and method behind the proposed 'aggregated annual profit analysis method' (AAPAM).

Contractor Selection Criteria and Sample

Drawing from the literature to select a suitable but varied range of contractors, four criteria were applied:

1. ASX listing for at least four years, between 1 Jan 2010 and 31 Dec 2019 - a full ten-year continuous listing was not required.
2. Mixture of contractor sizes but with >$20m turnover threshold.
3. At least 20% of turnover earned in the Australasian region; and
4. Selections from across five GICS, thus including resource sector infrastructure contractors, given its importance to the Australian economy.

ASX records a company's status as 'Trading', 'Delisted' or 'Suspended' at any enquiry date. These terms are adopted here. At 31 Dec 2019, 17 of the 33 contractors remained classified as Trading, with the other 16 as Delisted. Seven contractors were Delisted, during 2010-2019, because they had entered VA, herein referred to as 'Failed'. The other nine were Delisted because they were bought out by another company ('Buy-out'). Two long-term Suspended (for non-compliance with ASX listing rules) were grouped with the Delisted Buy-out contractors for this analysis.

While the selected 33 contractors are not a cross-sectional representation of the wider industry (Australian Bureau of Statistics (ABS) 2013), the sample reflects the targeted larger contractors in the Australian construction industry, a market heavily dominated by a few major contractors. For comparison purposes, contractors were also grouped by turnover: Tier 1 (>$1,000m pa); Tier 2 ($100m to $1,000m); and Tier 3 (<$100m). These groupings align with common industry references (Australian Contractors Association (ACA) 2020). Sample demographics are summarised in Table 1. The nine 'Buy-out' contractor demographics, not shown for formatting reasons, are $964m average turnover and average 18.5 years on the ASX.

Contractor Trading status numbers varied considerably over the study period, from a peak of 33 (2011-2013) down to 17 at 31 Dec 2019. Tier 2 sized experienced the biggest decline in numbers (50%) over 2010-2019. Only fifteen contractors in the sample were listed for all 10 years (four Tier 1, eight Tier 2 and three Tier 3, though three Tier 2 subsequently grew to achieve regular Tier 1 turnovers post 2019).

Table 1: Contractor sample demographics by groupings

	All	Trading	Failed	Tier 1	Tier 2	Tier 3
Number	33	17	7	8	20	5
Average years on ASX	19.5	22.6	13.4	33.3	14.2	18.4
Average turnover ($m)	1,953	3,051	557	6,816	479	69

Financial Performance Parameters Considered

Data used in this study were sourced from the Morningstar DatAnalysis Premium database (DatAnalysis n.d.) which carries company results released to the ASX. As this study's focus was sector performance rather than evaluation for investment purposes (Balatbat *et al.,* 2010), annual profit and loss result parameters were the prime consideration. Beyond ASX listing information and company backgrounds, data evaluated included: operating revenue; earnings before interest and tax/depreciation and amortisation (EBIT/DA); NPAT; NPAT before abnormals (NPATBA); NPAT after abnormals (NPATAA); outside equity interests; ROA; and ROE. Given contractors' senior and middle management place great importance on profit as a percentage of operating revenue, profit was logically used as the performance comparison parameter, aligning with Yip et al.'s (2009) approach.

Values were not escalated to 2019 dollars, using index adjustments, as escalation formulae do not improve past profits reported. As contractors vary in using 30 June or 31 Dec as their end of financial year, annual results are referred by calendar year without half-year alignment adjustments. For Delisted their last reported full year results were used, with final part-year data excluded - as per Yee and Cheah (2006).

Justification for Applying AAPAM Application

Most profit performance studies analyse averages, or medians, of individual year results (average-of-annual-results method) over a study period, rather than considering

aggregated profit outcomes over that period (Deng and Smyth 2014). Utilising individual year-by-year results does not provide a true picture of real financial positions. Contractors' business results derive from amalgamating their individual projects under contract, durations of which are not discretely divisible by annual reporting periods. Large construction projects, common within this sample, run for years. Individual annual reports do not necessarily reflect true profit positions in any one year (Assaad and El-Adaway 2020). A project's real financial position may not be known for years, especially when extended defect liability periods apply (7+ years is not uncommon on Australian Government Road infrastructure D&C contracts).

Individual year-by-year reported results are subject to exclusions buried in notes, albeit within accepted accounting practices (Cheah *et al.,* 2004). Contractors may apply different financial policies, within relevant accounting standards, to meet their strategic objectives. Results are permitted to include estimated recoveries from submitted, but not finalised, contract variation claims (Yee and Cheah 2006). Ambitious claim success estimates, raising profit figures one year, may be negated by a final lower resolution value reported years later, especially if arbitration or litigation is involved. As an example, the previously ASX listed CIMIC carried a projected $1.15b project variation claim outcome in its profit results from 2015 to 2020 that subsequently proved to be unsuccessful (CIMIC 2020). True profit results for an earlier year may never be fully disclosed (Bloomfield 2002), being 'lost' in subsequent reporting or balanced out by later profitable projects.

AAPAM helps negate these industry specific issues, as well shorter-term market fluctuations, smoothing out poorer result years or individual project profit result anomalies. Use of AAPAM in this research addresses Deng and Smyth's (2014) identified need for empirical studies of contractor performance assessments to consider the year-by-year performance fluctuations that occur over longer project/company time frames.

Calculation of Aggregated Profit Results

Various profit result parameters were analysed, e.g., EBIT/DA, and NPATBA and NPATAA. Abnormals include costs incurred by selling or re-structuring once normal business units to recover a loss position. For this paper's purposes, profit results analysed were calculated by considering NPATAA plus outside equity interests, called here 'Real Profit' (in some jurisdictions termed 'statutory profit'). As Real Profit is not openly publicised in DatAnalysis (n.d.), values were calculated for each contractor each year before application of AAPAM. Aggregated results were progressively calculated each year over 2010-2019 and then expressed as percentages of operating revenue: for example, 2012 being values for 2010, 2011 and 2012; while 2019 figures included the whole 2010-2019 period. Frequencies of negative annual Real Profit (i.e., Real Loss) were recorded, together with when negative abnormals were reported. Financial data were not winsorised to remove extreme outliers (other than one case detailed below), as those contractor results still exist. Given the non-normality of results medians, rather than averages, are presented, reflecting Deng and Smyth's (2014) approach.

RESULTS AND DISCUSSION

Differences Between Averages of Individual Year and Aggregate Real Profit Results
Across the sample, individual annual Real Profit results ranged from -122.3% to +20.9%. Aggregate Real Profit variations were smoothed out, over the 10 years,

varying from -13.2% to +14.9%. Results by contractor groupings are summarised in Table 2. The median of contractors' aggregate Real Profit was smaller than expected (1.7%), though Trading's was relatively like ABS's indicative heavy and civil construction contractors' profit of 2.3% (ABS 2013). These figures exclude one contractor's >300% loss in its final year (2015), when their costs were over a very small operating revenue base just before going into VA.

Contractors do not always deliver profits. Aggregate results are impacted by the frequency of Real Loss years. Only two (6.1% of the sample) returned Real Profit every year for the 10 years. Two others, undertaking resource sector construction, did so for each of the nine years they were ASX listed. Seven (21%) made Real Profit each listed year, though one went into VA the next year. Across the sample Real Loss occurred every fifth year. Abnormals, unlike their title, were regular features in various contractors' annual reports. Aggregated over the 10 years, negative abnormals represented a considerable impact on Real Profit (see Table 2), 68% of potential Real Profit in the case of Tier 1s, who declared negative abnormals every second year - considerably more frequently than other groupings.

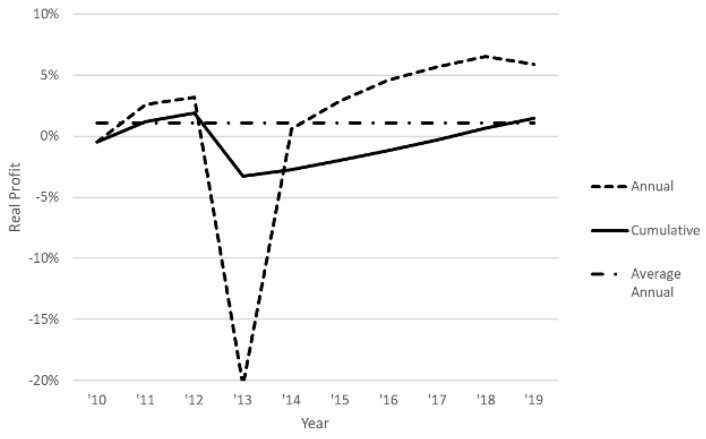
Table 2: Median annual and aggregate Real Profit levels for contractors (2010-2019)

	All	Trading	Failed	Tier 1	Tier 2	Tier 3
Annual Real Profit (%)	2.9	4.2	0.0	3.0	3.3	2.4
Aggregated Real Profit (%)	1.7	2.2	-1.0	1.8	2.0	0.6
Years with negative abnormals (%)	30	30	12	55	20	20
Years with negative Real Profit (%)	20	20	25	16	20	40

Buy-out's results, not shown in Table 2, were 1.2%; 2.0%; 71%; and 17% respectively. Their high percentage of recording negative abnormals, while still having a lower frequency of Real Loss years, may explain why they became buy-out targets. It was beyond the scope of this study to investigate this finding further.

Given managements' use abnormals in reporting, it highlights AAPAM's value in gaining a global picture of profit performance. For many *contractors, the* differences between AAPAM calculated and average-of-annual-results Real Profit was minimal. For *others, the* differences were greater, especially when longer term contracts and single big annual losses significantly impacted overall profitability for years - for Tier 1s: 1.8% aggregate compared to 3.0% average-of-annual. Individual company variations could be considerable. As an example, see Figure 1 for a Trading Tier 2. There were (unsurprisingly) statistically significant differences in aggregate Real Profit results between Trading and Failed (p=0.018).

Figure 1: A Trading Tier 2's annual and cumulative aggregate Real Profit result variations



Similar aggregate and annual comparisons were made for EBIT and EBITDA, though are beyond the scope of this paper. However, those median aggregate EBITs were like Balatbat et al.'s (2010): 4.3%, for the All, Tier 1 and Tier 2 groupings; higher for Trading; but, lower for the Tier 3 and Failed groupings.

Using AAPAM as an Additional Contractor Evaluation Tool

For nearly half the sample the average-of-annual-results method produced a lower/more conservative Real Profit than the AAPAM calculated position. The difference of 0.7 percentage points is considerable given the sample's median aggregate Real Profit of 1.7%. There was no material differences between the two methods found for approximately a quarter of the sample (see Table 3). Averaging annual results considerably underestimated Trading contractors' real financial positions. Hence for those cases average-of-annual-results evaluations would still meet a client's objectives of a financially stable contractor. For two thirds of the Buy-out (not shown in Table 3) their average-of-annual Real Profit was lower than their aggregate. Again, this may be a reason for them becoming acquisition targets for other contractors. Perhaps unsurprisingly, for about half the Failed averaging annual values overestimated their aggregated Real Profit position.

Table 3: Comparison of average-of-annual and cumulative aggregate Real Profit results, (percentages may not add due to rounding)

	All	Trading	Failed	Tier 1	Tier 2	Tier 3
Average of annual < cumulative aggregate (%)	48	35	57	38	50	60
Median of value difference (percentage points)	0.7	1.6	0.5	0.1	0.5	7.2
Average of annual > cumulative aggregate (%)	30	35	43	25	35	20
Median of value difference (percentage points)	0.4	0.3	0.5	0.3	0.3	0.4
Values the same (%)	21	29	0	38	15	20

On a straight calculation basis AAPAM may be no better an indicator/predictor of increased risk of contractor failure than traditional assessment approaches. However, AAPAM's benefit becomes clearer when cumulative aggregate Real Profits are plotted backwards in time for different contractor groupings. Trading and Failed median cumulative aggregate and individual annual Real Profits are plotted in Figure 2. Faileds' results are taken from their last full year before VA (Year 0) back eight years (Year -8). For comparison, Trading results are plotted backwards from 2019, as Year 0, in a similar manner.

Both groupings experienced a decline in cumulative aggregate and individual annual Real Profit over that timeframe, with market positions being likely contributors as described earlier. Faileds' aggregate Real Profit declines are more pronounced (significance levels of $p=0.130$ for Year -1 and $p=0.075$ at Year 0). Contractors did not suddenly 'fail' but rather experienced a steady, though increasingly rapid, reduction in aggregate Real Profit in the years immediately preceding VA. These findings reflect Alaka et al.'s (2016) secondary research-based proposition.

AAPAM has strengths and weaknesses, not least being it may not provide a material numerical difference to the traditional average-of-annual-results approach. However, for clients at tender or pre-selection stages AAPAM's value, as a further financial evaluation metric tool, is when it is used to compare a tendering contractor's progressive aggregate Real Profit performance against a wider benchmark sample of (Trading) contractors. The main effort in undertaking AAPAM assessments relates to

accessing and maintaining contractors' financial results data to enable establishment of benchmark aggregated profit curves, against which an individual contractor's results can be compared.

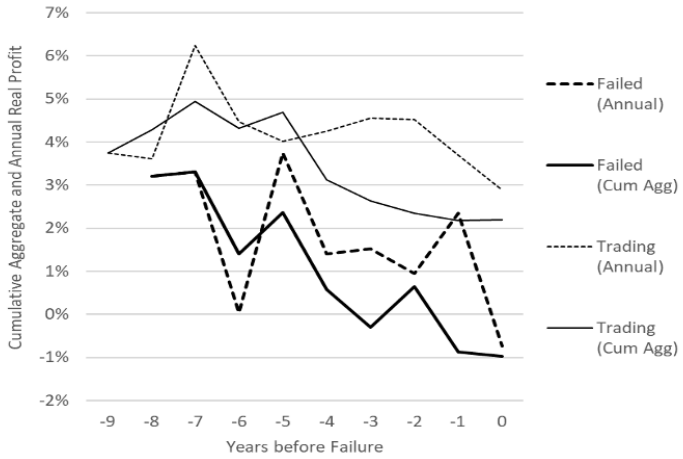


Figure 2: Steady decline in median aggregate and annual Real Profit towards failure

Ideally a client has access to spreadsheeted-based data of publicly listed contractors, from sources like DatAnalysis, which enable ready calculation of aggregated results. Alternatively, a client may need to manually calculate aggregated profits from contractors' annual reports (3-5 years commonly required) submitted with their tenders. Retention of this data facilitates ongoing subsequent benchmarking.

CONCLUSIONS AND RECOMMENDATIONS

Contractors' annual financial statements can be masked by larger longer duration projects and provisions for estimated variation claims outcomes on individual projects. Ultimately these projects may not be as successful as previously reported, thus resulting in lower overall profit levels within a contractor's overall portfolio of work. High frequency of loss years may increase a client's concern regarding a potential contractor's ongoing financial viability, especially when loss years coincide with major turnovers.

Profit results of 33 contractors, listed on the Australian Securities Exchange during 2010-2019, were analysed using traditional average-of-annual-results methods and the presented aggregated annual profit analysis method (AAPAM). For approximately a third of those contractors, averages-of-annual-results analysis overestimated their real long term profit positions. This finding itself may not change clients' approaches to how they evaluate their tendering contractors' potential financial security. However, comparing failed contractors' (those having gone into VA) time-based aggregated profit results with those still trading contractors showed aggregate differences became more pronounced. As part of their tender evaluations, clients can plot a potential contractor's AAPAM calculated progressive aggregate Real Profit backwards in time and compare it against a benchmark set of contractors' aggregate Real Profit results. Similar AAPAM approaches may be applied to assess broader profitability factors, including EBIT/DA, ROA and ROE.

While this study used Australian contractors' data, AAPAM evaluations are applicable in other countries, especially those where their accounting standards permit builders and construction contractors to adjust profitability reporting by including estimated, but not yet achieved, variation claims outcomes on longer running projects.

AAPAM provides clients, especially those with non-accounting backgrounds, with an additional means of addressing contractor viability, beyond consideration of averages-of-annual-profit results, to further minimise the risk of their selected contractor being one who goes into voluntary administration during their project's delivery.

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INDONESIAN PV POWER PLANT PERFORMANCE: FAILURE-MODE ALIGNMENT WITH AN OPERATION AND MAINTENANCE ENHANCEMENT STRATEGY

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Towards a 2060 net-zero-emission target, Indonesia has had slow growth in its solar photovoltaic capacity; current installations are plagued by performance problems. Detecting failure modes and augmenting operation and maintenance strategies for reliability enhancement of solar power plants is this study's aim and, fills a regional research gap by identifying the local causes of underperformance of photovoltaic power plants, giving an O&M strategy to mitigate these problems. The methodology builds upon secondary research, low-yield case-study company reports, structured interviews with 4 key Indonesian solar industry experts and, a Pareto analysis to identify the 20% of components (invertor faults/ battery drop-offs) responsible for 80% of energy-yield deficits. Failure mode effects analysis then populates a developed, structured maintenance framework for Indonesian PV plants. This work shows that improvement in the general energy-yield of Indonesian photovoltaic power plants is addressed by targeted O&M, which enhances solar power plant performance in rural Indonesia, towards helping attain the country's objectives on renewable energy, adding to the overall goal of sustainable energy development in the region.

Keywords: PV-power; energy-yield; failure-modes; O&M-framework; Indonesia

Background: Indonesian Power Plant Problems

Solar photovoltaics have emerged as a promising renewable energy source in Indonesia, with the ability to meet the country's rising power needs, while decreasing dependency on fossil fuels. According to Indonesia's National General Energy Plan (RUEN 2017), the country has a renewable energy 'potential' of 443GigaWatts, with solar energy estimated at 208GW (within a global potential of 5kGWs); however, actual solar photovoltaic PV growth in Indonesia is slow compared to other countries, thus more realistic increases in solar PV are pegged at 5GW by 2030 (PLN 2021).

Solar energy systems once installed require little in terms of maintenance or attention (Bosman *et al.,* 2020), but this assertion stems from research conducted into the reliability monitoring and servicing of the PV cell panels and, does not recognise that an overarching system's actual measurable performance is often much lower than predicted energy-yields. This is the problem that currently occurs in Indonesia (Nasir

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2024), where declining performance (low expected yields) of installed solar power plants are being recorded, particularly in rural provinces such as East Nusa Tenggara.

It is argued that this underperformance of Indonesian PV Plant occurs because of inadequate operation and maintenance (O&M) programmes (Rukijkanpanich 2020) and that, ad-hoc preventive and corrective maintenance programmes and, a lack of structured condition-based predictive maintenance (Iftikhar 2021), lessens predicted energy-yields. Indonesia's problem is a lack of suitable operation and maintenance methodologies, thus solar energy systems face knock-on issues, such as reduced energy output, component malfunctions, and a decreased operational lifespan (Gonzalo 2020). Well-designed programmes for operation and maintenance are argued to help identify issues early then resolve them, reduce costs, and ensure better system yield-performance (Hernandez 2019). Reductions in generation yield presents challenges for the growth of Indonesia's solar energy sector and hence, represents an urgent need to focus on a better methodology for maintenance in rural Indonesian.

Current Solutions for Solar Power Plants and Gaps in Indonesian Provision

The underperformance of Indonesian solar power plants not only affects energy production itself but also impacts the economic viability predictions of future solar projects and the reliability of its grid, although, theoretical approaches can be sourced to optimise operational and maintenance efficiency in solar energy installations; one such approach is the implementation of preventive maintenance programmes, regular inspections and proactive maintenance activities to identify and address issues early (Iftikhar 2021) such as: Cleaning panels, addressing electrical issues, and monitoring system performance. Other countermeasures include advanced maintenance strategies, such as predictive maintenance utilising sensor data, together with machine learning and other forms of analysis in searching for potential problems and, therefore scheduling maintenance on predictive outcomes (Bosman 2020).

Although valuable understanding has emerged for effective implementation of O&M practices for solar power plants, these approaches are uncommon in rural Indonesia, which needs a (currently lacking) user-friendly maintenance structure. The framework developed here addresses this pressing gap and outlines the key factors for decreased yields and offers a maintenance framework for O&M practices at PV plants; it applies Pareto's 80-20 principle (Kenton 2024) to identify key failures within a case-study with performance problems, in East Nusa Tenggara. To determine such causes, effects and mitigations of low energy-yields, a failure-mode and effects-analysis (FMEA) can rank plant variables and, suggest maintenance procedures of predictive, preventive, corrective, and condition-based. The goal here is to create a maintenance framework to mitigate critical failures by O&M activities. The 6 objectives of this work are:

1. review literature to identify of global trends, in solar power plant O&M.
2. investigate company reports that identify yield prediction-anomaly factors.
3. catalogue this case-study's solar PV failure modes and performance-decline factors.
4. conduct Pareto analysis of the key components that result in 80% of its poor-yield.
5. determine the causes, effects, and mitigation strategies by FMEA, and through a qualitative methodology to blend insights from 4 Indonesian PV expert stakeholders.

6. Validate (by expert-interview) a 'maintenance-framework' for the PV industry in (rural) Indonesia and thus, fill the current gap for a structured O&M approach.

Overview: Research Addressing Indonesian Solar Sector Efficiencies

This research deals the Indonesian solar energy industry's inadequate operational and maintenance routines that affect the efficiency of its existing facilities. While there is great solar resource potential of 200GW, current installed capacity amounts to only 0.2 GW, thus capacity-yield lags far behind solar potential (DENBEN 2020). This work seeks to improve solar plants' energy-yield by enhancing maintenance strategies.

Secondary Research: Plant Failure and Monitoring

Towards objective 1 and 2 above, a literature review of failure modes, PV performance and degradation mechanisms affecting solar power facilities, a synthesis of current practices and strategies for condition monitoring and predictive maintenance, follows:

Failure Modes of Photovoltaic Power Plants Globally: Indonesian Implications

Lorenzo's (2020) study of 80 large PV plants in Italy examined common failures and unexpected events in PV systems but was unable to find solutions to address diverse issues such as site instability, weather events and blown combiner-box string fuses. Iftikhar's (2021) research then postulated if simple O&M practices, performed by plant personnel themselves, with support from combining field data with simulated results, can increase energy yields (in 18-megawatt photovoltaic) grid-connected PV power plants and, although able to show that tracker-systems inverters and combiner-box malfunctioning do cause internal shutdowns and reduced energy output, he found current ad-hoc O&M approaches were ineffectual. Colli (2015) asked if a FMEA scoring system of severity, occurrence, risk and detection ratings, developed for a PV system, improves power yield but again found no causative improvement. Similarly, Triki-Lahiani's (2018) investigation of fault detection and monitoring and failures, occurring within PV systems, found that whilst PV systems experience failures that do reduce PV installation's reliability, no O&M solutions are available. Sarr's (2017) PV system failure work is in line with Colli (2015), in which applied FMEA can improve maintenance of PVs but need a targeted approach.

It is argued here that the current work has not analysed actual failure reports from site, using techniques like Pareto analysis to identify the critical failure modes contributing to the underperformance of PV power plants; indeed, there is no work looking at the failure modes of PV power plants in Indonesia. Therefore, this study aims to fill this research gap by conducting detailed analyses of failure data from PV power plants, using a case-study approach in the East Nusa Tenggara province of Indonesia, by applying Pareto analysis and a failure mode effects analysis (FMEA) method.

(Under)Performance Issues and Degradation Mechanisms of Solar Power Plants

Oh's (2018) longitudinal failure analysis of a Korean PV power plant indicated that the actual system yield output is 10% less than a nameplate/predicted capacity (via inverter losses). Relatedly, Iftikhar (2022) found that 5% underperformance of a PV plant faced an estimated yearly monetary loss of €175,000, but that predictive maintenance may reduce this. Baschel's (2018) work also looked at how reliability affects operation, and proposed strategies for improving maintenance and reducing downtime to enhance energy yield, by targeting local system components of transformers and inverters, as these contribute to two-thirds of the total energy losses due to their long lead/repair time, finding that even a small number of issues with

transformers lead to big energy losses. Underperformance in solar photovoltaic power plants can be derived from identifiable failure modes and degradation mechanisms. The Korean, Spanish, and Italian studies above inform this work's East Nusa Tenggara PV power plant's actual failure data and, help develop this regional O&M framework.

Condition Monitoring of PV Plant: Applications to Inform Indonesia
Globally, analytical condition monitoring systems are deployed to identify PV system malfunction (Betti 2019). Lorenzo's (2020) remote monitoring O&M techniques use data from Italian PV Plants targeting combiner-box analytics for fault detection and improved maintenance. Livera's (2022) decision support system (DSS) also monitor systems' early fault diagnosis in cloud-based platforms, where losses of 2100MWh or 14% of energy output, can then recover 7% of lost energy, by corrective, field mitigation activities. Indeed Abdulla's (2024) bibliometric analysis and systematic literature review of 186 articles found that maintenance strategies stemming from performance indicators and degradation modelling can lead to better O&M and thence energy-loss improvements. However, these reviewed studies have not discussed the potential of a centre-controlled remote condition monitoring, which is required for photo-voltaic (PV) systems, located in remote regions that are limited by accessibility and poor network connectivity, and based on this research gap, the present study is deemed necessary for Indonesia's multitude of islands and remote locations.

Predictive Maintenance of Solar Power Plants
Orosz (2024) summarised the challenges regarding operability and maintainability of solar power installations to highlight economic and technical relevance as contributory to increased efficiency and maintenance strategies, suggesting that advanced monitoring and AI and IoT-based diagnostic tools are needed. Bosman (2020) argued for third-party, system-level predictive maintenance tech applications but, notes that these still need manual diagnostics, failure modes and effects analysis and, machine learning through real-time analysis. Triki-lahiani's (2018) finds that again (advanced AI) monitoring techniques as crucial for the early detection of faults and the optimisation of performance. However, reviewed studies focus on developed nations' applications, and are less applicable to newly developing regions' distinct geographic and infrastructural constraints. The following method presents a way to fill this gap.

METHOD

This work adopts a qualitative, case-study approach to explore the operation and maintenance challenges faced by solar power plants in East Nusa Tenggara, to develop a maintenance framework for optimal operation in the localised PV industry. It draws on in-depth interviews with key stakeholders in the country's solar sector. This qualitative methodology gives understanding of the complex issues and contextual elements influencing solar power facility performance; the 4 expert practitioners' life-experience/ phenomenological reflections exhibit a grounded (saturation) of issues and therefore presents an appropriate sample (Creswell 2018).

The case-study is selected as it typifies the performance degradation in PV power plants in East Nusa Tenggara, Indonesia and thus can identify factors for low yield.

Qualitative Research Semi-Structured Interviews' Participants' Selection
Semi-structured interviews conducted with local PV stakeholders in Nusa Tenggara and Jakarta, inform the development of a new maintenance framework. Compliant with Creswell's (2018) life-experiences' quorum, they are: An Operations-Manager with direct experience operating and managing solar power plants; a Maintenance-

Manager with responsibility for implementing maintenance programmes and addressing performance issues for solar power plants; an Assistant-Manager-in-power-plant-evaluation charged to monitor power plant daily operations, evaluate equipment's' performance and create monthly generation reports; and, a PV power plant expert with in-depth technical knowledge of solar power system design, installation, and maintenance. 3 manager interviews were done face-to-face on-site; 1 virtual 'Teams' interview was conducted with the Jakarta based PV-expert. Accurate capture and preservation of the data followed overarching West Australian (WA) guidance(s) for datasets that log respective interviewee perspectives and insights.

Data Analysis, Validity and, Ethics

The semi-structured interviews use a thematic analysis methodology to discover and interpret recurring themes (Naeem 2023). The 28 questions posed built on secondary research. For this research of PV performance degradation, validity was done by cross checking responses by re-interviewing the 4th, PV-expert participant who also validity-checked the developed, maintenance framework. Respondent-confidentiality, right-to-consent, psychological-wellness, recruitment-material and data-management were pre-approved by the WA Ethics committee. The case-study's historical, documented failure-reports allowed a ranking of failure-modes using Pareto Analysis.

RESULTS

Pareto Analysis and Qualitative Data

Located on Mules Island in the Savu-Sea, this off-grid PV power plant in East Nusa Tenggara, Indonesia comprises panels, inverters, AC-distribution, LVMDP-panels, transformer, MV-cubicle and battery-systems. Five years of documented failure-events' reports (Sep 2019 - Feb2024) identify 24 key performance issues. Analyses of cumulative failure-modes is assessed by a Pareto analysis; resultantly, five critical issues, from the historical 24 items, can be stated in Table 1 and, Figure 1.

Table 1: Pareto tabulation of failure modes: Generated from 24+ key recurrencies (2019-24)

Recorded failure causes	#	Cumulative Total	Cumulative %
Battery drop-off	10	10	42%
Inverter Fault	10	20	83%
Inverter fan faulty	2	22	92%
MCCB Combiner Burnt	1	23	96%
UPS battery broken	1	24	100%

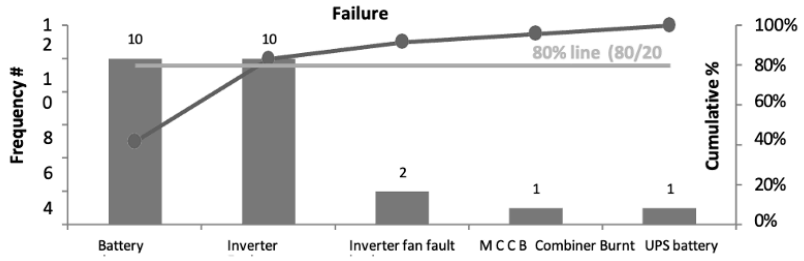


Figure 1: Pareto graphic of failure modes: Generated from 24+ key recurrencies (2019-24)

Pareto analysis identifies the top failure modes as: Battery-drop and inverter-fault.

Qualitative Results Respondents' Data-set Correlation Highlights.

Semi-structured interviews with 4 participants display role-perspectives. Correlation highlights linking to plant faults include Responses to Question 24 of 28 seeking

suggestions to mitigate plant failures. Respondant-1 said there's a need to "monitor battery temperature", whilst R-2 said, "inventor grid connections need constant updates"; R-4 argues for an "inventory of critical battery spare parts to minimise downtime during replacement". Asked if current advanced tech. might help maintenance (Q.25 of 28), R2 said "we must implement predictive maintenance through continuous data analysis of the most important items". Asked (Q.27) if O&M tools improve performance, R2 said "yes but make sure they connect to the entire enterprise-asset-management systems, so systems can action automatically, but we know this does not happen". R3 states that "predictive maintenance O&M tools are proven overseas for optimising PV plant performance, so we should also have this"

DISCUSSION

O&M Practices, Failure and Funding

This section discusses key findings (and comparisons with literature), highlighting gaps in knowledge, and outlining the implications for Indonesian sector best practice.

Insufficient O&M Practices and Critical Failure Modes

The interviews conducted with four participants indicate a consensus that there's a lack of supervision and maintenance that contributes to a decrease in the production of electricity from PVs in rural Indonesia. This aligns with existing literature on performance and maintenance issues of PV plants, that simple and efficient O&M practices optimise the energy output (Iftikhar 2021). Insight into the elements contributing to the deterioration in the performance of PV power plants finds a recurring theme from the responses that the battery energy storage system BESS and Inverter are the primary sources of problems in performance issues. The existing strategies directed toward overcoming these deficiencies, consist essentially of both preventive and corrective maintenance. Nevertheless, all participants agree that these strategies are inadequate and need improvement. This agreement underlines the considerable gap between current maintenance practice and, the attention needed.

Insufficient Funding and Training and, Local Technology Deficits

The interviews reveal a consistent theme of insufficient funding and training as a major hindrance to effectively addressing PV plant degradation, aligning with existing literature (Rediske 2022). The interviews reveal a need for a more comprehensive cost-benefit analysis of the different options for O&M strategies in diverse rural locals. Higher degradation rates mean less electricity yield, while associated shorter lifespans negatively impact the project's overall economic viability. Therefore, potential opportunities for investing in this technology may likely reduce in less populated or developing regions, where demand for renewable energy alternatives is often at its greatest. Inadequate training or upgrading of skills for maintenance staff, especially in remote locations, may result in a circle of inefficiency - improper skill-sets mean staff cannot maintain plant effectively, resulting in increased failure.

The semi-structured interviews with the four participants reveal a consistent theme of limited technological resources for maintenance strategies in PV power plants, specifically in remote locations. All participants highlight that current methodologies for performing maintenance rely on very basic technologies and indicate a large gap between the discussions of advanced technologies of scholarly literature and their deployment in remote photovoltaic power plants. This inconsistency underlines a critical gap in knowledge on how to adapt high-level tech. for remoteness and locals with resource constraints. The prevailing need is for research contributions to cost-effective, easily implementable monitoring solutions' structures and frameworks.

CONCLUSIONS

Addressing Underperformance

It is concluded that the main reason behind the degradation in performance of the Nuca Molas PV power facility is inadequate O&M strategies, and specifically: A lack of strategies concerning preventive maintenance and predictive failure analysis; access to higher levels of tech. and maintenance capabilities are limited in remote locations; insufficient training and capacity building for plant maintenance staff; and inadequate financial and human resources allocated to operation and maintenance activities.

These factors lead to more frequent unexpected failures, longer downtimes, and reduced overall efficiency that impacts the economic viability of rural PV power plant adoption. Recommendations for longer-term sustainability to address this follow.

Five recommendations to Enhance rural PV plants

This work presents the following Five-Recommendations to enhance O&M for rural solar photovoltaic power plants in Indonesia and, Nusa Tenggara Timur in particular:

Firstly - develop and implement comprehensive maintenance programmes. To address insufficient operation and maintenance practices, it is recommended that PV power plant operators implement a comprehensive maintenance strategy, namely: Develop a detailed schedule of check-ups, cleaning, and maintenance of all system components; Prioritise the critical components of Battery Energy Storage System and inverters; Implement cleaning procedures for panels to mitigate particulate-matter soiling; Create detailed standard-operating-procedures with detailed step-by-step guides for frequent tasks; and, Regularly record operational data and maintenance activities.

Secondly - enhance capacity building and training programmes for maintenance staff that includes hands-on training in installation, troubleshooting, repair, and preventive maintenance techniques. Online courses or periodic in-house training sessions need to include equipment manufacturers' specialised instructions for major components like BESS and inverters. Investing in the continuous professional development of maintenance teams is needed to empower their long-term performance activities.

Thirdly - a key recommendation here is relay of a (Pareto inspired) FMEA guide to mitigate critical PV failure modes analysis, from 5 years of company failure-reports and, in-depth interviews with the key stakeholders, Table-2 summarises the FMEA:

Table 2: Failure Mode and Effects Analysis - FMEA - critical failure modes' brief-summary

Item	Functional Failure effect	Failure Mode	cause	Improvement
Battery Storage System	reduced power output: Energy output nil	Battery drops	Extreme temp; low quality material; unit mischarge; controller issues	period inspection; monitor temp; routine clean; keep record; fit-for-use specs; charge optimise; spare parts inventories re downtime
Inverter	energy output nil	Inverter breaks	Bad vent; high temp; card/board overheats; overcurrent; software failure; protective relay miss-trips	period inspection; overheating checks; ventilate & cool; monitor grid connection & power quality; update firmware calibration; protect relay systems.

Recommendation-4: While there's increased capex/ upfront costs for condition-based monitoring and predictive maintenance technologies, these are recommended as they will lead to cost savings by reducing 'unexpected' failures and enhancing performance.

Recommendation-5: The 'maintenance-framework' (Figure 2) developed here is recommended for uptake by managers to enhance the reliability of rural PV systems.

Framework validation, by Respondent-4 of this work, argues that the East Nusa Tenggara PV plant generates 95,000,000kWh. With no action, future system failures and yields will decrease 8%, with a loss of 7,600,000 kWh (a revenue loss of Aus$1m); however, if the maintenance-framework's failure-detection is utilised (Figure 2) then production will decrease at the lesser rate of 4%, with 4,750,000kWh of energy recovered, generating a saving of Aus$0.6m. The deliverable developed here, the Maintenance-Framework (Figure 2); uptake is recommended.

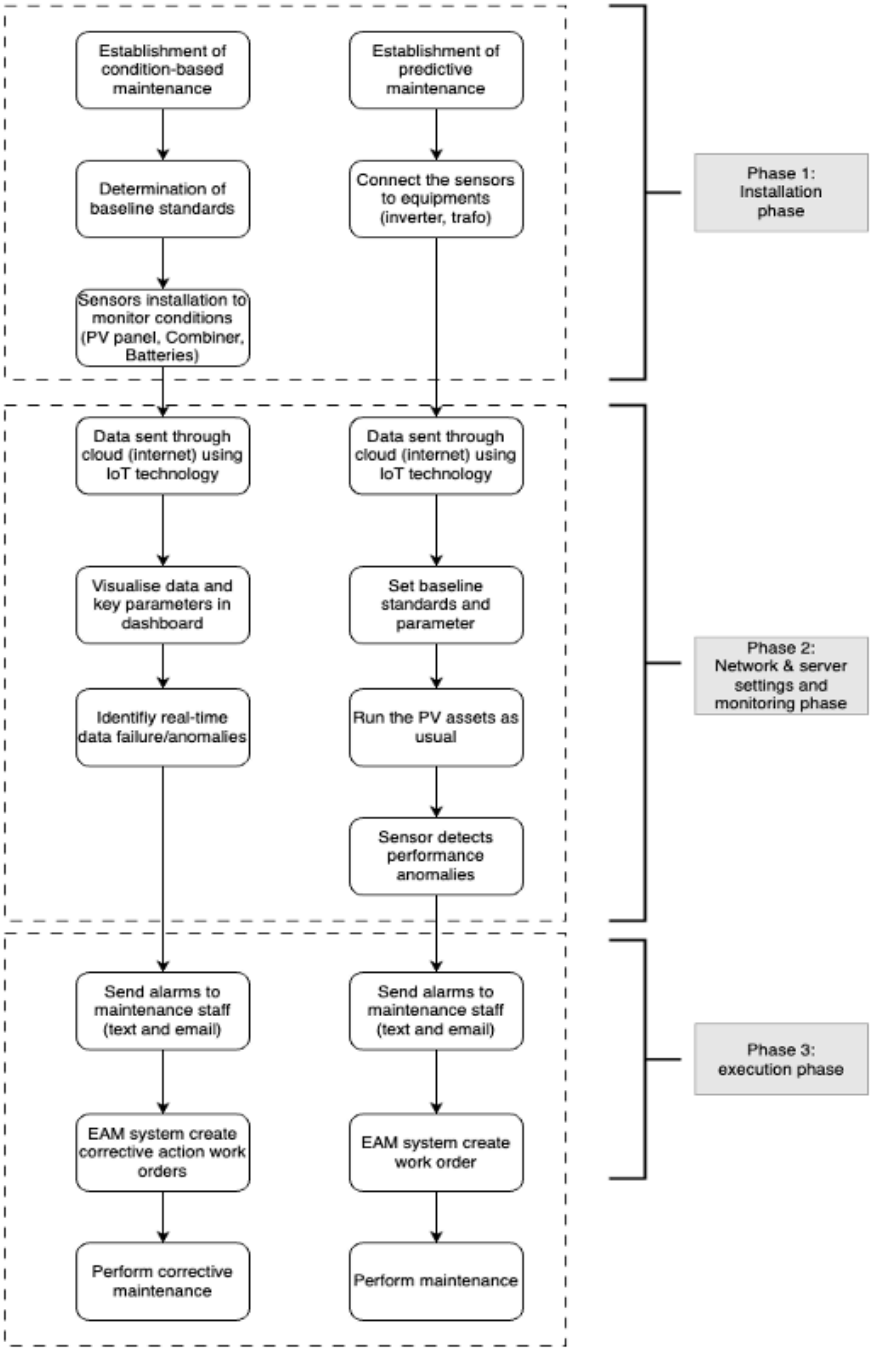


Figure 2: Maintenance-Framework: From Qualitative Research and Document Analysis

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PROCUREMENT

INTER-FIRM CONFLICT AND PROJECT DELAY IN MALAYSIAN CONSTRUCTION SECTOR: ROLE OF TENDERING PROCESS

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Conflicts in construction projects are strongly linked to project delays. Conflict between firms can happen in different stages of a construction project, from the tendering stage to project delivery. This study focuses on the early stages of a project and investigates what inter-firm conflicts may lead to project delay in construction projects in Malaysia. Using a qualitative approach grounded in constructivist ontology and interpretivist epistemology, 20 semi-structured interviews with practitioners in the construction sector in Malaysia were conducted. The data were analysed using the thematic analysis method. Findings highlight that political interference in contractor appointments, low tender pricing, and poor project planning are three main themes that lead to conflict and then project delay in the Malaysian construction sector. Political influence fosters inefficiencies and practitioners' dissatisfaction, while low tender pricing leads to financial strain, delays, and quality compromises. Inadequate project planning in tender preparation exacerbates coordination challenges and procurement inefficiencies. The study highlights the need for better procurement practices, such as avoiding low-cost bids, transparency in contractor selection, and better project planning to prevent delays due to inter-firm conflicts.

Keywords: tendering process; inter-firm conflict; contractor selection; project planning; low tender pricing; construction industry

INTRODUCTION

Conflict is a leading cause of delay in construction projects, often resulting in cost overruns and disrupted coordination (Cheung and Yiu, 2006; Tariq and Gardezi, 2022). While existing research tends to emphasize conflicts and disputes during the project implementation phase—particularly those related to rework, site coordination, and construction-phase claims (Kumaraswamy, 1997; Love *et al.,* 2019)—this study shifts focus to inter-firm conflicts arise between main parties in the construction sector such as clients, consultants, and contractors originating during the tendering stage, a crucial yet underexamined phase in the construction lifecycle. Studies in procurement literature highlight that poor tender documentation, inadequate risk allocation, and lack of early contractor involvement regularly cause disputes before construction starts (Heenkenda and Hadiwattege, 2012)

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Delays, defined as timeline overruns, are frequently rooted in early disputes over scope or responsibility (Aibinu *et al.,* 2002; Kumaraswamy, 1997). As trust breaks down, decision-making slows and workflows stall (Tariq and Gardezi, 2022). Yet, most studies overlook the procurement phase where these issues often originate.

Focusing on Malaysia's public sector, where delay in projects is a common problem, this study investigates what early-stage conflicts evolve into delays. Building on insights from interviews with senior practitioners in the Malaysian construction sector, it identifies patterns and mitigation strategies, addressing a gap in the literature by examining conflict generation rather than resolution—and linking delay to procurement systems and institutional context.

LITERATURE REVIEW

Conflict broadly refers to any form of disagreement, tension, or incompatibility between parties—whether at the individual, group, or organisational level (Ekpe *et al.,* 2022; Ronquillo *et al.,* 2023). In the context of the construction sector, inter-firm conflict refers to relationship breakdowns between legally distinct organisations engaged in formal contractual arrangements. Drawing on Vaux and Kirk (2018), such conflict can manifest as emotional tension, distrust, and adversarial behaviours between firms, which undermine collaboration and negatively impact project performance. These conflicts are often triggered by misaligned goals, unclear contractual expectations, or procurement-related tensions.

Unlike other types of conflict, which may include interpersonal or intra-organisational issues, inter-firm conflict is shaped by structural and transactional factors, making it particularly relevant to studies of tendering, project delay, and dispute resolution. This study focuses on inter-firm conflict because the tendering stage in construction is fundamentally an interorganisational process involving separate legal and contractual entities, such as clients, consultants, and contractors. By targeting this specific category, the study addresses a critical and underexplored source of delay, offering insights into how procurement structures contribute to project delay. This framing provides both conceptual clarity and practical relevance for improving tendering frameworks in the Malaysian construction sector.

Conflict and delay persist as major challenges in construction projects globally and are particularly acute in developing countries like Malaysia. These problems often arise from systemic weaknesses in early-stage processes, including procurement, planning, and coordination between firms (Azmi and Ismail, 2021). In Malaysia, as in several other contexts, cost-based contractor selection (CBCS) has drawn criticism for encouraging low bidding practices that lead to compromised quality and strained project relationships (Azman *et al.,* 2012; Othman *et al.,* 2010). Research further shows that poor communication, inadequate documentation, and unclear contract terms frequently cause early misalignment between stakeholders (Ali *et al.,* 2018; Chi *et al.,* 2015). During the tendering stage, agreement-related ambiguities and inconsistent planning introduce uncertainty, which often escalates into formal disputes during project delivery. Increasingly, conflicts are seen not as isolated incidents during execution but as the result of embedded institutional and procedural deficiencies (Azmi and Ismail, 2021).

Existing studies have examined early-stage planning processes prior to contract award in construction projects, identifying factors such as incomplete site assessments, underdeveloped design documentation, and limited coordination among stakeholders

during the pre-tender phase (Azman *et al.,* 2012; Azmi and Ismail, 2021). While the literature covers various planning-related aspects, there appears to be relatively limited focus on how procurement-stage decisions relate to subsequent project outcomes.

This study addresses that gap by examining how early-stage procurement decisions contribute to inter-firm conflict and delay. By foregrounding practitioner insights, it aims to advance a systemic and preventive understanding of conflict in Malaysian construction.

METHOD

This study employed a qualitative design grounded in constructivist ontology and interpretivist epistemology (Creswell and Creswell, 2017), which emphasizes context-specific understanding and the subjective experiences of participants. This approach was well suited to exploring inter-firm conflict in Malaysian construction, where political, contractual, and behavioural dynamics shape practitioner perceptions and actions.

Semi-structured interviews were selected for their flexibility in eliciting detailed, context-rich accounts while maintaining consistency across participants' responses (Kallio *et al.,* 2016). Twenty senior practitioners—including project managers, architects, quantity surveyors, and engineers—were interviewed. The participants were selected based on a mixed approach of convenience, purposive, and snowballing technique. All participants had over 10 years of experience in public-sector construction, ensuring exposure to multiple project cycles and conflict scenarios. Interviews were conducted virtually via Zoom, lasting 45-60 minutes each. Virtual platforms enabled participation across regions while maintaining data quality (Archibald *et al.,* 2019). The research followed the University of Manchester research ethics guidelines (Ethics Application Approval Ref: 2024-17398-33018).

Data were analysed using Braun and Clarke's (2006) thematic analysis with NVivo 12 software. Thematic analysis is a widely used method for identifying, analysing, and interpreting patterns or themes within qualitative data. Braun and Clarke (2006) outline a six-phase process: familiarisation with the data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the final report. After analysing 20 interview transcripts, 206 initial codes were generated using NVivo 12, which were refined into three overarching themes.

This method was selected for its flexibility and its ability to provide rich, detailed, and complex accounts of qualitative data (Nowell *et al.,* 2017). Thematic analysis is particularly useful in construction research for exploring relational and institutional dynamics—such as inter-firm conflict—because it enables the researcher to capture how participants make sense of their experiences. In this study, it enabled the identification of recurring patterns in practitioner narratives situated within the institutional structures and cultural context that characterise the Malaysian construction industry. These patterns— grounded in participants' lived experiences—formed the basis for the findings presented in the next section.

FINDINGS

The thematic analysis revealed that inter-firm conflict during the tendering process was frequently associated with delays in Malaysia's construction sector, based on practitioner accounts, with 70% of participants (15 out of 20 participants) identifying

it as a significant issue. Within these accounts, three recurring themes were identified: political interference, low tender pricing, and poor project planning. Each of these themes, happening in the tendering stage, leads to inter-firm conflict in later stages of construction projects in Malaysia. Research participants discussed how these inter-firm conflicts were associated with project delay in their experiences.

Political Interference in Contractor Appointments

Political interference in contractor selection was frequently reported, with politically connected but underqualified firms being appointed. This favouritism eroded trust, sidelined consultant input, and created conditions for inter-firm conflict, leading to delay. Table 1 summarises practitioner views on its impact.

Table 1: Interview Quotes: Political Interference

Participant ID	Role and Experience	Interview Quotes
P1	Consultant, Architect (32 years)	"Political involvement in project allocations, driven by affiliations and favouritism, sparked conflicts among stakeholders who felt decisions were made based on connections rather than merit."
P3	Consultant, Quantity Surveyor (30 years)	"We also have political interference, meaning that some political party will be involved in decision making, and their interest is more about getting the support of a certain racial group."
P7	Consultant, C&S Engineer (30 years)	"This project also involved political elements. The main contractor appeared to have secured the project through certain channels."
P14	Consultant, Architect (26 years)	"They didn't even ask whether the contractor could do it or not. They basically used their connections and just assigned it to finish the work."
P18	Consultant, Architect (30 years)	"Cronyism and nepotism have led to a competitive imbalance, demoralising professionals and creating friction between competing firms."

Low Tender Pricing

Participants described how contractors who won tenders through unsustainably low bids faced financial strain during execution, often resulting in disputes over quality, payment delays, and variation claims. This behaviour contributed to adversarial project environments. Table 2 illustrates how low tender pricing triggered inter-firm conflict.

Table 2: Interview Quotes: Low Tender Pricing

Participant ID	Role and Experience	Interview Quotes
P1	Consultant, Architect (32 years)	"They [contractor] had to accept a project at a low price, leaving only limited margins for profitability."
P9	Consultant, M&E Engineer (15 years)	"This project, in early tender stages, had a slightly lower contract price, and coincidentally, the Covid-19 pandemic occurred, followed by an increase in material prices after the pandemic."
P12	Consultant, Project Architect (20 years)	"The first contractor faced problems because, when tendering, they submitted prices for special items at a lower rate because they did not fully read the building specifications."
P14	Consultant, Architect (26 years)	"The project has been tendered, and during the tender phase, everything is rushed because contractors want to secure the project by tendering at a low price."

Poor Project Planning

Poor project planning during the tendering stage—especially the omission of foreseeable site risks and coordination gaps—was frequently cited as a root cause of inter-firm conflicts during later stages. Contractors often ignored known constraints

or rushed documentation to win bids, leading to misalignment and delay. Table 3 presents participants' accounts of how strategic or insufficient project planning contributed to inter-firm conflict.

Table 3: Interview Quotes: Poor Project Planning

Participant ID	Role and Experience	Interview Quotes
P2	Consultant, C&S Engineer (25 years)	"They [contractor] underestimated the rainy season—expecting three days of rain, but it lasted three weeks."
P10	Consultant, Quantity Surveyor (30 years)	"School exams are predictable, yet construction had to halt multiple times during critical phases, disrupting worker momentum and extending timelines."
P7	Consultant, C&S Engineer (30 years)	"The rainy season was longer than expected, but heavy rain is common here; the project schedule should have accounted for this."

Practitioner Strategies for Delay Mitigation

In response to conflict scenarios stemming from flawed tendering decisions, practitioners implemented a range of informal strategies during project execution. These include contract renegotiation, task re-sequencing, and risk management workarounds. Table 4 highlights the most common practitioner-led interventions aimed at mitigating conflict.

Table 4: Practitioner Strategies for Mitigating Inter-Firm Conflict and Delay

Code	Role and Experience	Strategies	Interview Quotes
P10	Consultant, Quantity Surveyor (30 years)	Mutual termination and retendering	"We had to mutually agree to terminate the first contract. The contractor had political links but couldn't perform, and things just got worse. Starting over was painful, but necessary."
		Conditional EOT without compensation	"We agreed to grant the EOT but without extra cost. It was partly their planning issue, and giving full compensation would have set a bad precedent."
P8	Contractor, Project Manager (24 years)	Task re-sequencing and workarounds	"We advised the contractor to continue with the substructure while we resolved the documentation issue. Stopping everything would have been worse."
P11	Consultant, C&S Engineer (16 years)	Frequent technical and coordination meetings	"After tendering, I conduct more frequent coordination meetings to ensure that all items are accounted for in the Bill of Quantities."
P6	Consultant, Architect (33 years)	Renegotiation instead of retendering	"Rather than go through the retendering process again, we reviewed the scope and agreed on new rates for the remaining works."

DISCUSSION

Conflict in construction projects is prevalent both globally and within Malaysia, but its characteristics and impact often differ due to distinct in procurement practices and governance structures. In global contexts, conflict frequently stems from complex contractual frameworks and technical specifications (Arantes and Ferreira, 2015). In contrast, conflicts within Malaysia originate during the tendering process. The key issues derived during this procurement process involved political interference in contractor appointments, low tender pricing, and inadequate planning. This is in line with other existing literature, such as Azmi and Ismail, 2021; Rashid *et al.,* 2018).

Political Interference in Contractor Selection

Political influence in contractor appointments emerged as a major driver of inter-firm conflict and delay in Malaysian construction projects. Participants described how

contractors were frequently chosen based on political ties rather than technical or financial competence. This aligns with Yap *et al. (*2022) and Azmi and Ismail (2021), who argue that political patronage undermines competitive tendering, particularly in public-sector projects with weak oversight. The research highlights that political interference extends beyond contractor selection into contract management, construction-phase decision-making, and dispute handling. Participants shared experiences of politically appointed contractors lacking expertise, which led to poor performance, delays, and disputes. These appointments often damaged trust between project stakeholders, especially consultants, who reported that their professional input was disregarded or overridden. This led to project delay through unclear roles, poor communication, and disrupted project activities—conditions conducive to inter-firm conflict.

From a governance perspective, this reflects institutional weakness, where political actors exert undue influence on procurement. While favouritism can occur in both sectors, recent studies of private-sector construction show that market-based incentives, such as profit and reputation, encourage more rigorous contractor selection and risk assessment (Khoso and Yusof, 2019). In contrast, the Malaysian public sector lacks strong enforcement mechanisms, allowing political considerations to override merit-based procurement.

This study adds to previous findings (Baránek and Titl, 2024; Celis Galvez *et al.,* 2025) by showing that favouritism not only causes cost overruns and delays but also erodes trust in procurement processes and impacts the power dynamic between consultants and contractors. When politically connected contractors dismiss protocols or challenge consultant authority, inter-firm conflict intensifies during project execution, further weakening collaborative project environments.

Low Bids, High Stakes

Low bid tendering, often described as the "winner's curse," remains a key challenge in Malaysia's public construction procurement. Despite international reforms favouring multi-criteria selection, Malaysia continues to rely heavily on cost-based contractor selection (CBCS), especially in public projects (Rashid *et al.,* 2018).

Practitioners described how contractors, under intense competitive pressure and short tender timelines, submitted bids without thoroughly reviewing project details. The result was poor scope alignment, unrealistic scheduling, and post-award disputes—particularly in managing client expectations versus contractor limitations. This study extends the literature by showing how low bids not only compromise project performance but also lead to project delay through inter-firm conflict. Contractors, working under unsustainable margins, were reported to cut corners, delay works, or rely on variation claims—behaviours that provoked disputes with consultants and subcontractors. These conflicts often stemmed from weakened financial resilience and adversarial posturing, confirming earlier critiques of CBCS (Olaniran, 2015).

While prior studies have noted pricing-related risks, this research offers new insights into how compressed timelines and competitive pressures interact with CBCS to create a culture of strategic under-pricing and mistrust. This behavioural lens on procurement adds to the Malaysian literature by framing low bid tendering as a systemic driver of conflict, not merely poor financial planning.

The Opportunistic Tender Planning

Poor project planning during the tendering stage was a key factor in inter-firm conflict and project delay. While often seen as technical oversight, this study found that many planning gaps were intentional, driven by competitive pressures. Contractors were incentivised to exclude known risks—such as monsoon seasons or school exam schedules—to submit more attractive bids. This aligns with findings by This aligns with findings that contractors in public procurement often intentionally minimise risk allowances to remain competitive in cost-oriented bidding environments (Hanák *et al.,* 2021).

This behaviour resulted in scope ambiguity, blurred accountability, and contractual misalignment—conditions that undermined cooperation once construction began. The findings resonate with Muhammuddin *et al. (*2022), who linked pre-tender risk neglect to downstream disputes. Unlike prior studies that frame poor planning as passive error, this research highlights its opportunistic nature in Malaysia's cost-driven tendering environment.

Not all omissions were intentional. Several participants noted that limited time and resources at the pre-tender stage restricted the ability to conduct detailed feasibility studies or engage stakeholders—echoing Mokoena *et al. (*2023)'s findings on incomplete cost estimates. Moreover, weak coordination among clients, consultants, and local authorities compounded these risks.

Mitigation Strategies Available to Practitioners in the Construction Sector

This study highlights inter-firm conflicts that originate during the tendering phase and lead to project delay. As a follow-up, the study explored the mitigation strategies available to practitioners in the construction sector in Malaysia to find out what they do to tackle these inter-firm conflicts to reduce project delay as much as possible. The findings suggest that mitigation efforts by practitioners were often reactive and implemented post contract award. In extreme situations, practitioners must terminate the contract and go through retendering. In less severe situations, practitioners must renegotiate the contract terms. Task re-sequencing, frequent coordination meetings, and conditional Extension of Time (EOT) without compensation are the most repeated themes in strategies available to practitioners in dealing with inter-firm conflicts to reduce project delay.

When politically appointed contractors failed to deliver, mutual termination and retendering were pursued—reflecting evidence that political affiliations increase contractor default risks (Ferris *et al.,* 2022). In less severe cases, contract renegotiation served as a more flexible, less disruptive alternative (Zhang *et al.,* 2023). Practitioners also used task re-sequencing and workarounds to maintain workflow despite poor planning, consistent with agile management approaches in Malaysian construction (Chia *et al.,* 2022). Frequent coordination meetings were held to address gaps in tender documentation, a known driver of cost and time overruns (Alaloul *et al.,* 2014). Finally, conditional Extensions of Time (EOT) without compensation were granted when delays were traced to low bids—echoing case law findings that such contractors often lack entitlement due to procedural non-compliance (Aminuddin *et al.,* 2024).

While these approaches provided short-term relief, they often occurred too late to prevent disruption. These strategies reveal how practitioners actively manage the consequences of flawed procurement.

CONCLUSION

This study examined the relationship between inter-firm conflict and project delay in the Malaysian construction sector. It highlights three major sources of conflict during the tendering phase—political interference, low bid pricing, and poor project planning—all of which commonly lead to delays in public construction projects.

Political interference in contractor selection undermined trust, transparency, and professional judgment, as politically affiliated but underqualified contractors were often appointed without thorough consultation. Low bid pricing, driven by competition or political pressure, led contractors to submit unsustainable bids that later resulted in quality compromises, payment delays, and disputes. Poor planning was not only seen as a technical oversight but also described as a strategic omission—where known risks, were deliberately excluded to make bids appear more competitive.

Theoretically, this study extends construction conflict literature by foregrounding the emergence of inter-firm conflict during procurement how it links to project delay, rather than focusing solely on disputes during project delivery. Practically, it informs construction practitioners and procurement authorities by exposing how inter-firm conflict is seeded during the tendering phase—long before project execution begins.

While the findings are rooted in the Malaysian context, they offer broader implications for developing countries where public construction procurement is shaped by similar political, economic, and institutional constraints. Although the study is limited by its qualitative scope and country-specific focus, future research could build on these insights to develop a conceptual or operational model that prevents project delays by addressing conflict triggers embedded in the tendering process.

In conclusion, reducing construction delays requires more than better project execution—it requires rethinking procurement structures, improving early-stage planning, and recognising how tender-stage decisions affect later project performance. Addressing inter-firm conflict at its source is essential to fostering more collaborative and efficient construction environments.

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EXAMINING SOCIAL PROCUREMENT POLICY: PROGRESS, GAPS AND FUTURE DIRECTIONS

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This study examines construction social procurement policy in Wales, one of the nations of the UK, through the lens of Bacchi's 'What's the Problem Represented to Be' (WPR) approach, based on the Foucauldian concept of governmentality. The research examines key policy documents from 2010 to 2023 including the groundbreaking Well-Being of Future Generations Act, which requires public bodies to consider the social, economic, environmental and cultural well-being of current and future generations. The policy analysis reveals that while Wales has taken progressive steps in social procurement, there are significant gaps between policy aspirations and implementation. The findings show tensions between top-down policy approaches, such as the Welsh Government's social partnership approach, where it has not been made clear how these arrangements include construction industry expertise and consider the needs of local communities. A focus on well-being goals could be used to achieve social value, share learning, and drive improvement. However, areas requiring attention are also identified, including improved community engagement mechanisms and the need to consider the capacity of the construction industry to deliver socially responsible public procurement.

Keywords: well-being goals; social value; governmentality

INTRODUCTION

The concept of social value remains contested, and its implementation through procurement policy is often complex and inconsistent (Raidén *et al.,* 2018). In Wales, this agenda has gained momentum with the introduction of the Social Partnership and Public Procurement (Wales) Act 2023 (the SPPP Act), which aims to enhance public services and promote fair work by promoting socially responsible public procurement (Welsh Government, 2023). As noted by Raidén and King (2022), despite progressive legislation, challenges persist; social procurement legislation tends to be prescriptive rather than empowering, which may encourage seeking loops; implementation and enforcement can also be challenging. Wales's distinctive social justice agenda, exemplified by the Well-being of Future Generations Act (WFG Act) 2015, positions procurement as a key tool for achieving long-term social, economic, environmental, and cultural goals (Future Generations Commissioner, 2021). Wright *et al. (*2023) note that in the construction sector complex supply chains, limited community engagement, and unclear integration of industry expertise have hindered its implementation.

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Bridgeman, J (2025) Examining Social Procurement Policy: Progress, Gaps and Future Directions, *In*: Thomson, C and Neilson, C J (Eds) Proceedings of the 41st Annual ARCOM Conference, 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 711-720.

The objectives of this research are: firstly, to analyse how social procurement policies in Wales construct and represent social problems; secondly, to identify the assumptions and power dynamics embedded in these representations; thirdly, to trace the evolution of policy framing over time; fourthly to highlight gaps in implementation particularly around community engagement and industry capacity; and fifthly to propose future directions for more inclusive and effective social procurement strategies in the Welsh construction context. The study applies Bacchi's (2015. 2016) core What's the problem represented to be (WPR) questions to the Welsh policy context to guide this analysis. These are the research questions, they are:

7. What is the problem represented to be in Welsh social procurement policies?
8. What assumptions or presuppositions underlie this representation?
9. How did this representation of the problem come about?
10. What is left unproblematic in this representation?
11. What effects are produced by this representation?
12. How is this representation being defended, questioned, or replaced?

By situating these questions within the Welsh context, this study contributes to broader debates on policy, social justice, and the role of industry and community voices in delivering meaningful social value.

LITERATURE REVIEW

Social procurement refers to the intentional use of purchasing power to generate positive social outcomes, both directly and indirectly, through the acquisition of goods, services or infrastructure (Loosemore *et al.,* 2020). In the construction sector, this has led to a shift from traditional evaluation metrics, such as cost and time, to include social value (Raidén *et al.,* 2018). Raidén *et al. (*2018) highlight that in the UK, legislation increasingly requires construction bidders to demonstrate community benefits, positioning procurement as a strategic tool for social impact across projects. However, defining and measuring social value remains complex. As noted by Raidén and King (2022), social value is influenced by context and varies across different communities and over time, making standardised definitions and evaluations difficult.

A common feature of social procurement in construction is the emphasis on employment and training for marginalised groups. Loosemore *et al. (*2020) highlight the rise of indirect social procurement, where clients require supply chains to deliver social outcomes, most commonly through employment and training opportunities for marginalised groups. Delivering these outcomes is not straightforward. Loosemore *et al. (*2020) note that subcontractors are often tasked with implementation and face risks such as reduced productivity and increased costs. Loosemore *et al. (*2020) highlight the lack of subcontractor's voice in policy development. Raidén *et al. (*2018) caution that if capacity issues are not addressed, there is a risk that policy ambitions will outpace the industry's ability to deliver social value.

In devolved UK nations like Wales and Scotland, procurement is increasingly used to promote social value and fair work. Legislation such as the SPPP Act embeds community benefits into public contracts (Wright *et al.,* 2023). Wright *et al. (*2023) note that while these policies aim to reduce inequality and improve working conditions implementation is often hindered by limited resources, legal complexity, and recruitment challenges. Conversely, Wright *et al. (*2023) highlight that with

strong political will and collaborative networks, public procurement holds the potential to drive meaningful social change.

This study adopts a critical policy analysis framework grounded in Foucault's (2019) concept of governmentality and Bacchi's (2009) WPR approach. Together, these perspectives offer a powerful lens for examining how social procurement policy constructs problems, allocates responsibility and shapes social outcomes. Foucault's (2019) theory of governmentality shifts the focus from top-down government control to the more diffuse ways in which modern states govern populations. Foucault (2019) argues that governance operates not just through control but through norms and practiced that shape how people live and interact. In social procurement, this means policy influences market behaviour and social outcomes through contractual mechanisms.

Building on this, Bacchi's (2009) WPR approach challenges the assumption that policies respond to pre-existing problems. Bacchi (2009) argues that policies actively shape and define problems based on underlying assumptions, power structures, and ideological frameworks. Bacchi's (2009) approach, involves questioning 'How is the problem represented here, and with what effects?' Bacchi's (2009) approach reveals how policy discourse shapes not only what is seen as the problem but who is responsible, who is affected and what solutions are considered legitimate.

In the context of social procurement, the WPR approach is particularly useful for examining how terms such as 'social value' and 'disadvantage' are defined and operationalised. It enables a critical examination of whose voices are included and excluded and how certain groups, such as construction organisations or marginalised communities, are positioned within policy narratives. For example, framing unemployment as a skills deficit may lead to training-based interventions while ignoring structural inequalities.

While the WPR approach can be a powerful tool for analysing policy, it has limitations. Cordeiro and Mello (2020) suggest that the focus on discourse may underplay material constraints such as institutional inertia or economic pressures. Moreover, Bacchi and Goodwin (2016) explain that the approach is more reflective than prescriptive; it does not offer ready-made solutions but instead fosters a deeper understanding and reflexivity. This conceptual framework is further informed by social justice theories (Fraser, 2009; Sen, 2009), which emphasize the importance of redistribution, recognition and participation. These principles align with the goals of social procurement and support the use of WPR to assess whether policies genuinely engage with the lived experiences of marginalised communities and promote equitable outcomes.

In summary, the WPR approach provides a rigorous and reflective framework for analysing how social procurement policy in Wales constructs problems, shapes power relations, and influences practice. It is particularly well-suited to the field of social procurement, where definitions of social value are far from settled.

METHOD

A purposive sampling strategy was employed to select 13 policy documents published between 2010 and 2023. These documents were chosen for their relevance to social procurement, construction, and the well-being goals outlined in the WFG Act. These documents represent a cross-section of perspectives from government, oversight

bodies, and industry stakeholders, including legislation, policy frameworks, guidance documents, and commissioned evaluations. The sample includes:

- 4 documents published by the Welsh Government (e.g., Community Benefits policies from 2010 and 2014, consultation responses and the explanatory memorandum of the SPPP Act.
- 2 legislative documents from Senedd Cymru, including the SPPP Act.
- 2 strategic reports from the Future Generations Commissioner (2020, 2021).
- 5 documents from third-sector organisations and industry bodies (e.g., Constructing Excellence in Wales, Cwmpas).

The analysis was structured around Bacchi's six WPR questions and the additional reflexive step (Step 7). The documents were examined using a hybrid approach that combines thematic and discursive analysis. Thematic analysis was employed to systematically identify, analyse, and report patterns (themes) within the policy documents, enabling the researcher to capture both explicit content and underlying meanings related to social procurement discourse. Thematic coding was used to identify recurring patterns and shifts in discourse, while discursive analysis was applied to examine how language constructs power relations and legitimises specific policy directions. The analysis was conducted manually, with codes and insights organised according to each WPR question.

Based on Bacchi's (2009) guidance on how to apply the WPR approach, the analysis proceeded in three iterative stages:

1. Document familiarisation: Each document was read multiple times to identify key themes, discursive patterns, and shifts in framing.
2. WPR coding: Bacchi's six questions were applied systematically to each document. This included identifying explicit problem representations, underlying assumptions, historical trajectories, silences, and discursive effects.
3. Cross-document synthesis: Representations were compared across time and institutional sources to trace the evolution of policy discourse and identify tensions, contradictions, and gaps.

Bacchi (2016) includes a seventh step in the WPR approach, which encourages researchers to reflect on their own positionality in relation to the problem representations they identify. In this study, the author's professional experience in delivering community-based social procurement initiatives in Wales may have influenced a preference for locally driven approaches over centralised models. While this insider perspective provided valuable contextual insights, it also introduced the possibility of bias. To address this concern, the WPR framework was applied rigorously and consistently across all documents, and reflexive notes were maintained throughout the analysis to document interpretive decisions.

RESULTS

WPR Q1: What is the problem represented to be in Welsh social procurement policies?

Bacchi's (2015) first question explores what is perceived as the problem in a specific policy. The evolution of the Welsh Government's social procurement policies reveals a consistent focus on poverty as the central problematised issue, though the approach and emphasis have shifted over time. The Welsh Government's (2010) community benefits policy used tentative language, 'helping suppliers deliver maximum value', whereas the Welsh Government's (2014) policy adopted a more assertive stance,

'delivering maximum value.' Marking a shift from supplier-led approaches to a more centralised government role in directing procurement strategies.

The Welsh Government's (2010) policy framed social value through a sustainable development lens, encouraging suppliers tendering for construction services and supplies contracts to address local socio-economic issues via training, employment, and community initiatives. The Welsh Government's (2014) policy explicitly identified poverty as the problem and targeted disadvantaged groups such as the unemployed and workless households through targeted recruitment and training (TR&T); at also promoted tailored solutions based on community needs.

The Future Generations Commissioner (2020) in the Future Generations Report identified a lack of strategy to use public procurement to lever social, economic, environmental and cultural outcomes in line with the WFG Act. At the same time, it maintains poverty as a central concern through the goal of achieving a prosperous Wales and sees outcomes-driven social procurement as a way of tackling poverty (Future Generations Commissioner, 2020). This may indicate a shift in policy focus, highlighting concerns about the absence of a coherent strategy for leveraging social procurement to achieve social value.

The SPPP Act provided a framework linking social value to improving economic, social, environmental and cultural well-being. This legislation mandates a socially responsible procurement duty on significant construction contracts and social public work clauses in major construction contracts, with an estimated value equal to or greater than £2 million (Senedd Cymru, 2023). In the Act's explanatory memorandum, the Welsh Government (2023) explains that the legislation explicitly addresses disadvantage, including age, employment status, race, religion, gender identity and sexual orientation. This comprehensive approach reaffirms poverty as the fundamental problem while recognising its intersectionality with other forms of disadvantage. Throughout the policy evolution, poverty consistently emerges as the core problematised issue that social procurement aims to address, with employment and training opportunities as the primary solution.

WPR Q2: What deep-seated presuppositions or assumptions underlie the problem representation outlined above

Bacchi (2015, 2016) suggests that answering question two involves understanding policy more deeply. Any presupposition about the construction industry tackling poverty should consider the Welsh economy. The Bevan Foundation (2020) highlights that public sector procurement in Wales is worth over £6.3 billion, with construction accounting for 28% of this spending. This gives the Welsh Government significant financial leverage. Several key assumptions underpin social procurement policies in Wales, reflecting a presupposition from the Welsh government about the industry's role in delivering social value to communities.

Policy language suggests that the construction industry is seen as a key provider of training and employment for disadvantaged groups. Later policies assume that formal procurement is the most effective route to creating social value. The Future Generations Commissioner (2020) reinforces this by promoting an outcomes-based approach under the WFG Act, positioning public bodies as the main drivers of social outcomes. This could reflect an assumption that social value is best delivered through government-led mechanisms rather than industry-led initiatives. However, the Commissioner (2021) also noted inconsistent practice and industry concerns that

public projects, such as new schools, often overlook opportunities to support well-being goals.

WPR Q3 How did this representation of the problem come about?
Bacchi (2015) explains that to answer question three, policies must be examined to explore how the problem has developed and how power relations have changed over time. Constructing Excellence in Wales (2010) positioned the construction industry as the deliverer of essential infrastructure - roads, hospitals and housing - while public bodies were under increasing pressure to maximise limited resources. This framing established the construction industry's position of power as an indispensable partner in Welsh development by emphasising a 'holistic approach to value' (Constructing Excellence in Wales, 2010, 5). However, there was also evidence of government control through targets on waste, carbon emissions and community development (Constructing Excellence in Wales, 2010).

The Welsh Government's power dynamics changed with the introduction of the SPPP Act. One of the objectives of this legislation is to make Wales a fair work nation (Thomas, 2022). This legislation marked a decisive shift in power relations, particularly for the construction sector. Regarding fair work, the Welsh Government (2023) specifically targeted construction's long and complex supply chains, identifying them as a risk of poor compliance with social obligations, including those concerning unfair and unlawful employment practices (Welsh Government, 2023). This may reflect a strategic use of social procurement legislation to extend the Welsh Government's influence over labour practices, potentially addressing limitations associated with devolved power. This also represents a shift from the Welsh Government's (2014) community benefits policy, moving from broad encouragement of workforce development to specific, legally mandated requirements.

The SPPP Act strategically uses this purchasing power to impose specific duties on major construction contracts worth £2 million or more (Senedd Cymru, 2023). Over time, the problem representation has evolved, and power has shifted. The analysis of the policies shows that the construction industry has gone from just a provider of buildings and infrastructure to an industry that creates social value through providing employment opportunities for disadvantaged groups. The policy evolution suggests a shift in governance dynamics, with the Welsh Government assuming a more directive role in shaping social procurement practices.

WPR Q4 What is left unproblematic
Bacchi (2015) suggests that question four involves identifying what is left unexamined in policy representations. In Wales, a key omission is the lack of a clear definition of social value. Research by Cwmpas (2022), based on interviews across 18 organisations, revealed widespread confusion about its meaning and strategic implementation. While the SPPP Act tasks contracting authorities with improving economic, social, environmental, and cultural well-being in line with the WFG Act, it leaves the concept of social value open to interpretation, often illustrated only through examples like employment for disadvantaged groups.

There are also silences around community engagement. Cwmpas's (2022) research highlighted that organisations often assume what constitutes social value for communities without direct consultation. While the aim of the SPPP Act is to strengthen social partnership arrangements working through trade unions, employer representatives, and government, it leaves questions about meaningful community involvement in determining social value priorities (Senedd Cymru, 2023). Welsh

Government's (2023) equality impact assessment explains that social partners, particularly trade unions, will provide a mechanism for capturing lived experience. However, concerns have been expressed about the skill profile of Social Partnership Councils and whether they possess adequate expertise in procurement, contract management, and construction - areas crucial for effective implementation (Cwmpas 2022, Welsh Government 2021). The observed omissions and ambiguities within Welsh social procurement policy may indicate a need for more comprehensive and inclusive approaches to policy design and implementation.

WPR Q5 What effects discursive, subjectification, lived are produced by this representation of the problem?

Bacchi (2015) suggests that understanding question five involves examining how policy descriptions influence our understanding and identity, and how these descriptions shape our perceptions of ourselves and others. The social procurement policies were examined to denote the subject positions of the intended beneficiaries of social procurement policies. Welsh Government's (2014) policy focuses on providing targeted recruitment and training opportunities for disadvantaged groups, focusing on workless households and the short and long-term unemployed. However, the policy also suggests that the decision on what groups to target should be based on the socio-economic needs of the local area and the activities that the contract or project will require (Welsh Government, 2014). Within the SPPP Act, the subject position of beneficiaries of socially responsible procurement is still one of disadvantage. The Act explains that employment opportunities should be provided to 'younger people, older people, the long-term unemployed, people with disabilities or people who may otherwise be disadvantaged (for example, because of their race, religion or belief, sex, gender identity or sexual orientation)' (Senedd Cymru, 2023). The policy documents provide limited guidance on how to effectively support the diverse needs of these groups in accessing employment within the construction sector.

The construction industry seems positioned as the deliverer of community benefits for the disadvantaged. Previous policies discussed training, education, community initiatives, employment, and targeted recruitment and training (Welsh Government, 2010, 2014). The SPPP Act mandates the industry provides employment opportunities for disadvantaged groups. Therefore, social procurement policies seem to be positioning the construction industry as a provider of employment opportunities to disadvantaged groups.

WPR Q6 How and where has this representation of the 'problem' been produced?

Question six of Bacchi's (2015) approach involves examining where else the problem has been produced to understand problem shaping and find alternative perspectives. Construction Excellence in Wales (2012) examined the supplier's views on the Welsh Government's community benefits policy. They found that the construction industry was already delivering community benefits but highlighted concerns about focusing on short-term targets and the need to apply community benefit targets better to ensure sustainable employment outcomes. Interestingly, in Construction Excellence in Wales's (2012) research, the industry was problematising the effectiveness of community benefits policy.

Construction Excellence in Wales (2019) in 'Constructing for Future Generations' explains that they were spearheading the campaign for real change alongside the industry and the office of the Future Generations Commissioner. Construction Excellence in Wales (2019) stressed the importance of aligning the activities of the

construction industry with the seven well-being goals while recognising the construction industry's impact on people's lives by building homes, schools, hospitals and infrastructure. Construction Excellence in Wales (2019) highlights the complexities involved in aligning construction sector activities with the well-being goals outlined in Welsh policy frameworks. The document reads as a call to action. It stresses the need for the construction industry to recognise its impact on people's lives while recognising that a commitment to social value and community benefits is becoming the norm (Construction Excellence in Wales, 2019). Interestingly, there was a shift from Construction Excellence in Wales (2012), which explained that the construction industry wanted better application of community benefits targets to ensure sustainable employment outcomes.

DISCUSSION AND CONCLUSION

Bacchi's (2015, 2016) WPR approach provided a valuable framework for critically analysing social procurement policy in Wales by examining how policy problems are constructed, thereby uncovering deeper insights into the underlying assumptions and power dynamics that shape policy development over time. The legislative approach to social procurement in Wales has increasingly emphasized centralised governance, which may limit the extent to which the expertise of the construction industry and the perspectives of local communities are incorporated into policy development and implementation. This positioned social procurement as primarily guided by government frameworks with less emphasis on delivery mechanisms involving the construction industry and local communities. Both Cwmpas's (2022) research and the Welsh Government's (2021) consultation on social procurement raised concerns that an increasingly top-down legislative approach to social procurement in Wales is failing to consider the expertise of the construction industry and the voice of the communities that benefit from social procurement interventions.

Using Bacchi's WPR approach, has proven to be a valuable method for uncovering the assumptions and power dynamics in social procurement policy in Wales. This analytical lens also has the potential for broader application in construction management research. This study offers a critical framework for examining how problems are constructed in policy and practice, revealing the discursive and institutional forces that shape industry behaviour. Future research could apply this approach to other areas of construction management, such as workforce development, sustainability or digital innovation. This application would enhance the theoretical foundations of construction management and promote more reflective and inclusive policymaking.

While this study focuses on a Welsh context, Bacchi's conceptual approach offers valuable insights that are transferable to other national and regional settings. Bacchi (2009) explains the WPR approach encourages forms of cross-cultural and cross-national comparison to tease out distinctions among problem relations. Social procurement policies across different jurisdictions often share implementation challenges as well as challenges in defining and delivering social value. By critically examining how problems are represented in policy discourse, this approach can be applied to explore social procurement policies in other parts of the UK, Europe or globally. Future research could adopt the WPR lens to compare how different governments conceptualise social value, engage with industry, and include community voices in procurement processes.

In conclusion, the Welsh Government's approach to social justice, from securing community benefits to socially responsible public procurement, reflects a growing commitment to leverage public sector funding to achieve social value and tackle poverty. However, the policy analysis shows that significant gaps remain, particularly in community engagement and the integration of industry expertise. The analysis showed that the construction industry has consistently expressed concern about the practical application of social procurement policies. Research by Construction Excellence in Wales (2012) highlighted the industry's desire for better-targeted community benefit initiatives to ensure sustainable employment outcomes. A focus on well-being could provide a valuable framework for advancing outcomes based social procurement to achieve social, economic, environmental and cultural goals. However, the policy analysis showed that industry stakeholders had concerns about the current policy direction. Particularly there is a perception that the existing approach may over rely on prescriptive legislation, which may overlook the expertise and experience of construction professions and communities. The new social partnership arrangement in Wales should include mechanisms to amplify the voice of the construction industry, enabling them to benefit from their expertise in social procurement. This could contribute to improved accountability mechanisms and support the delivery of social value outcomes that align with the needs of Welsh communities.

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BUILDING BETTER FUTURES: UNLOCKING THE POTENTIALS OF PUBLIC PROCUREMENT FOR SUSTAINABLE WORKERS AND COMMUNITIES

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This study focuses on building better futures by exploring how public procurement can be leveraged to foster sustainable worker welfare and community engagement in Nigeria's construction sector. Current procurement practices emphasize environmental and economic priorities but frequently overlook the social aspects. The research identifies deficiencies in Nigeria's Public Procurement Act (PPA) 2007, calling for reforms to better support social value creation that align with the United Nations Sustainable Development Goals. An exploratory sequential mixed-methods approach was employed, beginning with 19 semi-structured interviews within one public tertiary institution. The qualitative findings informed a survey of 121 construction professionals from public tertiary institutions across 11 Northern Nigerian states. Themes rooted in worker welfare, and community well-being were highlighted, alongside barriers like inadequate statutory frameworks and weak client commitment. It proposes practical strategies to embed social considerations into procurement, aiming to improve workers' condition, and strengthen community engagements. It also recognised legislative reforms as essential to adopting and advancing sustainable and socially responsible procurement practices in Nigeria.

Keywords: worker welfare; community engagement; sustainable procurement; social value

INTRODUCTION

The integration of social factors into public procurement is increasingly recognised as a pathway for achieving sustainable construction outcomes (Dobson *et al.,* 2020; Barron *et al.,* 2023). However, public procurement as practiced in Nigeria's tertiary institutions remain rigid and often neglect social considerations (Udeh and Ugwuanyi, 2022). This gap limits the ability of construction projects to contribute meaningfully to community well-being, equitable opportunities, and site workers' welfare.

Some international studies have demonstrated the benefits of incorporating sustainability factors into construction procurement. For example, the United Nations Development Programme (UNDP, 2018) reported that public procurement reforms in Costa Rica fostered community engagement and improved worker conditions. Similarly, Glass and Love (2015) examined the London 2012 Olympic Games, highlighting how social factors in construction led to measurable improvements in

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local communities' quality of life. In contrast, Nigeria's Public Procurement Act (PPA) 2007 has primarily focused on environmental and economic aspects, neglecting the social dimensions (Ojo and Gbadegesin, 2020). Given the significant role of public tertiary institutions in societal development (Oyediran, 2020), addressing this gap is crucial in unlocking the potential of public procurement. This portends the fostering of sustainable worker welfare and community engagement in Nigeria's construction sector through enhancing social value.

Problem Statement

Despite the strategic role of the Tertiary Education Trust Fund (TET Fund) in developing Nigeria's public tertiary education infrastructure (Oyediran, 2020), the lack of transparency in procurement processes often undermines the core principles of the PPA 2007 (Abdullahi *et al.,* 2019). Integrating social factors such as community engagement, labour rights, and corporate social responsibility could enhance social value and sustainability (Akinade *et al.,* 2020). However, there is limited research on how these factors can be systematically embedded within Nigeria's procurement framework. This study, therefore, seeks to investigate how public procurement can be leveraged to foster sustainable outcomes in tertiary institutions, particularly in safeguarding labour rights, promoting community engagement, and embedding corporate social responsibility. Given the limited research on systematically integrating social factors within Nigeria's procurement landscape, this study addresses a critical gap by proposing an approach to embedding social value in public tertiary institution constructions.

At the core of this investigation is an exploration of how procurement practices shape sustainability outcomes in construction. This study examines the extent to which existing procurement policies support sustainable construction. In addition, it identifies key social factors that enhance worker welfare and community well-being which can be developed into a framework for embedding social considerations into procurement processes. In doing so, it seeks to answer pertinent questions regarding the adequacy of current policies, the critical social dimensions that should be prioritised, and the structural reforms needed to institutionalise social value within procurement. By proposing policy recommendations that align with legislative frameworks, this research aims to reposition procurement as a strategic tool for sustainability, ensuring that construction projects contribute meaningfully to the workforce and the broader community as stakeholders (Mulholland *et al.,* 2020).

Embedding Social Value in Public Procurement

Public procurement significantly influences construction practices, extending its impact beyond economic considerations to broader sustainability outcomes (Montalb an-Domingo, *et al.,* 2019; Murtagh and Brooks 2019). While environmental and economic aspects have received considerable attention, the social dimension remains relatively underexplored (Mangialardo and Micelli 2017). At the heart of this gap lies the potential for procurement to drive social value, ensuring that construction projects contribute meaningfully to societal well-being. Social value, in this context, encompasses policies that enhance worker welfare, promote community development, and foster equitable opportunities (Barron *et al.,* 2023). Evidence suggests that procurement strategies prioritising local labour and training initiatives lead to improved working conditions and stronger community ties, reinforcing the argument for embedding social factors into procurement frameworks (Iles and Ryall, 2016).

Against this backdrop, the integration of worker welfare and community engagement within public procurement becomes increasingly significant. Procurement policies that mandate fair wages, enforce safe working conditions, and support skills development have been shown to yield long-term benefits for workers and the broader construction industry (Manu *et al.,* 2019). Equally, engaging local communities in construction projects fosters social inclusion and stimulates local economic growth, positioning procurement as a tool for sustainable development (Osuizugbo *et al.,* 2021). However, in Nigeria, the Public Procurement Act (PPA) 2007 remains largely cost-driven, often overlooking the social dimension in sustainability (Udeh and Ugwuanyi, 2022). While some scholars argue for ethical procurement frameworks in Nigerian tertiary institutions (Abdullahi *et al.,* 2019), others suggest that integrating social considerations could enhance long-term project outcomes and overall sectoral sustainability (Akenroye, 2013).

Aligning Procurement with SDGs

Given these considerations, aligning public procurement practices with the United Nations Sustainable Development Goals (SDGs) offers a viable pathway to embedding social value within Nigeria's construction sector. This is because the SDGs advocate for decent work, inclusive economic growth, and resilient infrastructure. These are objectives that public procurement is well-positioned to support (United Nations, 2015). The SDGs emphasize the importance of decent work and inclusive economic growth, as reflected in SDG 8. Public procurement can play a crucial role in achieving this by promoting fair wages, safe working conditions, and employment opportunities within the construction sector.

Similarly, SDG 11 focuses on making cities and communities inclusive, safe, resilient, and sustainable. Public procurement can contribute to this goal by ensuring that construction projects integrate social value considerations for a more sustainable and responsible development. By embedding social value into public procurement policies, Nigeria can not only enhance sustainability in construction but also contribute to broader societal well-being. Furthermore, SDG 9 underscores the need for resilient infrastructure, sustainable industrialisation, and innovation. Through strategic procurement practices, the public sector can prioritise the use of durable materials, support local industries, and encourage technological advancements that enhance the sustainability of construction projects. However, achieving this requires a deliberate shift in procurement priorities, from cost efficiency to a more holistic approach that recognises the social imperative.

METHOD

This study adopts an exploratory sequential mixed-methods approach, allowing for an in-depth examination of qualitative insights before validating them quantitatively (Creswell, 2014). By integrating both forms of data, the methodology ensures an understanding of the research problem, capturing nuanced perspectives while also enabling broader generalisability. In the initial qualitative phase, semi-structured interviews are conducted with 19 procurement professionals from a public tertiary institution. Participants are selected through purposive sampling to ensure relevant expertise and informed perspectives (Flick, 2007). The qualitative data is systematically coded and analysed using NVivo software, applying Braun and Clarke's (2022) six-steps to Reflexive Thematic Analysis (RTA). The RTA facilitates identification of recurring patterns to generate themes, with a focus on worker welfare and community engagement. Braun and Clarke (2022) six-step process includes first,

familiarisation with the data involved actively engaging with transcripts to gain an in-depth understanding; second, initial coding was conducted by systematically identifying meaningful features across the dataset; third, themes generation by grouping related codes into broader patterns; fourth, reviewing themes to ensure coherence and relevance to the research focus; fifth, defining and naming themes to clearly articulate their significance. Finally, the findings are reported in a structured narrative that captured key insights from the themes generated.

Building on the interview findings, the study proceeded to a survey involving 121 construction professionals from public tertiary institutions across 11 Northern Nigerian states. Convenience sampling was used to maximise participation, while acknowledging its limitations regarding representativeness (Saunders *et al.,* 2016). A combination of qualitative thematic analysis and quantitative statistical techniques employed therefore ensured methodological rigour. The reliability of the survey instruments was assessed using Cronbach's alpha (0.926), demonstrating internal consistency. To rank social factors based on their perceived significance, the Relative Importance Index (RII) was applied:

$$RII = \sum W/AxN \qquad (1)$$

Where:

- $\sum W$ is the sum of weights given to each factor by the respondents.
- A is the highest weight (e.g., for 1 to 5 Likert scale, A=5).
- N is the total number of respondents. (Sakhare and Patil, 2019).

This methodology is to ensure that findings are robust, contextually relevant, and applicable to policy and practice in Nigeria's construction sector.

FINDINGS AND DISCUSSION

The findings from both the qualitative and quantitative phases are synthesized to examine how social value can be embedded into public procurement to enhance worker welfare and community well-being. To contextualise these findings and strengthen their relevance, the key themes and their rankings within Nigeria's public tertiary institution procurement environment are analysed in relation to broader academic literature.

Qualitative Phase

The themes generated are summarised in Table 1 and Table 2, providing a structured representation of the findings. These themes are further elaborated in the discussion section, where participants are quoted and the implications subjected to the literature in discussing these findings.

Workers Welfare

The three key themes generated are Worker Health and Safety, Ethical Labour Practices, and Social Responsibility (see Table 1). These reflect how public procurement affects site conditions in Nigerian tertiary institution construction projects.

The theme "Worker Health and Safety" shows participants sharing their experience on unsafe working conditions and a lack of protective equipment. Although safety is included in contracts, it is often not enforced. Buttressing this point, Participant 3 stated that:

> "The contractor would usually provide the first aid box. But when it comes to the safety equipment like the safety boots, the safety helmets, and the reflective jackets... the workers, in an effort to maximize profit, sell the PPEs given to them and work without the safety equipment."

Table 1: Participants' feedback on Workers Welfare

S/N	Codes	Number of Coded Responses	Generated Themes	
			Sub-themes (categorised)	Theme (Naming)
1	Accident management	13	Health and Safety Measures	Worker Health and Safety
2	Deployment of first aid	13	Health and Safety Measures	
3	Workers attitude towards H&S	16	Behavioural Aspects of Safety Culture	
4	Enforcement of safety standards	29	Health and Safety Measures	
5	Inequitable distribution of Personal Protective Equipment (PPE)	12	Occupational Health Equity	
6	Proximity to health services	8	Access to Healthcare	
7	Standard of scaffolding	2	Site Safety Infrastructure	
8	Health and safety practices	90	Health and Safety Measures	
9	Provision of PPE	30	Health and Safety Measures	
10	Labour wages and payment	19	Labour Rights and Economic Welfare	Ethical Labour Practic
11	On-site labour issues	40	Working Conditions and Site Management	
12	Prevalence of child labour	5	Ethics in Labour Practices	
13	Insurance for workers	6	Social Protection and Welfare	Socially Responsible Practices
14	Welfare benefits and incentives	38	Social Protection and Welfare	
15	On-site sanitary facilities	3	Working Conditions on sites	

This highlights poor site safety culture where workers and contractors often trade safety for profit. Despite formal requirements, monitoring is weak, and breaches go unpunished. Similar concerns have been raised in previous studies on Nigeria's cost-focused procurement practices (Udeh and Ugwuanyi, 2022). By contrast, countries like Costa Rica and the UK have used procurement to improve worker safety and community benefits (UNDP, 2018; Glass and Love, 2015).

Under the next theme on "Ethical Labour Practices", participants noted issues such as low pay, unstable jobs, and lack of benefits. These are driven by contractors aiming to cut costs, with little pressure from clients to uphold standards. Participant 2 said:

> "The workers' interest can best be protected by the university engaging the contractor. But as I said, are we ready to pay the extra? I was in eh… about two weeks ago, one junk contractor was telling me how he was going to register his company with PENCOM (Pension Commission in Nigeria) but I know it's going to cost him some money."

This suggests that even where laws exist, compliance is poor because procurement processes rarely check whether contractors meet employment standards, leading to unfair treatment of workers. This supports studies arguing for stronger enforcement of fair labour practices in construction (Manu *et al.,* 2019; Iles and Ryall, 2016).

With regards to the third theme on "Socially Responsible Practices", participants highlighted the lack of commitment to worker welfare beyond wages. Legal requirements such as worker insurance are often ignored as stated by Participant 1 who noted that:

> "Even the issue of insurance for the workers that the contractor is compelled by law to carry out on all their workers for the duration of the project, they hardly ever do that. It is a thug of war for them to submit the policy document that all their workers on site have been insured against accidents."

This reveals a gap between what is required and what is being done. Contractors face no real consequences for neglecting worker protections, thereby weakening the social impact of construction projects. Previous studies confirm that Nigerian procurement rarely delivers on social value goals (Akinade *et al.,* 2020; Ojo and Gbadegesin, 2020). Hence, reforming the procurement system in this regard could help deliver better jobs (SDG 8) and safer infrastructure (SDG 9) (UN, 2015; Barron *et al.,* 2023).

Community Well-being

Three key themes emerged on how public procurement affects community well-being in construction projects within Nigerian tertiary institutions. These are Community Engagement and Inclusion, Corporate Social Responsibility, and Fair Land Compensation as presented in Table 2.

Table 2: Participants' feedback on Community Well-being

S/N	Codes	Number of Coded Responses	Generated Themes	
			Sub-themes (categorised)	Theme (Naming)
1	Enlightenment on project benefits	15	Community Sensitization	Community Engagement & Inclusion
2	Barriers to engaging from community	79	Community Engagement Gaps	
3	Community roles on projects	33	Community Participation	
4	Effective stakeholder management	2	Stakeholder Coordination	
5	Engaging community	23	Project-Driven Engagement Efforts	
6	Provisions to engage community	18	Procurement-Based Engagement Provisions	
7	Conflict situations	39	Sources of Community Conflict	
8	Conflicts resolution mechanism	56	Conflict Resolution Frameworks	
9	Contractor CSR initiatives	12	Firm-Led CSR	Corporate Social Responsibility
10	Institutional CSR	27	Government-Led CSR	
11	Compensation and land encroachment	26	Land Use and Compensation Issues	Fair Land Compensation

From the theme on "Community Engagement and Inclusion", the participants consistently reported that host communities are rarely consulted before or during construction. As Participant 11 noted:

> "Projects just show up in communities. People are rarely asked what they need or how they feel about it."

This illustrates a top-down planning culture where local needs are overlooked. Despite isolated efforts by some institutions to involve communities at project initiation, such engagement is neither consistent nor formalised. Participant 13 added:

> "… engaging community in every aspect of work that you are doing within any community is key… if they ask us, we will give them this input."

This underscores the willingness of professionals to support participatory planning if procurement systems make provisions for it. However, such frameworks are largely absent despite the literature confirming that effective community engagement in procurement enhances project acceptance and local benefits (UNDP, 2018; Glass and Love, 2015). By contrast, Nigeria's Public Procurement Act lacks enforceable community involvement mechanisms (Ojo and Gbadegesin, 2020).

Local hiring was also identified as another gap under this first theme. Participant 3 highlighted this when he said:

> "When young people from the area are hired, they feel ownership of the project, and it reduces vandalism."

This supports evidence that inclusive labour practices improve community relations (Loosemore, 2016). Yet, procurement rarely mandates or monitors local employment, limiting its potential to build social capital and reduce conflict.

On the second theme "Corporate Social Responsibility", the interviewed participants identified weak implementation of corporate social responsibility (CSR) in construction procurement. CSR efforts, such as community donations or skill development, were seen as voluntary and inconsistent. As Participant 4 explained:

> "Management even encourages the contractor to partner well with the host community."

While some contractors take the initiative, these actions depend more on goodwill than on procurement requirements. Without structured CSR guidelines, contractors are neither incentivised nor held accountable for their social impacts.

Previous studies argue that integrating CSR into procurement policies leads to better social outcomes (Barron *et al.,* 2023; Osuizugbo *et al.,* 2021). However, Nigeria's procurement system largely prioritises cost and timelines, sidelining opportunities for contractors to contribute meaningfully to community development (Akinade *et al.,* 2020).

The third theme generated, that is, "Fair Land Compensation", unveiled land use and compensation as another area of concern. Participants reported unresolved grievances and a lack of transparency when land is acquired for construction. This contributes to local resentment and sometimes open conflict. While land acquisition is guided by legal frameworks, participants noted these are not always followed. Where compensation is delayed or perceived as unfair, community trust erodes. This gap highlights the need for clearer, enforceable compensation protocols within procurement processes to reduce project disruption and foster goodwill.

Quantitative Phase

The survey involved 121 respondents, predominantly male (80.17%), with the majority holding either a Master's (39.67%) or Bachelors' degree (30.58%). Senior construction professionals (34.71%) formed the largest group, followed by directors (19.83%) and deputy directors (14.88%). Most respondents (56.2%) had over 16 years of experience, including 30.58% with more than 21 years. The Nigerian Institute of Quantity Surveyors (30.58%) and the Nigerian Society of Engineers (25.62%) were the most common professional affiliations.

Workers Welfare in Public Procurement Practices

Unsafe working conditions, poor wages, and limited access to healthcare were generated from the qualitative findings. These concerns are quantitatively confirmed as presented in Table 3 and graphically depicted on Figure 1.

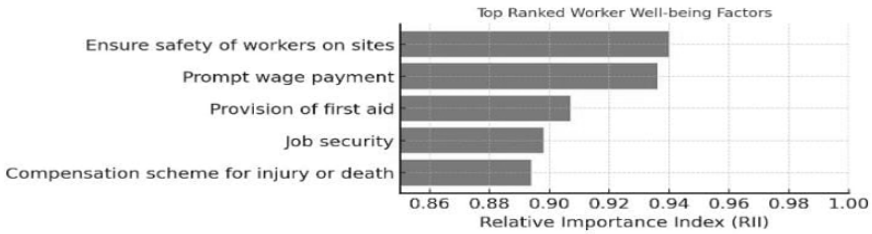
Table 3: Top Ranked Well-being Factors for Site Workers

Workers' well-being factors	N= 121, A = 5	Wi	RII	Rank
Ensure safety of workers on sites		569	0.940	1
Prompt wage payment		566	0.936	2
Provision of first aid		549	0.907	3
Job security		543	0.898	4
Compensation scheme for injury or death		541	0.894	5

From Table 3, "Ensure safety of workers on site" (RII: 0.940) and "Prompt wage payment" (RII: 0.936) rank highest with other key factors following. These include "Provision of first aid" (RII: 0.907), "Job security" (RII: 0.898), and "Compensation

schemes for injury or death" (RII: 0.894). These findings align with prior research emphasising worker welfare as core to sustainable construction (Barron *et al.,* 2023).

Figure 1: Bar Chart of Worker Well-being Factors



Community Engagement and Well-being

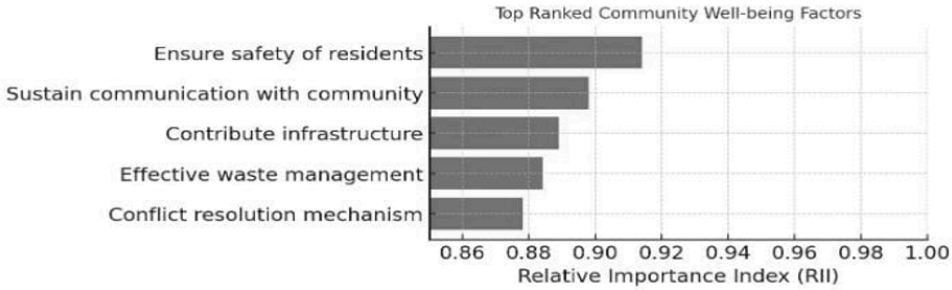
Qualitatively, community consultation is shown to be lacking, leading to tensions. Quantitative data (Table 4 and Figure 2) reinforces these concerns, identifying "Resident safety during construction" (RII: 0.914) and "Sustained communication" (RII: 0.898) as top community priorities. Other important aspects were "Infrastructure contributions" (RII: 0.889), "Effective waste management" (RII: 0.884), and "Conflict resolution mechanisms" (RII: 0.878).

Table 4: Top Ranked Well-being Factors for Communities

Communities' well-being factors N= 121, A = 5	Wi	RII	Rank
Ensure safety of residents during construction/demolition activities	553	0.914	1
Sustain effective communication with community	543	0.898	2
Contribute to community through specific infrastructural project	538	0.889	3
Effective waste management	535	0.884	4
Provide a conflict resolution mechanism throughout the project	531	0.878	5

These findings highlight the need for structured engagement strategies that prioritise long-term community benefits. As a lack of formalised community engagement leads to limited stakeholder inclusion, integrating these elements into procurement can enhance social value outcomes by managing stakeholder dynamics of the community (Mulholland *et al.,* 2020).

Figure 2: Bar Chart of Community Well-being Factors



CONCLUSION AND RECOMMENDATIONS

This study highlights the critical role public procurement can play in advancing worker welfare and community well-being in construction projects within Nigeria's public tertiary institutions. Findings from both qualitative and quantitative data reveal significant shortcomings in current procurement practices, particularly in enforcing worker safety, fair labour standards, and inclusive community engagement. Despite existing legal provisions, poor monitoring and enforcement allow unsafe site conditions, unfair wages, and neglect of worker rights to persist. Communities, too,

are often excluded from project planning, receive inadequate information, and experience delayed or unfair land compensation. These gaps diminish the potential of procurement to deliver social value and foster sustainable outcomes.

To build better futures through procurement, several steps are therefore recommended. First, health and safety standards must be better enforced. Contractors should be required to provide protective equipment, first aid kits, and accident insurance for all workers. There should be regular checks to ensure these rules are followed. Second, ethical labour practices must be made compulsory. Contractors should pay workers on time, offer job security, and register them for pensions. These conditions should be clearly stated in contracts and checked during project delivery. Third, communities must be involved in project planning. Host communities should be consulted before and during construction. This helps avoid conflict and builds trust. Fourth, corporate social responsibility should be part of the contract, not just voluntary. Contractors should be required to support local training or provide community services. Fifth, land compensation must be fair and transparent. Clear rules and a proper complaint system will help reduce disputes and delays. Finally, all these steps need legal backing. The Public Procurement Act should be updated to include strong social value requirements as this will help protect workers, support communities, and build sustainable infrastructure.

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THE INFLUENCE OF PROJECT MANAGER CAPABILITY ON PROJECT GOVERNANCE

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The design of project governance regimes has predominantly been based on the size and value of construction projects, with larger projects receiving most attention from a governance perspective. These regimes are generally ex ante with an emphasis on overview and control, with extensive involvement of PMOs, committees and boards. Further, such regimes take little account of the capability, skills, and experience of the Project Manager and other key project actors. This paper presents a qualitative study involving in-depth interviews with 31 leading project practitioners and investigates the influence of Project Manager capability on project governance design. The research findings represent a departure from what has become accepted practice, where an ex-post approach to project governance, commensurate with the capability of the Project Manager and the project type, will enhance the effectiveness of project governance; the leadership potential of project actors; and the consequential realisation of project value, all key elements in the efficacious regeneration of cities. The study also identified 16 critical capability attributes of a Project Manager from a wide range of project types.

Keywords: project manager capability; project type; project governance; autonomy

INTRODUCTION

Sound project management and the effective deployment of capable Project Managers are key factors in construction management. This is particularly important in regeneration projects which possess extensive constraints, uncertainty, ambiguity, and competing stakeholder interests, which combine to create a complex environment, not suited to prescriptive approaches to project planning and delivery.

The purpose of project governance is ultimately the provision of confidence to the owner, builder, or investor in a project that the right projects are being done, and they are being done in a way that realises value. To support this, the project governance design will: (1) establish clear roles and responsibilities for project actors; (2) establish mechanisms for flow of information and review of progress; and (3) mechanisms for timely decision making, risk management, and stakeholder engagement. The development of the project governance regime is thus an ex-ante activity. In practice, the design and operation of this project governance is increasingly independent of the Project Manager. Early literature clearly indicates that governance of projects existed prior to its documentation in 2005, but it was just regarded as part of doing good project management work. This aligns with the

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Wheeler, D, Rose, T and Kajewski, S (2025) The Influence of Project Manager Capability on Project Governance, *In*: Thomson, C and Neilson, C J (Eds) Proceedings of the 41st Annual ARCOM Conference, 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 731-740.

reflective experience of the researcher, and with Turner (2009) where the Project Manager had influence over the project governance regime in concert with the Project Sponsor/ Director. In this environment, the Project Manager was actively involved in the tailored design of the project governance regime in an ex-ante manner concurrently with the obtaining of necessary approvals, permits, and alignment of the project with organisational objectives. The subsequent operating, monitoring and controlling activities to respond to uncertainty, multiple interactions, stakeholders, changing circumstances, and enabling project forecasting, was undertaken in ex post manner. The early literature emphasized a separation between corporate governance and project governance with project governance providing the link between a project and the strategic interests of the organisation (APM, 2005, Turner, 2009). There is now a tendency for investment frameworks and corporate governance to displace sound project governance practices (Wheeler, 2025).

The authoritarian, prescriptive, and methodological approach to project governance can result in the form of governance having an emphasis on formal structure and control, and being independent of any other human, project and organisational factors such as: (1) the capability and experience of the Project Manager; (2) the type and complexity of the project; or (3) the level of trust or autonomy provided to the Project Manager. It has been found that large projects are subject to more stringent governance approaches than small projects, yet lower risk projects fail less than high risk projects. This anomaly questions the conventional wisdom where more governance and oversight are applied to larger projects due to perceived greater risk (Joslin and Muller, 2015; Muller and Lecoeuvre, 2014). However, the characteristics of the individual Project Manager have been positively linked to project success and to project type (Blaskovics, 2016; Moura *et al.,* 2017; Müller and Turner, 2007).

Therefore, there is a need to better understand the relationships between project type, the individual Project Manager, and the project governance regimes that match the needs of a unique project. Project governance was examined with respect to governance mechanisms of control and trust, and autonomy provided to the Project Manager.

Whilst it would be expected that the capability of the Project Manager should be a factor in the design of project governance, and research has been undertaken on the connection between Project Manager capability and performance, no previous research had been conducted on the influence of Project Manager capability, in consideration of project type, on project governance. This represented the gap in knowledge addressed by this study.

The identified primary research question was: How does project type and Project Manager capability influence project governance? Two (2) secondary research questions were subsequently developed: (RQ1) - How does project type influence project governance? (RQ2) - How does the capability of the Project Manager influence project governance?

By addressing these two questions, an expected additional outcome was understanding of the relationship between project type and the capability of the Project Manager.

METHOD

Consistent with the research aim, the research method and design had to support the enhancement of understanding on: (1) the capability attributes of the Project Manager; (2) a project typology that would have broad application and be compatible with the

capability attributes; (3) the project governance mechanisms of control and trust, and their relationship with the Project Manager's autonomy; and (4) the relationships between project type, Project Manager capability, and project governance. The absence of a hypothesis, and with the open style of interview questions, deductive, multivariate quantitative approaches to the research were not suitable.

An exploratory approach was adopted with an inductive, qualitative method being applied. This approach was underpinned by thematic analysis to uncover and develop the contributions to theory and practice.

In-depth interviews were conducted with 31 interviewees, following receipt of human ethics approval. The interviewees were selected against criteria which included minimum years of experience in the project domain, exposure to multiple contexts, and the holding of qualifications or certifications in project management. The collective experience of the interviewees at the time of interview exceeded 1000 years, there was an even distribution of consultant versus employee exposure, and an even cross-section of involvement in the private, government, and government owned corporation sectors. More than 80% of the interviewees have had exposure to construction, including building, public infrastructure, mining infrastructure, and defence assets. This cohort of interviewees was able to contribute broad and deep theoretical and experiential knowledge to this research.

A formal structured approach to the interviews was piloted in the first interview but this was found to be restrictive to conversation that would extract the interviewees knowledge in project governance, and the relationships of capability, project type, control, trust, and autonomy. After the first interview, a more open semi-structuredapproach was taken to interviews whilst mindful of all the factors and potential relationships being explored, and therefore still consistent with the original intent of the more structured approach.

The recordings from the interviews were transcribed and inserted into the NVivo software. The data was allocated to codes which included the variables of capability, project type, control, trust, and autonomy. In addition, codes related to the relationship between these variables were allocated, as well as a code for the Executive. Sub-codes were allocated for each of the four project types, and for the Executive. Through thematic analysis of the data against each of the codes, sub-themes were identified and compared against extant literature, as well as other themes and sub-themes. Through the concurrent application of inductive reasoning the interrelationships between the factors, themes and sub-themes became evident, and theory evolved.

FINDINGS

This section describes the research findings on: (1) the capability attributes applicable to a Project Manager; (2) the adopted project typology; (3) the relationship of governance mechanisms of trust and control to capability and project type; (4) autonomy provided to the Project Manager; and (5) the relationship between Project Manager capability, project type, and governance.

Project Manager Capability

The data included 243 references to Project Manager capability. Thematic analysis identified 16 sub-themes which represent the attributes of a Project Manager. These are listed in Table 1, together with some supporting interviewee comments.

Table 1: Project Manager Capability Attributes

Attribute	Supporting interviewee comments
1. Communication/ listening	"When we are talking about a good project manager, I will always probably judge them with the highest attribute, the ability to communicate" [Interviewee 3].
2. Dealing with ambiguity/ intangible space	"…they just seem to be able to navigate their way with people … they are not fazed by ambiguity" [Interviewee 24].
3. Domain knowledge, technical skill, explicit knowledge	"Capability is not just technical knowledge on what to build; nor the project management skills…leadership, including emotional intelligence; their ability to work and form strong partnerships…the right capability in place; not just somebody with a technical skill-set" [Interviewee 22].
4. Understanding and engaging with stakeholders	"Stakeholders and risk now represent 90% of the job" [Interviewee 5].
5. Change management	"Whenever I go into a project now… I tend to apply that change management hat and sort of lens over things as well" [Interview 14].
6. Awareness of organisational governance structures, power and politics, and context	"Very aware of the power and the politics…so would keep the senior hierarchy well-informed and the political hierarchy well-informed." [Interviewee 8].
7 Maturity/ experience	"It takes a very mature or astute project manager to find that their project is no longer viable" [Interviewee 31].
8. Innovation, adaptability, nimbleness, agility, resilience	"requires very nimble, agile, project management skills; … letting go of that control" [Interviewee 5].
9. Intuition, innate ability, ability to work in uncertainty	Based on reference to "innate ability" by Interviewees 4, 5, and 30, it is proposed that in the project context, 'intuition' is the innate ability to use tacit knowledge.
10. Open mindset	"… going in there with an open mind; understanding the organisation/people" [Interviewee 28].
11. Understanding of others/ emotional intelligence	"Traditionally, we would have said hard skills and soft skills… team dynamics and understanding people" [Interviewee 19].
12. Risk awareness and management	"You need that helicopter view in order to know what's happening around you; … look at a project very much from a risk perspective" [Interviewee 14].
13. Ability to deliver, dedication, mastery	"It's almost like project managers are born and not made" [Interviewee 21]; "once that knowledge becomes embedded, it becomes mastery" [Interviewee 26].
14. Leadership, character, ethics, integrity, people management, strategic view, unconscious competence	"trust, integrity, power and the ability for people to follow and/or lead" [Interviewee 31].
15. Confidence, courage, intimate understanding of project, conviction	"you are able to talk fearlessly and frankly about the issues, … commercial issues, technical issues, issues relating to risk or progress or cost" [Interviewee 15].
16. Humility and behaviour	"The number one capability… I guess I would say humility" [Interviewee 8]; "to acknowledge that you needed to complement your knowledge on skills with others around you" [Interviewee 10].

Project Type

A wide range of project typologies were examined. Some relate to attributes such as: (1) organisation benefit; (2) cost; (3) client/ customer; (4) application area; (5) complexity; (6) strategic importance; (7) risk level; (8) nature of work; (9) resources; and (10) size (Crawford, 2005). Others relate to the project outputs or industry: (1) engineering and construction projects; (2) Information Technology and Telecommunications (IT and T) projects; and (3) organisational change and business projects (Muller and Lecoeuvre, 2014). It is argued that project type based on inputs and other attributes are more relevant to consideration of a governance regime, than industry or nature of the work, and incorporates attributes such as complexity, uncertainty, ambiguity, and novelty. It was determined that the 'Goals and Methods Matrix' (Turner and Cochrane, 1993) would best represent the wide array of projects that the interviewees would be drawing on, representative of the construction domain.

Interviewees described Type 1 projects as: “pure engineering”, “repetition”, “process driven”, “relatively straight forward”, and “predictable” [Interviewees 5, 6, 21, 25, 26], all which align with what are regarded as traditional, linear, and methodological approaches. Interviewees equated Type2 projects to projects where iterative or agile methods are applied. Whereas in Type 1 projects, the Project Manager may also be a SME (Subject Matter Expert), Type 2 projects may contain SMEs and a key role of the Project Manager is to keep the SMEs ‘on track’ and avoid scope creep [Interviewees 3, 7, 9, 12, and 13].Interviewee 26 described Type 2 and 3 projects as “part of the continuum” with “Type 2 projects being where the processes are well-defined but the context within which it's going to be applied, we are not too sure about. Type 3 is where we are saying, we know the environment, we are comfortable in this environment, but we just don't know what we are going to be doing". Some interviewees considered the required abilities being closer to Type 4 projects [Interviewees 5 and 11]. Type 4 projects were described as: “front-ending, less tangible, and less measurable, relying on trust and skill” [Interviewee 4]; “long duration, conceptual, and big picture” [Interviewee 6] and “more exploratory, adaptive” [Interviewee 14].

The key findings in relation to project type were: (1) the Project Type can change throughout the lifecycle; (2) governance design differs with Project Type; (3) Project Type is not dictated by project cost or size; (4) there is a relationship between Project Type and capability of the appropriate Project Manager; and (5) it is appropriate to group Project Types 2 and 3, due to similarities, and consider them jointly.

Higher level capability is clearly required for Type 4 projects, with some of the descriptions by Interviewees including: (1) reliance on “trust and skill” [Interviewee 4]; (2) ability to do “top down and bottom up at the same time” [Interviewee 4]; (3) “open mindset, contextualisation skills, and creative visualisation” (drawing on intuition) [Interviewee 5]; (4) “savviness” [Interviewee 10]; (5) more leadership, less tactical [Interviewee 13]; and (6) “multi-dimensional capability” [Interviewee 15].

Notwithstanding the above discussion on each Project Type, most Interviewees suggested that “very capable Project Managers” can work on any Project Type. Further, irrespective of the Project Type, the Project Manager needs to understand the context of the project they are embarking on [Interviewee 9]. This has also been referred to by experienced Project Managers as having an “intimate” understanding of the project.

The relationship of trust and control to Capability and Project Type

Through extensive discussion with all Interviewees, a uniform view was that the governance mechanisms of control and trust are sound indicators of the style of project governance in place, as perceived by the Project Manager. The position on the control - trust spectrum, from the perspective of the Project Manager, is dependent upon the capability of the Project Manager, and the Project type [Interviewees 12, 16, 19, 23, 27, 29, and 31]. Capability was found to be a stronger indicator than experience [Interviewee 29], although 'experience' was conveniently expressed by many as a means of differentiating levels of capability (in terms of more or less experience).

A uniform view of Interviewees was that the most experienced/ capable Project Managers should be provided high levels of trust, with minimal overview, and less experienced/ capable Project Managers need more support, don't possess the necessary capability to operate independently, and therefore, deserve higher levels of control and support, and lower levels of trust. As commented by Interviewee 27: "more trust in most experienced…more overview with less experienced". According to Interviewee 17: "if I have trust in that person, it would be light touch engagement… more overview for less experienced". They explained that the 'overview' for the less experienced Project Manager would entail "coaching and mentoring so that they can develop the necessary skills".

Autonomy

Other considerations in the appropriate levels of autonomy versus control are: (1) the position in the project lifecycle; (2) the capability of the Project Manager; and (3) the influence of the executive. Interviewee 28 commented that: "once the budget was approved and contracts awarded; a fair degree of autonomy was provided". That is a response to the real and perceived risk by the Executive whereby they are reluctant to grant autonomy to the Project Manager during the investment decision phases, but once they are confident that they have the right solution, and commitments have been made, they become more prepared to place trust and therefore autonomy in the Project Manager. This ignores the relative capability of the Project Manager to influence investment decisions, and for highly capable Project Managers, this can be demotivating. Interviewees commented on the desire for the level of autonomy to be "adjusted for Project Manager capability" [Interviewee 30], with the predicable preference for highly capable Project Managers to be provided more autonomy (consistent with the level of trust provided to them), whereas less experienced and capable Project Managers need more support and are less able to cope with high levels of autonomy. This is independent of the Project Type.

These findings align with concepts from Self-Determination Theory (Ryan and Deci, 2000) the concept of 'responsible autonomy' (Abgeller *et al.,* 2024) that emphasizes the importance for work discretion and flexibility while maintaining accountability for actions and outcomes.

The relationship between Project Manager capability, Project Type, and Project Governance

Influence of Project Type on Project governance
it was found that: (1) there is not a clear distinction between Type 2 and 3 projects with respect to governance, but there is a clear spectrum from Type 1 to Type 4; (2) project governance is adequately represented by the mechanisms of control and trust,

and autonomy; and (3) the relationship of Project Type to project governance is represented in Figure 1, with the Type 1 end of the spectrum being associated with an emphasis on support, oversight, and control, and the Type 4 end of the spectrum being associated with an emphasis on trust, which permits higher levels of autonomy to be granted by the Executive.

Influence of Project Manager capability on Project Governance
It was found that less experienced and capable Project Managers require more support, coaching, or mentoring, with an emphasis on oversight and control, as they do not possess the requisite experience or capability to be engendered with high levels of trust and autonomy. However, more experienced and capable Project Managers should be entrusted to make good decisions, and plan and manage their projects effectively, yet maintaining timely and effective communication with the executive to provide confidence in the achievement of outcomes and realisation of benefits. This represents a spectrum of low capability to high capability, with an emphasis on control and with minimal trust and autonomy for low capability. Whereas high capability engenders an emphasis on trust and autonomy, with minimal control. This spectrum is depicted in Figure 1.

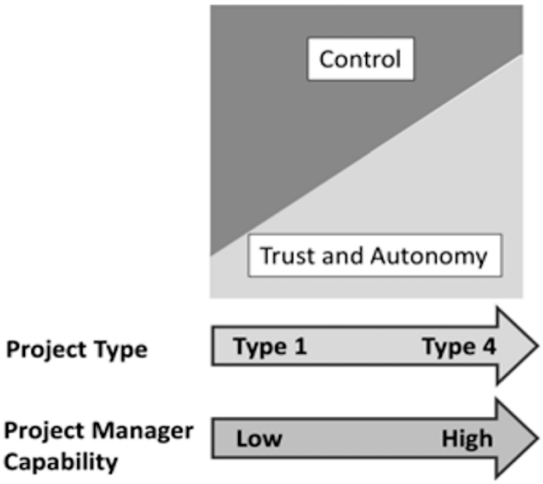


Figure 1: Spectrum of governance mechanisms (control and trust) and autonomy with Project Manager Capability and Project Type

Situational Leadership is associated with 'Contingency Theory' which proposes that there is no one best solution, rather the best solution or approach is one that appropriate the situation, or the state of the variables at a point in time (Donaldson, 2001). From the perspective of project governance, and in consideration of the number of variables, this supports a contingency approach, and methodological pluralism, consistent with 'tailoring' as included in the 'principles' espoused by the PMBOK® Guide Seventh Edition.

It is the holistic capability our best Project Managers who act as project stewards that enables awareness, leadership, adaptive capacity, and actions to deal with risk and the organisational challenges of team dynamics, retention, and motivation. Project governance itself does not achieve this, rather it enables capable Project Managers to be effective. While the model depicted in Figure 1 may be seen as 'common sense', it represents a heterodox view of project governance that challenges the fervent and didactic approaches commonly adopted.

Relationship of Project Manager Capability to Project Type
The relationship between Project Manager Capability and Project Type is a subset of the two research questions. Integrating the earlier discussion leads to the following findings: (1) it is desirable to match the Project Manager to the project; (2) a capability spectrum (refer Figure 1) can be linked to Project Type; (3) this is influenced by the point in the project lifecycle; (4) understanding project context is an important ingredient in determining suitability to a project; and (5) the influence of the Executive.

Project Manager Capability - Project Governance Framework
The study contributed to clarification of: (1) capability attributes specific to the Project Manager; (2), the relationships and interdependence of the factors: And (3) the influence of the Executive. This new evolved knowledge has been captured and represented in the Project Manager Capability - Project Governance Framework included as Figure 2.

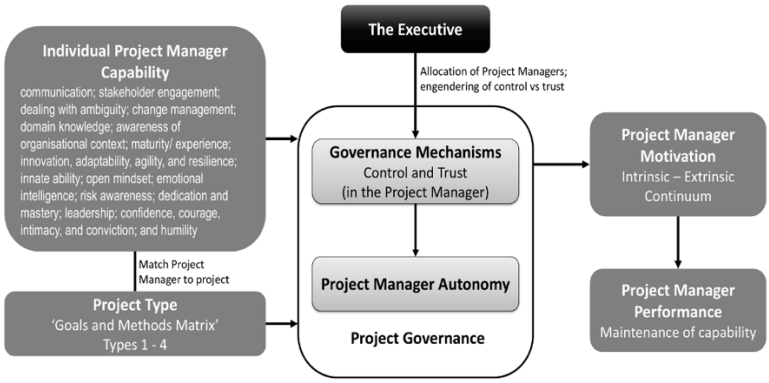


Figure 2: Project Manager Capability - Project Governance Framework

In relation to the factors in this framework: (1) the governance mechanisms of control and trust, in combination with autonomy have been found to reliably represent project governance and provide an appropriate means of interaction with the other factors of Project Manager capability, and Project Type; (2) capability has been found to be a reliable and holistic means of representing the range of skills, knowledge, and other attributes that determines the suitability of a Project Manager for a specific role; (3) the sixteen identified sub-themes represent the broad array of attributes that combine to describe Project Manager capability; (4) the 'Goals and Methods Matrix' (Turner and Cochrane, 1993) was found to be a reliable means of representing the various project attributes and the typology enabled the analysis of interaction with other factors.

CONCLUSIONS

Through an analysis of over fifty hours of in-depth interviews with 31 experienced practitioners and academics, most project governance practices are anchored in prescriptive approaches with emphasis on control and oversight. The governance design is predominantly 'one size fits all' although occasionally adjusted for the size and budget of the project, with proportional quantum of control and oversight. Commonly, the most experienced and capable Project Managers are allocated to the largest, highest budget, and most complex projects. While it is defendable that the best Project Managers should be allocated to such projects, the extent of governance (emphasis on control and oversight) can be perceived by Project Managers as micro-

managing or over-governance, resulting in frustration, loss of motivation, and constriction to creative or innovative endeavours.

This study has justified the need to transition from an ex ante methodological dogmatism approach to an ex post methodological pluralism approach which places Project Manager Capability as a primary determinant of project governance design and permits tailoring for the Project Type. This is applicable to all project types, and particularly the nature of regenerative construction projects. The Project Manager Capability - Project Governance Framework represents the interactions between these two factors of Project Manager Capability and Project Type, and project governance which is represented by the governance mechanisms of control and trust, and the autonomy provided to the Project Manager.

The design of project governance has been found to be strongly influenced by the Executive, and this influence demanded inclusion as a factor in the Project Manager Capability - Project Governance Framework. This acts as an exogenous variable as the Executive has direct influence over the levels of control versus trust imposed or granted to the Project Manager, and thereby the level of autonomy provided, and motivation realised. The detailed influence of the Executive was examined as a part of a larger study and is presented in Wheeler (2025).

Capability was found to be a more reliable indicator of the suitability of a Project Manager for a specific project, than competence, experience, or qualifications in this exploratory research. Sixteen (16) attributes have been identified that holistically represent Project Manager Capability. The allocation of a Project Manager to a project is often an afterthought once the project governance has been set. This study has found that the capability of the Project Manager should dictate the design of project governance which infers that the Project Manager should be allocated prior to design of the governance regime, and any established frameworks and methodologies should be tailored accordingly.

To realise the benefits of effective governance in construction projects, organisations should: (1) ensure their project governance regimes recognise Project Manager capability as the primary determinant in governance design; (2) tailor the governance design for project type; (3) establish a balance for control vs trust appropriate to the project context and Project Manager capability; (4) ensure separation of corporate governance (including investment frameworks) and project governance, but effective communication between both; and (5) enhance the capability of the Executive as well as project actors. This is crucial to the achievement of more resilient and inclusive, urban and regional regeneration projects.

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SUSTAINABILITY

DETERMINANTS OF MATERIAL REUSE IN A RESTORATIVE CIRCULAR ECONOMY IN THE BUILDING SECTOR: INSIGHTS FROM STEEL AND PLASTERBOARD SUPPLY CHAINS

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The reuse of building materials provides a circular approach to managing building stock and supports the transition to regenerative cities. However, recycling remains the dominant end-of-life pathway of circularity, and building materials have varying potentials for reuse, e.g., steel and plasterboard. The determinants of their reusability are yet to be fully explored. Semi-structured interviews with thirty practitioners from steel and plasterboard supply chains were conducted to investigate the factors influencing their reusability. Findings revealed the disparity in the economic value and ease of deconstruction between steel and plasterboard is critical in determining their practical feasibility for reuse. A framework including twenty-one factors was proposed to support the evaluation of the reusability of building materials. While plasterboard is barely reused, potential pathways for improving its reuse include adaptive reuse, modular construction, standardisation, reversible fixings, servitisation, and community-based business models. The upscaling of steel reuse is constrained by insufficient supplies from demolition. Future research should expand the framework to include other materials and develop a weighted scoring system for practical use.

Keywords: circular economy; reuse; building materials; steel; plasterboard

INTRODUCTION

Cities have been experiencing increasing pressure on their building stock, driven by societal trends such as ageing populations, rising affluence, and climate change, all of which entail additional urban space (EEA, 2024). However, construction activities currently account for over 35% of total waste generation, 50% of annual raw material consumption, and 5%-12% of total greenhouse gas emissions in the EU (EEA, 2024). These alarming figures pinpoint the critical need to develop restorative cities by strengthening the technical loop of building materials, represented in the "butterfly" diagram of circular economy (CE) depicted by the Ellen MacArthur Foundation (2013). The restorative approach seeks to remove the "end-of-life" notion and replace it with material cycles featuring a "cradle-to-cradle" process (Abadi *et al.,* 2021). The "3R" framework (i.e., reduce, reuse and recycling) has been extensively recognised as the foundation of CE, but its implementation in construction remains largely confined

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Huang, J, Abadi, M and Yeow, J (2025) Determinants of Material Reuse in a Restorative Circular Economy in the Building Sector: Insights from Steel and Plasterboard Supply Chains, *In*: Thomson, C and Neilson, C J (Eds) Proceedings of the 41st Annual ARCOM Conference, 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 743-752.

to recycling (Abadi *et al.,* 2023), despite reuse offering substantially greater environmental benefits. Reuse in construction is still in its early stages of development, confronting various barriers to its application that entail top-down policy interventions (Fufa *et al.,* 2023).

Recent regulatory developments in the UK, particularly the Circular Economy Statement introduced by the Greater London Authority (GLA), have spurred bottom-up reuse initiatives in major London developments. Reuse potential varies across building materials (Fufa *et al.,* 2023), e.g., steel and plasterboard. Steel reuse has emerged as a prominent example, with numerous successful cases demonstrating significant embodied carbon savings for developers (Huang *et al.,* 2024). However, not all building materials are inherently suitable for reuse due to differences in quality, durability, function, lifetime, and so forth (Iacovidou and Purnell, 2016). Plasterboard sits at the opposite end of the reuse spectrum as opposed to steel, despite accounting for the largest share in fit-out waste streams reported by a major waste contractor in London (Casas-Arredondo *et al.,* 2018). Current research tends to focus on individual material or broadly investigate multiple materials. Hence, this study aims to develop a framework to support the evaluation of the reusability of building materials drawing upon the sharp contrast between steel and plasterboard. It also seeks to uncover the untapped opportunities for plasterboard reuse.

LITERATURE REVIEW

ISO 20887 defines reuse in building construction as repeated use of building products or components for their original intended purposes, potentially involving minor reprocessing (ISO, 2020). Its application is typically manifested in three main approaches: Adaptive reuse, relocation, and building component reuse (Gorgolewski, 2008). First, adaptive reuse refers to repurposing an existing building for a new function, such as heritage buildings due to their strong cultural significance (Mısırlısoy and Günçe, 2016). Second, relocation involves moving a building in whole or in part to a new site. For instance, Pichlmeier and Lindner (2024) investigated the reuse of building services in three prefabricated buildings which were dismantled and rebuilt at new locations. Third, building component reuse, a more prevalent topic in the literature, concerns salvaging individual components at the end-of-life stage of buildings. Gobbo *et al. (*2024) adapted Brand's six shearing layers framework to classify component reuse across structure, skin, space plan, services, and outdoor spaces. Concrete, brick and steel constitute most structural components embedded in building stocks, but most existing studies focus on steel and timber structures due to their ease of deconstruction compared to concrete and masonry structures (Cai and Waldmann, 2019). Beyond structural components, recent projects shed light on reusing interior components within the scope of space plan and services (Devènes *et al.,* 2024). For instance, ongoing initiatives led by the Finishes and Interior Sector (FIS, 2025) in the UK explore opportunities for reusing suspended ceilings, luminaires and raised access flooring in commercial office buildings.

However, reuse in building construction remains a niche practice with limited types of materials considered and varying degrees of reuse potential. Iacovidou and Purnell (2016) consider reuse potential as the capacity of construction components to maintain the functionality beyond their initial use. Arora *et al. (*2020) calculated reuse potential based on recovery feasibility, retained functionality, and physical conditions, framing it as a key indicator for the availability of secondary resources in urban mining. Bellini *et al. (*2024) further added that a comprehensive evaluation of reuse potential

involves environmental impacts, technical performance, lifespan, disassembly feasibility, logistics, storage, and both risk and cost implications. These evaluation criteria can also be shaped by common barriers to reuse, including inadequate design and demolition methods, design iterations due to variability in supply, complex supply chain logistics, lack of technical guidance, economic constraints, and additional performance assessment and certification (Devènes *et al.,* 2024). In a national survey of the Norwegian construction industry, Fufa *et al. (*2023) revealed the lack of documentation as the most challenging barrier to reuse.

Building materials exhibit distinct potentials for reuse. For example, steel has high potentials for reuse due to strength and durability, while 'plasterboard' is more associated with recycling. Huang *et al. (*2024) compiled a list of recent initiatives on steel reuse featured in online records, but its reuse rate remains low. In response, researchers have proposed various solutions to support steel reuse, such as smart technologies to support structural steel tracking (Smeets *et al.,* 2019) and demountable and reusable structural connection systems (Kitayama and Iuorio, 2023b). At the other extreme, plasterboard presents low economic value and limited structural strength. It constitutes a significant portion of fit-out waste, whilst it poses greater disposal challenges than steel. Its waste can contaminate other inert construction waste, and produce hydrogen sulphide gas, a highly toxic substance, when landfilled with organic waste (Erbs *et al.,* 2021). To date, only one known study has explored the possibility of reusing plasterboard and concluded that it holds high reuse potential via prefabricated construction (Kitayama and Iuorio, 2023a). Current research tends to focus on its recycling. For instance, Erbs *et al. (*2021) demonstrated the feasibility of producing new plasterboard sheets using only recycled plaster and recycled paper, both sourced from plasterboard waste.

The literature has explored numerous design interventions and new business models aimed at promoting the reuse of building materials. For instance, Piccardo and Hughes (2022) discussed design for disassembly to increase the reuse of wood in buildings. Another notable design strategy is design for manufacture and assembly that focuses on off-site production and on-site assembly to streamline construction and facilitate reuse (Iacovidou and Purnell, 2016). In parallel, new business model have been studied to support reuse practices. For example, Nußholz *et al. (*2020) investigated how material reuse in circular business models creates added value that extends beyond the financial gains of traditional business models and delivers broader benefits for stakeholders, society, and the environment. Ness *et al. (*2019) approached circular business models through the lens of product service system (PSS) and proposed an ICT-enabled model where suppliers retain ownership of reusable components and provide them as a service. These strategies provide valuable insights into how reuse can be upscaled in practice for high-performing materials like steel, while informing the untapped potential for reusing more challenging materials such as plasterboards.

Reviewing the literature raises three main questions that guide the development of the framework for assessing the reusability of building materials: (1) What are the circularity pathways for steel/plasterboard? (2) What are the determinant factors of reusing steel/plasterboard? (3) What strategies can be used to improve the reusability of steel/plasterboard? These questions also shaped the initial set of questions used in the semi-structured interviews conducted in this study.

METHOD

This study employed a multiple-case study design to explore the determinants of material reuse, focusing on two widely used building materials, steel and plasterboard, each with distinct reuse potential. A case study is an empirical method used to investigate a contemporary phenomenon within its real-world context (Yin, 2018). The "case" can be any subject or topic that allows for close, in-depth, and detailed investigation (Yin, 2018). This study conceptualised the "case" as the material itself, an approach also seen in Nasir *et al. (*2017) who analysed two types of insulation materials to compare linear and circular supply chains. Following Yin's (2018) "two-tail" design that involves the deliberate selection of cases from both extremes, this study compared steel as an exemplar of successful reuse with plasterboard that faces significant challenges. Philosophically, the study is grounded in an interpretivist stance, which acknowledges that knowledge is socially constructed and best understood through the perspectives and experiences of those directly involved. An inductive approach was employed that allows themes and insights derived from the qualitative data. Data was collected through semi-structured interviews as part of a broader study. Participants were selected through purposive sampling based on inclusion criteria reflecting their involvement in circular construction supply chains. Participants engaged in either the steel or plasterboard supply chain were identified via LinkedIn, with additional participants recruited through snowball sampling. This process yielded a total of thirty interviewees, whose roles spanned building design (nine), construction (nine), material supply (five), demolition (three), and waste management (four). Most participants (twenty-three) had more than fifteen years of working experience. The interviews were conducted on MS Teams with live transcription enabled. The discussions were guided by the three key questions previously proposed. The initial exported transcript was refined against the audio recording and subsequently imported into NVivo 12 for thematic coding that involves organising interview data into themes relevant to each material case. From this inductive process, a structured reusability framework was developed that synthesizes the identified factors to evaluate the reuse potential of building materials.

FINDINGS

Circularity Pathways of Steel and Plasterboard

Thirteen interviewees had experience with steel reuse. While recycling via electric arc furnace remains the dominant end-of-life pathway for steel, whereby scrap from building demolition is sent to metal recyclers for re-melting or export, its reuse is gaining traction in recent years due to regulatory development. This process typically is preceded by a pre-demolition audit to assess reclaimable steel components. Two main reuse routes were identified: First, donor-recipient model, where the client has both the demolition and new construction projects, allowing steel to be transferred directly from the 'donor' to the 'recipient' building; and second, stockholder route, where demolition contractors sell reclaimed steel to stockists who undertake initial processing or reconditioning, coordinate with testing bodies for certification, and supply the steel for fabrication and on-site assembly.

In contrast, none of the interviewees reported any experience with plasterboard reuse. Different from steel, which is reclaimed during demolition, plasterboard is typically removed during the soft strip stage involving the removal of non-structural elements prior to demolition or refurbishment. Although some manufacturers offer take-back schemes, these are limited to waste from new products and exclude end-of-life waste

from refurbishment or demolition. While plasterboard reuse is hardly seen in practice, recycling is the main circular pathway for plasterboard. The process begins with on-site collection, which may include segregation or pre-treatment to meet acceptance criteria of recycling facilities. Subsequently, plasterboard waste is shredded and separated into gypsum and paper. The recovered gypsum is then either reintegrated into new plasterboard production or downcycled for use as filler, soil conditioner in agriculture, cement additive, or road base material.

Key Factors Influencing Steel Reuse

Discussions with the interviewees revealed four key factors that contribute to the success of reusing steel beyond its inherent properties: Embodied carbon benefits, technical feasibility, availability of reused steel, and supply chain engagement.

Steel reuse tends to be driven by high-profile clients with strong carbon agenda, motivated by the significant embodied carbon savings. The client support allows greater flexibility to plan, coordinate, and implement steel reuse. However, interviewees raised concerns over the current distribution of carbon benefits which are credited only to clients reusing the steel. This prompts questions about whether demolition contractors or the original property owners should also receive recognition. While demolition contractors do not gain carbon credits, they often leverage their involvement in reuse as a marketing tool to secure new contracts. Few interviewees also noted that encouraging buy-in from end-users or property owners is crucial but often overlooked, as many pay attention to EPC ratings rather than embodied carbon, potentially influencing client decisions to pursue reuse.

Technical feasibility plays a critical role in enabling steel reuse. Standards such as SCI P427 and P440, developed by the Steel Construction Institute, provide essential technical guidance and confidence in incorporating reused steel in structural design. However, several interviewees noted that some safety indicators within the guidance are conservative, suggesting room for refinement to encourage wider reuse. Additionally, digital stock-matching tools have been developed to support alignment between reclaimed steel availability and design specifications, allowing designers to adjust specifications based on available stock. Demolition contractors reported that recovering steel for reuse involves largely the same processes and equipment as preparing it for recycling. The key difference is additional time and careful planning, such as using cranes to lower intact steel sections rather than cutting them into scrap.

Stockholding is another critical factor that provides the availability of processed and quality-assured reclaimed steel. Stockholders purchase reusable steel from demolition and conduct initial processing and reconditioning and often prepare it to be indistinguishable from new steel, but with significantly lower embodied carbon. These reclaimed materials are tested and certified with CE/UKCA markings, meet quality assurance standards. A pre-demolition audit is vital to assess steel reuse potential early on to help demolition contractors identify salvageable components and direct them to stockholders. However, the lack of financial incentives persists to be a significant barrier for demolition contractors. One interviewee stated: "we get paid well for recycling. Actually, for the amount of additional time, cost and effort, is it worth it?".

Effective steel reuse relies on early and continuous engagement across the supply chain. The intention to use reclaimed materials should be embedded from the outset, ideally during RIBA stage 0 or 1, when the project brief is being developed. Early engagement helps ensure reused steel is technically feasible, logistically viable, and

commercially practical. Designers develop efficient structural systems with high utilisation and low weight, which can later be adapted to accommodate reused steel. Close and timely communication with stockholders is essential to align design decisions with available stock and avoid tying up reusable steel that could otherwise serve other projects. Stockholders, in turn, coordinate with demolition contractors to improve pre-demolition audits and boost the supply of reusable steel.

Key Factors Influencing Plasterboard Reuse

Interview findings indicate that plasterboard reuse is primarily constrained by its low economic value and the complexity of deconstruction. Unlike steel, which is durable and retains structural integrity, plasterboard is fragile, prone to damage, and difficult to extract in a reusable condition. While other factors, such as design standards, quality assurance protocols, and stockholding infrastructure, also impede reuse but are secondary concerns that become relevant only once the fundamental feasibility of reuse is established. At present, plasterboard reuse remains largely impractical.

The low economic value of plasterboard is the primary impeding factor to its reuse. Many interviewees claimed that plasterboard reuse is not considered due to its brittleness. However, "nobody complains that their iPhone is too fragile", an analogy made by one interviewee. Other fragile materials, such as windows, glazed partitions, and lighting fixtures, are handled more carefully because of their higher material value. Plasterboard, by contrast, is inexpensive and mass-produced. Manufacturers typically operate near gypsum sources and run highly efficient production lines, making the production of new boards fast, cheap, and convenient. Consequently, contractors tend to over-order plasterboard to prevent delays with insufficient consideration of its wastage. Interestingly, one interviewee suggested that the economic value of gypsum mining is not limited to the extraction of gypsum itself but also tied to the use of hollowed-out mines as profitable landfill sites.

The technical complexity of deconstructing plasterboard further undermines the business case with substantial labour and cost involved. Plasterboard is typically fixed to metal or timber studs or bonded directly to walls using the dot-and-dab method, both of which make removal without damage highly challenging. Screws used to secure plasterboard to framing are often concealed beneath skimmed finishes, making them nearly impossible to locate or access without damaging the board. In addition, there is no standardised screw pattern, and each sheet may be fastened with dozens of screws placed irregularly. Even if plasterboard could be deconstructed intact, handling intact plasterboard sheets requires careful lifting with mechanical aids that are often unavailable during soft-strip operations. Further logistical challenges include protecting the board from moisture and damages during transport and storage. As one interviewee commented that “even if you did get it off the wall, you’ve got to protect it, store it, and eventually cut it again on the next site”.

Reuse Opportunities for Plasterboard

Interview findings revealed three broad categories of reuse opportunities for plasterboard with each addressing different stages of intervention. First, one route to improving reuse is by eliminating the need for removal. This can be achieved through adaptive reuse, where materials are reused in situ without incurring the damage, labour, or cost associated with removal and reinstallation. Another strategy in this category involves integrating plasterboard into modular or prefabricated components (Kitayama and Iuorio, 2023a), allowing entire wall panels to be relocated as a unit. Second, when removal is necessary, designing for disassembly can significantly

enhance reuse potential. Traditional screw-fixed plasterboard is difficult to recover intact due to concealed fixings and its fragile composition. This challenge can be addressed through innovations in reversible mechanical fixings, such as sliding tracks, magnetic attachments, or click-together panel systems. Additionally, standardisation of panel sizes and fixing methods would further improve efficiency in deconstruction and make it easier to match reclaimed boards with new applications. Third, alternative business models offer new ways of enabling plasterboard reuse. For instance, servitisation models, where manufacturers retain product ownership and provide them as a service, have the potential to shift incentives toward designing for multiple lifecycles by introducing more durable and modular plasterboard systems. Moreover, community-based reuse models (Ward, 2024), where surplus plasterboard from construction sites is diverted to local hubs for use in community projects. These projects typically have lower performance thresholds and offer added social value.

Reusability framework for Building Materials

Table 1: The Proposed Framework of Determinant Factors for Building Materials Reusability

No	Group	Reusability Factor	Steel	Plasterboard
1	Material Attributes	Durability and strength	High	Relatively low
2		Economic value	High	Relatively low
3		Carbon saving	Significantly greater than their recycling	
4		Function in buildings	Structural; hidden	Non-structural; finishes
5	Design	Reuse specified in brief	Reuse tends to be a target and voluntary practice	
6		Design for deconstruction	Most buildings design not suitable for reuse	
7		Reuse standards and guide	SCI P427, P440	Not available
8		Regulatory incentive	GLA CE statement	Not applied to fit-out
9		Supply chain engagement	Reuse-oriented design entails early engagement	
10	Construction	Fixings and connections	Bolted/welded	Screwed/glued
11		Use of modular elements	Both can be integrated into modular systems	
12		Records and traceability	Both requires traceable provenance for reuse	
13	Operation	Adverse conditions	Both cannot be exposed to fire and moisture	
14		Functional degradation	High durability	Relative low durability
15	Deconstruction	Ease of deconstruction	Feasible with care	Technically difficult
16		Damage of removal	Low	Highly possible
17		Lifting machinery	Cranes	Unavailable in soft strip
18		Market demand	Mature recycling market but niche for reuse	
19	Post-deconstruction	Transport distance	Carbon impact influences transport distance	
20		Stockholding	Stockists available	Not available
21		Test and certification	Supported by norms	Not available

Iacovidou and Purnell (2016) posit that the most fundamental factors of a component's end-of-life potential are its embodied carbon value and its technical feasibility for deconstruction. Similarly, the survey by Fufa *et al. (*2023) revealed emission reduction and supply chain coordination as the most influential factors in driving construction products rese. These factors align well with the case of steel. In contrast, plasterboard reuse remains impractical due to its low value and difficulty in deconstruction. Therefore, this study proposes that technical feasibility and product value are the primary factors of reuse. When these are addressed, secondary factors, such as standards, stakeholder coordination, or stockholding infrastructure, become relevant and influence the ease and scale of reuse.

Drawing on the interview coding, Table 1 presents twenty-one factors that influence the reusability of building materials classified into two dimensions: Material

attributes, which establish the baseline inherent suitability for a second life; and building lifecycle stages, with each enhancing or undermining the baseline reuse potential. Mapping the framework against the two materials illuminates why steel is successfully reused in practice while plasterboard struggles. It is important to note that as more materials are considered, the factor list will likely expand. For instance, in the case of mechanical and electrical components, designing for access and maintenance can be a critical factor that determines future reuse potential.

The proposed framework deepens the insights into reuse factors and extends those identified in prior studies (Arora *et al.,* 2020; Bellini *et al.,* 2024; Iacovidou and Purnell, 2016) by contextualising them through case studies of steel and plasterboard and providing a structured checklist for practitioners to assess material reusability. Following the two-dimension classification, decision-makers can see whether a material's baseline characterises merit further investigation, whilst actors involved at each building stage can pinpoint targeted interventions to improve material reuse potential. This framework also reveals opportunities for industry innovation, such as researching alternative materials with strong inherent reuse properties or designing connection systems that facilitate straightforward deconstruction.

CONCLUSIONS

This paper proposed a framework including twenty-one factors to support the evaluation of building materials reusability based on the insights from thirty semi-structured interviews with steel and plasterboard supply chain stakeholders. Findings revealed that embodied carbon benefits, technical feasibility, availability of reused steel, and early supply chain engagement are the key enablers of steel reuse. In contrast, low economic value and the complexity of deconstruction emerged as primary barriers to plasterboard reuse. Despite these barriers, potential pathways for enhancing plasterboard reuse were identified, including adaptive reuse, modular construction, standardisation, reversible fixings, servitisation, and community-based business models. The upscaling of steel reuse is constrained by limited supplies of salvaged steel from demolition, primarily due to lack of incentives for demolition contractors. The comparison between steel and plasterboard revealed that technical feasibility and product value form the foundational prerequisites for reuse. When these are met, other factors, such as standards, stakeholder coordination, and stockholding, become increasingly relevant, shaping the ease and scale of implementation.

This study contributes to the body of knowledge by providing deeper insights into material reusability using case studies of steel and plasterboard. For practitioners, the framework provides a structured checklist to assess material reusability and pinpoints targeted interventions to improve material reuse potential. It also helps identify where industry innovation can better support material reuse. However, this study does not exmaine specific projects where steel/plasterboard have been reused and may have overlooked some complexities of real-world reuse processes. In addition, the scope of this study is limited to steel and plasterboard. Future research will expand the framework by exploring a wider spectrum of building materials and based on real-world project contexts. Moreover, weighting each factor to develop a scoring system would improve the framework's practicality and decision-support value.

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A FRAMEWORK OF MATURITY LEVELS FOR BUILDING FIRMS TO INFORM THE STRATEGIC TRANSITION TO SMART CIRCULAR CONSTRUCTION

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Industry 4.0 technologies have potentials for addressing challenges to circularity of building materials and facilitate the transition to regenerative smart circular construction (SCC). However, building firms lack guidance from a maturity model on the systemic adoption of technologies and the steps needed to achieve the transition. This study aims to develop a framework of maturity levels to guide the implementation of SCC. A systematic literature review, including 157 journal articles, was conducted to develop a conceptual framework comprising five maturity levels of smart technology implementation to support building firms in achieving circularity. Level descriptors were created based on smart circularity achievement that firms need to accomplish per level. Findings revealed that maturity towards completing the transition to SCC requires a strategic progression from ad-hoc practices to a systemic embedment of technology use to prioritise circularity in firms' operations. Findings emphasized the need for indicators to measure actual achievement of each maturity level and, ultimately, firm's progression towards SCC. The framework will be used in future research to develop a maturity model to guide firms' transition to SCC.

Keywords: construction circular economy; digital transformation; Industry 4.0; maturity model

INTRODUCTION

Circular Economy (CE) Emerges as a viable, sustainable, and innovative solution to address the escalated dominant linear model issues (Norouzi *et al.,* 2021). The construction industry's reliance on a linear "take-use-dispose" model has made it heavily waste-intensive. Approximately 40% of global resource consumption and 40% of total waste generation are attributed to construction activities, with the sector also contributing around 33% of global carbon emissions (Swetha *et al.,* 2022; van Stijn and Gruis, 2019). The scale of waste closely mirrors resource consumption rates, while rising emissions have become unsustainable. In response, the transition to

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CE has gained momentum, aiming to preserve resources, close material and energy loops, reduce emissions, and promote sustainable development (Alonso *et al.,* 2022).

CE in construction can be driven by Industry 4.0 technologies, which serve as its key enabler. Construction 4.0 technologies, i.e., Industry 4.0 in the construction context, are digital technologies, cyber-physical systems and industrial production. Digital transformation, through the integration of processes and Construction 4.0 technologies, can address long-standing challenges hindering CE adoption (Mêda *et al.,* 2021). While other industries have successfully leveraged technologies to optimise resource flows and enhance efficiency (Circularise, 2016), digital transformation in construction remains slow and relatively recent (Marichova, 2021). Therefore, addressing the barriers impeding Construction 4.0's role in advancing CE is critical.

The adoption of Construction 4.0 technologies to support circularity in the construction sector is marked by several persistent challenges. Most research efforts focus on the uptake of Building Information Modelling (BIM) (e.g., Adekunle *et al.,* 2022). More studies have explored the fragmented use of technologies, mostly digital technologies, for specific CE concepts (e.g., Li and Kassem, 2021). Critical aspects such as technological interoperability, value proposition articulation, information governance, and stakeholder management remain underexplored within the context of digital transformation and CE (see Çetin *et al.,* 2021; Yu *et al.,* 2022). Moreover, although building firms are central to implementing Construction 4.0 technologies for CE in construction, how these firms use these technologies to implement circular economy practices is currently unknown (Abiodun *et al.,* 2024). This gap underscores the need for a more integrated and structured approach to guide the digital transition toward circularity in construction.

Despite the potential of Construction 4.0 technologies for improving the circularity of building materials, the value derived from their integration is unknown, and the adoption route by building firms to attain these values is underexplored. Pirola *et al. (*2019) emphasize the necessity of a strategic development roadmap to enable the consistent and effective adoption of technologies. This emphasis is essential in the construction industry since construction firms struggle to identify intermediate steps to embrace the change associated with technologies (Weking *et al.,* 2020). Abiodun *et al. (*2024) developed dimensions covering attributes to guide the implementation in firms by adopting the maturity model perspective. However, since the construction sector is keen to obtain quick wins (Robert, 2016), the levels of achieving these attributes are essential. Therefore, this study aims to develop a conceptual framework of maturity levels that will lead to the implementation of smart circular values in building firms to achieve smart circular construction (SCC). Moreover, SCC in this study is the integration of Construction 4.0 technologies to facilitate the circularity of building materials (Abiodun *et al.,* 2024).

The transition to SCC can be seen as a maturity process. However, the literature lacks a strategic plan to inform the transition (Abiodun *et al.,* 2024). Values are expected to be achieved from the integration of technologies towards circularity (Ghobakhloo *et al.,* 2022). Bertassini *et al. (*2022) sees these circular values as the most essential to achieving a circular organisation. These values regarded as smart circular values in this study are currently nascent but are required to achieve SCC. Hence, we regard these smart circular values as the way of life that should be continuously improved by construction firms operating SCC. Abiodun *et al. (*2024) adopted a maturity model

paradigm to identify the dimensions that can lead to achieving smart circular values in a building firm. However, the specific maturity levels or sequential developmental stages required to attain these values remain unarticulated in current literature, representing a critical gap in understanding the pathway to SCC implementation.

Maturity levels are sequential stages of growth that an organisation or a process goes through reflecting its degree of advancement, proficiency and efficiency (Gatell and Avella, 2024). In Poghosyan *et al. (*2020) it was outlined that maturity levels can be developed using either a top-down or bottom-up approach, depending on the field's maturity. In new fields, the top-down method, which involves defining maturity levels before identifying measures, is preferred (Poghosyan *et al.,* 2020). This study adopts the top-down approach due to the nascency of studies on SCC. Defining maturity levels requires clarifying underlying concepts using literature, practitioner input, and cross-organisational comparisons (Poghosyan *et al.,* 2020). This study adopts a systematic literature review to elucidate the definition of maturity at each stage in the progression toward achieving smart circular values. Accordingly, the objectives are twofold: (1) To identify the smart circular values essential for transitioning to Smart Circular Construction, and (2) To develop a conceptual framework outlining the maturity levels required to achieve smart circularity in building firms.

METHOD

This study employed a Systematic Literature Review (SLR) To identify smart circular values and assess maturity levels essential for attaining these values in building firms. The review followed the four-phase Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) Framework, identification, screening, eligibility, and inclusion, ensuring methodological rigour and transparency. This structured approach minimises subjectivity and selection bias, thereby enhancing the findings' reliability, validity, and replicability (Silva *et al.,* 2025). The results of the SLR are illustrated in Figure 1.

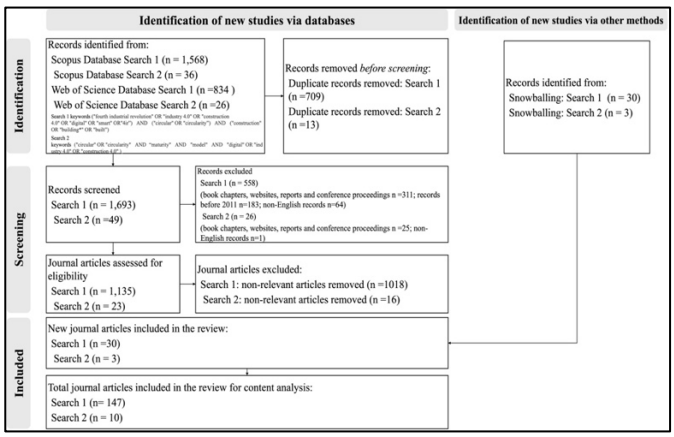


Figure 1: PRISMA flow diagram

Scopus and Web of Science, the two most widely used databases for scholarly research in the construction domain (Montag *et al.,* 2021), were utilised for article retrieval in this study. This selection ensured comprehensive coverage of relevant literature while minimising the risk of omitting pertinent studies. Given the dual focus on smart circularity and maturity levels, the literature search was conducted in two distinct phases. The first search targeted keywords related to CE and Construction

4.0, while the second search focused on maturity models concerning CE and Construction 4.0, as illustrated in Figure 1.

The initial search yielded 2,402 results for search one and 62 in search two. To refine the sample, articles were screened using the following inclusion criteria: (1) Peer-reviewed journal publications, (2) Written in English, and (3) Published after 2011, the year Construction 4.0 was introduced. Subsequently, a detailed eligibility assessment was conducted based on title, abstract, keywords, and full-text review.

For search one, only articles specific to the construction industry that explored the applications and potential of Construction 4.0 technologies were included. In search two, the selection focused on studies proposing maturity models, particularly those discussing maturity levels across industries which have proximity and demonstrate relevance to the construction sector. This focus was necessary given the absence of maturity model for smart circularity within the construction industry.

In total, 157 articles met the criteria and were included in the final sample. The selected articles were compiled and organised in Microsoft Excel and analysed using content analysis in alignment with the study's objectives.

FINDINGS

Figure 2 presents the chronological distribution of the articles selected for content analysis. Interest in smart circularity began to emerge around 2013, coinciding with when CE began to gain ground (Abadi *et al.,* 2023). A notable surge started in 2019, reflecting increased focus on the integration of Construction 4.0 technologies with CE. This was largely driven by the recognition of Construction 4.0 as a key enabler of circularity (Abiodun *et al.,* 2023). Overall, the literature reveals a clear upward trend, underscoring the expanding academic and practical relevance of this research domain. It is anticipated that future investigations into the nexus of CE and Construction 4.0 technologies will continue to gain momentum, potentially catalysing a paradigm shift in the construction industry to drive sustainability.

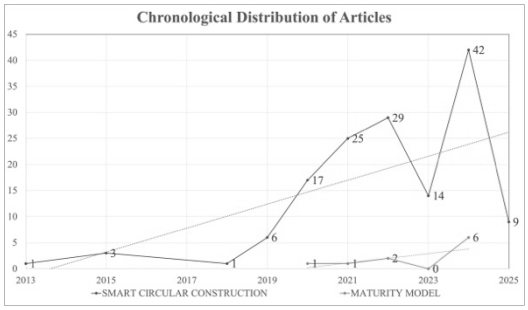


Figure 2: Chronological distribution of sample

Concurrently, the assessment of maturity levels in firms adopting Construction 4.0 for circularity has recently emerged as a critical focus area in the implementation of smart circularity as shown in Figure 2. Since 2020, there has been a marked increase in related studies, particularly within the manufacturing sector. Maturity level determination serves as a strategic tool for institutionalising smart circularity by guiding investment decisions and aligning organisational practices with circularity requirements (Kayikci *et al.,* 2022). Given the growing importance of this approach, there is a compelling need to extend maturity-level frameworks to traditionally resource-intensive and waste-inhibiting sectors such as construction. Doing so could

curtail inefficiencies and result in adopting a strategy to ingrain smart circularity in building firm practices.

Five key themes emerged from the content analysis of literature addressing the integration of Construction 4.0 technologies with CE concepts. These themes were derived using a framework informed by the circular construction lifecycle (C1-C5) Proposed by Abadi *et al. (*2021), the classification of CE concepts across the lifecycle stages (C1.1, C2.1, C3.1…), and the categorisation of Construction 4.0 technologies in the construction sector (T1, T2, T3) As outlined by Sawhney *et al. (*2020).

The results of this analysis are presented in Figure 3. Achieving SCC requires the realisation of smart circular values (SCVs) Through the integrated application of multiple Construction 4.0 technologies. This approach shifts away from fragmented, technology-specific interventions and instead emphasizes the value generated by synergistic deployment across the building lifecycle. Such integration supports core CE strategies, narrowing, slowing, closing, and regenerating resource loops (see Çetin *et al.,* 2021). The five themes representing the smart circular values identified in the literature include: Smart Energy Management (SEM), Smart Construction Methods (SCM), Smart Resource Optimisation (SRO), Smart Tracking and Tracing (STT), and Smart Waste Management (SWM). These themes currently represent an aspirational goal within the construction sector that corresponds to the key process areas for achieving smart circularity.

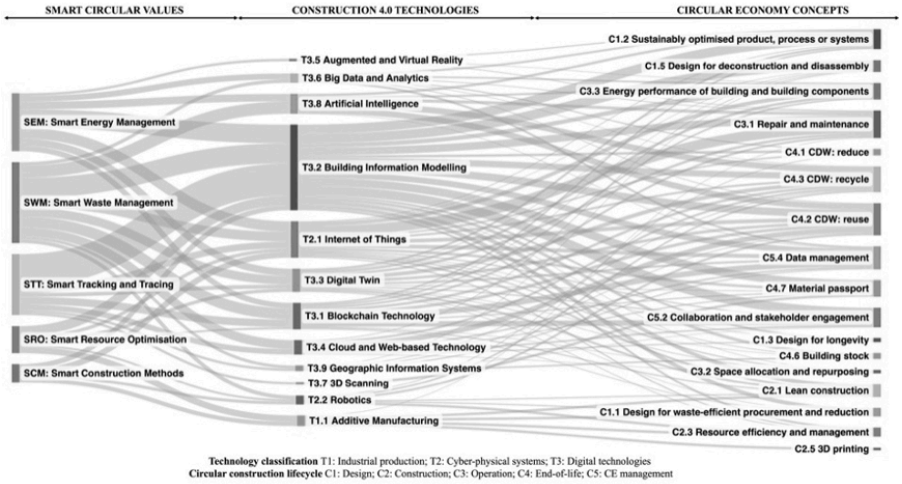


Figure 3: Smart Circular Values

SEM, a key smart circular value, integrates seven Construction 4.0 technologies, BIM, AI, blockchain, AR/VR, IoT, Big Data Analytics (BDA), and digital twin to support four CE concepts across the design, operation, and end-of-life phases as shown in Figure 3. BIM is the information hub enabling interoperability, particularly with AI, blockchain, and AR/VR, to enhance design quality and accurate assessment of environmental impact. AI optimises energy use and supports regenerative building design (. Blockchain ensures transparent carbon tracking, while AR/VR aids resource optimisation. IoT and BDA, via digital twin, inform predictive maintenance and accurate lifecycle assessments.

SCM leverages four Construction 4.0 technologies, additive manufacturing, robotics, IoT, and BIM, to support five CE concepts across all lifecycle phases. These technologies promote lean production and the reuse of secondary materials through modular construction and prefabrication. They reduce virgin material use and enable

planned, efficient production. This value focuses on (1) Building production and waste sorting via additive manufacturing and robotics, and (2) Data provision to enhance production, traceability and predictive modelling through IoT and BIM. SRO employs six technologies, BIM, blockchain, IoT, digital twin, robotics, and additive manufacturing, to support four CE concepts during design and construction. BIM and blockchain enhance design accuracy, procurement, and accountability, while IoT can update a digital twin to provide real-time project insights. Robotics aids in material sorting to boost recycling and reduce waste. This value emphasizes effective design planning and resource classification across both traditional and manufacturing-based construction.

STT integrates seven technologies, BIM, GIS, IoT, 3D scanning, blockchain, cloud/web-based systems, and digital twin, to support six CE concepts across design, operation, end-of-life, and CE management phases. It uniquely incorporates collaboration and stakeholder engagement, positioning circular supply chain management at the heart of SCC. These technologies facilitate material circularity, real-time stock visibility, and secondary material marketplaces. CV4 is pivotal for closing resource loops, though challenges in feasibility and adoption remain.

Lastly, SWM supports three CE concepts, reuse, recycle, and data management through nine technologies focused on end-of-life strategies. It relies heavily on BIM, IoT, blockchain, AI, robotics, and BDA for secure data management, timely predictions, and efficient material sorting. CV5 complements other clusters by enabling the reintroduction of secondary materials through informed and rapid decision-making. Overall, these smart circular values are essential for attaining circularity in building firms. However, several steps precede the achievement of these values, which is why the feasibility and adoption of these values remain challenging. Hence, we now turn to the maturity levels specific to firms to define the path to achieving the smart circular values and enabling SCC.

Maturity models typically comprise two main components: (1) Key process areas; and (2) Maturity levels (Abiodun *et al.,* 2024). The key process areas represent the areas that determine maturity, while the maturity levels depict progression and distinguish maturity within the key process areas. For this study, the SCVs previously discussed represent the key process areas. The subsequent sections then discuss the maturity levels regarding SCC maturity modelling.

Analysis of existing studies in smart circularity revealed most maturity models have five maturity levels: Level 0 - 4 or Level 1 - 5. The distinctions between these levels depict the growth to attaining smart circularity in diverse industries. Hence, the levels relevant to the construction industry are discussed below.

Level 1 represents a reactive, chaotic, unstructured, or non-compliant state, where issues are addressed as basic and ad hoc without formal processes, definition or planning rigour (Alberto *et al.,* 2024; Gatell and Avella, 2024; Hernandes de Paula e Silva *et al.,* 2024; Hetmanczyk, 2024). Level 2 is characterised by organised and semi-automated operations, with conscious implementation in selected areas of the firm (Fatimah *et al.,* 2020; Alberto *et al.,* 2024). It marks the initial, planned emergence of smart circularity, though lacking a comprehensive long-term strategy (Hetmanczyk, 2024).

Level 3 is considered the piloting and deployment stage, where implementation is goal-oriented and rapidly advancing (Acerbi *et al.,* 2024; Gatell and Avella, 2024). Activities are documented and progressively standardised across organisational

processes (Kanojia and Visvanathan, 2021; Gatell and Avella, 2024; Tiron-Tudor and Deliu, 2024). Level 4 is the managed and autonomous stage, where smart circularity is fully implemented, well-established, and measurable (Kanojia and Visvanathan, 2021; Tiron-Tudor and Deliu, 2024). Lastly, level five is the optimised level considered the way of life of an organisation (Gatell and Avella, 2024; Hetmanczyk, 2024). At this stage, smart circularity drives the system and action to refine and improve the process is innovatively adopted (Alberto *et al.,* 2024). Feedback on performance is consistent (Tiron-Tudor and Deliu, 2024). At Level 5, smart circularity is already the firm's practice. To contextualise this within the construction industry, a framework was developed reflecting the unique characteristics of smart circularity in the sector.

Figure 4 presents the maturity levels toward achieving smart circular values. The systematic review led to the decision to adopt 5 levels of maturity for "smart circular construction." The naming of each level reflects insights from existing smart circularity maturity models. This framework defines each maturity level. However, the specific activities required to attain each level lie beyond the scope of this paper and warrant further research.

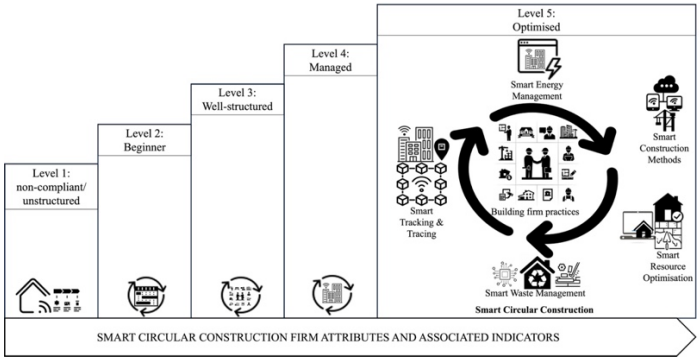


Figure 4: Framework of maturity levels to attain smart circular construction

The maturity levels for smart circular construction explain the logical sequence of achieving the five smart circular values. Based on the understanding of levels of maturity in existing models, the high-level description of the five levels of maturity for the SCC maturity model is proposed. At Level 1, firm practices remain predominantly linear, and any circular actions by the firm are either incidental or compliance-driven, with no strategic alignment to any of the smart circular values. At level 2, smart circularity becomes intentional, where firms focus on planning to achieve low-barrier, easy-to-achieve, smart circular values. At level 3, the firm has advanced beyond planning to concentrate on defined pathways for achieving multiple smart circular values. At this stage, implementation milestones are set, and the low-barrier smart circular values are piloted. At stage 4, smart circular values are being implemented with procedures in place to measure performance. At level 5, all the smart circular values are fully integrated into the firm’s practice, where changes to the existing implementation drive continuous improvement and innovative advancements of SCC. Future research would entail developing detailed descriptors for each maturity level for the firm activities relevant to achieving the key process areas.

Hernandes de Paula e Silva *et al. (*2024) acknowledged that prior models often concentrate on lifecycle, product, or process concepts, either in isolation or in pairs. The framework developed in this study focuses on the levels of achieving SCC, incorporating the three concepts as they are implicitly characterised in the firm's practices, which will reflect the smart circular values. Moreover, the literature lacked

indicators reflecting actual firm performance at each level; therefore, they were incorporated into the framework to enhance its practical applicability. Given the inherent complexity and interdependence of construction activities, achieving these values and honing the practicality of the framework justifies the need for a dedicated, industry-specific maturity model.

CONCLUSIONS

This article represents a point of departure towards transitioning to Smart Circular Construction (SCC) By proposing a conceptual framework for SCC maturity levels. Through a rigorous Systematic Literature Review of 157 peer-reviewed journal articles, a conceptual framework was developed to guide building firms through five maturity levels of technology implementation to attain smart circular values. These values, Smart Energy Management, Smart Construction Methods, Smart Resource Optimisation, Smart Tracking and Tracing, and Smart Waste Management, represent the outcomes of systemically applying technologies to achieve circularity across a building lifecycle. The findings highlight a strategic progression that firms must undertake, moving from fragmented and ad hoc technology use to institutionalising smart circularity as a core organisational ethos. The framework underscores that achieving SCC is not an isolated event but a developmental journey that demands alignment between digital transformation efforts and circular objectives. Each maturity level reflects a shift in mindset, operational sophistication, and integration depth, starting from incidental compliance or non-compliance with circular principles (Level 1) To the full optimisation and continuous innovation of smart circular values (Level 5).

Fundamentally, this study situates smart circular values within the operational realities of building firms, emphasising that SCC maturity is achievable only when technologies for circularity are applied with strategic intent across the firm's activities. By mapping out these developmental stages, this research provides a practical, scalable pathway for firms seeking to embed smart circularity in their operations and move beyond the limitations of current project-based interventions. The findings presented in this paper have two limitations. First, its reliance on secondary data and second, its theoretical nature. The framework proposed requires empirical validation and the development of firm attributes' descriptors and indicators to assess firm-level progression across the maturity levels. Future research will focus on integrating the maturity levels into a robust maturity model. Ultimately, this study lays the groundwork for creating a comprehensive maturity model capable of guiding construction firms toward regenerative, data-driven, and smart circular practices. Such a model holds the potential to inform policy, incentivise industry uptake, and accelerate the construction sector’s transition to SCC.

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EXPLORING STAKEHOLDER STRATEGIES FOR CIRCULAR ECONOMY ADOPTION IN THE WELSH CONSTRUCTION INDUSTRY

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The construction industry in Wales faces significant environmental challenges due to its high levels of resource consumption and waste generation. As part of broader sustainability goals, adopting Circular Economy (CE) principles is increasingly promoted to reduce environmental impact and improve resource efficiency. This study aims to explore context-specific strategies for enhancing CE adoption in the Welsh construction sector by engaging key stakeholders, including government representatives, industry professionals, and academics. Using a qualitative research approach, semi-structured interviews were conducted with 16 participants and analysed through thematic analysis. The findings reveal that while several policy-driven and industry-led initiatives are currently in place, such as material reuse practices and waste management regulations, significant barriers remain, including inadequate financial incentives, weak regulatory enforcement, and limited collaboration across sectors. Based on stakeholder insights, key strategies recommended for promoting CE adoption include enhanced financial support, stricter regulatory frameworks, the development of local supply chains, and stronger industry-academia partnerships. These findings provide a roadmap for policymakers and industry leaders aiming to foster a sustainable and circular construction industry in Wales, contributing to national sustainability targets.

Keywords: circular economy; construction industry; stakeholders; sustainability; Wales

INTRODUCTION

The construction industry's transition to a Circular Economy (CE) has gained increasing attention as stakeholders seek to address resource depletion, construction waste, and environmental sustainability (Bello, 2025; Martin *et al.,* 2024). The traditional linear economic model, characterised by extraction, production, consumption, and disposal, has led to significant environmental degradation and inefficiencies in material use, making the construction sector one of the most significant contributors to global waste production (Nie *et al.,* 2024). The CE, in contrast, aims to create a closed-loop system where resources are continually reused, reducing waste and minimising the consumption of finite resources. CE principles that emphasize material reuse, resource efficiency, and waste minimisation have been positioned as a sustainable alternative to conventional construction practices (AlJaber *et al.,* 2025). Implementation of CE involves adapting existing processes to prioritise sustainability, through practices such as recycling, refurbishing, and designing for

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reuse. However, it is not a single, unified concept; its application varies across sectors and stakeholders.

Despite the increasing emphasis on circularity, the adoption and implementation of CE principles remain inconsistent, with challenges related to policy enforcement, financial mechanisms, supply chain integration, and multi-stakeholder engagement (Bello *et al.,* 2024; Ding *et al.,* 2023). While some stakeholders, like policymakers, are focused on establishing broad regulatory frameworks, others, such as contractors or suppliers, are more concerned with operationalising these principles. In Wales, CE adoption is supported by key policy initiatives, including the Well-being of Future Generations (Wales) Act 2015 and the Zero Waste by 2050 Strategy, both of which aim to promote sustainable resource management and waste reduction (Eduljee, 2023; Reynolds, 2021). While these policies are foundational, they lack specific, enforceable guidelines for stakeholders at the operational level to effectively implement CE.

While these policies provide a framework for transitioning towards circular construction, their effectiveness depends on how well they are translated into industry-wide practices (Hjaltadóttir and Hild, 2021). Existing research indicates that CE adoption is influenced by various economic, regulatory, and infrastructural factors (Osei-Tutu *et al.,* 2023; Idris and Bello, 2023), and while some industry-led initiatives have emerged (Itanola *et al.,* 2024), challenges persist in the form of weak financial incentives, fragmented supply chains, and a lack of cross-sector collaboration (Meltzer *et al.,* 2024; Giorgi *et al.,* 2022). Additionally, a disconnect between CE research and industry application limits the scalability of circular construction solutions and underscores the need for stronger industry-academia collaboration (Leising *et al.,* 2018).

Given these complexities, understanding the distinct roles of various stakeholders is crucial in shaping CE adoption strategies (Osei-Tutu *et al.,* 2024). Policymakers, construction professionals, and academic researchers contribute to formulating, implementing, and advancing CE principles (Bello, 2025). However, the role each stakeholder group plays vary significantly. Policymakers set regulations and create financial mechanisms, contractors and suppliers focus on operational challenges and feasibility, and academics develop research-driven innovations. CE implementation relies on individual stakeholder efforts and how well these actors collaborate to address existing gaps in policy enforcement, funding mechanisms, and supply chain management (Karaca *et al.,* 2024). While prior research has examined technical innovations and policy frameworks for CE (Charef *et al.,* 2024; Bello *et al.,* 2023), limited studies have focused on stakeholder-driven strategies as enablers of CE implementation, particularly in the context of Wales and the broader UK construction industry.

This study aims to explore existing CE initiatives in the Welsh construction sector and stakeholder-driven strategies to enhance CE implementation. By clearly defining the roles of different stakeholders and understanding how their distinct needs and challenges intersect, the study offers a more targeted approach to understanding CE adoption in this context. This study adopts a qualitative research approach through semi-structured interviews with 16 key stakeholders. This research investigates how existing policies, industry initiatives, and academic contributions shape CE adoption and identifies practical strategies for improving CE. Focusing on stakeholder-driven insights, this study provides a holistic understanding of how CE principles can be

effectively embedded into construction practices, moving beyond theoretical discourse to address real-world implementation challenges and opportunities.

LITERATURE REVIEW

Policy and Regulatory Frameworks for CE Adoption

The Circular Economy (CE) challenges the traditional "take-make-dispose" model with a regenerative approach that promotes sustainability (Sharma *et al.,* 2023). While CE is widely embraced globally for its potential to drive resource efficiency (Mubarik *et al.,* 2024), the literature on policy and regulatory frameworks reveals key gaps. For example, policies like the EU's Circular Economy Action Plan (CEAP) and Japan's initiatives have been successful in addressing waste and resource depletion (Kurniawan *et al.,* 2023), yet the practical application of these policies in the construction sector remains underexplored. The UK's Vision Construction 2025 targets—50% emissions reduction and 33% cost savings—are ambitious, but the barriers to meeting these goals, including regulatory and infrastructural constraints, are often understated (Li *et al.,* 2024). While the ILO and UNEP's Green Jobs Initiative has explored employment impacts (Adam *et al.,* 2017), there is limited research on the real-world job creation effects in the construction industry under CE policies. Additionally, the literature presents conflicting views on regulations—some argue they impose high compliance costs (Iraldo *et al.,* 2011), while others suggest they foster innovation (Bello *et al.,* 2023). The Porter Hypothesis, which claims that strict regulations can drive innovation (Porter and Linde, 1995), is not without contradictions, as it may also create barriers for new firms (Albrizio *et al.,* 2017).

Stakeholder-Driven Strategies for Enhancing CE Implementation

Stakeholder theory posits that stakeholders, both internal (e.g., management, staff) and external (e.g., suppliers, customers, NGOs), have distinct needs and influence organisational systems (Schaltegger *et al.,* 2012). While the literature emphasizes the importance of aligning stakeholder interests for long-term value creation (Chang *et al.,* 2017), this focus often overlooks the practical challenges of stakeholder coordination in CE implementation. Bertassini *et al. (*2021) classify stakeholders into internal, value chain, and value network categories, but the literature lacks a deeper exploration of how these roles intersect or conflict in real-world applications, especially in sectors resistant to sustainability practices.

While stakeholder engagement is frequently cited as a key factor in successful CE implementation (Bertassini *et al.,* 2021; Berardi and de Brito, 2021), there is limited discussion on how to overcome organisational barriers like lack of leadership commitment, limited expertise, and siloed departments (Hofmann and Jaeger-Erben, 2020). These challenges are acknowledged, but few studies provide actionable strategies for overcoming them. Additionally, the supply chain barriers identified, such as poor coordination and knowledge gaps (Jaeger and Upadhyay, 2020), are rarely linked to broader industry trends, such as market resistance to recycled materials or fluctuating consumer interest in sustainable products. Furthermore, consumer behavior is largely underrepresented in the literature, particularly how low recycling rates impact CE adoption. While stakeholder engagement is critical, further research is needed on how to foster deeper collaboration among stakeholders across organisations and supply chains, addressing both the organisational and cultural barriers hindering CE.

METHOD

This study employs qualitative research to explore stakeholder-driven strategies for CE adoption in the Welsh construction industry. Due to the study's focus on diverse stakeholder perspectives across policy, industry, and academia. Qualitative research was deemed appropriate to capture the depth and complexity of these insights (Creswell and Poth, 2018). Semi-structured interviews were used to allow flexibility while ensuring consistency across two thematic areas: (i) current CE initiatives in Welsh construction, and (ii) strategies for enhancing CE implementation. Purposive sampling was adopted to select participants with relevant expertise and involvement in CE policymaking, construction practices, and academic research (Patton, 2015). This ensured that each interviewee provided meaningful, experience-based insights. Three key stakeholder groups were targeted:

i. Government policymakers and regulators responsible for CE policy

ii. Industry professionals—contractors, developers, suppliers, and consultants

iii. Academics and researchers working on CE-related innovations

Sixteen stakeholders participated: five from government, six from industry, and five from academia. All had a minimum of five years of CE-related experience. Sampling continued until thematic saturation was reached, ensuring the comprehensiveness of the data collected (Guest *et al.,* 2006). Interviews were conducted in-person or online, lasting 15-30 minutes. All sessions were audio-recorded with consent and transcribed verbatim. Thematic analysis was conducted manually following Braun and Clarke (2006) six-phase framework. This method allowed the researcher to deeply engage with the data and uncover nuanced patterns in stakeholder narratives. Unlike automated software tools, manual analysis supported iterative theme refinement and better captured the interactions across policy, industry, and academia (Nowell *et al.,* 2017). This approach enabled a rich understanding of the challenges and opportunities surrounding stakeholder engagement in circular construction practices.

DISCUSSION OF RESULTS

Demographics of the Participants

A total of sixteen purposively selected participants participated in this study, representing government (n=5), industry (n=6), and academia (n=5). This distribution ensured a balanced representation of key stakeholder groups relevant to CE adoption in the Welsh construction sector. All participants held academic qualifications (Bachelor to Doctorate) appropriate to their roles. Years of experience ranged from six to twenty years above, with the majority exceeding a decade of involvement in CE-related work. This combination of academic standing and professional experience gave the study a robust foundation for capturing informed, practice-oriented perspectives. The diversity and depth of expertise across the sample strengthened the validity of the findings and enabled a nuanced understanding of stakeholder-led strategies for CE implementation.

Stakeholder-Driven Strategies to Enhance CE Adoption in Construction Sector

This study confirms that key policy frameworks, such as the Well-Being of Future Generations (Wales) Act 2015 and the Zero Waste by 2050 Strategy, are central to the promotion of Circular Economy practices in Wales' construction sector. However, the study reveals that these policies lack mandatory enforcement mechanisms, which significantly limits their effectiveness. As P5 pointed out, "We have policies, but

enforcement is the issue—there are no consequences for non-compliance". This finding aligns with the work of Kirchherr *et al. (*2018) and Pomponi and Moncaster (2017), who argue that policies that rely on voluntary compliance are insufficient for achieving systemic change. Unlike countries such as Finland and the Netherlands, where CE regulations are legally binding, Wales' reliance on soft policy measures creates inconsistencies in implementation across different local authorities. As P12 noted, "Some authorities support CE, others don't—it is inconsistent". This fragmentation in policy application underlines the need for stronger regulatory frameworks to ensure uniformity and accountability in CE adoption.

Financial barriers are another major challenge identified in this study. Participants expressed frustration over the lack of financial incentives to support CE adoption, particularly for Small and Medium-sized Enterprises (SMEs), which dominate the Welsh construction industry. P3 emphasized that "SMEs do not have the financial flexibility to experiment with material reuse", highlighting the economic divide between large firms, which may have access to financial resources, and smaller firms that struggle to adopt circular practices. While financial grants exist to support CE, P10 noted, "If there were financial benefits linked to CE targets, companies would not hesitate to invest", pointing to the inefficiency of current incentives. The disparity between the high cost of recycled materials and the lower cost of virgin materials exacerbates the situation. As P6 noted, "Recycled materials are often priced higher than new ones". This reflects a broader market inefficiency, aligning with Akinade *et al. (*2017), who argue that the high cost of recycled materials remains a major barrier to CE adoption. The lack of standardised pricing and quality assurance in recycled materials further undermines their competitiveness, leaving many construction firms reluctant to switch to circular practices.

While financial incentives are crucial, the findings also highlight significant barriers related to industry-academia collaboration. Despite extensive research on sustainable materials and circular construction methods conducted by Welsh universities, stakeholders expressed frustration over the slow adoption of this research in industry practice. P1 stated, "We have conducted studies on material reuse and lifecycle design, but the construction sector is slow to adopt these insights". This underscores a disconnect between academic research and industry needs. This gap in knowledge transfer mirrors the findings of Giorgi *et al. (*2022) and Leising *et al. (*2018), who suggest that academia fails to address the practical challenges faced by the construction sector in adopting sustainable practices. Participants such as P9 emphasized that "we need practical, hands-on training programs, not just theoretical reports that sit on a shelf". This highlights the need for applied research that directly engages with the realities of construction practices, suggesting that government-supported initiatives could play a crucial role in facilitating this bridge between research and practice. P1 proposed, "The government should fund applied research projects where universities work directly with contractors and developers to test circular solutions". This calls for a more integrated approach, where industry-driven research is used to directly address barriers to CE adoption.

Cultural resistance within the construction industry emerged as another key theme. The sector's focus on short-term financial savings, speed, and traditional practices often conflicts with the long-term investment required for CE. As P7 noted, "The financial burden often outweighs the long-term benefits". This view highlights the deep-rooted issue in the construction sector, where economic considerations often override sustainability goals. In a context where profitability and fast project turnover

are prioritised, the reluctance to invest in long-term sustainability measures remains a significant cultural barrier to CE adoption. Akinade *et al. (*2017) argue that SMEs face this dilemma, with limited capacity to absorb the upfront costs associated with circular construction technologies. The study thus identifies a need for greater cultural alignment within the industry, where the focus shifts from immediate cost-saving to long-term value creation through CE adoption.

The findings also highlight organisational barriers to CE adoption, particularly in how companies are structured. Many construction firms operate in silos, with sustainability teams often isolated from other departments, as noted by Hofmann and Jaeger-Erben (2020). This siloed structure leads to lack of coordination between different departments, such as procurement, operations, and sustainability teams, making it difficult to implement CE practices at scale. P6 observed, "We need clearer distinctions—current regulations discourage reuse", referring to the lack of clear regulatory frameworks for distinguishing recyclable materials from waste. The fragmentation in regulatory frameworks across local authorities further exacerbates this issue. A more coordinated, holistic approach to policy enforcement, as proposed by stakeholders like P8, "Integrating CE into planning approvals to ensure early consideration of material reuse and waste reduction", is needed to streamline adoption.

While stakeholder engagement is critical for CE adoption, the findings reveal that voluntary compliance, lack of financial incentives, and fragmented regulatory enforcement remain significant barriers. The disconnect between academia and industry, cultural resistance, and organisational silos further hinder the widespread adoption of CE. To address these challenges, this study suggests that stronger regulatory frameworks, financial incentives linked to performance, and enhanced collaboration between industry and academia are essential for creating a more conducive environment for CE adoption in Wales's construction sector.

CONCLUSION

This study examined stakeholder-driven strategies for CE adoption in Wales's construction industry. While policies like the Well-being of Future Generations (Wales) Act 2015 and the Zero Waste by 2050 Strategy demonstrate Wales's commitment to sustainability, their implementation faces challenges due to voluntary compliance, inconsistent enforcement, financial limitations, and infrastructure gaps. A key contribution of this research is its focus on financial incentives—such as targeted grants, tax reliefs, and performance-based funding—as essential drivers for industry engagement. However, these incentives remain limited and are often insufficient to encourage full industry-wide adoption. The study advocates for regulatory reform, including mandatory CE reporting and more explicit waste classification frameworks. While regulatory measures are essential, their effectiveness is hindered by insufficient enforcement mechanisms and a lack of standardisation across the industry. Barriers like limited access to certified secondary materials and underdeveloped recycling infrastructure hinder CE practices. The study also highlights the need to bridge the gap between academic research and industry practice through government-supported collaborations, CPD programs, and structured knowledge-sharing. Future research should explore the role of digital technologies in enhancing circularity and extend this work to cross-national comparisons.

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BUILDING OBSOLESCENCE: KEY FACTORS INFLUENCING DEMOLITION DECISIONS FOR COMMERCIAL BUILDINGS

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Buildings, while primarily serving to provide shelter, can deteriorate over time without proper maintenance and planning, leading to obsolescence, a significant threat to their functionality. This study investigates the factors contributing to building obsolescence and how they influence the selection of adaptation strategies, focusing on commercial buildings as a case study. Questionnaire data were gathered from 386 business owners and occupants of obsolete buildings in Klang Valley, Malaysia, to capture their perspectives on the issue. Principal Component Analysis (PCA) and Multiple Linear Regression (MLR) were employed to rank obsolescence factors and solution options on strategies on obsolescence factors. PCA results highlight occupiers' demands to improve facilities and maintenance policy implementation were the most critical obsolescence factors, while the MLR model generated through SPSS revealed eight (8) significant factors that contributed to decision to demolish. They were the oversupply assets, natural disaster, outdated M&E services, space layout arrangement, technological aspect, changes of legislation and policies, existing building condition and disagreement between landlord and occupier. This study offers recommendations for sustainable adaptation strategies tailored to address the root causes of building obsolescence effectively.

Keywords: building obsolescence, demolition, maintenance planning, sustainability

INTRODUCTION

Buildings are vital assets that provide people with shelter and facilities for daily activities. However, despite of their primary function to shelter occupants, buildings can deteriorate over time due to factors like dampness, bio-decay and structural movement (Yacob et al., 2022), which unfortunately can result obsolescence if they are left unattended with no proper maintenance and planning. While the beginning of building's life is easily identifiable, predicting the end of its service life is challenging due to varying objective and subjective demands (Silva et al., 2022).

ISO 15686-1 defines obsolescence as the failure of a building element to meet performance expectations due to changing requirements. Obsolete buildings drive up both product and operational costs, making maintenance increasingly expensive

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Ali, A S, Norhanim, Z, Umi-Kalsum, Z and Faiz, Z (2025) Building Obsolescence: Key Factors Influencing Demolition Decisions for Commercial Buildings, *In*: Thomson, C and Neilson, C J (Eds) Proceedings of the 41st Annual ARCOM Conference, 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 772-781.

(Bagdiya & Wadalkar, 2015). Building obsolescence arises from multiple interrelated factors. Yacob et al. (2018) identified physical deterioration due to aging, misuse, and inadequate maintenance as key accelerators of obsolescence. In addition, Grover & Grover (2015) mentioned that functional, economic, technological, and socio-regulatory shifts further contribute to a building's diminished utility. When structures fail to meet evolving environmental, functional, and legal requirements, they impede sustainable urban development (Wilkinson et al., 2014). Thereby, obsolescence often leads to premature demolition, underscoring the need for adaptive reuse strategies to enhance building longevity and urban sustainability. Moreover, Nedeljkovic et al. (2023) observed a rise in unused office spaces worldwide due to changing market demands. In Malaysia, Ali et al. (2009) found that functional improvements and increased comfort were major drivers of building adaptation, with obsolescence being a more prominent cause than physical decay. Many Malaysian buildings undergo adaptation due to obsolescence before reaching the end of their lifecycle. However, while such adaptations support the rise of reuse projects, they often yield unsatisfactory returns on investment. A holistic approach that incorporates predictive models to assess obsolescence risks before they become critical and potentially lead to unnecessary demolition. This paper addresses this gap by systematically examining the three primary forms of obsolescence, which are the economic, functional, and physical factors, and their relative influence on demolition strategy. By analysing these relationships specifically within the commercial building sector, the research provides actionable insights for building managers facing obsolescence challenges in dynamic urban environments.

Building Obsolescence

Building obsolescence is the process of an asset going out of use, which indicated the tendency for the objects and operations to become out-of-date or old fashioned (Abramson, 2016, Ali & Akashah, 2022). Obsolescence is looked at as one of the categories that led to property depreciation besides deterioration (Rodi et al., 2015; Ali et al., 2018). Pourebrahimi et al. (2020) concludes that obsolescence can be defined as a decline or fall of utility, performance, usefulness or value of an object, building or product, which is a threat to sustainability. Building obsolescence has emerged as a pivotal concern in sustainable urban development, significantly impacting the economic viability, environmental performance, and functional adequacy of built assets. While extensive research has examined the causes and consequences of obsolescence (Baum, 1994), current scholarship reveals a critical gap in predictive methodologies that could enable proactive adaptation strategies. Baum's foundational work (1994) established a crucial distinction between depreciation and obsolescence, positing that while depreciation reflects quantifiable value loss in existing use, obsolescence represents a more complex phenomenon that can precipitate such depreciation. This conceptual differentiation shows the need for more multi-dimensional analyses to assess obsolescence risks, particularly in rapidly evolving urban contexts where buildings must adapt to changes in technology and environmental aspects. Types of depreciation and obsolescence for buildings have been identified from previous research (Crosby et al., 2012; Beekmans et al., 2013; Hoesli & Macgregor, 2000; REIA, 2014). Wilkinson et al. (2014) highlighted that the building’s lifecycle and state of obsolescence is directly connected which means building’s lifecycle decreases as the rate of obsolescence increases. For instance, old buildings that were completed between the 1960s to 1970s generally have limited space to add new communication systems. This shows that technological

advancements make the existing building system become obsolete (Ali, et al., 2009). According to Pourebrahimi et al. (2020), it is crucial to identify the type of building obsolescence as a measure to mitigate or prevent building obsolescence to achieve sustainability in built environment. Buitelaar et al. (2020) identified obsolescence into two types, namely absolute obsolescence and relative obsolescence. Absolute obsolescence refers to the state of the building itself, regardless of the states of other buildings or of user demands. This means that the building is wearing out and not being adequately maintained to either stop the process or roll it back; which can be referred to as physical deterioration, physical obsolescence or structural obsolescence (Golton, 1989; Korteweg, 2002; Ali et al., 2018). Nevertheless, as highlighted by Pourebrahimi et al. (2020), the dispersion of categories or types of obsolescence by different scholars happens because of the use on different terms but referring to the same meaning. This study adopts the classification of obsolescence established by professional bodies in property valuation. The International Valuation Standards Council (IVSC, 2021) and the Royal Institution of Chartered Surveyors (RICS, 2019) systematically categorize obsolescence into three distinct yet interrelated types: economic, functional, and physical. The IVSC and RICS classifications provide a comprehensive foundation for examining how different obsolescence drivers collectively influence building performance and valuation outcomes.

Generally, economic obsolescence occurred as a result from change of demand for the goods and services produced by the asset or as result of excess capacity in a sector. The locational factors also contribute as the cause to economic obsolescence. Additionally, functional obsolescence happens when the design of an asset of any specification becomes outdated no longer fulfils its original purpose. This obsolescence arises could be because of technological advancement or due to the changes in legal frameworks. In contrasts, physical obsolescence caused by the wear and tear over the years, which also contributed by the lack of maintenance for the building. Physical obsolescence also refers to the loss of utility or its components due to age and usage. Interpretations given by these bodies refer to obsolescence which is caused by the asset itself and every potential reason within the asset boundary. For instance, Baum (1994) supported that inflexibility in building design and configuration is the vital cause to building obsolescence because it fails to adapt to modern needs. Significantly, there are some notes justify that obsolescence does not only happen because of the inflexibility of the asset but the view should be extended to neighborhood area that might contribute to building obsolescence (Nutt et al., 1976; Raftery, 1991; Blakstad, 2001; Remoy, 2010; Jin-Lin, 2015) as interpreted by IVSC (2021) that locational factor contributes to economic obsolescence.

Factors Contributing to Obsolescence

A comprehensive review of previous works examining the determinants of building obsolescence was carried out. While existing literature demonstrates variation in obsolescence categorizations (Pourebrahimi et al., 2020), such discrepancies primarily reflect terminological differences rather than conceptual distinctions. Following the methodological framework established by RICS (2019), the identified obsolescence factors were systematically classified into three principal dimensions: economic, functional, and physical. Through this analytical process, twenty-seven distinct obsolescence drivers were identified and catalogued in Table 1, providing a structured foundation for subsequent analysis.

Building Adaptation and Demolition

Building obsolescence arises from factors, including technological advancements, political shifts, and evolving stakeholder demands. Sustainable adaptation encompassing policy interventions, financial incentives, and technological upgrades has been proposed as a strategy to mitigate obsolescence and extend building lifespans. However, current decision-making processes often remain reactive rather than proactive (Douglas, 2004). For instance, the impact of information technology (IT) on workspace demand. The rise of remote work, enabled by IT advancements, has reduced the necessity for in-person meetings, altering traditional workspace requirements (Pourebrahimi et al., 2020).

Table 1: Factors contributing to obsolescence based on three categories

Categories of Obsolescence	Operational Definition	Factors of Obsolescence	Referenc
Economic	Change of demand for the goods and services produced by the asset or as result of excess capacity in a sector	i. Reduces in product demand and services ii. Oversupply similar asset iii. Change of social needs and behaviors iv. Increase in land value v. Physical deterioration of the neighbourhood assets vi. Limited accessibility vii. Absence of land use control viii. Negative environmental area ix. Natural Disaster x. Supernatural elements	Saria (2006), Pourebrahimi e (2020), Reilly (Reed et al. (201 Pinder and Will (2001), Thomsc Flier (2011), Gı and Grover, (20 Yusof (2000), N al. (1976), Raft (1991), Blaksta (2001), Remoy Wilkinson et al Reed (2007)
Functional	Design of an asset of any specification becomes outdated no longer fulfills its original purpose.	i. Building performance ii. Increasing demands by occupiers to improve facilities iii. Disagreement between landlord and occupier iv. Inflexible building design v. Original use is no longer required vi. Absence of facilities vii. Technological obsolescence viii. Old building services ix. Change of legislation or policies x. Increase in greenhouse emissions, incompliance with climate conditions xi. Disability to use renewable and clean energy sources or other green building features xii. Poor maintenance policy implementation	Rodi et al. (201 Sarja (2006), Doughlas (200 Wilkinson et al (2014), Pourebrahimi e (2020), Kraus ((2009), Baum (1994), Nutt an Sears (1991), R (2012), Reed e (2010), Evelyn Guangming (2(Reed and Warr Myers (2010), & Macgregor (
Physical	The wear and tear over the years, which also contributed to the lack of maintenance for the building.	i. Building appearance ii. Building age iii. Building condition iv. Building structure v. Space configuration or layout	Nutt et al. (197 Blakstad (2001 Remoy (2010), (2017), RICS (Brand (1997), Ashworth, (20(Douglas (2006 (1991), Bottom (199), Remoy (Wilkinson et al (2014), Jin-Lin Ali et al., (201 Pourebrahimi e (2020)

Consequently, buildings must incorporate cutting-edge IT infrastructure to remain functional, driving demand for refurbishment. Conversely, Cabeza et al. (2014) demonstrate how lifecycle assessment (LCA) methodologies can inform sustainable

building management by quantifying environmental impacts across all phases, from initial construction through to demolition. Their findings particularly emphasize the value of early intervention strategies in reducing resource consumption and waste generation, thereby supporting the case for proactive obsolescence mitigation frameworks. Expanding upon these insights, Conejos et al. (2016) developed an innovative adaptability assessment tool that systematically evaluates buildings' capacity for functional transformation based on key design parameters. While this model provides valuable insights into obsolescence risk through measurable architectural and spatial metrics, its static analytical approach lacks integration with real-time data streams, potentially limiting its effectiveness in rapidly evolving technological and market contexts.

While adaptation is seen as one strategy to improve obsolescence, there is a limitation in predictive approaches of which adaptation solutions to be selected or if an obsolete building needs to be demolished. Yet, certain obsolescence factors, such as irreparable structural deficiencies or drastic regulatory changes, which pose huge challenges, often leading to premature demolition before the end of a building's physical lifespan (Pourebrahimi et al., 2020).

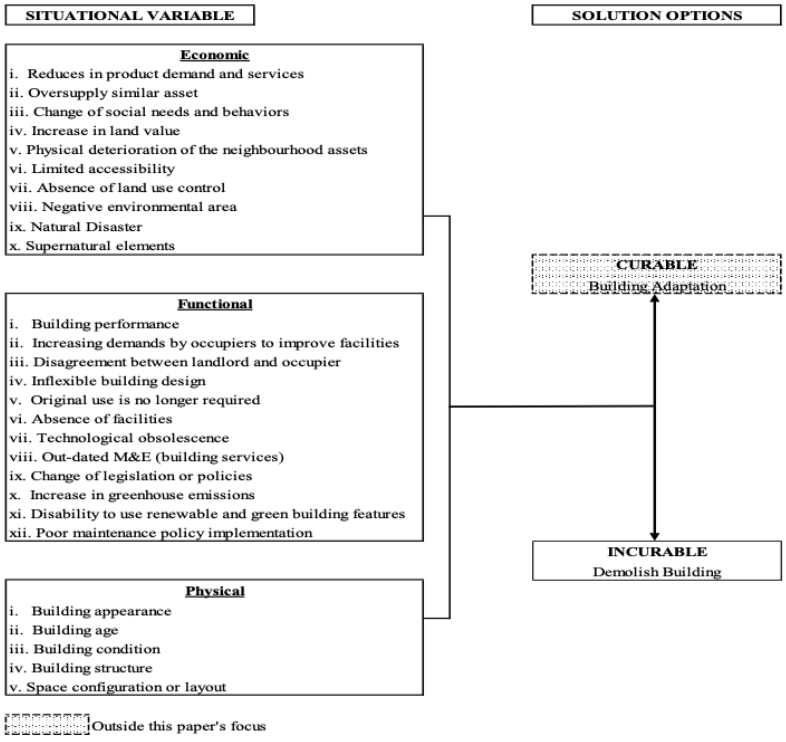


Figure 1: Conceptual Framework

In addition, Wilkinson et al. (2014) highlighted that obsolescence could lead to unnecessary building demolition. Thomsen and van der Flier (2011) argue that while obsolescence may warrant building demolition, adaptive strategies such as modernization can effectively extend building lifespans. Their research emphasizes that the viability of such interventions depends on the degree of obsolescence curability, necessitating comprehensive data to inform stakeholder decision-making processes. This highlights the critical need for detailed building assessments when evaluating demolition options. The conceptual framework is built upon established research identifying twenty-seven key obsolescence factors (situational variables) across three primary categories, which are economic, functional, and physical. By

differentiating between curable and incurable obsolescence factors, this approach enables more differentiated decision-making regarding demolition options.

METHOD

A questionnaire survey was deemed the most suitable approach for data collection. The factors linked to building obsolescence were identified through an exhaustive literature review. The research focuses on commercial buildings in the Klang Valley, as this region is recognized as Malaysia's most vibrant hub for commercial activity. Due to challenges in selecting appropriate study samples, the identification of buildings relied on archived records from local authorities (LA) within the study area. The survey was carried out between April and May 2024The study targeted commercial buildings, particularly shopping malls, shophouses, and shop buildings, that exhibited indication of obsolescence. The criteria used for selection for cases were high rate of tenant turnover, unit with frequent renovations, probably due to changes in business activities, and commercial areas with less visitors or gloomy. Through the recommendation and site observation conducted through the process, a total of nine (9) obsolete commercial buildings/ area were selected based on the feedback and access granted from each of the building's management or authorities. The adopted questionnaire measures the respondents' level of agreement on factors that cause obsolescence in their buildings as well as their potential suggestion for solution by using Likert Scale, ranging from strongly disagree to strongly agree. The unit of analysis implemented in this study is by the number of occupied units in every obsolete commercial building. Krejcie & Morgan (1970) table used in determining the sample size to achieve 95% confidence level and 0.05 of margin error, with the 1608 population size, the minimum sample size required is 380 responses.

A total of 600 questionnaires were distributed during the survey, with 386 valid responses received from building owners, tenants, and facility management personnel of obsolete commercial buildings. This represents a response rate of 64.3%, which is acceptable for reliable data analysis. As mentioned by Xu et al. (2024), a larger sample size enhances accuracy and more robust interpretation of research findings. The demographic and background data of the 386 respondents were analysed using descriptive statistics, with the results summarized in Table 2 to Table 4.

The survey findings reveal that the largest proportion of respondents (38.2%) were involved in fashion retail and beauty salon businesses, followed by those operating laundry services (19.5%). Service-oriented enterprises constituted 16.5%, while education-related businesses represented the smallest portion at 10.3%. Regarding respondent roles, tenants formed the majority (86.6%), whereas building owners and facilities management personnel accounted for 10.5% and 2.9%, respectively. Tenants play a crucial role in shaping spatial demand, as their direct interactions with customers offer valuable insight into consumer preferences, market trends, and expectations for commercial infrastructure. Building owners largely shared these perspectives, with statistical analysis revealing no significant differences between the views of tenants and owners.

Regarding the duration of occupancy or management, the highest proportion of respondents (49%) had been associated with the building for 3–9 years, followed by those with 10 or more years (27.5%). The smallest group, which is 23.5%, had been involved for less than 3 years. For data analysis, descriptive and inferential statistics were applied using SPSS (Version 29). Principal Component Analysis (PCA) was employed to rank the obsolescence factors, while multiple regression analysis was

conducted to assess the strength of the relationship between obsolescence factors and the decision to demolish a building.

Table 2: Respondents' demographic profile

Description	Percentage (%), n= 386
Type of Business	
Finance/Banking	15.6
Education	10.3
Service (Logistic, Telco, Real Estate, Insurance and IT)	16.5
Other Services (Professional, Admin, Health & Support)	0
Fashion Retail and Beauty Salon	38.2
Laundry Services	19.4

Table 3: Respondents' status

Description	Percentage (%), n= 386
Owner	10.5
Tenant	86.6
Facilities Management	2.9

Table 4: Ownership/rental/managing period

Description	Percentage (%), n= 386
Less than 3 years	23.5
3-9 years	49
10 years and above	27.5

FINDINGS

Prior to the regression analysis to examine the prediction of obsolescence factors toward demolition of the buildings, data from the questionnaire survey was first analysed through Principal Component Analysis (PCA), where the contribution of obsolescence factors was arranged by rank. A total of 600 questionnaires were administered to the selected commercial buildings selected, and 386 sets of questionnaires were returned, representing 64.3% response rate. Through PCA, type of building, selection of obsolescence factors by the respondents are ordered by the amount of variance they represent in the dataset presented in the questionnaire survey. Table 5 lists all the contributions that involve with building obsolescence, including type of building, factors of obsolescence and recommendations for adaptation with their corresponding PCA coefficients. Increasing demands by occupiers to improve facilities as the significant obsolescence factor with the highest contribution (4.1480) compared to the other factors. This followed by poor maintenance policy implemented with 3.8551 score and disability to follow new standards with 3.8489 score. This shows that these factors play a crucial role as contributors to the obsolescence of commercial buildings. On the other hand, factors like natural disaster (2.5834) or) increase in greenhouse emissions, incompliance with climate conditions or toxic waste generation (2.1024) have smaller contributions, indicating they explain less of the variance in the dataset. In this context, low variance implies that most respondents gave similar answers to those questions. They provide limited information about the differences between data points. They do not help much in distinguishing between different observations and, as such, are less likely to reveal significant patterns or relationships in the data.

Table 5: PCA contributions of building obsolescence factors

Components	Features	Contributio
Obsolescence Factors [Economic, Functional & Physical]	Increasing demands by occupiers to improve facilities	4.1480
	Poor maintenance policy implementation	3.8551
	Disability to use renewable and clean energy sources	3.8489
	Building age	3.6935
	Increase in land value	3.6827
	Building space or layout	3.6530
	Absence of land use control	3.6461
	Disagreement between landlord and occupier	3.6334
	Limited accessibility	3.6332
	Original use is no longer required	3.6092
	Oversupply similar asset	3.5739
	Building condition	3.5336
	Physical deterioration of the neighbourhood	3.5211
	Reduces in product demand and services	3.4699
	Technological obsolescence	3.4622
	Building structure	3.4185
	Supernatural element	3.3797
	Inflexible building design	3.3602
	Negative environmental area	3.2719
	Absence of facilities	3.2253
	Change of legislation or policies	3.1936
	Change of social needs and behaviors	3.1360
	Building appearance	3.0415
	Outdated building services system	3.0200
	Building performance	3.0060
	Natural Disaster	2.5834
	Increase in greenhouse emissions	2.1024

Multiple Regression Analysis

Regression analysis was conducted to examine the obsolescence factors influencing the decision to demolish obsolete buildings. The dependent variable was "To demolish", while 27 obsolescence factors are the independent variables or predictors that were considered. Results for the stepwise regression analysis are presented in model summary (Table 6) and regression coefficients (Table 7).

Table 6: Main parameters of the multiple linear regression model

Model	R	R Square	F	p-value
1	.689[a]	.504	33.388	<.001[b]

Table 6 shows the regression model achieved an R-value of 0.689, indicating a moderate to strong correlation between the predictors and the dependent variable. The R^2 value of 0.474 suggests that approximately 50.4% of the variance in the decision to demolish a building is explained by the independent variables included in the model. The F-statistics were 33.388 and $p < 0.001$, indicating that the overall regression model is statistically significant. This suggests that at least some of the independent variables have a significant impact on the likelihood of demolition.

Table 5 presents the regression coefficient result on obsolescence factors that influence the decision to demolish obsolete buildings. Oversupply plays a significant role in contributing to the decision to demolish obsolete buildings ($\beta = 0.241$, $p < 0.001$) where excess availability of similar business strongly suggests demolition, followed by natural disaster ($\beta = 0.255$, $p = <.001$) which means obsolete buildings in disaster-prone areas are more likely to be demolished. Change in legislation, space layout arrangement and technological obsolescence significantly can affect to the demolition decisions ($\beta = 0.146$, $p = 0.009$), ($\beta = 0.132$, $p = <.001$) and ($\beta = 0.155$, $p = 0.023$) respectively. Other 19 situational variables, did not show statistical significance ($p > 0.05$), which indicating a weaker influence on demolition decisions.

The results suggest that 8 factors, which are the oversupply assets, natural disaster, outdated M&E services, space layout arrangement, technological aspect, changes of legislation and policies, existing building condition and disagreement between landlord and occupier played crucial roles in determining an obsolete building should be demolished. Strategies aimed at adaptive reuse, policy adjustments, and technological upgrades may help mitigate premature demolitions as mentioned by Thomsen and Flier (2011).

Table 7: Regression Coefficients (stepwise)

Obsolescence Categories	Obsolescence Factors	Unstandardised Coefficients, B	t	Sig.
Constant		0.754	2.229	0.27
Economic	Oversupply (similar business)	.241	4.794	<.001
Function	Natural Disaster	.255	3.429	<.001
	Disagreement between landlord and occupier	.131	2.204	.028
	Technological obsolescence	.155	2.290	.023
	Old M&E	-.238	-3.945	<.001
	Changes of local or federal legislation/ ad-hoc policies	.146	2.639	.009
Physical	Existing building condition	-.092	-2.544	.011
	Space/layout	.132	3.046	<.001

The result suggests the decision to demolish could be predicted from the 8 situational variables. Furthermore, the p-value for Hosmer–Lemeshow goodness of fit was 0.552, which was more than 0.05. Thus, the model adequately fits the data. The regression equation was produced as follows, as indicated in Table 5:

Decision to Demolish = 0.754 + 0.241 (Oversupply) + 0.255 (Natural Disaster) - 0.238 (Old M&E) + 0.132 (Space Layout Arrangement) + 0.155 (Technological Obs) + 0.146 (Changes Legislation or Policies) - 0.092 (Existing Building Condition) + 0.131 (Disagreement Landlord and Occupier)

The finding offers valuable insights into how building obsolescence factors influence demolition decisions, as analysed through multiple linear regression. Previous study, such as Cabeza et al. (2014), has highlighted the role of lifecycle assessment (LCA) in sustainable decision-making, particularly in evaluating buildings' environmental impact. Our findings align with this by revealing those economic factors, particularly oversupply assets due to an excess of similar business, which contribute a significant role in demolition choices.

CONCLUSIONS

This study discussed the understanding of how obsolescence factors influence decisions to adapt or demolish buildings. By providing empirical evidence on the key factors that contribute to demolition, it enhances existing research on building obsolescence and supports better management of aging structures. The regression analysis confirms that economic, functional, and physical factors with 8 significant situational variables are pivotal in these decisions, underscoring the importance of strategic interventions to extend building lifespans. Future research should investigate real-time predictive analytics to improve obsolescence management and promote sustainable urban development.

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ORGANISATIONAL RESPONSES TO SUSTAINABILITY DEMANDS: EXPLORING RESPONSE VARIETY IN THE DANISH CONSTRUCTION INDUSTRY

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Due to the construction industry's significant environmental impact; there is increasing pressure for more sustainable practices. This study explores how Danish construction companies experience and respond to sustainability demands. Drawing on institutional theory - particularly the concepts of institutional demands and organisational responses - the study is based on 100 questionnaire responses and in-depth interviews with company representatives. Findings show that companies face regulative; normative; and cultural-cognitive sustainability demands and respond in varied ways. Four distinct response types are identified: procedural; human resources; schematic; and reputational. These responses; mobilised by the companies; align sustainability demands with internal practices without directly affecting project execution. The study contributes by showing that companies experience sustainability pressures differently and therefore adopt diverse strategies. It also highlights the importance of understanding how internal organisational responses are shaped by external sustainability expectations. In line with this, we suggest that future construction management research should explore normative and cultural-cognitive responses to sustainability demands instead of focusing primarily on regulative ones, which have been the overarching focus in recent years.

Keywords: decoupling; EU regulation; institutional demand; organisational response; sustainability

INTRODUCTION

Due to its high energy and resource consumption, the construction sector faces intense pressure to reduce its environmental footprint by 2030 and transition towards more sustainable solutions. This pressure has intensified in recent years, culminating, from a Danish perspective, in the 2021 Danish Climate Act. However, sustainability is not only a political ambition driven by regulatory means, but a broader societal concern rooted in normative and cultural-cognitive beliefs. For instance, climate and

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environmental issues have ranked among the top priorities for Danish voters in recent elections (cf. Hansen and Stubager 2021). In response, the Danish Climate Act aims to cut Denmark's greenhouse gas emissions by 70% by 2030, compared to 1990 levels, exceeding the EU's target by 15% (European Commission 2023). This ambition has made sustainability and green transition central objectives across sectors, including construction, and has prompted companies to support national climate goals.

These sustainability demands are disrupting established industry practices, reshaping work routines and business models (Havenvid *et al.,* 2024). Prior research highlights that this disruption creates tensions between project efficiency and sustainability goals (Fredslund *et al.,* 2022) - a pattern also evident in our empirical data. While much research has focused sustainability demands as being distinctly regulatory (e.g., de Gier *et al.,* 2022), this study shifts the focus to their normative and cultural-cognitive dimensions. This is done by examining how sustainability demands interact with organisational responses during the transition towards a more sustainable construction industry. Specifically, it investigates how companies in the Danish construction industry experience and mobilise different responses to these demands.

The study adopts an institutional theoretical perspective, which is well suited to analysing both sustainability demands and organisational responses. Empirically, it is based on a mixed-method approach, combining questionnaire data (quantitative) and interviews (qualitative). Rather than defining sustainability a priori, we allow respondents and interviewees to articulate their own understandings, shaping how they experience and respond to related demands.

In our analysis, we identify four distinct response types found in our dataset. These responses offer insight into how companies address sustainability demands and demonstrate that they are primarily mobilised for reasons of legitimacy rather than regulatory compliance. By introducing these response types, we aim to enrich the construction management literature on sustainable construction with insights into what organisational responses look like and how they may vary (de Gier *et al.,* 2025) from one company to another.

Theory

The interaction between institutional demands and organisational responses is crucial for understanding how sectors navigate and adapt to external demands (Pache and Santos 2010). Institutional demands shape the environment within which companies operate, influencing organisational structures, strategies and daily routines (Fu *et al.,* 2024). Yet, organisations do not simply comply, they interpret and respond to demands based on their organisational characteristic (Delmas and Toffel 2008) and community affiliation (de Gier *et al.,* 2025). Hoffman (2001) highlights that these organisational responses are shaped not only by external demands but also organisations internal characteristics and position in the field. This dynamic interplay shapes how companies respond to sustainability demands.

Institutional Demands

Pache and Santos (2010: 457) state that institutional demands are "various pressures for conformity exerted by institutional referents on organisations in a given field." Scott (2008: 48) describes institutions as comprising “regulative, normative and cultural-cognitive elements that, together with associated activities and resources, provide stability and meaning to social life." Each element offers a pathway to legitimacy (Palthe 2014), which is critical for organisational acceptance.

In highly institutionalised sectors like construction (Kadefors 1995), change is often driven by macro-level disruptions, such as new regulation or shifting public expectations (Kadefors *et al.,* 2024). The sustainability represents such a disruption, placing new demands on companies from multiple sources. Scholars such as Palthe (2014) points out that regulative demands ("have to") involve complying with changing legislation. However, companies must also navigate legal uncertainty and shifting standards. Normative demands ("ought to") are driven by increasing professionalisation among consultants, contractors, clients, and investors. Finally, cultural-cognitive demands ("want to") reflect broader societal expectations, such as citizen activism and generational shifts in values, epitomised in the so-called "climate election of 2019" (Hansen and Stubager 2021). Young professionals now explicitly seek to address societal challenges through their work (YPAI 2024). In the same vein a new survey done by Universum (2024), highlighting that the most attractive employers in the Danish construction industry are all consulting companies - Ramboll, COWI, and Sweco - known for leading the sustainability transition.

Organisational Responses

When organisations face institutional demands, they typically choose to conform, decouple, or do both (Bromley and Powell 2012; Pache and Santos 2010). Conformity enables legitimacy, as organisations must align with legislation and norms to remain credible in their field (Bromley and Powell 2012: 26). However, construction companies often struggle to align strategic goals with project-level realities (Fredslund *et al.,* 2022), creating room for decoupling.

Some companies comply symbolically, while others decouple to avoid costs or maintain operational flexibility (Ahrens and Khalifa 2015). Decoupling can stem from structural fragmentation: construction is tightly coupled in projects but loosely coupled across organisations (Dubois and Gadde 2002). Teelken (2015) shows that such loose coupling fosters critical attitudes and symbolic compliance, especially during changes processes like the green transition.

METHODS

A mixed-methods design was used in this study. The rationale was to provide a “more in-depth understanding of the quantitative results” (Creswell and Creswell, 2018: 237). As Frederiksen (2022) notes, mixed methods combine methodologies to yield more nuanced and comprehensive insights. He also highlights that a sequential design, quantitative followed by qualitative, allows specific questions to clarify patterns in the numerical data. Thus, findings from the first phase informed the next phase. By integrating both quantitative and qualitative data, areas where statistical analysis alone falls short can be supported by qualitative interview data.

Data were collected in fall 2023 by the first author. First, a questionnaire was distributed to the construction sector professionals via LinkedIn and SurveyXact. Using the educational institution's official LinkedIn page greatly expanded outreach because of its broad national network. However, most responses came from individuals already connected to the institution, such as former employees, collaborators, or former students, reflecting specific opinions rather than being statistically representative of the Danish construction sector. The questionnaire included themes on:(1) company size, (2) sustainability in relation to everyday work activities, (3) personal experiences and perceptions of sustainability, (4) sustainability

in relation to legitimacy acquisition, (5) symbolic sustainability activities, and (6) time, cost, and quality regarding sustainability ambitions.

We received 109 responses: 23 partially answered and 86 complete. The responses were collected from a heterogeneous group of professionals within the Danish construction industry, representing a wide range of experience levels—from recent graduates to highly experienced practitioners. Notably, the majority (43%) of respondents reported having more than 16 years of professional experience. The closing question in the questionnaire asked whether respondents could be contacted for a follow-up interview, and 27 consented. After analysing the quantitative data, four professionals representing different companies were selected for follow-up interviews. The purpose of the interviews was to gain a deeper understanding and elaborate on their questionnaire responses. All interviews were recorded, and all interviews were in person interviews. The interviewees are listed in table 1.

Table 1: Overview of interviewees

Interviewee:	Contractor	Consultant	Project developer	Non-profit client organisation
Role in company:	CEO	Department director	Procurement manager	Operations manager
Experience:	20 years	25 years	4 years	3 years
No. of employees:	~16	+2000	~80	~130
Interview duration:	38.21 min	22.57 min	34.26 min	44.35 min

The interviews were semi-structed, following the questionnaire themes while allowing in-depth elaboration. All four informants have held or currently hold management roles (representing strategic, tactical and operational level) and participated in the online questionnaire before agreeing to interviews.

FINDINGS

We analysed two data sets. The first set consists of the quantitative responses (each theme had between 4-10 questions) while the second set comprised qualitative insights from the four interviews. Since our interest is to explore companies' responses to sustainability demands, we focus on how organisations experience and, consequently, respond. Findings are presented in sections. The first part focuses on highlighting regulative, normative, and cultural-cognitive sustainability demands. Analogously, the second part focuses on how companies responded to the experienced demands.

Sustainability Demands

Looking at the empirical data through the lens of institutional demands, companies are pressured on a regulative, normative and cultural-cognitive level. In relation to the regulative dimension, new national and EU sustainability regulations such as EU Green Deal are pushing the companies. For instance, "To what extent is sustainable transition a priority?" 40 of 88 answered "much" or "very much." And 68 of 88 said their company was actively reducing CO2 in projects. A contractor noted that: "...small businesses are being pressured by the new demands (e.g., the EU-Taxonomy) for documentation, as we are indirectly affected by it and have to deliver regarding reporting and so on. You feel that pressure all the time, and we [small businesses] are navigating in the dark." small companies feel constant pressure from documentation demands like the EU taxonomy. It is also highlighted that several large project developers are pushing the demands for green solutions and the transition to an extent that is stricter than the regulatory requirements. For example, one of Denmark's

largest pension funds stated in its 2020 annual report that all new projects must obtain a DGNB certificate. By 2024, the fund reported having restructured half of its approximately €2 billion portfolio to align with sustainable investment criteria, emphasising that sustainable property investments and financial returns are mutually reinforcing (PFA 2024). This corresponds with the project developer's assertion that "… all new customers require their buildings to be certified" (e.g., DGNB).

In relation to the normative dimension, it is noted that major industry actors, such as pension funds, are setting standards that exceed legal requirements—for example, by requiring square metres with an environmental footprint below 7 kg CO^2/m^2, compared to the legal threshold of 12 kg CO^2/m^2—a tendency acknowledged by the project developer stating "… customers are placing additional demands, particularly concerning CO^2 emissions. For example, they request levels below 7 kg CO^2/m^2. Although this can be challenging to achieve, it is something we are able to deliver".

This is also reflected in the questionnaire results. When respondents were asked, "Is sustainability more important today than 2-3 years ago?", 50 out of 94 answered "much" or "very much". Both the contractor and the project developer agreed that high sustainability demands from customers have become the new normal in the industry. Furthermore, it is reported that if companies fail to meet these expectations, clients are likely to take their business elsewhere.

In relation to the cultural-cognitive dimension, public opinion also plays a role. A Epinion (2024) survey found 43% of Danish voters prioritise the climate and the environment, which is an increase from 18% in the last EU election in 2019. This demand for action can be seen in the data as well as in the consultant's statement: "Almost every application that the department receives from young and newly graduated applicants' states that they want to work with sustainability." This creates a cultural-cognitive pressure on the organisation to address sustainability concerns if they wish to attract future employees.

Outlining Four Organisational Responses

Looking at the organisational responses drawn from the interviews, there are four different ways the companies respond to the sustainability demands, each corresponding to a particular type of response. Identifying these response types is crucial for understand why companies do or do not conform/decouple to experienced demands.

Contractors adopt what could be called a "procedural response," viewing sustainability as a necessity for aligning with everyday procedures and ensuring organisational survival. They adjust their business operations and daily activities to meet sustainability requirements. This is evident in the interview with the contractor, who states that the construction company - of which he is both CEO and owner - has invested a significant amount of capital in Environmental Product Declarations (EPD), not due to customer demands, but because they want to be first movers. He also argues that such investments will be necessary to stay competitive and ensure survival. This is backed by 31% (12 out of 39) of the quantitative responses from contractors, who said that adopting sustainability practices is "highly" or "very highly" important for delivering services and tasks. Or, as the project developer puts it about his company's subcontractors: "If they do not adapt, they will simply not be assigned projects, which can threaten their survival.".

For consultants (i.e., architects and engineers), sustainability demands are dealt with through a "human resources response," meaning it is a prerequisite for recruiting and retaining talented employees. As the consultant explains: "There is a huge focus on sustainability in the workforce. We have an entire department with around 80 people working nationally on sustainability, because almost all projects involve customers demanding it." He also sees growing pressure from employees: "The young generation of applicants wants to work with sustainability and includes this demand in their job applications. So, we want to offer them sustainability-focused work to attract them.". stating that there is high competition between the consulting companies, when it comes to projects involving sustainability.

Project developers exhibit a "schematic response," treating sustainability as a requirement for meeting environmental certification standards, such as DGNB. Their response is centred on aligning with these standards to meet customer expectations. As the project developer says: "There are many customers who want a green portfolio, mostly in the form of certified buildings. They use these certifications to sell the buildings. So, there is a clear commercial interest. They can simply sell them at a higher price if they are certified."

Similarly, the consultant notes that sustainability is also good for business, with the price for an engineering project increasing by 10-15%, a point confirmed by the professional client, who states that project costs have increased by approximately 5%. When asked: "how has sustainability changed your construction projects?" 47% of respondents said that it has made projects more expensive.

Finally, professional clients/non-profit housing associations demonstrate a "reputational response", treating sustainability as essential for maintaining a positive corporate image. Their approach to sustainability is shaped by politics, democracy, and diversity. As the non-profit client explains: "Our organisation has a general sustainability strategy, but sustainability is also driven by our residents, so the strategy comes from the bottom up. There are differences between departments, especially due to the makeup of residents." He adds that while some departments focus on biodiversity, circularity and sustainability and similar initiatives, other departments do not prioritise sustainability but has a more traditional focus on e.g., cost and maintenance.

DISCUSSION

The findings in this study should be seen as indicative rather than representative of the Danish construction sector. They reflect the views of the participants involved but do not constitute a statical representation of the industry. A larger-scale survey with more respondents could potentially yield different insights. Similarly, the qualitative findings are based on a limited number of interviews, and the selection of different participants—particularly those without managerial roles—might have offered a more practical, on-the-ground perspective of how organisations respond to sustainability demands. The validity of the study could also have been strengthened if the questionnaire had been kept open longer and more interviews had been conducted with a broader and more diverse sample. Therefore, while the results reflect the views of those who participated, we argue that the identified patterns are highly generalisable, as they are likely to recur across organisational contexts with similar roles and pressures.

As previously noted, societal demands often generate a tension between productivity and sustainability goals (e.g., Fredslund *et al.,* 2022). This tension is evident in the quantitative results. Of the 92 responses—most from contractors or consultants (e.g., site managers, architects, engineers)—88 respondents stated that they view the sustainable transition in construction positively. However, when asked whether it is acceptable to deviate from sustainability requirements, 61 out of 86 responded that such deviation is legitimate if the requirements seem unreasonable or harm project timelines or costs. This supports Hoffman's (2001) argument that responses to institutional demands are shaped by internal organisational characteristics and constraints. It also highlights the risk of decoupling between strategic sustainability visions and project-level decision-making.

Thus, these results align Ahrens and Khalifa's (2015) suggestion that compliance is often driven by self-interest, and that institutional demands require meaning-making to become actionable. In line with this, the study intentionally left the concept of sustainability undefined for both questionnaire and interview participants. While this approach allowed respondents to express their own interpretations, which was central to the study's interest, it also poses limitations. The lack of a shared definition may have led participants to interpret questions differently, resulting in responses grounded in varying assumptions. One consequence is that all organisational changes may be framed as responses to sustainability for legitimacy reasons, even when they are primarily driven by business logics rather than broader environmental or social concerns.

Despite these limitations, the study contributes to construction management research by showing how sustainability demands are internalised differently across companies. A key takeaway is that sustainability, despite its broad conceptual scope—including environmental, social, and economic dimensions—is generally reduced to environmental aspects. More specifically, sustainability becomes something practical and deliverable, often through certification schemes and documentation. This is significant because such schemes do not necessarily equate to sustainable practices (Consumer Ombudsman 2024). Instead, they can provide an impression of compliance without reflecting a deep commitment to underlying goals such as CO2 reduction. This is also evident when looking at one of the questionnaire's findings: 53 out of 86 respondents answered 'yes' when asked if there is a discrepancy between what is communicated at the strategic level and what is being done at the project level.

Revisiting the Four Response Types

This final section elaborates on the four types of organisational responses identified in the study (see table 2), which we consider to be the study's main contribution. Importantly, the study finds that most responses to sustainability demands are not primarily regulatory, but rather normative and cultural-cognitive and aligning the characteristics with Palthe's (2014) behavioural reasoning. This is significant because it shifts the focus from compliance through enforcement to more voluntary internalisation of sustainability expectations.

Table 2: Identified responses to sustainability demands

Response type:	Central actors	Characteristics	Source of legitimacy	Behavioural reasoning
Procedural	Contractors	Sustainability as a necessity for aligning with everyday procedures	Normative	ought to
Human resources	Consultants	Sustainability as a prerequisite for recruiting and retaining talented employees. This is regarded as a key competitive factor between consulting firms.	Cognitive - Cultural	want to
Schematic	Developers	Sustainability as a requirement for complying with environmental certification schemes	Normative	ought to
Reputational	Clients	Sustainability as critical for ensuring positive corporate reputation	Cognitive - Cultural	want to

As demonstrated, the four company types respond differently to sustainability demands based on how these demands intersect with their core activities, strategic priorities, and sources of legitimacy.

Contractors adopt a procedural response, viewing sustainability as embedded in their everyday activities. Their main concern is operational efficiency, and failure to adapt to sustainability demands is perceived as a potential threat to survival.

Consultants demonstrate a human resources response, leveraging sustainability as a strategic instrument to attract and retain highly qualified staff. In response to growing expectations from both employees and clients, sustainability emerges not only as a core element of the business case but also as a critical dimension of strategic human resource management.

Project developers display a schematic response, aligning their practices with certification standards such as DGNB. Since certified buildings hold greater market value, developers align their sustainability efforts with these frameworks to enhance commercial viability.

Non-profit client organisations take a reputational response, driven by public legitimacy, political expectations, and democratic values. Sustainability is guided from the bottom-up by community stakeholders, making it less about compliance and more about symbolic alignment with public values.

CONCLUSION

Based on the presented findings, and the interest of the study to investigates how actors in the Danish construction industry experience and respond to demands aimed at promoting sustainability, it can be concluded that companies adopt distinct types of responses, depending on the nature of the demands they at facing. These responses—procedural, human resource, schematic, and reputational—reflect how sustainability becomes internalised into everyday work activities, incentives, and legitimacy strategies. Furthermore, it can be concluded that the sustainability demands experienced by the companies may originate from national and international regulatory frameworks but have progressively evolved into normative and cultural-cognitive demands. This evolution has led to an enhanced professionalisation of companies' sustainability practices and their capacity to leverage these practices as potential new business opportunities. Internal pressures on companies, as elucidated by the informants, primarily emanate from newly graduated employees who, even during the recruitment process, insist on engaging in sustainability work. This cultural-cognitive pressure, particularly from the younger generation, is described as a catalyst that motivates experienced colleagues and pushes the company towards more

sustainable practices. This observation is interesting as the industry in general faces significant issues attracting new employees and therefore this pressure can propel the green transition as it is a demand from the young generation when applying for a job.

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OPPORTUNITIES AND CHALLENGES FOR PROJECT BASED ORGANISATIONS IN LIGHT OF CLIMATE CHANGE: A CALL FOR INSTITUTIONAL ENTREPRENEURSHIP WITHIN PROJECT BASED ORGANISATIONS FOR REGENERATIVE CITIES

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Since Project Based Organisations (PBOs) deliver projects, their resilience and contribution towards building sustainable and regenerative communities cannot be overemphasized. Yet, research on climate change focuses more on the environment and the people with limited consideration of how PBOs are impacted. This study therefore reviews how climate change and subsequent demands for sustainability may impact PBOs within the UK construction industry by conducting a systematic literature review involving 28 papers. Institutional theory was adopted as the theoretical lens. Findings reveal that, as a positive impact, increased demand for sustainability-related services in response to climate change creates opportunities for PBOs. As a negative impact, response to new regulations, upskilling employees and acquiring sustainable materials/products create financial and operational constraints for PBOs. New planning regulations, sustainability activists and extreme weather may also disrupt supply chains, reduce job opportunities and delay projects. The implications are that instead of perceiving climate change and resulting regulations as constraints, PBOs should consider these as an opportunity to innovate and improve their project delivery. This is by engaging in institutional entrepreneurship mechanisms (developing internal practices, values and beliefs) and institutional linkages through 'causation', 'effectuation' and 'bricolage'.

Keywords: climate change; challenges, institutional entrepreneurship, project-based organisation, opportunities

INTRODUCTION

The devastating impact of climate change is being felt by communities across the globe such as the earth's rising average temperature due to human activities (Le *et al.,* 2024; Simath *et al.,* 2024). For instance, construction related activities account for 32% of materials consumed, 37% carbon emissions and 40% solid waste (Afzal and Tumpa, 2024). As such, building generative and resilient communities is being

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encouraged to spur and sustain social, economic and environmental benefits (Gallego-Schmid *et al.,* 2025). Consequently, communities are now adopting renewable energy, low transport systems and sustainable construction practices (Peek and Stam, 2019). The aim is to build regenerative and resilient cities which maintain their function in times of change or disturbance without the socio-ecological and socio-technical networks being strained by current or future demands (Peek and Stam 2019). Furthermore, the business world relies more on delivering services via projects due to increase in project complexity, size and population (Afzal and Tumpa, 2024; Hobday, 2000). This locates construction organisations at the very core of delivering sustainable projects in response to climate change and are a classic example of project-based organisations (PBOs). Hobday (2000, p. 874) defines PBOs as organisations "in which the project is the primary unit for production organisation, innovation, and competition". Though PBOs operate in different sectors such as advertising, entrepreneurship, film and aero industry, this study focuses on PBOs involved in the delivery of construction projects. Thus, this study refers to PBOs as permanent organisations operating within the construction industry (with a focus on the UK construction industry) that offer their services via (bespoke and one-off) projects. These range from large prime contractors to specialised subcontractors, small and medium enterprise (SME) and service firms (consultancies). With PBOs being involved in the design and delivery of various infrastructure which if poorly done impacts the natural environment and communities negatively (Griffiths *et al.,* 2020), sustainability competencies are no longer optional but imperative for PBOs to thrive in the evolving business world (Kato, 2024). Thus, adopting sustainability measures such as circular economy practices serves as an opportunity for PBOs to be efficient in their operations (reduced waste, streamlined value creation) and reduce harm to the environment (Afzal and Tumpa, 2024). Though such benefits exist, adopting sustainability measure and mitigating climate change may lead to business failures due to costs arising from standardisation and certification processes (Amankwah-Amoah and Syllias, 2020). PBOs also have perennial challenges such as scarcity of resources and finance, low profit margins, cost and schedule overruns (Chiponde *et al.,* 2022) which are exacerbated by measures (and regulations) in response to climate change (Afzal and Tumpa, 2024; Kato, 2024). Therefore, natural resource conservation does not encourage PBOs since they prioritise increasing market share and profitability (Kato, 2024). However, instead of a defeatism approach, this study encourages a growth approach amongst PBOs by embracing benefits arising from climate change and sustainability such as job creation, economic prosperity in regions, social responsibility, competitiveness and positive societal impact (Kato, 2024). Hence, the originality of this study is based on the adoption of institutional entrepreneurship through 'causation', 'effectuation' and 'bricolage' principles among PBOs. This enables PBOs to be initiators of change instead of the typical compliance approach which views climate change as a barrier. Thus, key research questions for this study are: What are the challenges and opportunities due to climate change that PBOs may face? How can PBOs harness opportunities presented by climate change?

Theoretical Positioning - Institutional Entrepreneurship Logics

Response to climate change involves interaction of a multilayer of actors and complex institutions (Pregnolato *et al.,* 2024). These may include, government (through existing and new policies and regulations), pressure groups, learning institutions, PBOs, environmental agencies, and non-governmental organisations (Matsler *et al.,* 2023; Bataleblu *et al.,* 2024). Therefore, to understand the impact of climate change,

the study adopted institutional theory. Institutions are defined as the rules of the game or norms that guide, restrict or influence behaviour of actors (Garud *et al.,* 2007; Pacheco *et al.,* 2010). Table 1 gives a summary of the main actors, pillars (sources of institutions/norms) and their impact on PBOs with respect to climate change. Since Institutional theory is criticised for discouraging change by favouring stability or stasis (Pacheco *et al.,* 2010), this led to the development of institutional entrepreneurship (IE) which encourages change and transformation (Garud *et al.,* 2007). IE is defined as "as individual actors, collective actors or processes creating, changing, maintaining or destroying institutions" (Weik, 2011, p. 474). Pacheco *et al. (*2010, p. 975) further note that "institutional entrepreneurs recognise the obsolescence of institutions, design new institutional arrangements, and engage in a variety of strategies (e.g., garnering resources, mobilising constituents, and framing issues to their advantage)". Two perspectives of IE are considered in this study. The first is economic IE, where an actor uses a current situation to gain economic benefits (self-vested agent). The second is sociological IE which ensures that proposed changes are desirable and align with norms, values and beliefs of a particular community.

Table 1: Sources of Institutions and Impact on PBOs Operations

Pillar	Examples	Key Players	Positive Impact	Negative Impact
Regulatory (coercion)	Planning regulations; Sustainability Development goals.	Government; local authorities; Funders; International organisations.	Raises standards; eliminates bad practice.	Higher costs; diminishing job opportunities. Long and costly planning process.
Normative (good/acceptable practice)	Training, knowledge standards, linked to climate change; new technology;	Professional bodies; learning institutions.	Improves tools, management and ability to mitigate climate change	Time and Training costs; Rigid;
Cultural-cognitive (values and belief).	Value and demand for sustainability	PBOs, social actors	Opportunity to deliver and demand for sustainability services/products.	Protests delay projects; competition from peer PBOs; ambiguating in understanding meanings.

Thus, instead of being implementers of regulations, PBOs through IE may alter (and improve) existing regulations (mode of operations) and introduce new ones. This may include developing institutional networks within construction and other sectors (Chiponde *et al.,* 2024), market research, reviewing policies and seeking legitimacy (acceptability of new products) (Hertin *et al.,* 2003). Thus, the study builds on the works of Fisher (2012) and Pacheco *et al. (*2010) who identify three mechanisms of IE namely; (i) 'causation' - focused on identifying problems and providing solutions or means; (ii) 'effectuation' - responding to unexpected situations, e.g., through research to improve mitigation measures and new solutions; and (iii) 'bricolage' which hinges on creativity (turning challenges into opportunities) by using available resources to solve problems. These three measures also serve as means of identifying challenges and mechanism of capitalising on the opportunities presented by climate change.

METHOD

The study adopted and exploratory research approach and secondary data was collected using a Systematic Literature Review (SLR) as discussed by Bryman (2012). This involved the following steps. Firstly, the databases were identified, namely Scopus and Google scholar. Secondly, the search phrase was formulated: "Project-Based Organisation" or ""Climate Change" or "Resilience" which produced 674, 181 results. Further refining the search phrase to "Project-Based Organisation" or ""Climate Change" or "Resilience" AND "Opportunities" AND "Barriers" reduced the articles to 2091. The third stage was the inclusion and exclusion criteria. The

articles related to other areas of study such as agriculture, medicine, fishing; petrochemical and biology were excluded. The inclusion was also limited to articles published between 2015 and 2025. This gave a total of 968 articles. Though the study focused on the UK construction industry; to better understand the problem and the wide-ranging impact climate change has globally, the selection criteria did not restrict articles from a specific region. Further review of the articles based on relevant sectors (e.g., construction, engineering, economics, and business) led to 55 papers being selected. The same search phrase generated 120 from Google Scholar and a total of 3 articles were selected based on the inclusion and exclusion criteria. The fourth stage involved title and abstract review for relevance which led to 28 papers being used in the analysis. Though, a limited number of articles with the term 'PBOs' were found, related terms were considered e.g., 'SMEs', 'implementors', 'practitioners' (Abbott *et al.,* 2024; Pinedo-López *et al.,* 2024; Simath *et al.,* 2024), 'large companies' (Bataleblu *et al.,* 2024); 'construction firms', 'design firms' (Griffiths *et al.,* 2020). Equally, though 'Climate Change' was not directly mentioned, related terms such as 'Circular Economy', 'Green Infrastructure' 'nature-based solutions' were considered. Thus, as a limitation, based on the search phrase, some articles may have been missed.

FINDINGS AND DISCUSSION

The data was analysed thematically by identifying the following main themes; (a) actors (b) challenges (d) impact of climate change and (d) opportunities. These were informed by institutional theory's regulatory, normative and cultural cognitive pillars and three I.E. mechanisms 'causation', 'effectuation' and 'bricolage'.

Key Players and Regulations in the Climate Change Agenda

Regulatory pillar-related organisations were prominent actors e.g., government, civic organisations and municipal council (Cuevas 2018; Op de Beeck *et al.,* 2024; Wilding *et al.,* 2024). This shows a 'push' and 'conform' approach to climate change with less participation of other key players. Other parties include non-governmental institutions, academic/research institutions, community groups and private companies (Azhoni *et al.,* 2024; Bataleblu *et al.,* 2024). Notable institutions include laws, policies, regulations, traditions, norms, and practices (Cuevas, 2018). Such examples include international climate change agreements e.g., Kyoto protocol, Millenium Development Goals (SDGs), Global Reporting Initiatives (GRI), Corporate Sustainability Due Diligence Directive, COP Paris 2015 agreement (Bataleblu *et al.,* 2024; Birchall *et al.,* 2023; Richardson-Barlow *et al.,* 2022). Leaders within construction organisations are also cited (Afzal and Tumpa, 2024). These findings further highlight how 'causation' as a response to climate change is common among actors and promotes conformity (to regulations and rules) without encouraging innovation or transformation among PBOs. Therefore, for PBOs operating within the UK construction industry to capitalise on any opportunities and mitigate climate change, it is crucial that they navigate the various, international and local complex regulations. This calls for collaboration with key players from local and international communities (Cuevas, 2018) to initiate change which benefits the wider community.

Challenges faced by PBOs

Though the various players share the common goal of mitigating the negative impact of climate change, achieving this is hindered by several barriers. The primary one is a lack of clear definition of climate change which is "ambiguous…, unpredictable and multifaceted (caused by multiple factors from multiple sources)" (Cuevas, 2018, p. 500). The unpredictable nature of climate change therefore renders most of solutions,

especially regulations, and to address such, PBOs are encouraged to adopt 'effectuation' which is focused on responding to unpredictable situations through research. In addition, guidelines of defining sustainability within SMEs are also lacking (Mura *et al.,* 2020). Griffiths *et al. (*2020) also note that measuring tools simplify the complexity of sustainability and hide other underlying issues. Normative responses (academia, research, professional practice) to climate change such as risk management, environmental and infrastructure management are rigid, slow and incomplete, with complex responsibilities and structure (Cañavera Herrera and MacAskill, 2021; Bataleblu *et al.,* 2024). These challenges are summarised in the following main themes. The first theme covers direct challenges such as technological barriers e.g., lack of data or details on technologies on waste management and infrastructure, insufficient technologies, design and standards for reusable, recycled, and recovered materials (Pinedo-López *et al.,* 2024; Simath *et al.,* 2024; Thirumal *et al.,* 2024); limited number of contractors with the necessary technical skills, knowledge and experience, e.g., in retrofitting sustainable drainage systems (SuDs) (Wilding *et al.,* 2024). Le *et al. (*2024) and Kanyilmaz *et al. (*2023) also noted a lack of tools and data to compare alternative sustainable materials. Sustainable products being new with limited design and experience amongst actors are also not welcome since thy slow productivity (Le *et al.,* 2024). This may be due to lengthy permit processes and several documents that must be completed (Matsler *et al.,* 2023). The second theme covers institutional, or indirect challenges which include the following subthemes: Subtheme 1 - market-related barriers e.g., increased competition and cost due to lack of economic resources (Pinedo-López *et al.,* 2024) and competing public expenditure (Op de Beeck *et al.,* 2024). Influence of low-cost substitutes technology and products compared to sustainable products; high initial costs and risks in developing and adopting new products were cited e.g., low carbon railway transport and electric vehicles are expensive and face competition from cheaper alternatives. Taxes and surcharges, permits, fees, developer obligations and betterment levies, and licences though perceived as funding sources stifle PBOs (Kato, 2024; Herrador, 2024; Op de Beeck *et al.,* 2024). Subtheme 2 - PBO and industry related challenges e.g., company size, financial capacity, culture, and strategy may hinder adoption of sustainable technologies. For instance, Pinedo-López *et al. (*2024) echoed that large/financially stronger companies use digital tools e.g., artificial intelligence (AI), robotics, 3D printing, the Internet of Things, which small organisations may not afford. The industry's slow uptake of new technologies, fragmented stakeholders and regulations, lack of trained labour was also cited (Thirumal *et al.,* 2024). Subtheme 3 are political and regulatory-related barriers e.g., political office and regulatory changes. Since sustainability practices are long term based, politicians favour short term gains (to demonstrate their achievements) and in some cases new office bearers may not continue with existing sustainability agenda (Op de Beeck *et al.,* 2024; Wilding *et al.,* 2024). Inadequate regulatory enforcement; focus on end life instead of the whole life cycle; unqualified professionals and understaffing, lack of dedicated department to respond to climate change were also observed (Simath *et al.,* 2024; Zea-Reyes *et al.,* 2021). Subtheme 4 covered long standing social-related challenges e.g., low employment rates; housing shortage, poor waste management and transport all these vie with establishing sustainability measures. Corruption and bribery; reluctance to change from traditional building construction were other barriers observed (Simath *et al.,* 2024; Zea-Reyes *et al.,* 2021). Banwell *et al. (*2020) note cognitive and behavioural barriers (attitudes, beliefs, values, behaviours towards sustainability) e.g., poor public perception,

understanding, and clients with less emphasis on sustainability hinder sustainable practices (Wilding *et al.,* 2024; Tuydes-Yaman *et al.,* 2024). With such varying challenges, relying on regulations alone is insufficient. Therefore, adoption of collaborative and discovery centred approach by establishing IE practices via causation, effectuation and bricolage. For instance, sociological IE is key in mitigating behavioural barriers by ensuring that proposed sustainable practices align with norms, values and beliefs of a particular community through bricolage.

Impact of Climate Change on PBOs - Vulnerabilities

The first theme of the impact of climate change is direct impact (physical vulnerabilities). These include damage to the environment, water contamination, harming species and habitat by extended dry periods (Abbott *et al.,* 2024). Floods, landslides and rising sea levels also displace people damage infrastructure, crops and business (supply chain) interruptions (Wilding *et al.,* 2024; Pregnolato *et al.,* 2024). Such events reduce land (and job opportunities for PBOs) that can be used for construction or habitation purposes (Zea-Reyes *et al.,* 2021; Birchall *et al.,* 2024). The second theme is economic (institutional vulnerabilities) or indirect impact, E.g., cost of training and importing material; lack of finance or withdrawal; increase in insurance cost for flood prone areas; lengthy planning processes due to complex regulations, bureaucracy and protests. Introduction of international regulations also disrupt local businesses who cannot meet expected standards (Gallego-Schmid *et al.,* 2025). Emotional impact on communities by triggering anxiety, worry and stress due to uncertainty, imminent harm that threaten communities was another notable impact (Simath *et al.,* 2024). Thus, PBOs are encouraged to adopt cognitive measures (transforming the mind), from defeatism/resignation (anxiety, uncertainty, unawareness) to opportunity (need for change, creativity and innovation). This aligns with bricolage which encourages creativity and engaging different stakeholders. However, benefits may accrue from climate change responses, by adopting 'effectuation' such as developing rating tools which may enable the industry to have a common purpose, clarity, raise awareness, training and an indication of the market status. For instance, PBOs may assist with developing sustainability project management systems and diffusion of such ideas (Griffiths *et al.,* 2020).

Opportunities for PBOs

The first theme of opportunities includes economic opportunities such as job opportunities arising from sustainability measures e.g., retrofitting. This also encourages resource efficiency leading to reduced operational/maintenance costs, improved reputation, competitiveness and increased market share (Kato, 2024; Gallego-Schmid *et al.,* 2025). Financing opportunities arise such as European Grant funding to prioritise nature-based solutions projects; co-finance arrangements with utility companies (Op de Beeck *et al.,* 2024); multilateral funding eg. World Bank and The Asian fund. Private sector investments such as public private partnership (Uzuegbunam, 2024) and venture capital are also available (Kato, 2024). Thus, PBOs can capitalise on such opportunities through effectuation by adopting research-oriented responses. The second theme are Institutional related opportunities - Various organisations involved with climate change create networking opportunities to build compliance, awareness, knowledge and skills within PBOs and communities (Birchall *et al.,* 2023). For instance, Wilding *et al. (*2024) identified, aesthetics, environmental and education benefits of SuDs (teaching aids) when installed in schools. Thus, building on bricolage principles (working with stakeholders), PBOs can build a network of key actors in the sustainability agenda and further gain legitimacy from

communities. Overall, PBOs' opportunities can be associated with following areas; material manufacturing and recycling, waste management, and product/process design (Mura *et al.,* 2020; Harrador 2024; Mura *et al.,* 2020). Yet, majority of the studies discussed energy and transportation systems in developing smart cities (Pinedo-López *et al.,* 2024). Thus, from a causation of IE perspective (known opportunities), PBO's are encouraged address energy and transport related solutions to capitalise on opportunities presented by climate change. Worth stating is that it is difficulty to draw the relationship between climate change and benefits/opportunities due to lack of clear, relevant and accessible research data. Comparable costs or gains varying due to various factors such as location (Abbott *et al.,* 2024; Wilding *et al.,* 2024).

IE Response and Framework for PBOs to Develop Opportunities

The findings highlight limited consideration of IE principles of change and transformation. Instead, standardisation through regulations is common. For instance, Gallego-Schmid *et al. (*2025) suggest isomorphism via coercion force (climate change-related regulations and policies) and emphasize the role of the government and regulatory bodies. The normative force was evident from best practice (design standards, retrofitting, passive and nature-based solutions), research and learning institutions (Op de Beeck *et al.,* 2024; Simath *et al.,* 2024). Such approaches are restrictive in responding to climate (which uncertain ambiguous in nature) since they encourage conformism and standardisation. However, the cultural-cognitive force can be observed from Zea-Reyes *et al. (*2021) and Gallego-Schmid *et al. (*2025) who encourage participatory design and implementation of nature-based solutions to involve universities, schools and neighbourhoods in implementation and maintenance of 'green infrastructure'. Therefore, to enable PBOs actualise opportunities presented by climate change and avoid conformism (institutionalisation) to encourage change, creativity and discovery, the study recommends three mechanisms of IE, 'causation', 'effectuation' and 'bricolage' discussed by Fisher (2012) and Pacheco *et al. (*2010) shown in Table 2. These IE practices also offer opportunities of implementing long term measures and bridging regulatory, normative and cultural cognitive practices in mitigating climate change (Matsler *et al.,* 2023; Bataleblu *et al.,* 2024).

Table 2: The Three Mechanisms of IE in Response to Climate Change

Mechanisms	Description	Nature	Mode	Examples
Causation - Rely on Regulatory pillar	Known outcome and opportunities; selecting means to create the effect.	Predictable; Controlling the future; starting with the ends; outcome centred.	Problem identification; internal strategy.	Respond to design standards; sustainability goals.
Effectuation - Rely on Normative pillar	Situational approach; avoid; experiment; research.	Unpredictable; Subjective/unknown situations.	Discovery/Research; collaborating; networking; learning from others.	Propose new systems; rules; sustainable products and practices.
Bricolage - normative and Cultural cognitive.	Use resources at hand to solve problems;	Contextual/socially constructed; Perceive challenges as opportunities.	Creativity; multilevel actors.	Work with given resources and new solutions to solve challenges.

To support IE measures in Table 2, the study further recommends enabling factors grouped into the following themes. The first theme is PBO internal adjustments (micro): Strategy, leadership, values, training, and new tools aligned with mitigating climate change (Afzal and Tumpa, 2024; Kato, 2024). PBOs should leverage on AI and digital technologies to simulate reuse, recycling, production and waste reduction (Mura *et al.,* 2020; Kanyilmaz *et al.,* 2023; Pinedo-López *et al.,* 2024; Azhoni *et al.,* 2024). The second theme is external (institutional) or macro level factors e.g., collaboration and partnering with other key players such as government, peer PBOs, communities and learning institutions. Governments should also provide incentives

such as capital for green technology, reduced taxes and research subsidies and grants (Matsler *et al.,* 2023; Kato, 2024). Incentivising recovery of brownfields and using local suppliers and materials and including sustainability themes in selection criteria should be encouraged (Mura *et al.,* 2020). To advance knowledge, best practice, inform national policy strategies, PBOs are encouraged to share success and failure-related stories or poor performing climate change practices (Mura *et al.,* 2020; Simath *et al.,* 2024). Therefore, the implications at that rather than calling for individual PBOs generating distinctive logics, multidisciplinary actors should be engaged with varying needs, across institutions (local and international), time and size (Garud *et al.,* 2007; Bataleblu *et al.,* 2024). Changing the actors' perception of climate change remains key by avoiding a fatalism approach (climate change perceived as harmful) by adopting the 'opportunity' (creativity) perspective which embraces transformation through effectuation and bricolage. Overall, by adopting a sociological perception of IE, PBOs should develop sustainability measures that benefit actors at individual, firm, and society levels instead of focusing on personal or organisational gains.

CONCLUSIONS

Overall, though climate change presents challenges, there is potential for benefits such as job creation, resilience, business efficiency, and improved public health (Herrador, 2024). To achieve that, PBOs should embrace creativity and transformation instead of standardisation by adopting 'causation', 'effectuation' and 'bricolage. IE will therefor transform PBOs from being deliverers of projects or abiding to regulations and rules to drivers of change. This can be achieved through proactively setting their own research agenda, new systems and processes, sustainability goals and guidelines to mitigate the negative impact of climate change. Furthermore, PBOs should build institutional network so that they are not only shaped by the external environment but equally influence the external environment. Thus, response to climate change and building regenerative cities, requires initiating and embracing change by building a cadre of regenerative PBOs instead of standardisation and response to regulations.

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FROM CLAUSES TO CARBON: A SMART SUSTAINABLE PROCUREMENT TOOLKIT USING NLP AND LCA FOR INFRASTRUCTURE PROJECTS

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Public procurement plays a pivotal role in achieving net-zero targets, yet current tendering practices often lack the tools to evaluate and operationalise sustainability commitments at scale. This paper presents a deployable Smart Sustainable Procurement Toolkit that enables procurement professionals to assess and benchmark sustainability clauses in infrastructure procurement documents. Developed and tested using UK railway sector data, the toolkit integrates Natural Language Processing (NLP) and Life Cycle Assessment (LCA) to semantically benchmark clauses against standards such as BREEAM, PAS 2080, and ISO 20400, and to quantify carbon impacts using verified Environmental Product Declarations (EPDs). Applied to over 300 procurement documents, the toolkit reveals patterns in credit prioritisation, actor-specific performance, and the weakening of sustainability across contractor tiers. While clients tend to issue strong, aligned clauses, suppliers and subcontractors often rely on vague or non-quantified language. By clause-level scoring, traceable carbon metrics, and an interactive dashboard for procurement, the toolkit enables transparent, enforceable, and data-driven procurement decisions. This work advances the use of NLP and LCA in construction management with a new model for semantic and carbon governance in sustainable procurement.

Keywords: BREEAM; environmental product declarations; life cycle assessment; natural language processing; sustainable procurement; semantic similarity

INTRODUCTION

Public procurement in the UK constitutes nearly a third of total public expenditure, with approximately £300bn spent annually on goods and services (Cabinet Office, 2022). This strategic purchasing power positions public infrastructure projects as a critical mechanism for delivering national sustainability and net-zero targets. Despite a growing policy momentum—from the Construction Playbook to the Transforming Infrastructure Performance: Roadmap to 2030—there remains a significant implementation gap in translating these frameworks into enforceable and measurable sustainability outcomes at the procurement stage (BEIS, 2021; Davies *et al.,* 2023).

Procurement for complex infrastructure like rail, is heavily document-driven. Early-stage procurement documents—including pre-qualification questionnaires (PQQs), specifications, and invitation to tender (ITT) materials—contain many of the embedded decisions that influence sustainability performance. Yet these texts are

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typically unstructured, fragmented, and reliant on discretionary language, which undermines enforceability, comparability, and accountability (Olanrewaju *et al.,* 2024). The absence of standardised semantic classification for procurement clauses further impedes consistency in sustainability evaluation across actors and projects.

Recent studies highlight the potential of digital tools, particularly NLP, to address some of these challenges. Ding *et al. (*2022) demonstrate how NLP can automate semantic interpretation in construction contexts, while Gbadamosi *et al. (*2021) show its value in improving procurement decision-making through clause-level analysis. However, most applications remain conceptual, with limited deployment in real-time procurement environments or integration with enforceable sustainability benchmarks. More critically, the use of NLP to assess clause enforceability—e.g., mandatory versus suggestive language—remains underexplored in construction literature.

Simultaneously, LCA provides a robust, standardised method for quantifying the environmental impacts of materials and products. Despite this, LCA remains largely disconnected from early procurement processes due to barriers in data availability, integration, and tool accessibility (Waldman *et al.,* 2020). While studies such as Gachkar *et al. (*2025) explore the use of text-based algorithms to automate life cycle inventory analysis, real-time integration of LCA data—especially via EPDs—into procurement document analysis is still rare.

The literature also lacks consensus on how procurement clauses should be semantically classified and evaluated against established sustainability frameworks. For example, while frameworks like BREEAM and ISO 20400 offer high-level guidance, there is little empirical work on how their requirements are embedded (or diluted) across different procurement actors (Loosemore, 2016; McNutt and Casey, 2022). The lack of clause-level traceability across clients, contractors, and suppliers' limits accountability in delivering sustainable outcomes.

In response to these gaps, this research develops a deployable Smart Sustainable Procurement Toolkit that semantically benchmarks procurement clauses against sustainability standards and quantifies their carbon implications using verified LCA data. By aligning textual procurement data with environmental performance metrics, the toolkit addresses the dual challenge of unstructured clause language and the absence of standardised sustainability evaluation in procurement workflows.

METHOD

This study adopts a mixed-methods research design, integrating NLP and LCA into a clause-level benchmarking framework to evaluate the sustainability performance of procurement documents in infrastructure projects. The objective is to determine how well clauses in pre-construction procurement documents align with established sustainability standards and whether material-related language can be linked to verified carbon impact data.

The approach was implemented through the development of the Smart Sustainable Procurement Toolkit, which performs two core functions:

- Semantic benchmarking of clauses using NLP,
- Quantification of environmental impact using verified data from EPDs.

Data Sources

Two categories of data (Figure 1 and 2) were used in the analysis:

- Historical data: including BREEAM New Construction manuals, PAS 2080, ISO 20400, the Procurement Act 2023, NEC4 contracts, and the BRE GreenBookLive EPD database.
- Live procurement data: consisting of real Invitations to Tender (ITTs), Pre-Qualification Questionnaires (PQQs), technical specifications, and supplier ESG submissions obtained from a UK railway redevelopment via the Find a Tender portal, RISQS, and TfL Procurement Portal.

Documents were segmented into clauses and categorised by procurement actor (client, Tier 1 contractor, Tier 2 contractor, or supplier).

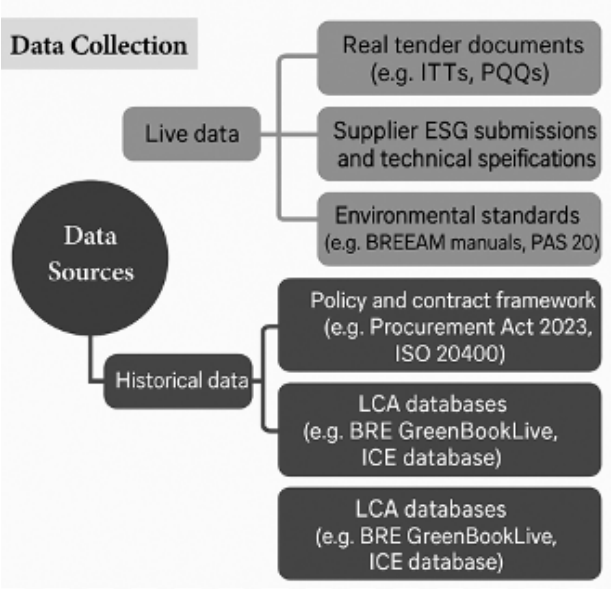


Figure 1: Phase 1 of Research Process: Data Collection

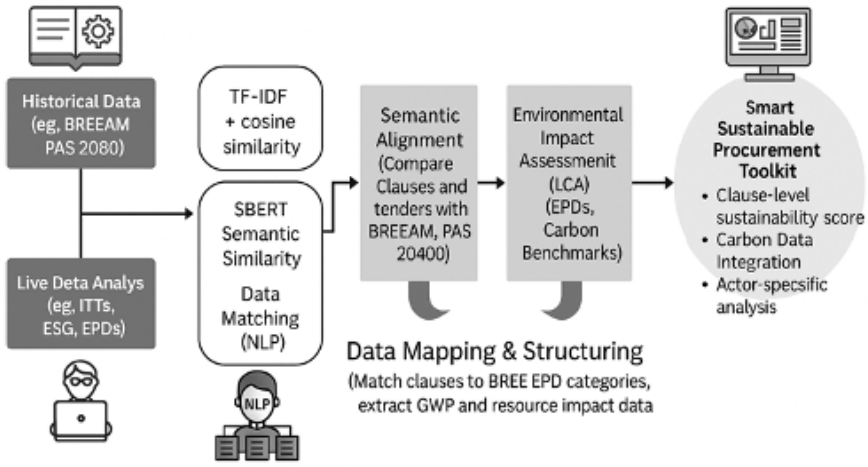


Figure 2: Phase 2 of Research Process: Analysis and Findings

NLP Tools and Justification

To assess semantic alignment between sustainability clauses and benchmark credit definitions (e.g., BREEAM Mat 01, ISO 20400), we employed two complementary NLP techniques:

- TF-IDF (Term Frequency-Inverse Document Frequency) was used to identify and weigh significant terms across documents, capturing how important a word is within a clause relative to the entire corpus.
- SBERT (Sentence-BERT) was applied to generate dense vector representations of clauses and benchmark definitions. SBERT captures contextual and semantic meaning at the sentence level, making it suitable for comparing full-length procurement clauses with structured sustainability credits (Reimers and Gurevych, 2019).

This dual method allows for both statistical term weighting (TF-IDF) and deep contextual understanding (SBERT), improving the reliability of clause-credit matching.

Clause Vectorisation and Similarity Scoring

To quantify semantic similarity, each clause and benchmark credit was vectorised using SBERT, and compared using cosine similarity:

$$\cos(\theta) = \frac{\vec{A} \cdot \vec{B}}{||\vec{A}|| \cdot ||\vec{B}||}$$

where A is the clause vector and B is the benchmark credit vector. Cosine similarity measures the angular distance between two vectors, ranging from 0 (no similarity) to 1 (identical match).

Thresholds for alignment were defined based on empirical testing and aligned with prior studies (e.g., Ding *et al.,* 2022; Castelblanco *et al.,* 2021):

- Example of bullet points
- Strong alignment: cosine score ≥ 0.80
- Partial alignment: 0.50 ≤ score < 0.80
- Weak alignment: score < 0.50

These thresholds were validated on a 50-clause pilot set, with manual review confirming the reliability of the 0.80 threshold for high-quality semantic matches.

Clause Modality and Enforceability

Each clause was analysed for modality—i.e., the strength of obligation—using rule-based identification of modal verbs. Clauses were classified as:

- Mandatory: use of "shall," "must," or "is required to"
- Suggestive: use of "should," "may," or "is encouraged to"

Modality was used to assess the enforceability of sustainability language across procurement tiers and linked to semantic and carbon performance.

Material Reference Detection and Carbon Quantification

Clauses with strong alignment to BREEAM Mat 01 were further screened for references to materials using Named Entity Recognition (NER) and rule-based keyword extraction. Phrases such as "steel frame," "timber panels," or "recycled concrete" were matched to corresponding product categories in the BRE GreenBookLive database.

To ensure traceability and validity:

- Only materials with third-party verified, ISO 14025-compliant EPDs were included.
- Carbon intensity data ($kgCO_2e/kg$) was extracted from modules A1-A3 (product and manufacturing stage), consistent with the scope of early-stage procurement decisions.

Clause Scoring Framework

Each clause was assigned a composite sustainability score based on three weighted components:

- Semantic similarity score (from cosine analysis) - 50%
- Carbon impact score (based on EPD data) - 50%
- Modality classification (used as an adjustment factor to penalise weak enforcement)

This scoring system enabled direct comparison of clauses across projects and procurement actors. Clauses with strong alignment, low-carbon material references, and mandatory framing received the highest scores (e.g., 4.5-5.0), while vague, suggestive, or non-quantifiable clauses scored below 2.0.

ANALYSIS AND DISCUSSION

4. Clause Alignment with Sustainability Standards

A key objective of the study was to assess how well sustainability-related clauses in procurement documents align with established benchmarks such as BREEAM, PAS 2080, and ISO 20400. Using NLP techniques—TF-IDF for term relevance and SBERT for semantic similarity—312 clauses from live and historical procurement documents (2020-2024) were analysed.

Clauses were categorised based on cosine similarity with BREEAM credit descriptors:

- Strong alignment (≥ 0.80)
- Partial alignment (0.50-0.79)
- Weak alignment (< 0.50)

Five key BREEAM credits were applied: Mat 01 (Life Cycle Impacts), Man 01 (Project Strategy), Mat 03 (Responsible Sourcing), Ene 01 (Operational Energy), and Pol 01 (Emissions). Among these, Mat 01 appeared most frequently, especially in client-issued documents, reflecting a dominant emphasis on early-stage material considerations. Man 01 and Mat 03 followed with strategic integration in procurement strategy and material sourcing. In contrast, Wat 01 (Water Efficiency) and Pol 01 (Refrigerants) were underrepresented, in contractor and supplier documents.

This uneven distribution highlights an important insight: sustainability credits closely linked to early procurement decision-making are more likely to be embedded, while those requiring long-term tracking or operational controls are deprioritised. This is consistent with prior findings from Olanrewaju *et al. (*2024), who argue that procurement documents act as "vehicles of sustainability intent"—where the presence, clarity, and structure of clauses directly influence project delivery outcomes.

However, intent alone does not guarantee delivery. Without strong semantic alignment and standardised framing, even well-meant clauses may lack enforceability or traceability downstream. This underlines the need for clause libraries and benchmarking tools, like the one developed in this study, to systematically assess how procurement texts reflect sustainability frameworks.

From a theoretical standpoint, this also reinforces Castelblanco et al.'s (2021) view of procurement as a semantic interface—not merely a legal or technical mechanism, but a medium through which environmental standards are operationalised across fragmented supply chains.

5. Modality and Enforceability of Clauses

Beyond semantic alignment, the enforceability of sustainability clauses—i.e., how strongly they are expressed—plays a critical role in translating procurement intent into action. To evaluate this, each clause was analysed for modality using rule-based detection of modal verbs. Clauses were classified as:

- Mandatory (e.g., shall, must)
- Suggestive (e.g., should, may)

Findings reveal a sharp decline in enforceability down the procurement hierarchy. 78% of client-issued clauses were mandatory, compared to 41% for Tier 1 contractors, and just 18% at the supplier level. This suggests a progressive weakening of sustainability commitments as documents cascade downstream.

This trend is further shaped by the type of BREEAM credit. Credits like Mat 01 (Life Cycle Impacts) and Man 01 (Project Strategy) were more frequently framed as enforceable requirements at the client level, whereas credits such as Pol 01 (Emissions) or Wat 01 (Water Efficiency) often appeared in suggestive language, especially among Tier 2 and supplier documents.

These findings align with McNutt and Casey (2022) and Loosemore (2016), who highlight that sustainability language is often diluted through subcontracting layers, contributing to a breakdown in accountability. From a theoretical perspective, this points to a critical weakness in procurement as a governance mechanism: while procurement documents may encode sustainability goals, they lack systemic enforcement structures to maintain obligation strength across all actor tiers.

ISO 20400, which promotes sustainable procurement practices, emphasizes the importance of clear, enforceable language to ensure consistent application. However, the observed variability suggests that compliance with such standards remains uneven. Without consistent modality across documents, even semantically aligned clauses can fail to drive measurable outcomes—particularly in relation to carbon-intensive materials or scope 3 emissions.

The Smart Sustainable Procurement Toolkit addresses this gap by automatically classifying clause modality alongside semantic benchmarking and carbon data. This feature allows procurement teams to detect where obligations are weakening, and to intervene early—either by strengthening downstream contract language or revising clause libraries for future tenders.

In sum, the enforceability of sustainability clauses is not only a technical issue but a theoretical one, exposing the limits of procurement documents as instruments of transformation unless supported by consistent linguistic and structural alignment.

6. Carbon Quantification Using EPDs

To move beyond qualitative alignment, the study introduces a clause-level carbon quantification process using verified data from EPDs. This component of the Smart Sustainable Procurement Toolkit links material-referencing clauses to ISO 14025-compliant product entries in the BRE GreenBookLive database, enabling a practical assessment of embedded carbon intent within procurement language.

Clauses aligned with BREEAM Mat 01 (Life Cycle Impacts) were screened using Named Entity Recognition (NER) and custom rule-based extraction to detect references to construction materials (e.g., "steel frame," "recycled concrete," "timber cladding"). A total of 102 Mat 01-aligned clauses were analysed:

- 46 clauses (45%) contained material references that could be matched to EPD categories.
- Carbon intensity values ($kgCO_2e/kg$) were retrieved from A1-A3 life cycle modules—the manufacturing stage most relevant to procurement-stage decision-making.

Table X presents examples of matched clauses, their semantic similarity scores, EPD carbon data, and final sustainability scores. For instance, a mandatory client clause referencing "recycled steel frame" received a composite score of 4.7 due to its strong semantic alignment (0.88) and low carbon intensity (0.92 $kgCO_2e/kg$). In contrast, a vague, suggestive supplier clause mentioning "durable concrete materials" without EPD linkage scored below 2.0.

This quantification process introduces a novel contribution to sustainable procurement practice: the ability to trace not just whether sustainability is mentioned, but to what extent it is measurable and enforceable through quantifiable product data. It supports prior calls by Waldman *et al. (*2020) and Gachkar *et al. (*2025) for more robust, automated integration of LCA data into early-stage construction decisions.

Theoretically, this work positions clause-based carbon scoring as a missing link between sustainability frameworks and procurement execution. Standards like PAS 2080 and ISO 20400 call for value-based, transparent procurement, but provide no operational guidance for evaluating unstructured text against environmental metrics. By filling this gap, the Toolkit enhances procurement's role as a carbon governance tool—not just through policy alignment, but through traceable, data-backed benchmarks embedded directly in contract language.

Furthermore, this approach reveals where semantic alignment fails to translate into carbon-conscious decision-making. Several clauses showed high similarity to BREEAM credits but lacked specific material references or EPD-compatible language, limiting their practical enforceability.

In sum, the integration of EPD-based quantification enables procurement teams to move from qualitative intent to quantitative verification, directly linking procurement language with measurable climate outcomes. This enhances both the accountability and granularity of sustainable procurement evaluations and suggests a new research avenue in clause-level LCA analytics for infrastructure governance.

7. Actor-Level Comparisons and Toolkit Use Case

A central function of the Smart Sustainable Procurement Toolkit is its ability to compare sustainability performance across procurement actors—clients, contractors (Tier 1 and Tier 2), and suppliers—based on clause alignment, enforceability, and carbon intent. These actor-level comparisons are visualised through the toolkit's interactive dashboard, which aggregates semantic scores, carbon intensities, and clause modalities for benchmarking.

Actor Comparison Insights

We studied five key BREEAM credits across actor tiers. The results indicate:

- Clients and delivery partners demonstrate the strongest semantic alignment, particularly for Mat 01 (Life Cycle Impacts), Man 01 (Project Strategy), and Ene 01 (Operational Energy).
- Tier 1 contractors exhibit moderate alignment, with noticeable gaps in enforceability and specificity, especially around Mat 03 (Responsible Sourcing).
- Suppliers and Tier 2 contractors show the lowest alignment across nearly all credits, and their clauses often lack carbon data or measurable commitments.

These findings underscore a declining gradient of sustainability ambition and precision as one moves downstream in the supply chain. While this pattern reflects the structural reality of construction contracting, it exposes a vulnerability in sustainability delivery: even if client-level clauses are robust, their downstream translation often weakens without standardised language, tools, or incentives.

This breakdown supports prior literature on fragmented accountability in procurement networks (Loosemore, 2016; Ghosh *et al.,* 2023), and extends Olanrewaju *et al. (*2024)'s argument that procurement systems must be audited not just at contract award but across the full document flow and actor hierarchy.

Toolkit Use Case and Practical Application

To address this fragmentation, the toolkit provides a visual and interactive interface where procurement teams can:

- View clause-level scores by actor and project phase.
- Identify underperforming credits or actor groups.
- Detect clauses lacking enforceability or carbon benchmarks.
- Compare clause wording side-by-side against high-scoring exemplars.

For example, a procurement officer preparing an Invitation to Tender (ITT) for a new rail station can use the dashboard (Figure 3) to:

- Review whether Mat 01 is already strongly embedded at the Tier 1 level.
- Flag supplier clauses that are suggestive rather than mandatory.
- Recommend the insertion of a pre-validated clause referencing low-carbon materials with linked EPDs.

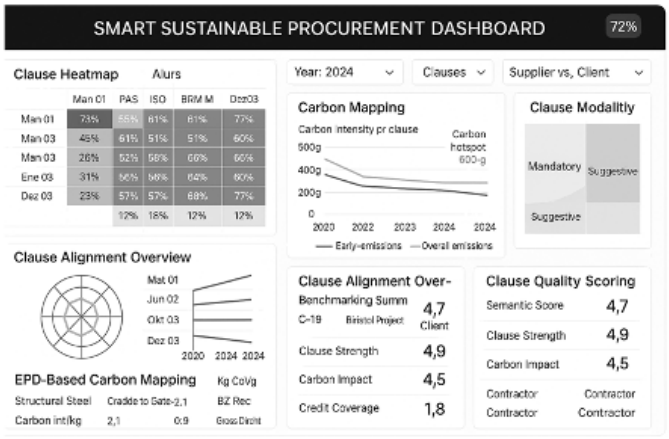


Figure 3: Smart Sustainable Procurement Dashboard: Clause-Level Insights and Carbon Benchmarking

This functionality transforms the toolkit from a research prototype into a practitioner-facing decision-support tool. It facilitates learning across projects, enforces

consistency in sustainability language, and supports alignment with frameworks like the Construction Playbook and PAS 2080. It enables procurement actors to not only comply with sustainability frameworks, but to do so with traceable, standardised, and verifiable documentation—a key missing mechanism in current infrastructure delivery.

CONCLUSIONS

This study presents a Smart Sustainable Procurement Toolkit that integrates NLP and LCA to benchmark sustainability clauses in infrastructure procurement documents. Developed using UK railway data, the toolkit aligns clauses with standards such as BREEAM, PAS 2080, and ISO 20400, assesses enforceability, and quantifies carbon impacts using verified EPDs.

Findings show strong clause alignment and enforceability at the client level, but a consistent decline downstream among contractors and suppliers. The toolkit highlights these gaps through actor-specific benchmarking and offers a practical decision-support interface for procurement teams.

Theoretically, the research contributes a clause-to-carbon model that positions procurement documents as tools for semantic and carbon governance. Practically, it enables traceable, standardised, and data-driven sustainability evaluations. Future work will extend the toolkit's scope, enhance generalisability across sectors, and integrate broader lifecycle data and international standards.

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A MIXED METHODS APPROACH TO DEVELOPING A FRAMEWORK TO MANAGE THE LEGAL AND CONTRACTUAL RISKS IN GREEN BUILDING

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Legal and contractual risks in green building (GB), such as ambiguous contract wording, certification delays, and the underperformance of green materials, pose significant challenges to the successful delivery of GB projects. To address these challenges, the broader research aims to develop a risk management framework tailored to the unique legal and contractual dimensions of GB projects. This paper focuses on the methodological approach underpinning the framework's development, guided by a pragmatic research philosophy and a sequential mixed-methods design. The qualitative phase involves semi-structured interviews with key stakeholders, including project managers, legal professionals and contractors, to explore risk perceptions and capture GB projects' diverse experiences. These findings will inform the design of a quantitative survey, aimed at validating and generalising insights across a broader sample. The methodology is designed to ensure that the proposed framework is both context-sensitive and generalisable, bridging theoretical and practical perspectives. By providing a robust and flexible methodological foundation, this work supports the development of tools to better manage legal and contractual risks in GB projects and contributes to the wider adoption of sustainable construction practices.

Keywords: contract law; green building; research methods; risk; sustainability

INTRODUCTION

In this methodology paper, the term "green building" (GB) refers to any materials, technology, or construction methods, including the construction, refurbishment, or upgrades to buildings and their systems aimed at reducing carbon emissions and meeting climate change requirements. GB introduces unique legal challenges, particularly as it intersects with complex regulatory frameworks and contractual obligations governing sustainability and environmental compliance (Mohammadi, 2016; Darabpour *et al.,* 2022).

As the construction industry aligns with the global push for sustainable development, there is increasing pressure to meet ever-stringent climate change regulations, which often translate into legally binding commitments within construction contracts (Gibbs and O'Neill, 2014). The lack of established legal precedents, coupled with the use of innovative materials and technologies, has resulted in legal and contractual uncertainties (Guan, 2016; Zhao, 2019; Wang *et al.,* 2023). Notably, the failure to incorporate clear sustainability clauses and green warranties into contracts can result

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Dickson, D (2025) A Mixed Methods Approach to Developing a Framework to Manage the Legal and Contractual Risks in Green Building, *In*: Thomson, C and Neilson, C J (Eds) Proceedings of the 41st Annual ARCOM Conference, 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 812-821.

in significant legal complications, as standard construction contracts frequently do not account for the specific requirements of GB projects (Shi *et al.,* 2015; Dickson 2024).

The importance of risk management in addressing these challenges cannot be overstated. Risk management provides a structured approach to identifying, assessing, and mitigating potential uncertainties (Smith *et al.,* 2014). Deloitte's (2021) guidance emphasizes the integration of climate related risks into risk management frameworks, particularly in industries like construction that are heavily impacted by environmental changes. Similarly, Smith *et al. (*2014) highlight that integrating risk management into construction projects enables practitioners to balance performance, compliance, and sustainability objectives.

This paper outlines the proposed methodology for a study that aims to develop a framework to manage legal and contractual risks in GB projects. Guided by a pragmatic research philosophy, the study will integrate qualitative and quantitative methods to ensure the framework is both context-sensitive and broadly applicable. Ethical approval for the study has already been secured, and this paper provides a detailed account of the planned research philosophy, design, methods, and anticipated contributions.

The proposed methodology builds on a series of foundational reviews conducted by the author to identify key challenges in managing legal and contractual risks in GB projects. The prior studies provide the basis for identifying the research gaps, shaping the methodology and informing the study design. The findings are summarised in the following sections.

Identification of Contractual Risks in Green Building

Findings from a state-of-the-art review identified the contractual risks in green building, that are in addition to traditional construction risks, these are summarised in Table 1. Noted studies highlighted GB projects share traditional project concerns (delay, performance, cost) but have additional challenges (Shi *et al.,* 2015; Yaman and Ariff, 2022). Risks from novel design paradigms, new construction technologies, and untested materials, coupled with the mandate for green certification were noted (Guan *et al.,* 2019; Zaoh *et al.,* 2016; Hwang, 2017; Koc, 2023; Yang, 2014). Schedule disruptions in GB are attributed to prolonged approval processes and insufficient green materials (Guan, 2016; Zaoh, 2015; Yang, 2014). Huo *et al. (*2023) identify imperfect contract drafting as a primary risk factor in public building green retrofit projects in China.

Repercussions of green specifications, payment delays, and inadequate dispute resolution mechanisms as discerned by Nguyen (2021) via a comprehensive review and hierarchical regression analysis. Kamfranfar *et al. (*2022) recognise legal risks as impediments to GB adoption, while Mohammadi (2016) categorises 18 legal risks within GB projects, stressing the significance of management strategies and macro-policies alongside technical aspects for successful project completions. Yaman *et al. (*2022) assess the viability of standard forms of contract for GB projects in Malaysia, unveiling deficiencies in accommodating GB advancements.

Table 1: Summarises the GB risks identified and corresponding author/s

GB Risks Identified:	Risk Identified by Author(s)
Deficiencies/Ambiguous Contract Wording	Prum and Del Percio (2009), Robinson and Smith (2012), Martin (2013), Huo *et al. (*2023) and Elowitz (2009)
Design failures	Loulakis (2009), Adriaanse (2016), Guan *et al. (*2019), Zaoh *et al. (*2019), Hwang (2017) and Koc (2023)
Delay in Green Certification	Guan *et al. (*2019), Zaoh *et al. (*2016), Hwang (2017) and Yang (2014)
Regulation/ Specification Risks	Shi *et al. (*2015), Yaman and Ariff (2022) and Nguyen (2021)
Failing/Underperforming Green Materials/Technology:	Prum and Del Percio (2009) and Kubba (2019)
Expertise Deficiencies	Ashuri (2010) and Prum and Del Percio (2009)
Scheduling Complexities	Guan *et al. (*2019), Zaoh *et al. (*2016) and Yang (2014)
Potential for Disputes	Brewster (2011), Alabady (2017) and Prum and Del Percio (2009)
Insurance Coverage	Riggs (2009), Glavinch (2009) and Shifton (2021)
Green Washing	Delmas and Burbano (2011) and Seele &Gatti (2017)
Green Finance	Feitas Netto *et al. (*2020) and Piper (2022)

The UK legal framework for green building (GB) reflects significant progress toward sustainability and alignment with national and international climate goals. It covers areas such as energy efficiency, biodiversity, and carbon reduction, supported by key legislation including the Climate Change Act 2008, Environment Act 2021, and Building Regulations 2010 (Dworkin *et al.,* 2022; Jones, 2021).

Judicial decisions, such as R (on the application of Finch) v Surrey County Council and Others [2024] UKSC 20, have addressed critical legal gaps, enhancing accountability and incorporating evolving sustainability standards (McCarthy, 2024). However, enforcement challenges and inconsistencies in contractual obligations underscore the need for more robust compliance mechanisms and clearer guidance (Foster and Green, 2019).

While the legal framework offers flexibility and supports innovation, it lags behind rapid technological change and insufficiently incentivises circular economy principles (Zhao, 2020). Moreover, fragmentation across statutes and regulations adds complexity for stakeholders (Smith, 2021). Strengthening the legal landscape through improved enforcement, standardised contract clauses, innovation incentives, and streamlined regulation would better support the demands of sustainable construction (Thomas and Williams, 2023).

Evaluation of Existing Risk Management Frameworks, Industry Standards and Legal Guidance

This analysis reviewed existing risk management frameworks, industry standards, and legal guidance relevant to the construction sector. Key findings indicate that while tools such as ISO 31000, the RICS Management of Risk and Whole Life Carbon Assessment (WLCA), NEC secondary X29 clauses, and The Chancery Lane Project (TCLP) climate clauses offer valuable resources, none fully address the combined legal, contractual, and sustainability risks inherent in green building (GB) projects (Dickson, 2025). Deloitte (2021) highlights the importance of embedding climate-related risks within existing frameworks like ISO 31000 or BS 31100, while Smith *et al. (*2014) emphasize the role of structured risk frameworks in mitigating uncertainty.

Professional standards also enhance accountability and inform decision-making (Jones and Cooper, 2016).

The RICS (2023) WLCA standard, complemented by PAS2080:2023, provides a comprehensive method for assessing both embodied and operational carbon across project lifecycles. However, like other standards, it lacks coverage of legal and contractual risk dimensions, necessitating integration with broader frameworks or contract-specific tools. While current frameworks offer robust methodologies, they often require adaptation to address sector-specific GB challenges (Smith *et al.,* 2014). Sustainability standards provide clear benchmarks yet frequently omit legal and contractual considerations (Jones and Cooper, 2016). Similarly, legal instruments support compliance and risk allocation but may need bespoke amendments to align with GB objectives (Deloitte, 2021).

Overall, no single tool offers a holistic solution to the intersecting risks faced in GB projects. These findings reinforce the need for an integrated framework that combines risk management principles, sustainability targets, and legal compliance.

Gap in Existing Literature and Contribution

Despite a growing body of research addressing general risks in GB, the existing literature reveals several critical gaps. Firstly, while numerous studies identify the contractual risks unique to GB, such as ambiguous contract wording, and certification delays, these risks are identified in isolation with no recommended solution for risk management. Secondly, a review of academic models and professional approaches to risk management in general shows, although there are tools available, none comprehensively address the intersection of legal, contractual and sustainability risks in GB. The paper contributes to knowledge by presenting a methodologically rigorous and philosophically grounded approach to developing a risk management framework that addresses the underexplored intersection of legal, contractual, and sustainability risks in GB projects.

Rationale for a New Framework

The findings highlight a pressing need for a new framework that specifically addresses the legal and contractual risks of GB projects. Such a framework would need to:

- Manage the identified risks effectively, including regulatory compliance and sustainability certifications
- Align with industry standards, such as PAS2080 and the RIS WLCA standards, to ensure compatibility with existing practices
- Provide practical tools and guidelines for stakeholders, ensuring clarity in contracts and reducing the likelihood of disputes

The findings informed the development of the study's research questions and methodology, ensuring the proposed framework is grounded in the specific challenges of GB projects and aligned with industry needs.

Objectives

The overarching aim of the study is to understand the legal and contractual risks associated with GB projects and propose a framework to manage the risks effectively. The specific objectives are:

8. To identify the legal and contractual risks in GB
9. Understand the features and trends/themes of current studies on the legal and contractual risks in GB

10. Identify solutions already in place (traditional or otherwise) and how effective they are in managing risks in GB
11. Develop a risk management framework to manage the legal and contractual risks in GB

PROPOSED METHOD

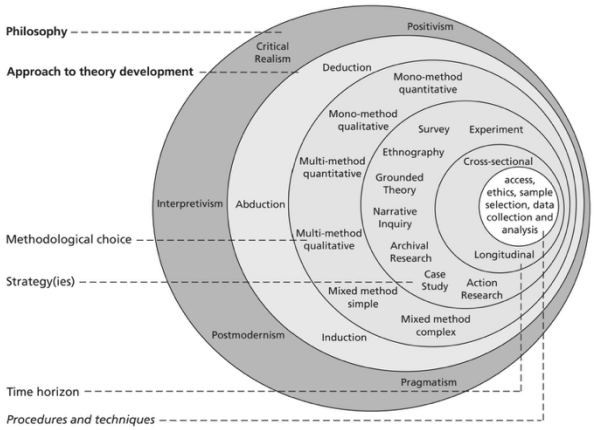
Research Design Selection

Several research design frameworks were evaluated for their suitability for the study. Tashakkori and Teddlie's Pragmatic Approach was examined for its focus on practical, mixed methods strategies (Tashakkori and Teddlie, 2003). While their model is effective for integrating simultaneous methods, it is less appropriate for the step-by-step sequential approach required by this research. Creswell's Mixed Methods Typology, which places strong emphasis on sequential designs, offer clear guidance on integrating qualitative exploration with quantitative validation (Morse, 1991; Creswell and Plano Clark, 2018).

The Saunders' Research Onion is a conceptual framework comprising of six distinct layers (as shown in Figure 1), which guides researchers through a series of design considerations leading to the selection of data collection and analysis methods at its core. The outermost layers address overarching factors, such as the researcher's philosophical perspective and approach to theory development. In alignment with Creswell's (2018) framework, the layers are interconnected, with the early decisions reflecting the researcher's underlying worldview and beliefs, which then influence all subsequent aspects of the research design (Saunders *et al.,* 2019).

Although Saunders' Research Onion does not specifically focus on mixed methods as Creswell's framework does, it was chosen for this study due to its simplicity, flexibility and well-structured layered approach to methodological selection (Saunders *et al.,* 2019). This robust framework ensures coherence between the study's research philosophy, design, and methods. The sequential approach outlined in the Research Onion allows for iterative refinement of the research design, making it suitable for addressing the study's aims effectively.

Figure 1: The research 'Onion' Framework (Mark NK Saunders, developed from Saunders et al., 2019)



Research Philosophy

This study adopts a pragmatic research philosophy to balance academic contribution with practical relevance for industry stakeholders. Pragmatism, which emphasizes

real-world applicability and outcome-driven inquiry, supports methodological flexibility through the integration of qualitative and quantitative methods (Patton, 2002; Tashakkori and Teddlie, 2003). Ontologically, the study aligns with realism, recognising risks, such as non-compliance with environmental regulations or certification disputes, as objective phenomena. Simultaneously, it acknowledges the socially constructed nature of risk perception, shaped by roles, professional practices, and industry norms.

Epistemologically, it adopts an interpretivist stance to explore how various stakeholders (e.g., project managers, legal professionals, contractors) perceive and manage legal and contractual risks. For instance, interpretations of sustainability-related contractual obligations may vary significantly depending on stakeholder priorities, necessitating a flexible and context-sensitive approach to data collection and analysis. Axiologically, the study is grounded in values of sustainability, fairness, and transparency, ensuring ethical alignment with the construction sector's real-world challenges while delivering actionable outputs for green building (GB) projects.

Approach to Theory Development

An abductive reasoning approach underpins the study, consistent with its pragmatic orientation. Abduction begins with real-world observations, derives patterns from stakeholder input, and validates these through quantitative methods (Saunders *et al.,* 2019). This iterative process bridges theory generation and testing, allowing for continuous refinement of the framework and responsiveness to GB's contextual complexities.

Research Design

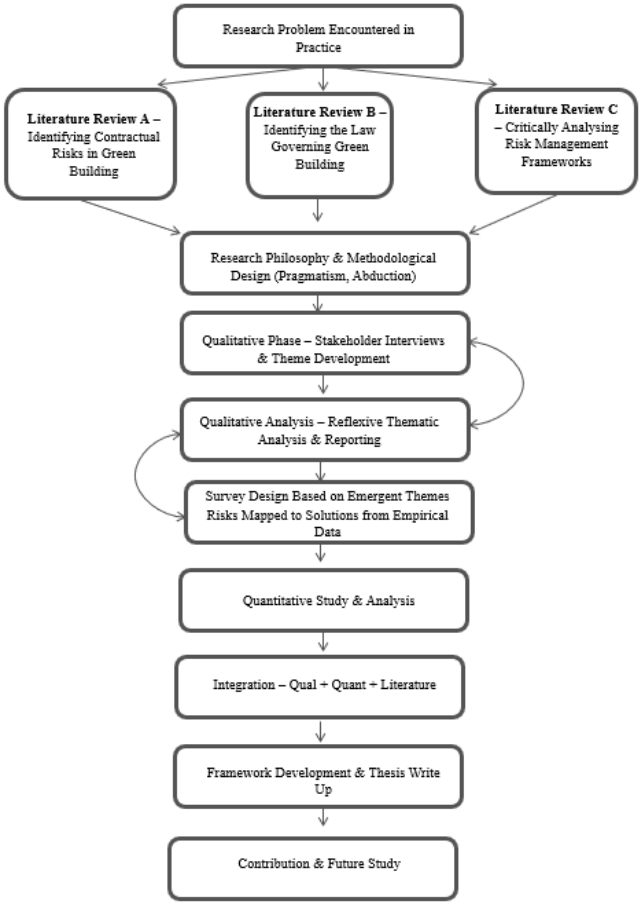
The study employs a sequential mixed-methods design, aligned with the pragmatic philosophy. The qualitative phase, via semi-structured interviews, captures stakeholder perspectives on legal and contractual risks. The quantitative phase, using structured surveys, validates these findings across a broader sample. This dual-phase strategy ensures both contextual sensitivity and generalisability, reinforcing the coherence between the research philosophy, objectives, and methods.

Primary Data Collection and Analysis

The qualitative phase will consist of semi-structured interviews with purposively selected stakeholders, including project managers, contractors, and legal professionals, chosen for their expertise in green building (GB) projects. A flexible interview protocol will allow for in-depth exploration of experiences while enabling the researcher to probe emergent themes. The subsequent quantitative phase will deploy structured surveys to validate the qualitative findings, test stakeholder consensus on identified risks, and assess the applicability of the preliminary framework to a broader context.

Qualitative data will be analysed using Reflexive Thematic Analysis (RTA) with a latent focus to identify themes and underlying assumptions (Braun and Clarke, 2019). Quantitative data will undergo descriptive and inferential statistical analysis to evaluate the reliability of findings and support framework validation. This dual-phase approach ensures both interpretative depth and empirical rigour. Figure 2 presents a conceptual flow diagram of the research process leading to framework development.

Figure 2: Conceptual flow diagram demonstrating the methodological process to develop a framework to manage the legal and contractual risks in green building



CONCLUSION

This paper presents the methodological foundation for the development of a framework to manage legal and contractual risks associated with GB. Through a pragmatic, mixed-methods approach, the study aims to bridge academic theory and industry practice.

The qualitative phase captures diverse stakeholder insights, while the quantitative phase validates findings across a broader sample.

Existing tools like PAS2080, RICS WLCA and ISO 31000 provide partial guidance, but fail to address the legal, contractual, and sustainability risks in GB projects. The study addresses that gap by developing a tailored, integrated framework.

This methodology supports the research's overarching objective: to build a practical, theoretical tool to support sustainable construction.

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ORGANISATIONAL COLLECTIVES FOR SUSTAINABLE CHANGE: HOPE OR HOAX?

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The sustainable transition of the construction sector represents a collective problem that necessitates collective efforts to address. This study presents preliminary findings from a study of 12 organisational collectives, defined as formal or informal assemblies of organisations pursuing collective entrepreneurial actions aimed at tackling sustainability challenges in the Danish construction sector. Empirically, the study is based on interviews with representatives from the organisational collectives, providing insights into their respective composition and activities. Mobilising the theoretical concept of collective institutional entrepreneurship, this study explores the efforts of four ideal types to drive sustainable change. It contributes to construction management research by offering new perspectives on organisational collectives as a distinct type of field-level institutional entrepreneur and by exploring whether these interorganisational arrangements represent genuine hopes or mere hoaxes for advancing sustainable change.

Keywords: collective action; collective institutional entrepreneurship; grand challenge; organisational collective; sustainability

INTRODUCTION

As a major contributor to environmental degradation and climate change, the construction sector is under pressure to deliver solutions that can address short-term sustainability challenges and advance long-term sustainable change. While construction management research has increasingly explored these issues in recent years, drawing on both macro- (Coenen *et al.,* 2023), meso- (de Gier *et al.,* 2025), and micro-level perspectives (Andersson and Buser 2022), a common denominator across studies is their emphasis on business ventures (Salmi *et al.,* 2022) and the everyday work of individual organisations (Gluch and Hellsvik 2023). One explanation for this focus, as Gluch and Hellsvik (2023) suggest, is the widespread understanding that the main barriers to sustainable construction are organisational rather than technical.

However, the dominant focus on individual organisations in construction management research is somewhat surprising, as sustainability challenges represent meta-problems (Seidl and Werle 2017)—problems that, while faced by individual organisations, go

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Frederiksen, N, Gottlieb, S C, de Gier, A, Holmegaard, R, Koch, C and Buser, M (2025) Organisational Collectives for Sustainable Change: Hope or Hoax?, *In*: Thomson, C and Neilson, C J (Eds) Proceedings of the 41st Annual ARCOM Conference, 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 822-831.

beyond their capacity to resolve alone (Ferraro *et al.,* 2015). Moreover, meta-problems are often situated at the organisational field level (i.e., a term comparable to an economic sector) rather than within individual organisations (Grodal and O'Mahony 2017). This suggests that current research may overlook the importance of field-level configurations and forms of interorganisational coordination in advancing sustainable change. Therefore, a gap exists in the literature concerning how interorganisational dynamics and collective agency contribute to sustainability transitions in construction, particularly given the sector's fragmented and project-based nature (e.g., de Gier *et al.,* 2025). To address this gap, we ask: how do organisational collectives in construction coordinate and pursue collective entrepreneurial actions for sustainable change?

To explore this, we present preliminary findings from a study of 12 organisational collectives operating in the Danish construction sector. Organisational collectives can be defined as formal or informal assemblages of organisations (Hofherr 2014) that are purposefully formed to leverage collective entrepreneurial actions at the field level. In this way, organisational collectives can be seen as a specific type of field-level institutional entrepreneur (Scott 2014) that aims to change existing rules, norms, and belief systems collectively. Yet, despite attention to institutional entrepreneurship among construction management researchers (e.g., Andersson and Buser 2022), few studies have examined how organisational collectives operate and function as vehicles for sustainable change.

Our empirical material consists of interviews with representatives from the 12 identified organisational collectives. We first group them according to the four ideal types of organisational collectives—agglomerate collectives, confederate collectives, conjugate collectives, and organic collectives—as outlined in the collective strategy typology formulated by Astley and Fombrun (1983). This typology offers a helpful heuristic for analysing their strategic orientations and allows us to distinguish how different types of collectives may have different strengths and weaknesses. We then discuss how each ideal type engages in collective entrepreneurial actions to foster sustainable outcomes. The study contributes to construction management research by offering insights into how organisational collectives, through coordinated entrepreneurial efforts, strive to address sustainability challenges and advance sustainable change in construction.

Collective Institutional Entrepreneurship

Institutional entrepreneurship has long been a central concept to understanding how actors initiate and drive institutional change. Traditionally, institutional entrepreneurs are seen as individuals or organisations that use resources, skills, and social positions to create new or transform existing institutions by changing existing rules, norms, and belief systems (Battilana *et al.,* 2009). However, growing attention has been directed toward collective forms of institutional entrepreneurship, where change efforts exceed the capacity of any single actor and emerge through the coordinated actions of multiple organisations or groups (e.g., Hardy and Maguire 2017). This shift highlights the distributed nature of institutional change, especially in fields where no single actor has the authority or resources to act independently.

Collective institutional entrepreneurship is defined by Wijen and Ansari (2007: 1079) as 'the process of overcoming collective inaction and achieving sustained collaboration among numerous dispersed actors to create new institutions or transforming existing ones.' Unlike traditional accounts that focus on heroic,

individual agents of change, this perspective emphasizes the collaborative and networked nature of institutional transformation (cf. Aldrich 2011). It recognises that institutional change is often too challenging for any one actor to drive alone and instead requires alignment among multiple actors (Aldrich 2011) with overlapping interests, complementary resources, and shared concerns (Hardy and Maguire 2017).

A central challenge in collective institutional entrepreneurship is mobilising resources, building legitimate narratives, and navigating institutional constraints through coordinated action (Fligstein and McAdam 2011). Collective institutional entrepreneurs must operate within existing power structures, using formal and informal networks to build support for new institutional arrangements (Garud *et al.,* 2007). These efforts often involve the construction of collective identities (Hofherr 2014) that bring diverse stakeholders together around a common purpose. Such identities do not exist from the outset but are gradually formed among actors who are, formally or informally organised around a shared purpose (Wry *et al.,* 2011).

The notion of collective entrepreneurial actions (Hofherr 2014) helps explain how collective institutional entrepreneurship unfolds in practice. These actions refer to the coordinated efforts of multiple actors who, through joint initiatives, aim to change rules, norms, and beliefs systems within a field (Pacheco *et al.,* 2010). Examples include lobbying, interorganisational partnerships, and the creation of new standards or normative frameworks.

METHOD

Our study draws on empirical material from 12 organisational collectives that have expressed an interest in addressing sustainability challenges or advancing sustainable change in the Danish construction sector. Over the past decade, such collectives have become increasingly prominent in the sector, likely due to growing awareness of the environmental impact of construction activities (e.g., Danish Ministry of the Interior and Housing 2021).

To identify relevant organisational collectives, the authors conducted a series of brainstorming sessions in spring 2023. Inspired by Alvesson and Sandberg (2022), these sessions involved sharing personal reflections and discussing key characteristics—such as purpose, membership, and activities—of collectives with which we were already familiar. Between sessions, one author conducted desk research to identify collectives that might have been overlooked.

The study employs a collective case study approach (Stake 1994) and is based on interviews with a representative from each of the 12 organisational collectives. The interviews followed an epistemic approach, emphasising the co-construction of knowledge (Berner-Rodoreda *et al.,* 2020). Informants were given predefined topics, including their collective's purpose, organising principles, and approaches for achieving intended sustainability goals. Interviews lasted between 42 and 73 minutes.

After conducting the interviews, we grouped the 12 organisational collectives into four ideal types of organisational collectives—agglomerate, confederate, conjugate, and organic collectives—based on the typology developed by Astley and Fombrun (1983). This grouping allowed us to analyse at the level of ideal type rather than at the level of each individual collective, thereby reducing our analytical scope from 12 to four units. Agglomerate collectives include competing organisations that do not directly interact. Confederate collectives include competing organisations that interact directly. Conjugate collectives include organisations that are not in direct competition

but interact directly. Finally, organic collectives include organisations that do not compete and do not interact directly. All types of collectives are present in our empirical material. Figure 1 presents an overview of the four ideal types of organisational collectives, while Table 1 provides a list of the identified collectives, the roles of the informants, and their grouping according to the four ideal types. The organisational collectives appear under pseudonyms for anonymity reasons.

Figure 1: Overview of organisational collective ideal types

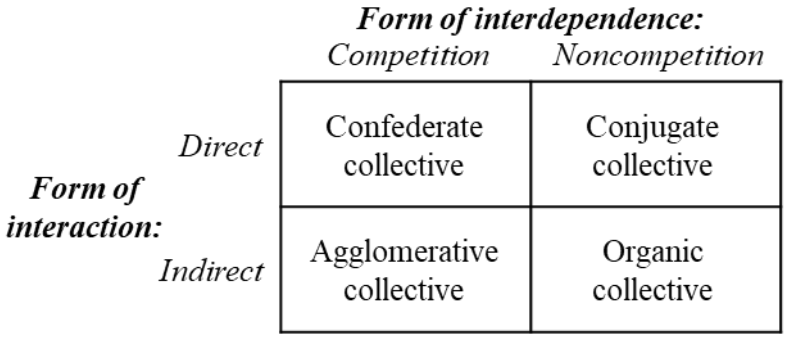


Table 1: List of organisational collectives, informants, and grouping

Name	Role of informant	Ideal type
Action Tank Towards Sustainable Construction	Project manager	Agglomerate
Coalition for Green Property and Construction	Coordinator	Agglomerate
Ecological Building Society	Chairman	Agglomerate
Partnership for Local Climate Innovation	Program manager	Agglomerate
The Circular Build Initiative	Project manager	Agglomerate
Community for a Circular Built Environment	Orchestrator	Confederate
Urban Regeneration and Circularity Partnership	Coordinator	Confederate
Circular Construction Knowledge Hub	Chairman	Conjugate
Circular Demolition and Waste Network	Chairman	Conjugate
Green Innovation Cluster	CEO	Conjugate
Green Building Network Burgundia	Coordinator	Organic
National Forum on Circular Building	Coordinator	Organic

FINDINGS

This section provides empirical insights into each of the four ideal types at an aggregate level. We specifically outline how coordination takes place and what collective entrepreneurial actions they pursue to change existing institutional arrangements in construction for sustainable purposes.

Agglomerate Collectives

Agglomerate collectives consist of organisations that, although in direct competition with one another, recognise shared sustainability challenges that cannot be addressed individually. These collectives are formed mainly to influence policymakers involved in formulating hard (e.g., the building code) and soft law (e.g., industry standards). This is exemplified by a coordinator: "In practice, we are a voluntary association lobbying to influence policymakers to make sustainability regulations stricter. And we believe they are more willing to listen if we speak as one coherent unit" (Coalition for Green Property and Construction). In practice, agglomerate collectives have two

different member compositions. On the one hand, they consist of organisations of the same species (e.g., client organisations), which are strategically important, powerful, or influential, with the argument that the more strength the collective attains, the more likely it is that it can influence policymakers. On the other hand, they can also consist of a wide spectrum of organisations of various species, which are, however, interrelated in the sense that they represent different parts of the construction value chain. The argument here is that the collective is more likely to come up with pragmatic solutions that can influence the work of policymakers if the solutions are collectively developed and reflect the needs across the value chain. A reflection of the latter is presented by a project manager: "We wanted to gather actors from across the construction value chain, as sustainable solutions will likely fail if they do not take the entire value chain into consideration. Therefore, our aim was to ensure that solutions were practical and operational, and addressed political sustainability goals" (Action Tank Towards Sustainable Construction).

The effort of agglomerate collectives to bring together strategically important member organisations to influence policymakers is also highlighted as a significant challenge of this specific type. For instance, a chairman indicates that the strength of certain collectives can be used to skew the debate and to promote greenwashing: "I would consider us a first mover within sustainable construction. But today, we're just one among many. However, it seems like most of the other associations who are interested in sustainability are in it for the profit and not for the sustainable change. I would say that they are frontrunners of greenwashing rather than sustainable construction, and we don't want to be compared to them" (Ecological Building Society). Another challenge is that the strategic composition of members may also be a strategic reason to opt out for some, which is a critique raised by several of the informants, arguing that most of the collectives claiming to represent the entire value chain are only represented by a selected few.

Confederate Collectives

Confederate collectives bring together organisations that are direct competitors but engage in active, direct interaction to address shared sustainability challenges. Unlike agglomerate collectives, where collaboration is characterised by a joint effort to influence policymakers, confederate collectives are jointly developing innovations, sharing knowledge, and coordinating efforts to address sustainability challenges in the construction sector.

Common to the confederate collectives is that they consist of members who work in parallel with each other in relation to a related topic, but where each party has a high degree of autonomy. For instance, one of the examined confederate collectives is the Community for a Circular Built Environment, which consists of 20 research and innovation projects that produce knowledge and practical solutions related to various dimensions of circular construction without the projects having any direct interdependencies. Membership only entails meeting with other members and sharing knowledge and experiences. The other examined confederate collective is a partnership consisting of different European municipalities, which meet to share and discuss experiences on urban development. In the same vein as the first example, the activities performed by the member organisations are highly detached from one another albeit being related to the same theme of urban development.

One of the weaknesses of this type of collective is that coordination is extremely difficult, which is likely because members are competitors who are supposed to share

knowledge and experiences. An orchestrator elaborates on this: "It is extremely difficult to uphold an efficient coordination among the members as they prioritise other things over attending activities. And why should they show up and talk about all their findings to some of their closest competitors?" (Community for a Circular Built Environment).

Conjugate Collectives

Conjugate collectives bring together organisations that are not in direct competition but are closely interlinked, for example as parts of the same value chain. These collectives are characterised as having a distinctly pragmatic focus, either on developing and disseminating new knowledge or facilitating innovation in pursuit of pragmatic solutions that require coordination and participation from member organisations working in different parts of the value chain where there are certain junctures. This is exemplified by a CEO: "We are working with business development through innovation processes with the participation of our member organisations. We have some money ourselves to invest in the process, but we do also fundraise so we can invest in more development activities. We are very focused on ensuring that the development activities should result in knowledge and practical solutions that our members can use" (Green Innovation Cluster).

As indicated by the CEO, conjugate collectives' strengths lie in fostering value chain innovation, either in the form of new knowledge or guidelines. The developed knowledge and guidelines can serve two different purposes. On the one hand, they can inform specific parts of the value chain about how to deal with specific issues at the borders of other parties, for example, issues regarding design-for-disassembly or selective demolition, which require the involvement of designers as well as contractors. On the other hand, they can serve to coordinate and guide parties across the value chain on how to work to align their activities.

One of the main challenges of conjugate collectives, as mentioned by several of the informants, is that they possess a power imbalance in the sense that business development and innovation processes are initiated top-down. In other words, the collective can decide on its what activities and agendas to support. This is explained by a project manager: "They can of course listen to their members needs and they are also dependent on having members, but ultimately they decide for themselves what they want to initiate in development activities and what topic to promote. This can potentially result in a very skewed development" (Action Tank Towards Sustainable Construction).

Organic Collectives

Organic collectives consist of organisations that only interact indirectly and do not directly compete. These collectives are characterised by their informal and highly voluntary nature, with participants coming and going as they want and having no responsibilities associated with their participation. Additionally, they do not prescribe any fixed roles or governance structures. These collectives emerge locally, rooted in specific local needs in relation to a bounded area, such as at the level of municipalities or regions, where the motivation is not only to address environmental concerns but also to enhance the social and cultural fabric of the local area. However, they can remain narrow and focused in scope or evolve significantly. For example, one of the examined collectives is operating within a municipality and striving to promote sustainable construction through the engagement of citizens in the municipality. The other started as a regional forum for circular building but turned out to be a

nationwide collective with participation of organisational members from all over Denmark, and occasionally also from abroad.

These collectives are distinctly focused on disseminating and sharing knowledge, thereby exchanging perspectives and maturing a specific dimension of sustainable construction. This is exemplified by a coordinator: "We meet to disseminate knowledge and discuss how we together can contribute to greening the construction activities in the municipality. It is about highlighting what opportunities there are, and then it is up to the members to materialise them themselves" (Green Building Network Burgundia).

One of the challenges of the organic collectives is their informal and voluntary nature. As indicated by the quotation by the coordinator, it is up to members to realise the identified potentials themselves, indicating that organic network itself has a weak position in terms of realising or implementing sustainability changes.

DISCUSSION

This section, we first discuss organisational collectives as field-level institutional entrepreneurs followed by a reflection of whether the collectives represent genuine hopes or mere hoaxes for advancing sustainable change.

Organisational collectives as field-level institutional entrepreneurs?
Organisational collectives in the Danish construction sector function as field-level institutional entrepreneurs, actively engaging in reshaping norms, rules, and belief systems related to sustainability. While individual organisations lack the ability to drive change alone, organisational collectives strive to coalesce organisations at the field level, which provide special opportunities for realising desired sustainable change.

Each collective type engages in efforts to facilitate institutional change through distinct patterns of coordination and collective entrepreneurial actions. Agglomerate collectives aim to influence policymakers by lobbying for stricter sustainability regulations and developing pragmatic policy solutions through either homogenous or value chain-spanning membership. However, they face legitimacy issues when collectives become venues for greenwashing or intentionally opt out key actors.

Confederate collectives promote sustainable change through joint knowledge development and innovation among competitors. However, the absence of strong interdependencies and the competitive dynamics among members create major barriers for effective coordination, often leading to weak participation and limited integration of outcomes across projects.

Conjugate collectives, by contrast, create pragmatic innovation across the construction value chain. They seek to develop actionable knowledge, practices, and guidelines that help resolve interdependencies, such as those between design and demolition. However, top-down control and power asymmetries may marginalise member priorities, raising questions about inclusivity and representativeness.

Organic collectives offer highly voluntary and informal spaces for idea exchange and local sustainability engagement. Their strength lies in fostering local knowledge sharing and opening debates regarding specific dimensions of sustainable construction (such as the circular construction), but their weak governance structures and voluntary nature also limit their capacity to implement or enforce change.

Together, these four types of collectives illustrate the variety of institutional entrepreneurship at the field level, highlighting different trade-offs between coordination, inclusion, autonomy, and impact. Table 2 summarises the some of the identified strengths and weaknesses.

Table 2: Identified strengths and weaknesses in organisational collectives

Type of organisational collective	Strengths	Weaknesses
Agglomerate	Lobbying power	Marginalisation of non-members; lobbying does not reflect broader sector needs
Confederate	Covering and disseminating insights on various aspects of a theme of common interest	Complex coordination
Conjugative	Value-chain innovation	Potential power imbalances and top-down focus
Organic	Possible solutions to sustainability challenges are explored	No interest in implementing and facilitating the needed sustainability changes

Organisational collectives - hope or hoax?

Despite their intentions to drive sustainable change, organisational collectives often experience collective inaction rather than meaningful collective action (Wijen and Ansari 2007). Several factors contribute to this. First, while organisational collectives are not commercial businesses, they often employ staff who depend on collective survival for their livelihoods, which can foster risk-averse behaviours that prioritise continuity over transformation.

Second, organisational collectives rarely hold formal authority over their member organisations, limiting their ability to enforce sustainability commitments. Specifically, the organisational collectives are in a position where they must balance the actions initiated with the needs and interest of their members, meaning that a significant number of members can be a strength (as demonstrated in the section on agglomerate collectives), while a too progressive search for sustainability results may cause members to give up their membership.

Third, many organisations, indirectly explained by several of the interviewees, join collectives for legitimacy purposes, using their membership to signal commitment to sustainability without necessarily engaging in substantive actions. This is particularly prevalent in agglomerate collectives, where perceived power and influence attract members who wish to benefit reputationally without contributing meaningfully.

Although organisational collectives and members seemingly acknowledge the importance of sustainable change, their motivations are often both substantive and symbolic. Substantive motivations stem from the need to address grand challenges collectively, while symbolic motivations serve individual interests—either for the collective itself or for its members.

This raises some critical questions that could receive further future attention. For example, would organisational collectives be willing to dissolve if they successfully

achieved their goals, or would they simply redefine their purpose to justify continued existence?

A final concern is whether collectives that lack formal governance, particularly organic collectives, can transition from norm-shifting discourse communities to impactful change agents. Conversely, in conjugate collectives, the potential for substantive innovation may be undermined if decision-making becomes too centralised and disconnected from member needs.

CONCLUSIONS

This study examined how organisational collectives in the Danish construction sector function as field-level institutional entrepreneurs and how four distinct ideal types—agglomerate, confederate, conjugate, and organic—mobilise coordination and entrepreneurial action. While these collectives recognise that sustainability challenges require collective effort, their ability to enact systemic change remains limited.

Agglomerate collectives aim to influence policymakers through joint lobbying; confederate collectives coordinate knowledge-sharing across independent efforts; conjugate collectives foster value chain innovation through top-down agendas; and organic collectives serve as informal spaces for dialogue. However, each type encounters specific challenges—ranging from coordination difficulties and power asymmetries to symbolic membership and weak implementation capacity.

These findings raise concerns about whether organisational collectives are genuine agents of transformation or symbolic constructs that maintain the status quo. Their structural characteristics—voluntary participation, symbolic signalling, and lack of authority—often impede their capacity to drive substantive change. To have greater impact, collectives must find ways to move beyond discourse and develop mechanisms that strengthen commitment, accountability, and alignment between goals and actions.

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REGENERATIVE CITIES IN ACTION: THE INTERPLAY OF STRATEGIES TO RESTORE ECOSYSTEMS, STRENGTHEN RESILIENCE, AND DRIVE SUSTAINABLE URBAN TRANSFORMATION

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The call for climate-resilient urban design has never been more urgent as cities worldwide grapple with rapid urbanisation, extreme weather events, and dwindling resources. This study adopts a systems thinking approach to uncovering the interconnected strategies for building regenerative cities that restore ecosystems, strengthen resilience, and drive sustainable urban transformation. Through a desk study and interviews with 17 experts from the UK, Sri Lanka, and Australasia, the research identifies seven core urban design principles with 36 strategies that restore, renew, and revitalise urban spaces and communities. The findings emphasize that sustainable energy and water management, governance, policy frameworks and technological innovations, and nature-based solutions are central to achieving regenerative cities. Using causal loop diagramming, the study uncovers 47 reinforcing feedback loops, including the dynamic between policy support and community engagement, that propel sustainable practices forward. A balancing loop was identified, showing how compact development reduces green infrastructure, mitigated by permeable surfaces. By advancing urban resilience frameworks, this study provides practical guidance for policymakers and planners, pinpointing areas where governance and practice should focus to overcome barriers and foster long-term sustainability.

Keywords: causal loop diagramming; regenerative cities; systems thinking; urban planning; urban resilience

INTRODUCTION

Urban areas, responsible for over 79% of global carbon emissions (UN-Habitat, 2024), urgently require transformative approaches to address climate risks. Regenerative cities—a paradigm shift beyond sustainability—aim not only to reduce harm but to actively restore ecosystems, foster equity, and create net-positive outcomes (Axinte *et al.,* 2019; Schurig and Turan, 2022). Unlike conventional sustainability models focused on efficiency, regenerative urbanism prioritises renewal, embedding cities as dynamic systems that enhance planetary health.

Global initiatives like Freiburg's renewable energy integration and Melbourne's urban greening programs demonstrate the potential of regenerative strategies to reduce

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emissions, boost biodiversity, and improve liveability (City of Melbourne, 2020; Rohracher and Späth, 2014). Key principles include nature-based solutions (NBS), circular economies, and participatory governance, which together restore ecological and social resilience. However, implementation barriers vary starkly: developed regions face infrastructural inertia, while developing nations grapple with resource constraints and inequity (World Bank, 2019).

Existing research often isolates components like renewable energy or green infrastructure, neglecting systemic interdependencies. This study addresses this gap by employing a systems thinking approach to map 36 interconnected strategies across seven urban design principles, validated by experts from diverse sectors. By analysing causal linkages and feedback loops, the research identifies synergies among regenerative city-building strategies, demonstrating how their integration can amplify ecological restoration, social equity, and climate resilience. It further pinpoints pathways to overcome systemic barriers, such as policy fragmentation or technological gaps, and offers actionable guidance for policymakers and planners to scale regenerative transitions. The findings bridge theory and practice, providing a roadmap for cities to operationalise regeneration through integrated ecological, social, and technological interventions.

Literature Review Synthesis

The regenerative cities paradigm challenges conventional urban sustainability by prioritising active ecological restoration, equity, and systemic resilience over mere harm reduction. Rooted in resilience thinking and circularity principles, this approach reimagines cities as living systems that repair ecosystems while fostering social and economic vitality. NBS and ecosystem-based adaptation (EbA) exemplify this shift, leveraging green infrastructure (e.g., urban forests, wetlands, permeable surfaces) to mitigate climate risks while enhancing biodiversity and liveability (Casteli Figueiredo Gallardo and Bond, 2025; Davies *et al.,* 2021). Case studies like Singapore's "City in a Garden" and Melbourne's urban greening initiatives illustrate NBS's dual role in cooling cities and improving air quality (City of Melbourne, 2020; Zingoni de Baro, 2022). However, critics caution that NBS's scalability depends on contextual factors like governance capacity and funding—variables often overlooked in Global North-centric success stories.

Similarly, circular economy (CE) models, which replace linear resource flows with closed-loop systems, face implementation asymmetries. While cities like Austria (59%), Wales (59%) and Taiwan (53%) achieve high recycling rates through advanced waste valorisation (Reloop and Eunomia, 2024), developing regions struggle with infrastructural gaps and informality, raising questions about CE's universal applicability. Critics argue that CE's techno-centric focus risks sidelining informal waste economies, which dominate in the Global South (UN-Habitat, 2024).

Participatory planning, another pillar of regenerative urbanism, emerged as a counter to top-down urbanism, emphasising community agency in shaping equitable spaces (Geekiyanage, 2020). Medellín's library-parks and Melbourne's "Open Streets" exemplify how co-designed public realms can bridge social divides (Cruz, 2025). Yet, the literature reveals tensions: while participatory frameworks theoretically empower marginalised groups, they often perpetuate exclusion when tokenistic or poorly institutionalised. For instance, Copenhagen's cycling networks, though lauded for accessibility, initially overlooked low-income neighbourhoods, underscoring the gap between inclusive rhetoric and practice (Gehl, 2010).

Climate-responsive design further illustrates the interplay of tradition and innovation. Bioclimatic strategies, such as passive solar design and green roofs, draw from vernacular architecture (Toroxel and Silva, 2024) but face modern barriers. For instance, Freiburg's Vauban district, despite its carbon-neutral ethos, required heavy subsidies, highlighting cost challenges in replicating such models (Rohracher and Späth, 2014). Meanwhile, debates persist on balancing compact development—praised for reducing sprawl—with green space preservation, as seen in Melbourne's contentious trade-offs between density and canopy cover (City of Melbourne, 2020).

Energy and mobility transitions reveal similar contradictions. While renewable energy systems and smart grids promise decarbonisation (IRENA 2019), their equity implications remain contested. Prosumer models, which decentralise energy production, often benefit wealthier households, exacerbating energy poverty (Milčiuvienė *et al.,* 2019). Similarly, digital mobility platforms (e.g., MaaS) risk excluding non-tech-savvy populations, challenging the inclusivity of "smart" transitions (Hensher, 2017).

Governance innovations, particularly polycentric and data-driven frameworks, are touted for enabling adaptive planning (Huang-Lachmann, 2019). Yet, Barcelona's sensor networks, though efficient, raise concerns about surveillance and data monopolies (Fernandez-Monge *et al.,* 2024). Such tensions underscore a broader critique: regenerative urbanism's reliance on technology and growth-oriented policies may inadvertently replicate neoliberal paradigms, prioritising efficiency over equity.

In synthesising 25 years of literature, a critical gap emerges: while strategies like NBS, CE, and participatory planning are well-theorised, their systemic interdependencies remain underexplored. Most studies isolate components (e.g., renewable energy or green infrastructure) neglecting how their integration amplifies or undermines regeneration. This fragmentation mirrors real-world policy silos, limiting cities' capacity to address climate change and inequality holistically. By foregrounding these gaps, this study's systems approach seeks to advance a more cohesive framework for regenerative urban transitions.

METHODS

A qualitative approach was adopted, combining a desk study of policy documents, urban regeneration case studies, and peer-reviewed literature with semi-structured expert interviews. This design aimed to identify regenerative city-building strategies and analyse their systemic interdependencies in achieving ecological restoration, social equity, and climate resilience. A purposive sampling technique ensured diverse perspectives from 17 experts in urban planning (34%), architecture (24%), climate resilience and policy (24%), and ecological engineering (18%) across the UK (41%), Sri Lanka (29%), and Australasia (29%). Experts were selected based on their academic contributions and involvement in regenerative urban projects, with 12 out of 17 (70%) having over 10 years of industry experience in relevant fields.

Interviews, conducted virtually, focused on validating 36 pre-identified strategies derived from the desk study and mapping their causal relationships through a participatory systems thinking lens (Sterman, 2000). Experts engaged in interactive discussions via the MURAL platform, where they identified interconnections between the 36 regenerative city-building strategies and established relationships between them. This process facilitated causal mapping within the urban system, revealing patterns of influence and key leverage points (Sterman, 2000). By integrating

theoretical frameworks, such as resilience thinking and circular economy principles, with practical insights, this approach ensured robust triangulation, strengthening the identification of feedback loops critical to regenerative urban transitions.

The qualitative data were analysed by coding thematic patterns to classify the 36 identified strategies into key urban design principles. These were then mapped within the causal loop diagramming (CLD) framework to establish causal relationships and systemic interdependencies (Forrester, 1995). CLDs visualise feedback loops, capturing reinforcing and balancing relationships in urban systems (Sterman, 2000), making them ideal for identifying leverage points for intervention in regenerative cities (Meadows, 2015). Each regenerative city principle was developed into a distinct CLD, integrating expert insights and literature synthesis. The CLDs were iteratively refined based on expert feedback to ensure an accurate representation of interdependencies. This process revealed reinforcing loops, where strategies amplified positive effects (Meadows, 2015), and balancing loops, where interventions mitigated urban challenges (Sterman, 2000). By structuring the analysis this way, the study provided a dynamic understanding of how regenerative principles interact and evolve.

Systems Thinking Data Analysis and Findings

The desk study identified 36 regenerative city-building strategies, systematically categorised under seven core urban planning and design principles that emerged from thematic coding. These strategies were validated by the experts, confirming their relevance without introducing additional ones. A causal analysis was conducted to map cause-and-effect relationships between strategies, identifying both intra-system (within a principle) and inter-system (across principles) interactions. The analysis captured directionality (positive or negative) to understand systemic correlations (Sterman, 2000). For example, Social Equity in Planning (n) positively influences Urban Green Infrastructure (a) and Public Transportation Networks (v). Conversely, Social Equity in Planning (n) is positively influenced by Cross-Sectoral Collaboration (ae) but negatively impacted by Compact/Mixed-Use Development (p). Table 1 summarises these interdependencies.

The causal linkages in Table 1 were structured in a CLD to analyse the cause-and-effect dynamics within and across urban design principles, highlighting key reinforcing and balancing feedback loops (Meadows, 2015). Each set of strategies under a principle was mapped to examine mutual influences and systemic effects, providing insights into how these principles drive regenerative urban transformation. The CLD framework revealed leverage points where strategic interventions could accelerate or regulate urban regeneration. The final CLD models, capturing these interdependencies with overall 47 reinforcing loops and one balancing loop, are presented in Figure 1.

(i) Nature-Based Solutions (NBS) and Ecosystem-Based Adaptation (EbA)
As shown in Figure **1(**i), experts identified seven feedback loops (R1-R7) where Urban Green Infrastructure (a) forms the core strategy for achieving NBS/EbA. Loops R1, R3, and R5 highlight the role of green infrastructure and biodiversity corridors in enhancing pollinator-friendly spaces and green surfaces, fostering ecological resilience. R2 and R4 focus on Blue-Green Networks and Integrated Water Management, ensuring water security.

Table 1: Systemic interdependencies between the strategies for building regenerative cities

Variable	Influences (Direction)	Influenced By (Direction)
(i) Nature-Based Solutions (NBS) and Ecosystem-Based Adaptation (EbA)		
a. Urban Green Infrastructure	e (+), f (+), h (+), m (+), r (+), s (+), t (+)	ac (+), ad (+), p (-), ae (+)
b. Wetland Restoration	e (+), s (+), o (+), aa (+)	ad (+), c (+), ai (+)
c. River/Coastal Restoration	h (+), o (+), e (+), f (+)	aa (+), ac (+), ae (+)
d. Urban Rewilding	e (+), f (+), m (+), n (-)	ad (+), p (-)
e. Urban Biodiversity Corridors	f (+), g (+), a (+), r (+)	a (+), d (+), ac (+)
f. Pollinator-Friendly Spaces	e (+), g (+)	a (+), d (+), n (+)
g. Biophilic Design	l (+), ai (+)	e (+), k (+)
h. Blue-Green Networks	a (+), s (+)	c (+), aa (+)
(ii) Circular Economy (CE) and Resource Efficiency		
i. Zero-Waste Cities	j (+), k (+)	ac (+), m (+)
j. Decentralised Wastewater Treatment	ab (+), aa (+)	i (+), o (+)
k. Sustainable Material Use	l (+), i (+)	ai (+), ab (+)
l. Resource-Efficient Building Design	q (+), x (+)	k (+), ai (+)
(iii) Climate-Responsive Urban Design		
o. Climate-Adaptive Infrastructure	s (+), r (+)	ad (+), aj (+)
p. Compact/Mixed-Use Development	t (+), v (+), a (-), n (-)	ac (+), l (+)
q. Passive Design Principles	z (+), w (+)	l (+), g (+)
r. Permeable/Green Surfaces	s (+), e (+)	h (+), o (+)
s. Stormwater Management	ab (+), o (+)	r (+), aa (+)
(iv) Governance, Policy Frameworks and Technology Innovations		
ac. Sustainable Urban Policies	a (+), i (+), p (+)	ad (+), ae (+)
ad. Climate Action Plans	a (+), b (+), d (+), w (+), u (+), o (+)	aj (+), ae (+)
ae. Cross-Sectoral Collaboration	n (+), af (+), aa (+)	ag (+), ah (+)
af. Smart City Solutions	ah (+), aj (+)	ae (+), ag (+)
ag. Digital Twin Models	aj (+), y (+)	ah (+), af (+)
ah. IoT Networks	z (+), y (+)	af (+), ag (+)
ai. Green Building Certifications	g (+), k (+)	l (+), w (+)
aj. Geospatial Analytics	ad (+), aa (+), o (+)	ag (+), ah (+)
(v) Sustainable Energy and Water Management		
w. Renewable Energy Integration	y (+), z (+)	ad (+), ai (+)
x. Energy Retrofitting	z (+), l (+)	w (+), ai (+)
y. Smart Grid Technologies	w (+), z (+)	ah (+), ag (+)
z. Building Energy Management (BEMS)	q (+), y (+)	ah (+), x (+)
aa. Integrated Water Management (IWM)	j (+), ab (+)	ac (+), aj (+)
ab. Rainwater Harvesting	s (+), k (+)	aa (+), o (+)
(vi) Sustainable Mobility Systems		
t. Non-Motorised Transport	p (+), v (+)	n (+), a (+)
u. EV Infrastructure	w (+), y (+)	ad (+), ac (+)
v. Public Transportation Networks	t (+), p (+)	n (+), ac (+)
(vii) Community-Led Inclusive Planning and Place-making		
m. Community Resilience Hubs	n (+), t (+)	o (+), y (+)
n. Social Equity in Planning	a (+), v (+)	ae (+), p (-)

R6 and R7 emphasize biophilic design and green building certifications, promoting sustainable architecture. These loops together create a self-reinforcing urban system that enhances biodiversity, water and energy efficiency, and climate resilience. Effective policy-driven collaboration (ac, ae) is essential for long-term success, with

cross-sectoral collaboration seen as critical for the implementation of regenerative strategies.

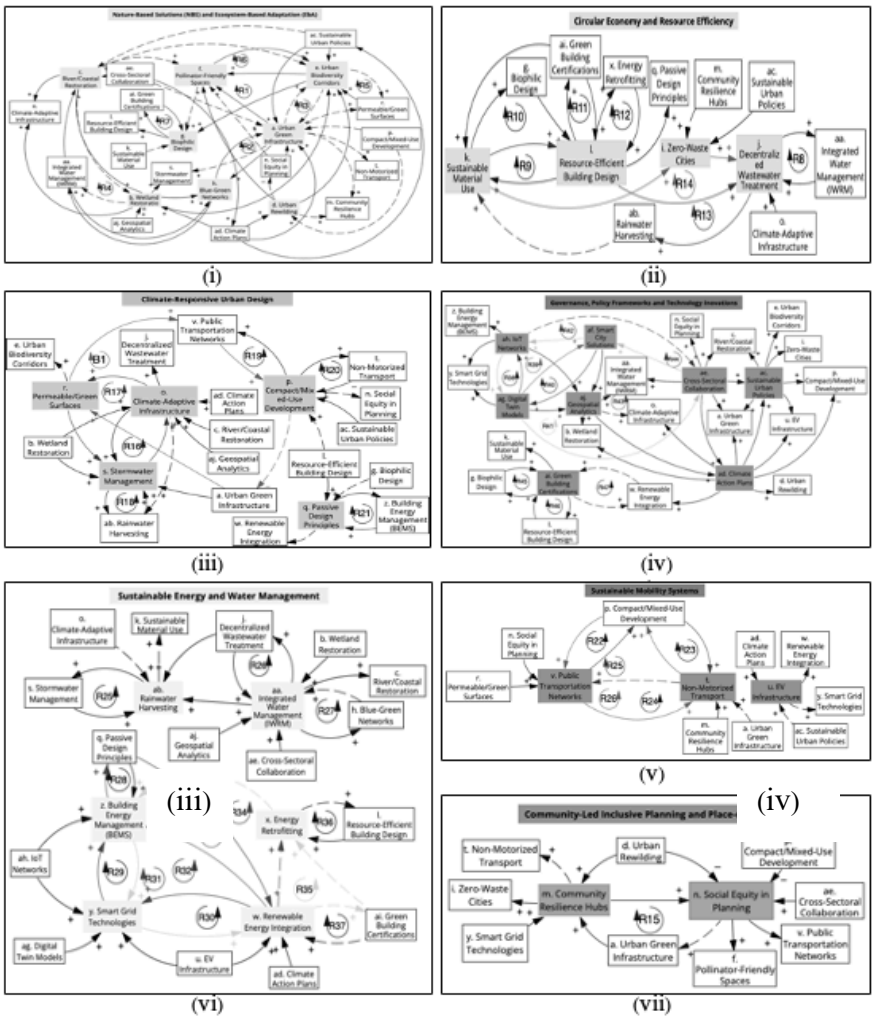


Figure 1: Causal loop diagrams illustrating interactions among strategies under seven urban planning and design principles of: (i) Nature-based solutions and eco-based adaptation, (ii) circular economy and resource efficiency, (iii) climate-responsive urban (vi) (iv) governance, policy frameworks and technology innovations, (v) sustainable mobility systems, (vi) sustainable energy and water management, (vii) community-led inclusive planning and place-making for building regenerative cities

(ii) Circular Economy (CE) and Resource Efficiency

Seven feedback loops (R8-R14), shown in Figure **1(**ii), illustrate how CE strategies support a self-sustaining urban system. Loops R8 and R9 link wastewater treatment and sustainable materials to resource-efficient construction and water management, creating closed-loop systems. Loops R10 and R11 connect biophilic design and green building certifications to material efficiency. R12 and R13 integrate energy retrofitting and rainwater harvesting into resource-efficient systems. Experts stressed that zero-waste policies (R13 and R14) and decentralised wastewater treatment are vital enablers of circularity. Aligning regulatory incentives with CE principles is key to supporting regenerative resource cycles.

(iii) Climate-Responsive Urban Design

Six reinforcing loops (R16-R21) and one balancing loop (B1) are identified, as shown in Figure **1(**iii). Loops R16-R17 highlight the synergy between stormwater

management and green surfaces, contributing to flood mitigation and urban cooling. R18 links stormwater management and rainwater harvesting for water conservation. Compact/mixed-use development (R19-R20) and passive design principles (R21) further promote energy efficiency and sustainable mobility. Balancing loop (B1) reflects land-use trade-offs, where increased compact development may reduce green infrastructure, though permeable surfaces mitigate these effects. As proposed by several experts in Sri Lanka, regulatory frameworks must incentivise green infrastructure in compact city designs.

(iv) Governance, Policy Frameworks, and Technology Innovations

Ten feedback loops (R38-R47) in Figure **1(**iv) demonstrate how governance, technology, and sustainability practices work together to support regenerative cities. IoT networks and digital twins (R38-R44) enhance smart city solutions, enabling adaptive policymaking and resource efficiency. Loops R45-R47 show how green certifications accelerate biophilic design, resource-efficient buildings, and renewable energy integration. While these loops can drive market shifts, experts caution that equity-centred governance is needed to avoid technological exclusion and ensure inclusive outcomes. Therefore, successful regenerative transitions require coupling technological innovation with inclusive governance and circular material flows.

(v) Sustainable Energy and Water Management Systems

Thirteen (13) reinforcing loops (R25-R37) demonstrate the integration of water and energy systems (Figure **1(**v)). Loops R25 and R26 show the bidirectional effects of rainwater harvesting and Integrated Water Management (IWM) on water strategies and policy. Loops R27-R33 highlight the role of smart grids and renewable energy integration in advancing energy efficiency. Loops R34-R37 emphasize energy retrofitting and renewable energy in strengthening the sustainable energy framework. These interconnected loops underscore the importance of governance, policy, and technology in achieving sustainable energy and water systems.

(vi) Sustainable Mobility Systems

Six feedback loops (R22-R26) reinforce sustainable urban mobility (Figure **1(**vi)). Non-motorised transport and public transportation networks (R22-R23) create mutual benefits by enhancing each other. Loops R24-R26 emphasize the interdependence of non-motorised transport, public transit, and transport infrastructure, promoting sustainability and reducing congestion. Given that, integrated transport systems are essential for reducing urban sprawl and fostering sustainability.

(vii) Community-Led Inclusive Planning and Place-making

As shown in Figure **1(**vii), a single feedback loop (R15) demonstrates the connection between community resilience hubs (m) and equitable urban planning (n). Green infrastructure (a) enhances community resilience by prioritising access to green spaces in underserved areas, which in turn supports social equity and climate adaptability. Experts emphasize the importance of participatory planning for long-term sustainability and regenerative urban transformation.

DISCUSSION AND STUDY IMPLICATIONS

This study advances regenerative urban discourse by quantifying systemic interactions among 36 regenerative city-building strategies through a CLD analysis, revealing 47 reinforcing and one balancing loop. While aligning with the literature on NBS and CE, it extends these frameworks by identifying critical governance and equity

dimensions often overlooked in practice. The CLD demonstrates how Urban Green Infrastructure (a) and Biodiversity Corridors (e) enhance ecological resilience through feedback loops (R1-R7), corroborating NBS's multifunctional benefits (Davies *et al.,* 2021). However, it uniquely highlights policy-driven collaboration (ac, ae) as a prerequisite for scaling NBS—a gap in cases like Singapore's "City in a Garden," where governance fragmentation risks undermining success without adaptive frameworks (Zingoni de Baro, 2022). Similarly, CE literature emphasizes closed-loop systems (Kara *et al.,* 2022), while the study reveals how decentralised wastewater treatment (j) and green certifications (ai) create self-reinforcing resource loops (R8-R14). Certifications, when enforced by policy (ac, ad), accelerate biophilic design (g) and renewable energy (w), bridging a gap in CE's market-driven scaling mechanisms. This aligns with Amsterdam's circular construction but stresses regulatory rigour to avoid greenwashing. The study also critiques equity narratives in participatory planning. While Medellín's Green Corridors validate place-making's potential (Silberberg *et al.,* 2013), the CLD's singular feedback loop (R15) exposes fragility in community-led systems compared to techno-centric models. Experts caution that grassroots initiatives require institutionalisation to prevent tokenism, as seen in Melbourne's balancing act between compact development (p) and green infrastructure (a) (City of Melbourne, 2020). Notably, the findings challenge techno-optimism in smart city literature (Huang-Lachmann, 2019). Smart grids (y) and IoT (ah) drive efficiency (R25-R37) but risk exclusion without equity-centred governance (n), echoing Milčiuvienė et al.'s (2019) energy justice principles. For instance, digital twins (ag) enhance predictive modelling but may marginalise underserved groups without participatory frameworks-a tension reflected in the weak influence of social equity (n) on pollinator spaces (f).

Theoretical and practical implications

The findings advance regenerative urban theory by framing cities as interconnected socio-technical-ecological systems rather than siloed domains. The CLD's 47 reinforcing loops illustrate how circularity, climate resilience, and equity are co-dependent, supporting Larsen's (2020) concept of "climate-adaptive urbanism" while offering a tangible framework for operationalising it. Practically, the study identifies leverage points: cross-sectoral collaboration (ae) amplifies policy coherence, while green certifications (ai) and IoT networks (ah) act as multipliers for sustainability transitions. However, experts cautioned that compact development (p) and technological innovations must be deliberately coupled with equity safeguards to avoid trade-offs-a lesson for cities like Freiburg and Copenhagen aspiring to carbon neutrality (Rohracher and Späth, 2014; Khan *et al.,* 2021).

Policy implications

The CLD underscores the need for adaptive, polycentric governance to manage systemic complexity. For example, Climate Action Plans (ad) strongly influence NBS, energy systems, and mobility (R38-R44), but their effectiveness depends on integrating informal governance networks-a gap noted in Medellín's grassroots initiatives. Policymakers must prioritise metrics for socio-ecological co-benefits (e.g., stormwater management (s) linked to public health) to align with UN-Habitat's (2024) regenerative goals. Additionally, the study advocates for mandatory equity assessments in urban policies to mitigate risks of technological exclusion, ensuring that regenerative transitions benefit all demographics.

CONCLUSIONS

This study systematically maps the interdependencies among 36 regenerative city-building strategies, revealing 47 reinforcing feedback loops and one balancing loop that drive synergies and tensions across seven urban design principles. Key findings highlight the centrality of cross-sectoral governance in amplifying policy coherence, the multiplier effects of green certifications and IoT networks in scaling sustainability, and the critical role of equity-centred planning in preventing technological exclusion. Urban policymakers, planners, and developers can leverage these insights to prioritise high-impact interventions, such as integrating nature-based solutions with compact development or coupling CE practices with participatory governance, to accelerate regenerative transitions. The study's limitations include its reliance on expert perspectives from Sri Lanka Australasia and the UK, which, while diversely sampled, may underrepresent region-specific challenges in other Global South contexts, such as Sub-Saharan Africa or South America. Additionally, the CLD's complexity, while illustrative of systemic interactions, requires simplification for practical application. Future research could validate these causal relationships through longitudinal case studies, incorporate citizen perspectives to enhance equity considerations and explore the role of informal governance networks in polycentric systems. By expanding the model to diverse urban contexts and integrating real-time data from digital twins (ag), cities can refine adaptive strategies that balance ecological restoration, technological innovation, and social justice in their pursuit of regeneration.

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A REGENERATIVE STRATEGY FOR CIVIC PRECINCT, NEWCASTLE, NSW, AUSTRALIA

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The purpose of this paper is to report on a study that investigates a traditional, but fragmenting part of a city centre. It demonstrates the challenges for the post-industrial city and proposes a strategy to help regenerate it as an enjoyable, culturally meaningful, and productive place. The theoretical standpoint reflects the literature on Linear, Compact and Sustainable City models, together with types of placemaking tools. It critiques the Australian interpretation of the Compact City and highlights its flaws as a regenerative process. The research design is a qualitative methodology. It involves three methods ie semi-structured interviews with leaders of organisations active in the city centre, observational data from international placemaking events, and scrutiny of planning documents. Key findings are that the strategy requires interaction between the environmental, social, economic, political, and cultural sustainability perspectives, through standard, strategic, infrastructure, tactical, and creative placemaking; and the uniting regenerative placemaking. This study presents a comprehensive analysis of the factors involved in the regeneration of a symbolic part of a city centre and serves as a touchstone for others to assess their own city centres.

Keywords: buildings; city centre; community; nature; spaces

INTRODUCTION

A settlement was established in New South Wales soon after 1800, at the estuary where coal was loaded onto ships, and called Coal River. As it developed, the title changed to Kingstown, and finally it was named after Newcastle upon Tyne in England. It remains a huge coal exporter, but this is now situated several miles up the Hunter River and away from the centre. It was also a steel city with the opening of the BHP Steel works in 1915. At its peak, the works employed 11000 people, but it closed in 1999. Thus, for the 21st Century, Newcastle NSW has become a post-industrial city. The city centre expanded along the harbour from East to West and now comprises five precincts (see Figure 1). The most culturally significant is the middle one known as Civic, containing most of the symbols of society. The decision in 2017, to move the Council offices from this precinct to the West End has been

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detrimental and undermined its position as the core of local government. The challenge for the city centre and for Civic in particular, is how to establish a regenerative place that meets current and future demands. The aim of the strategy is to restore Civic as the heart of the city centre.

Thomson *et al. (*2024) summarise much of the literature calling for transdisciplinary approaches to addressing the grand challenges and wider societal debates. They identify a need for construction management to broaden its horizons to a holistic outlook rather than just operating at the project level. Leringer and Dainty (2023) suggest that there is a tendency for construction management researchers to remain within the CM bubble and not engage with knowledge outside the specific domain. They assert that this approach fails to acknowledge the context for their research. The desire to investigate at the city level is an interesting departure for construction management and situates the discipline as a real player in the transdisciplinary setting.

LITERATURE REVIEW

The literature is based on city models and placemaking. Of the post-industrial city models, two of them especially encourage pedestrianisation and the use of public transport. The Linear City concept was developed by Spanish inventor, civil servant and town planner, Arturo Soria y Mata in the 1880s. It was founded on the construction of a light rail line to link Madrid with surrounding settlements. He proposed that city form should be determined by public transport (Soria y Mata,1882). The pattern is that the line runs along the length of the city centre, enabling short perpendicular walking distances. The concept had a revival in the late 20th Century, when there was concern about motor vehicles dominating city centres, and authorities started to introduce pedestrianised streets (Lynch, 1984). It also offers access to nature, especially where streets stretch along a natural feature, such as a waterfront. The limitation is concern about lack of centrality. There could be absence of a focal point, which otherwise promotes community cohesion and sense of place. Further, there is a potential for social segregation as different parts along the city centre could become socially isolated from one another. The Compact City or city of short distances has become iconic as a city form, and there is a plentiful literature associated with it. Originally conceived as a monocentric arrangement, various polycentric variations have been proposed in recent years. The principles of both versions of the model have numerous advantages in tackling climate change, environmental degradation, social cohesion, and economic development. There is also potential for meeting green growth objectives (Kain *et al.,* 2021). The concentration on density is justified by a list of positive benefits. They include enhanced public realm; reduced energy consumption; less pollution; greater diversity and choice of workplaces; increased social communication; reduced travel, decreased car dependency and less commute time. The underlying premise is that density in the compact city has multi-dimensional positive effects on life in the city centre. A noteworthy issue is that there is no established definition of high density, and interpretations vary in cities around the world. There has also been different measurements of building density and population density resulting in ambiguous analyses. The Australian interpretation of a compact city has essentially been the construction of high-rise buildings. These can create several negative effects, including urban heat islands due to their large surface area, disrupting wind patterns, reduced daylight access to surrounding areas, impact on air quality, and contribution to increased energy consumption (Nugroho, *et al.,* 2022). Social effects involve decreased interaction, feelings of isolation, reduced community cohesion, and increased anonymity among residents due to the limited

opportunities for casual encounters with neighbours compared to low-rise living. These can particularly impact mental health and well-being (Chile *et al.,* 2014).

Both models have been integrated into the Sustainable City. The first iteration of this model was that it should be designed and managed regarding environmental, social and economic impact. This was often referred to as the triple bottom line or three-legged stool. It required a resilient habitat for existing populations with walkable neighbourhoods, efficient transportation systems, green spaces, and mixed-use development to promote quality of life. As the concept developed, it included political and cultural perspectives, and several other dimensions. The environmental objectives are to create more comfortable and lasting spaces by mitigating the effects of temperature, wind, and flooding, especially with respect to climate change. Equally important is to reduce noise and pollution, conserve energy and support the natural world. These objectives may be achieved through the design of spaces defined by buildings at a human scale to generate coherent urban patterns, rather than the development of individual buildings in space. Particularly significant is the reduction of road space, and the increase of pedestrian and green spaces (Fields and Renne, 2021). Within the social perspective, Unruh (1980) identifies three groups who could populate the city centre. Insiders are permanent residents, regulars are people who frequently come into the city centre from the region, and national and international visitors, who are there for short periods of time. It is consistently argued that a wide demographic of insiders is essential to a vibrant city centre. It offers permanency and heterogeneity. Regulars are vital to trade and supporting activities. Visitors are often termed tourists. The latter are generally perceived as an economic benefit and are welcome in controlled numbers. Some recent experiences in Europe have demonstrated overtourism, which is having a negative effect on some places. Visitors can have more educational value. They may be keen to learn about the people and place and take knowledge back to their own cities (Środa-Murawska *et al.,* 2021).

There is a growing group of temporary residents that does not fit any of these categories. Increase in numbers of the affluent retired means that there is a noticeable increase in second homeowners, who move between properties in major cities, and towns or smaller cities when they are seeking a more peaceful environment. At the other end of the spectrum is the world-wide phenomenon of studentification (Smith *et al.,* 2014), and the large influx of students into a small city centre can considerably alter its character, with impact on housing, business, and social dynamics. High numbers of students may create a shortage of housing options and inhibit the desire of families to live in the locality. They can engender the increase of cheap eateries, bars, and convenience stores, replacing more diverse local shops. Their enjoyment of a vibrant nightlife could generate social tensions. There is also the close-down effect during holidays, which impacts local businesses and community dynamics. The objective is to positively plan for a demographic mix and develop housing in an urban design context that avoids conflict (Key Cities, 2019).

Economic sustainability is long-term economic growth while protecting the environment. The first issue is ensuring that enough insiders, regulars, and visitors are active in the city centre. However, it also includes the responsible use of resources, and energy conservation, in particular. Strategic planning and design is therefore an essential process. It is inextricably linked with the circular economy. In terms of the sustainable city, the design of buildings should enable them to be long-lasting and the materials durable. They should also be adaptable for unknown future re-use, rather than being part of the demolition and rebuild cycle. Nature needs to be an integral

part of the city centre and enjoy circumstances in which it can be regenerative (Girardet, 2015). In political systems, there are generally four tiers of government i.e., local, regional, state and federal. Nevertheless, most countries function with three layers, and there is often constant strain between them. Thus, the position and status of lower levels, ebbs and flows. The most contentious is the regional level, which sometimes does not exist as an elected entity, creating a large space between the local and state. The sustainable city promotes governance at the local level, as a way of creating more inclusive representation, and reducing dependence on the state. The partners are intended to be the council (local authority or municipality) business and the community. Business can be represented by a chamber of commerce or business improvement district (business improvement association) but representation of the community is more difficult to achieve unless there are clear community structures. There are numbers of situations where councils take advice from business and communities, but there are no evident examples of equal partnerships (Davies *et al.,* 2022). A cultural perspective encourages participation by diverse cultural groups in urban planning and decision-making processes to ensure inclusivity and address local needs. Protecting and promoting historic buildings, landmarks, and intangible cultural practices enhances a sense of place and distinctiveness. The design of urban spaces should reflect local cultural identity, promoting a strong sense of belonging, and care of the environment. The creative potential of a city's cultural sector can assist economic development and innovation (Boccella and Salerno, 2016). There are common themes in these city models, especially regarding public transport, short walking distances, access to nature, response to climate change; environmental, social and economic dimensions, and the development of political and cultural perspectives.

Placemaking comprises powerful tools in achieving sustainability objectives. It is not the province of any specific discipline and is best conceived when disciplines work together. Wyckoff (2014) notes that four types of placemaking have been defined. Standard (Project for Public Spaces) creates quality spaces for living, working, learning and playing. Strategic (MI Place Partnership Initiative) expresses long-term goals for economic growth, transport, infrastructure and housing. Tactical (Project for Public Spaces) involves low risk, low cost, short-term projects such as pop-up markets, and Creative (US Conference of Mayors, American Architecture Foundation) promotes culture, arts, festivals, museums and events. The term Regenerative Placemaking appears to originate in the research for a PhD thesis (Ostlund, 2017) as a response to a growing call to move beyond sustainability, and since championed by Dominique Hes and Cristina Hernandez-Santin (eg Hernandez-Santin, *et al.,* 2020). It is a derivative of regenerative design theory and overlays the traditional types of placemaking with a holistic approach that encompasses the core principles of environmental, social, economic, political and cultural perspectives. According to Schurig and Turan (2022), the regenerative city centre will restore its built environment and public spaces in a natural collective human-centred manner, rather than being focussed on manufactured and polluting activities such as property development and provision for individual car use.

METHODS

A qualitative research design was adopted to capture policies, perceptions, and potential actions for regenerating the Civic Precinct in Newcastle (Tracy, 2025). It involved three methods ie semi-structured interviews, observational data from international placemaking events 2023-2024, and planning documents for Newcastle and New South Wales 2022-2025. This enables triangulation of evidence. Strategic

organisations working in the city were approached for interview, and the leaders of six organisations agreed to take part, following ethical approval by the University. They are identified in Table 1, but the respondents' names are omitted. In three cases, there were two participants, and one in each of the other three interviews. To achieve flexibility within a format, semi-structured interviews were selected. They took place in person during March 2024 and lasted between one and two hours.

Table 1: Interviewees

organisation	number of participants	code
Cities Leadership Institute, Sydney	2	a
Institute of Regional Futures, Newcastle	1	b
Australian Community Media, Newcastle	1	c
Inner City Residents Alliance, Newcastle	2	d
Newcastle Alliance, a service provider for the City Council	1	e
Newcastle City Centre Business Improvement Association	2	f

The interview content was derived from the themes in the literature review applied to the Civic Precinct (see Table 2).

Table 2: Interview Schedule

Environmental: noise, pollution, energy - climate change; buildings - development; spaces - roads, pedestrian, green
Social: permanent residents, people from the region, visitors and tourists; temporary residents
Economic: economic growth; people, planning, quality of building, nature
Political: state and local governments; governance - involvement of local businesses and community
Cultural; future role of civic precinct and civic park; local cultural identity, diverse cultural groups, inclusivity, place, identity, belonging; historic buildings and landmarks; intangible cultural assets; cultural sector and economic development
Place Making standard: living, working, learning and playing strategic: long-term - transport, infrastructure, housing tactical: pop-up activities creative: arts, festivals, events

Observational Data taken during participation in placemaking events provided further evidence. These are the pre-eminent forums in the world for best practice in placemaking (see Table 3).

Table 3: International Placemaking Events

Event	code
Project for Public Spaces 4th International Placemaking week, Baltimore 2024	1
New York City Public Realm Roundtable 2024	2
Placemaking Week Europe, Strasbourg 2023	3
Placemaking Week Europe, Rotterdam 2024	4

and data from planning documents for Newcastle and New South Wales were also retrieved (see Table 4).

Table 4: Documents

Document	Code
Wren St. (2022) Newcastle Cultural Precinct. City of Newcastle.	t
City of Newcastle (2023) Newcastle Development Control Plan.	u
Port of Newcastle (2023) Development Plan 2023-2028.	v
Newcastle City BIA (2024) Strategic Deliverables Plan 2023-2024	w
and meeting minutes 2024-2025.	x
NSW Government (2025) Low and mid-rise housing policy. NSW Planning.	y

FINDINGS

Environmental, Social, Economic, Political and Cultural Perspectives

Generally, the local environmental plans have been weakened. There is an Urban Design Panel of private consultants that assesses building proposals, but the criteria are unknown. A proper urban design strategy is needed (d). The amount of empty commercial property and low retail activity in Civic continues to accumulate. Conversely, there is on-going development of commercial buildings in the

Honeysuckle part of the Precinct. NSW Government owns most of the land in the city centre but is selling it to private developers and speculators and land prices are rising as part of the sell-off (c). Chris Johnson, Government Architect NSW introduced the huge increase in permissible building height to 90m (u) which has added to a lack of active ground level activity (d). Almost contrarily, he has recently proposed that there should be a focus on apartments with a human scale, that include greenery and are well located in relation to public transport and jobs (e); and NSW Government Planning is now promoting town houses, terraces, low and medium-rise apartment buildings (y). Yet, large developments are already moving into the Civic Precinct from the West End, where several projects are on hold (c). Community concerns were reported in January this year over proposals for yet another high-rise development less than 300m from Civic Park. The minimum separation for buildings over 45 metres high is 24 metres (u), which inhibits defining external space with buildings (y). The effects on the microclimate from these kinds of developments have already been identified, especially regarding heat islands and wind eddies, exacerbating extreme events that seem to be part of climate change. Community activity requires public and green spaces at a more intimate scale, and permeability in the buildings (d). The Council recognises the need for a substantial increase in planting to protect people from climatic effects (u). There is a proposal for a north-south walking route between Honeysuckle Drive and Civic Park(t). However, it lacks sufficient continuity, definition, and attractions to make it worthwhile. The bars, restaurants and specialist shops in Darby Street would still be isolated, and they should be more accessible (f). In addition, it would need to engender a reduction in road space and increase natural ground to mitigate against increased flooding (e).

Social aspects are identified as requiring a broader range of demographics and increasing the number of permanent residents in Civic (c). A more diverse housing mix will be necessary to attract this heterogeneous population. Students can be part of the mix but studentification has been noted in other city centres (d). Expanding the number of visitors will help to populate the Precinct (f). A comparatively recent venture is the berthing in Newcastle of cruise ships (x). The Australian cruise ship business is worth A$5.63 billion (£2.8 billion) and is almost exclusively located between Sydney and Brisbane (v). Yet, the city centre has not been benefiting economically from the cruise ships, and it barely increases the number of visitors (f). At present, most passengers go to the Hunter Valley wineries. There is a shuttle to the city centre, but it is little used, and direct ferry access to Civic is required across the harbour (e). All businesses pay taxes to the NSW State Government, and the coal industry continues to be an especially lucrative source of income. It has effectively been funding the Development Corporation in re-shaping Newcastle since 1992 (e). Public space can incubate small businesses to enliven the city centre (2), and these are the kinds of businesses that are needed in Newcastle (f). The City Centre Business Improvement Association (BIA) is run by a group of volunteer small businesspeople, with the goal of boosting local business demand (f). A BIA is required to have a contract with the Council, which collects the special business rates currently totalling $1.2 million (£580,000) for the city, of which only $350,000 (£170,000) was allocated to Civic Precinct for projects in 2024 (e). The rates are collected from commercial property owners rather than businesses, and reserved exclusively for promotion, beautification, and economic development (w). The current allocation could be contrasted with NE1, the Business Improvement District for Newcastle upon Tyne city centre. It has currently secured £37 million for the City Centre Transformation Programme, in addition to the £2.2 million levy that it collects from local businesses.

An arrangement of this kind, independent of the Council, would really help the City Centre BIA to play a substantial role (e).

The political context is controlled by the NSW State and greatly influenced by Sydney (b). The City Council is small. There are only four wards, each represented by three councillors plus the mayor, and therefore does not have great influence (c). There is concern in Newcastle that much of its income and potential budget is being used for the development of the state capital. The Greater Cities Committee, which operated at regional level, was recently disbanded by the NSW Government. It had involved communities in setting the agenda (b) and needs to be replaced by a real governance structure for the city, involving the community and business, as well as the Council (a). As the City Council has moved out to the West End to engage with property developers, Civic has lost its purpose; but there is a notion that it could be reborn as a cultural centre, especially as the Old Town Hall, Civic Theatre, City and University Libraries, and Art Gallery already exist in the Precinct (c). Newcastle Museum is already exploring the industrial heritage of the city, and this heritage could be enhanced as integral to the future of Civic (c).

Placemaking

Standard: living, working, learning and playing
This type requires a sufficiently dense and heterogeneous populus, that is prepared to act as a community in public spaces (a). Temporary residents are unlikely to form a community of this kind due to their lack of commitment to the city centre (d). A synergy of knowledge-based employment, expressing the advantages of interacting in person rather than online, should be promoted (a). The main emphasis in policy is on jobs (d), but a central business district, such as being developed in the West End, is an outdated and sterile concept and it is time to embrace the concept of a central living district (1). People enjoy the city's liveability compared with metropolitan Sydney (b). There has been considerable influx of people from Sydney and rural NSW. Most residents are retired and young professionals (d), and the centre is perceived as a retirement destination (b). The proposed 500-bed student residence will support activating the Precinct, but its effects need to be monitored (a). Most of the shopping is done in the massive out-of-town centres at Westfield and Charlestown (e). Bringing more people into Civic's public spaces will enable local and visitor shopping to take place in the Precinct (d).

Strategic: long-term - transport, infrastructure, housing
In Newcastle, there is little city scale strategic planning (b). Since 2023, New York has had a chief public realm officer (2). A similar post would be appropriate for the city centre. Encouraging pedestrian activity will require a more connected public transport system (3). The proposed High-Speed Rail is at an advanced planning stage (see Figure 2). Work on the first phase, Sydney to Newcastle, is due to start on site in 2027 (a). There is criticism of the light rail for only having six stops. Interviewees noted that it needs sizeable extensions to the suburbs, Airport, University, and Lake Macquarie as part of reducing reliance on cars (a, b,c, d, e,f). There is a proposal for a cruise ship terminal (e), supported by the Port of Newcastle (v, x). The harbour ferry service from the Stockton and Queens Wharfs could include a Civic Cultural Wharf and west of the proposed Cruise Ship Terminal. This will enable passengers to directly access the Precinct and provide a starting point for the intended north-south walking route. It should be extended to a new pedestrianised central Darby Street, enabling the road space to be reduced (a, f). The Development Corporation could

meet the infrastructure costs for this proposal, as well as addressing the housing shortage (c, d).

Tactical: pop-up activity

Pop-ups are temporary uses, often in under-utilised spaces (4). They are good low-cost ways to trial innovative ideas, services and products and enhancing economic activity in the area (1). They can take place in established venues in need of re-activation (3). Newcastle Museum in Civic has started pop-up science, especially for young people, to both populate the building and popularise the subject (t). There are also job fairs on buses (a). In 2008, a not-for-profit company called Renew Newcastle was founded to enable empty retail spaces to be available on an interim basis as creative enterprises and community groups (f), and act as a catalyst for reactivating the city centre (c). It was a successful venture, but the team has moved on to Renew Australia. There needs to be a mechanism for re-localising this initiative (b). At present, there are no dedicated pop-up external spaces, although they could be designated (x). As with the Precinct generally, these activities require sufficient people. There could be markets, especially seasonal markets (t), and mobile food outlets may position themselves adjacent to Civic Park, as approved by the City Council (f).

Creative: Arts, festivals, events

The Civic Precinct could be revitalised as a cultural centre with a variety of activities during both day and night (a). This will not happen without programmed events (4). In 2024, the BIA special business rate fund supported Newcastle food month ($145,000), a series of performances in Civic Park ($100,000), 2025 Darby Street festival ($80,000) and the well-being festival ($25,000) (w). With increased finance, there would be significant scope for the number of events to be expanded (e). Also recently, New Annual, a ten-day festival of art, music and ideas had its first outing. Situated in Civic, it presented Newcastle as a creative city with accessible art and culture. The leading partner is the University of Newcastle, supported by Multicultural NSW, Transport for NSW; Create NSW, and Destination NSW (b). First Nations People arts and crafts, and cultural history have been neglected in the city, and could form part of developing Precinct activities (a). The harbour needs an attraction, and this could prompt the rejuvenation of the Newcastle Maritime Centre (c) at the beginning of the north-south walking route, as part of the cultural facilities.

Figure 1: Newcastle City Centre Precincts

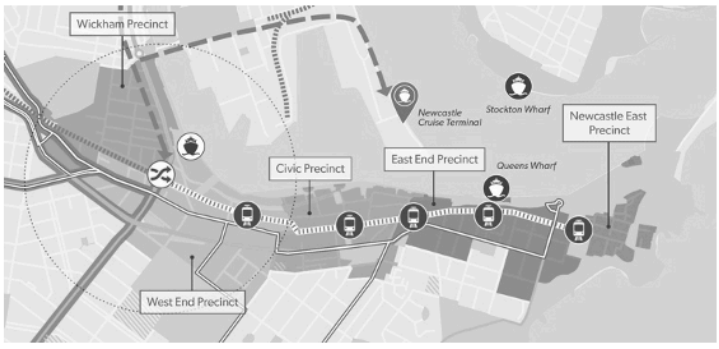


Figure 2: High-Speed Rail



STRATEGY AND CONCLUSIONS

The Strategy Framework responds to the issues raised in the Findings, and each aspect of the Findings is included in it (Figure 3).

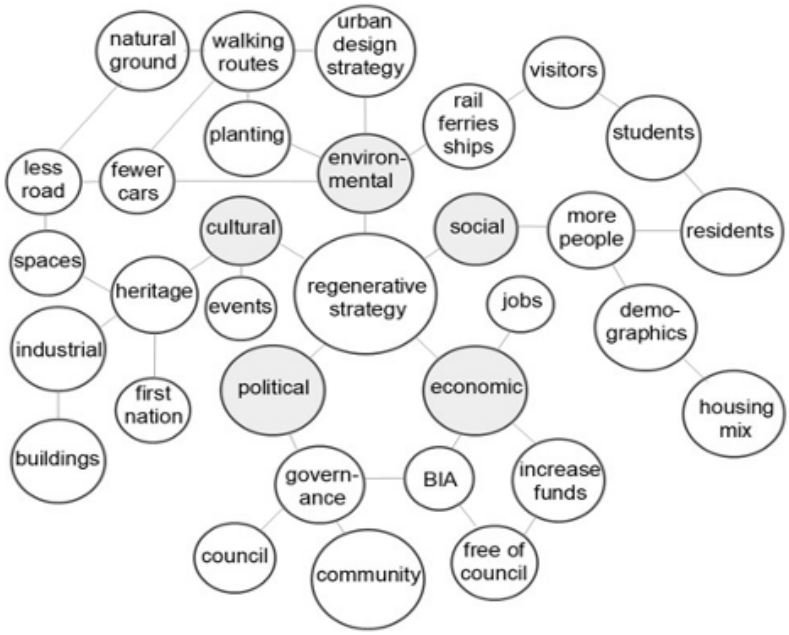


Figure 3: Strategy Framework

Newcastle is a linear city centre with compact precincts. With the Council's move to the West End, as part of the proposed central business district, the Civic Precinct has lost its original purpose as the hub of local government. There are the beginnings of neglect, and it needs regeneration with a new purpose. Existing independent cultural buildings indicate a future strategy. Based on perspectives of the sustainable city and placemaking tools, the regeneration strategy for the city's cultural centre is a multi-faceted concept. Arguably, the most important feature is to bring people into the area to populate its public spaces and heritage buildings. The associated increase in spending power would also enable the growth of small businesses and re-use of redundant buildings. A heterogeneous population is needed, with affordable housing for more insiders, better public transport for regulars, and provision for visitors and tourists. These groups can be supported by temporary residents. Essential to the needs of people is a comfortable and pleasurable external environment. The harbour is a great natural resource, and there should be extensive greening throughout the precinct. The benefits of planting are well-known, and include shade from increasing heat, lessening air pollution, reducing wind speeds, and mitigating flooding. It also offers pleasure through the colour of blossoms and the scent of flowers. It is unlikely that detailed consideration of this centre will be provided by the State Government. The City Council's priority is developing the West End and then moving further in that direction to Broadmeadow. The local business improvement association is willing but hampered by the current structure. It needs to be independent of local government to raise substantial funds. The community should also be involved as part of a new governance structure. The aim of this research is to show how a particular place might be regenerated, but no two places are the same. Nevertheless, it could provide a means for other city centres to reflect on their own situations.

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PERCEPTIONS OF SUSTAINABILITY FROM SMALL GERMAN CONSTRUCTION FIRMS: AN AUTOETHNOGRAPHY

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I examine the influence of regulations and bureaucracy on sustainability in the German construction sector, drawing on my dual experience as both academic and entrepreneur. The purpose is to explore how regulatory frameworks influence industry attitudes and practices, particularly for small enterprises, and to identify strategies for advancing sustainable construction. I employ a qualitative, autoethnographic approach, combining personal experiences, informal discussions with industry peers, and reflections on sustainability practices. While sustainability certifications, such as DGNB, are essential for accessing subsidies and promoting greener practices, they impose significant bureaucratic burdens that disproportionately affect small enterprises. Larger companies manage these processes more effectively, creating a divide. Despite these challenges, the paper highlights opportunities for innovation through informal structures, collaboration, and iterative processes. Circularity principles, such as reusing materials, are identified as promising but require a shift in mindset, training, and resources. I provide insights into overcoming bureaucratic hurdles and promoting sustainable practices, highlighting the importance of less burdensome regulations accommodating practitioners' lifeworld and a collaborative approach to sustainability in the construction sector.

Keywords: autoethnography; bureaucracy; Germany; small businesses; sustainable certification

INTRODUCTION

> *During a discussion about sustainability and circularity in the construction sector, I heard an academic say, "We need more intelligent regulation to advance sustainable building." The first thing I thought was, "Seriously, more intelligent, i.e., more sophisticated?"*

In this paper, I draw on my experiences as both an academic and an industry practitioner to highlight the impact of regulations and the subsequent bureaucracy on the attitudes and views of industry practitioners in the German construction sector. I aim to highlight the risks and opportunities associated with a regulatory approach to addressing sustainability.

I write this piece from an entrepreneurial perspective. My aim is to comprehend what this means to me and my business, and to identify the strategies that arise from this understanding. Hence, the research can be understood as an approach to strategy as practice. It employs a 'strategy as practice' approach to utilise an "in-depth analysis

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of what actually takes place." (Golsorkhi *et al.,* 2010, p. 1). As I wear the researcher's and practitioner's hat, I seek to close the gap between research and practice to produce "engaged" scholarship (Van de Ven, 2007). In that way, I can do "knowledge integration and idea generation" and pursue research where the interaction between my academic and practitioner roles promotes learning for both worlds (Antonacopoulou, 2010: 225).

METHOD

The research employs an autoethnographic approach to explore and discuss what sustainability and respective policies mean to practitioners. I, therefore, utilise my experiences from running a construction company and simultaneously teaching at the university. Additionally, I informally discuss sustainable construction with business partners to gather their perspectives. That helps me to gain an understanding of different perspectives from the industry on sustainability and circularity. Hence, my approach comprises autoethnographic writing, which is focused on the researcher (Sparkes, 2002) but also connects to my environment and researches my "cultural milieu" (Reed-Danahay, 2009, p. 30). Thus, in this text, one will find occasionally evocative elements (Bochner and Ellis, 2016), yet I predominantly use an analytical lens on my observations and conversations with peers (Anderson, 2006).

In contrast to other research approaches, autoethnographers write in the first-person voice. By doing so, autoethnographers seek to clarify their personal perspective from which these works are composed (Ellis, 2004). An absent author would imply that autoethnographers can distance themselves from their experiences, which remains challenging. Consequently, I follow the same example.

As I strive to understand the implications of my research for my business, I will reflect on these implications within this text. They have been indented and marked by five asterisks (*****) along with the ethnographic vignettes and conversations.

Background

> *It all started when a fellow researcher said, "We need more intelligent regulation." The entrepreneur in me started rolling his eyes, thinking, "What is intelligent regulation? Does it equal more paperwork? Go ahead, impose more bureaucratic burdens on those who run businesses. We've got enough regulation to keep up with and other things to do."*

I have heard this often, and I have typically seen a very sophisticated body of regulations, which amounts to a bureaucratic burden with little or no impact on the ground.

My interest is undoubtedly rooted in 25 years of experience as a construction business owner. I employ approximately 25 staff members who build houses from brick and concrete in the Berlin area. In this role, I had numerous encounters with bureaucracy, one of which left a particular mark on me: I required 4.5 years to obtain a building permit for a small five-party residential building on the outskirts of Berlin. During that process, my project was severely delayed by a bureaucratic and legal process that, although justified in principle, has significant side effects, causing projects to take significantly longer to complete. In the project I developed, the substantial effect on the project, e.g., size, use, and design, is rather small, compared to the prolongation of the process. Hence, it was burdensome but had little impact on the outcome. This experience was certainly one of the main causes I got interested in this topic.

My personal experience in the German construction industry provides me with numerous instances of companies expressing an overwhelming amount of paperwork necessary to run their daily business. Yet it might be a specific German problem, because we're often said to have a reputation for extensive bureaucracy.

There is undoubtedly a necessity for change towards more sustainable practice, which practitioners acknowledge. I will address this in the first section. Yet, although this is recognised, bureaucracy surrounding sustainability and respective certifications is felt as a burden, which I will discuss in the following section. Despite the burden and drawbacks, policymakers can tackle the issue in various ways, and with a different approach to running a company, small businesses can create opportunities for themselves. It then becomes an approach to use autoethnographic writing as a tool for strategising, as I did elsewhere (Grosse,2020).

SUSTAINABILITY: NECESSITY, BURDEN, AND CHANCE

I use my environment, i.e., the construction business I run and the partners I interact with, as a data source. I, therefore, begin by highlighting their personal attitudes toward the discussion of sustainability.

Necessity

> *A construction engineer in his fifties, who primarily specialises in steel constructions, with whom I worked, is well aware of his carbon footprint. "My work had a significant impact on my CO2 emissions, but what can I do? I am designing steel construction. That is what I can and do, " he told me.*

In the ensuing conversation, it was apparent that he is aware of his impact and seeks ways to mitigate it, but given his occupation, this is challenging. In a similar vein, years ago, a development engineer from a major European formwork producer told me during a personal exchange at the BAUMA construction equipment fair in Munich the following:

> *As the cement-using industry, we must address our environmental footprint; otherwise, we are missing opportunities.*

The point is that both engineers - and I could offer even more examples - are climate-conscious. They acknowledge the underlying problem: we are emitting too much CO2 directly or indirectly into the atmosphere. However, none of them has the silver bullet to solve it. The problem with sustainability and DGNB[2] certificates is that, although these specialists have considered sustainability for some time, they have yet to develop effective solutions.

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> *Although solutions are unavailable, the shift seems inevitable, as the vignettes above indicate. Hence, my business is in the early stages of the process Grinyer et al. (1988) describe when they talk about sharpbenders. Sharpbenders are characterised as acting early when revenues are still comfortable, but they may decline in the future. Doing so, they avoid running into a crisis. In the long run, I cannot sustain the way my company operates - sustainability measures and adaptation are inevitable. Hence, moving early enough may bring a competitive advantage.*

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[2] DGNB Deutsch Gesellschaft für Nachhaltiges Bauen. German Sustainable Building Council https://www.dgnb.de/en

During a phone call, a construction manager from a midsized company focused on housing for private investors emphasized the importance of sustainability, noting that it extends way beyond energy efficiency into other aspects.

For his employer, it is important to gain sustainability certification because that ensures access to subsidised loans and public (KfW, 2025). Hence, they need to conduct an audit of the DGNB. Similarly, de Gier *et al. (*2025, p. 11) note "sustainable finance legislation plays a significant role in creating market influence in the private sector," making it both a business necessity and a marketing tool.

Burden

Due to the bureaucratic burden, the construction manager also mentioned that obtaining these certificates is a full-time job. Acknowledging his company's capability to run the process due to their resources, whereas small companies struggle with the bureaucracy. They view sustainability and certification as a "pain in the neck." This creates a divide between larger companies, which have the capacity to manage bureaucracy, and smaller ones that do not.

When we look beyond sustainability issues, bureaucracy often significantly affects small businesses. Loosemore (2015) made similar observations when researching social enterprises, highlighting the burden for small businesses. Bureaucracy is a particular burden for small businesses, potentially leading to exclusion from tender processes. Landin's (2000) observation regarding ISO 9001 accounts for a fear of overburdening bureaucracy, particularly for small contractors. This concern is also shared among German practitioners regarding sustainability certificates and auditing.

Large corporations find it much easier to navigate bureaucracy compared to small businesses. Examples show that many companies offering prefabricated houses already have certified options on offer. Similarly, big developments are also often certified. Due to scale effects, it's economically feasible. With smaller and non-repetitive projects, it usually doesn't pay off.

Although it's cumbersome, it's needed. Bureaucracy is essential to promoting sustainability (Carmin *et al.,* 2012). It serves to manage, check, and control processes. Therefore, it is not inherently negative; we could not manage tasks effectively without bureaucracy—forms, certificates, guarantees, declarations, and approvals. No one would question the value of a quality check by a certified construction engineer regarding building safety or the work of a certified public accountant.

However, there remains a discrepancy between the bureaucratic system and the lifeworld of industry practitioners, to use Habermas' terms (1976). The lived cultural norms do not necessarily promote sustainability but predominantly emphasize economic concerns. This does foster the risk of greenwashing, which limits the acceptance and, most of all, the impact of certificates:

> *"Getting a decent sustainability level according to DGNB isn't really a problem. It's mostly just about the paperwork. At the end of the day, it doesn't feel any more sustainable than if I'd done it my own way", as a befriended engineer told me.*

Another peer, an architect familiar with DGNB procedures, told me:

> *"It doesn't really matter what we put together; we'll still get a certificate. The only thing is, we need to keep track of every little piece we use, even the skirting board."*

These statements show vividly that certificates may have only a limited impact. From yet another ticked box, no building will be more sustainable only because it is

certified (Murtagh *et al.,* 2016). "It may also lead to abdication of responsibility or minimal compliance." (Murtagh *et al.,* 2016, 70-71) Knowledge of the process seems to be key.

Unfamiliar contractors struggle with bureaucracy, as shown on infrastructure projects (Järvenpää *et al.,* 2022). However, bureaucracy on infrastructure projects was not seen as that challenging once the contractors gained some familiarity (Järvenpää *et al.,* 2022). This resonates with the notions of an architect trained as an auditor regarding sustainability, which indicates opportunities.

Chance

> *Over lunch, I had a conversation with some architects working in the same office. One of them, an auditor for DGNB, replied to my question about how to obtain a DGNB certificate:*
>
> *"Just get the EPDs (Environmental Product Declarations), and I'll handle the rest. It's no big deal."*

Although he saw the bureaucracy, he did not see it as too big a burden, supporting the point of Järvenpää *et al. (*2022). In other words, the bureaucratic system was not too removed from his lifeworld because he had already acquired some familiarity.

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> *There are different implications here. First, we'll have to collect the EPD for the materials we use. That forms the basis for obtaining certification. Second, a deeper technical and procedural understanding is required to influence the outcome of a certification process, i.e., identifying which materials, activities, etc., have a negative impact, and reducing them. And third, I need at least some familiarity with the process to be better equipped to handle it. Consequently, the next development should be certified, even if the certification may not yield a return.*
>
> *However, I feel like some of my team have their doubts and frustrations about sustainable building. It's extremely important to get everyone on the same page, because simply going through the bureaucratic motions won't make my company more sustainable. This is where the whole strategy-as-practice idea really matters: I don't have a clear-cut strategy to make it happen. I believe that having some talks and negotiations will help steer things in the right direction. Some strategic ideas will pop up along the way, but what really makes a difference will only show itself in our day-to-day operations.*

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The auditor architect I met over lunch expressed another experience he had regarding the auditing process:

> *"You know, I actually use this certification process as a way to reflect. As soon as I start answering the questions and filling out the forms, it gives me a chance to look at my project and make it even better, like more sustainable and all that."*

This vignette clearly demonstrates that executing a bureaucratic procedure can help practitioners become more sustainable. However, it depends strongly on the person's attitude. In this case, I was speaking with someone who was already convinced. However, if the conviction of the importance of sustainability is lacking or the impact of the paperwork is unclear, then the procedure is of little value.

There are risks associated with bureaucracy, including upsetting the workforce, the adoption of cumbersome processes in industry and among large companies, the loss of acceptance for small and medium-sized enterprises, and the erosion of support for the Sustainable Development Goals (SDGs). This may also lead to reactiveness on the

part of practitioners, resulting in compliance without fully embracing the concept of sustainable construction. Additionally, suspicions of greenwashing and an overly bureaucratic system can result in diminished confidence in the system, particularly given O'Neill's (2002) observation that increased "quality control and quality assurance" will not lead to improved outcomes. She suspects it could lead to less trust in the system.

Formal procedures are necessary but insufficient, so one needs to go beyond bureaucracy. As demonstrated above, neither an architect nor an engineer saw much difficulty in obtaining certification, with one of them implying that it wouldn't matter how we built. Both embrace green building, but recognise the shortcomings of solely relying on regulations, especially when they are complex. They work with what they consider sustainable and make it fit the standards. This demonstrates that, for sustainability, informal structures are just as important as formal structures (Kuitert *et al.,* 2024). So, what really supported sustainable building was not the certification system but their values.

Similar pattern Landin (2000, p. 511) observed when researching on ISO 9001 in Sweden: "The standard is often experienced as being difficult to understand; many of the companies had decided to create their own quality manual, structured not according to the Standard, but according to principles that seemed better adapted to the tasks with which the company was faced." There should be options to do exactly that. Adhere not to stiff bureaucracy but adhere to principles. The principles are easier to communicate, and their acceptance is much higher, essentially translating the bureaucratic system to the language of the practitioners' lifeworld.

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> *In other words, having some experience with the system can really help in figuring out workarounds for the most frustrating bureaucratic hurdles without compromising the core principles. This will definitely make it easier to get staff members on board.*

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Further, linking new policies and regulations to existing procedures and plans helps in implementing and adapting (Carmin *et al.,* 2012). In other words, integrating sustainability certification into already existing bureaucratic systems (Kuitert *et al.,* 2024) might lower the threshold for practitioners to deal with additional bureaucracy.

Besides, although the necessity to act on sustainability becomes more and more obvious to construction professionals, some pressure from other stakeholders is important for success (Carmin *et al.,* 2012). This can create, besides the regulatory pressure, some clan control (Ouchi, 1980). Consequently, it may lead to new cultural norms, i.e., a new lifeworld of industry practitioners.

Turning away from the bureaucratic effort to the underlying principle of sustainable construction, one needs to consider greener materials, less material, or, in the best case, reusing materials.

Talking to staff, I get the impression that they think the whole concept of circularity and reuse is a playground for people with too much money. They have difficulty connecting with something that does not belong to their world. An idealist utopia, so to speak. To many people, it appears to be a step backwards. Material use was not a problem. Instead, it was the solution to productivity problems. Now, using less material or reusing it ought to be the new solution - this represents a fundamental shift in the way we run our business.

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> *Adopting this thinking will be a challenge. I am not trained and not accustomed to circularity, nor are my staff members. Intellectually, we can grasp it, but this understanding does not immediately translate into practice. It'll take a while to get hold of. But there are chances for small businesses in particular.*

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The construction sector is geared toward standardised materials. We are accustomed to working with them. Yet used materials aren't of that shape.

> *The engineer using steel told me regarding reusing steel beams: I would like to, but I don't know how to work with it. What stress can they bear, and how much carbon dioxide is contained in the steel? Can I even wield it, or does the old cast-iron shatter immediately? It isn't that easy.*

There are no certificates or specifications available, and it is almost certain that they will not be available in the future when it comes to dismantling present houses. We are accustomed to providing certificates for immediate use - i.e., to demonstrate that we have completed our work in accordance with building regulations. Testing and evaluating old material isn't impossible, but it requires time and consumes a significant amount of available human resources.

> *During our lunch talk, we discussed how to reuse old steel beams.*
>
> *An architect said: Well, if you have got a beam, tell us the length and dimensions, and we will see how it fits.*

That means the design and construction process must undergo an overhaul. To extend the Bauhaus architects, I dare to say: "Form follows function and availability." Hence, a building cannot be understood solely in terms of its end product. It is a process of going back and forth. Multiple iterations will be necessary to accommodate the client's needs and the available materials. Furthermore, a different approach to collaboration is necessary. It cannot work as a top-down approach, but as an interactive, collaborative process that includes a bottom-up approach.

Additionally, it will challenge bureaucratic processes. No innovation occurs if bureaucracy stifles the iterative design and construction process. If bureaucracy does not stifle innovation, a process ensues where design is adopted from available materials that contractors and craftspersons provide. Subsequently, the builder will inevitably innovate on the ground level.

In this duality of bureaucracy and lifeworld, both need to align with each other. Reusing old materials will require a different technical and cultural approach to building; hence, the bureaucratic system is founded within a different lifeworld.

Here, opportunities for businesses emerge. As Duong *et al. (*2021) have shown, incremental sustainability innovations positively affect the company's valuation. However, these innovations are time- and resource-consuming (Ding, 2008; Duong *et al.,* 2021).

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> *The challenge for a business like mine is to find the right partners in the first place. Then, get into an efficient working mode. Bottom-up sounds nice, but it also entails a significant amount of responsibility and accountability. In this case, as a business, we would be more responsible; therefore, there are more demands on us. We must provide the design team with information and feedback on their ideas. That can become, if not managed properly, an exhaustive task. However, it would create closer ties to planners and clients, which may be advantageous for us.*

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However, as of now, the reuse of materials has its limits.

> *A manager of a concrete plant that frequently supplies my building sites said, "I don't know where to get enough RC material".*

On that notion, a building material expert added:

> *We can produce RC-concrete and a variety of other RC materials, but we are in dire need of skilled labourers in the waste sorting plants. The people on the belts need to know exactly what to do.*

This indicates that with more sustainable practices, the demand for skilled labourers, as well as engineers and architects, will increase, as we are substituting valuable and CO2-intensive materials with human labour. That may provide many businesses with a comfortable market position.

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> *The potential for my business lies in the fact that builders will be in high demand in the years to come, as they are the only ones who possess the expertise and can effectively fix, rework, and rebuild old houses. They have a feel for material that only a few non-tradespersons have.*

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SUMMARY

Exploring sustainability practices and respective bureaucracy led me to three emerging themes: necessity, burden, and chance.

Industry practitioners increasingly acknowledge the necessity of embracing sustainable construction. Changing their professional practices to more sustainable ones remains difficult. Complying with bureaucratic procedures (e.g., DGNB certification) is ever more important to them because of financial incentives and market demands. The need to comply feeds into the perception of sustainability as a burden. The bureaucratic procedures are often more difficult for small companies to manage. However, some familiarity with the processes appears to ease the burden. However, the bureaucratic system needs to adapt to industry practitioners' lifeworld, not to frustrate their efforts. As I have demonstrated using my company as an example, sustainability can provide opportunities for small businesses.

More profound cultural change in the industry appears necessary because construction practices must change to reuse materials. A shift toward reusing materials leads to substituting CO2-intensive materials with skilled labour. Hence, creating a high demand for skilled labour. It will moreover involve an iterative, collaborative design and construction process, challenging longstanding top-down practices. This requires bureaucracy to accommodate these processes, not to stifle necessary innovation.

Despite challenges to small businesses' values, practices, and working practices, the change provides chances for small businesses. Navigating through the change process using a strategy-as-practice approach, small companies can profit from the increased demand for skilled labour and deeper integration in the design process.

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SUPPORTIVE HERO AND TROUBLEMAKER? DIVERGING ENVIRONMENTAL WORK EXPECTATIONS IN CONSTRUCTION

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Despite being key agents in the transition toward a more sustainable built environment, environmental professionals often struggle with unclear responsibilities and ambiguous work expectations—hindering their ability to drive meaningful change. This paper explores how everyday dynamics in construction projects shape environmental professionals' work expectations. Drawing on 20 semi-structured interviews and 80 hours of observational fieldwork from a large Swedish infrastructure project, the study analyses how project actors invest different meanings and activities into the use of space and time, using a practice-based lens. The findings suggest that diverging work expectations emerge from conflicting spatial and temporal understandings between the production and client organisations—tensions that environmental professionals must continuously navigate. This research contributes to the literature on environmental professionals in construction management and offers new insight into the spatial and temporal dimensions of environmental work that they are navigating.

Keywords: environmental professional; environmental work; practice; tensions; work expectations

INTRODUCTION

Infrastructure in terms of systems, networks, and structures (road, railway) are important foundations for society and enable social and economic development (Davies *et al.,* 2019). Especially, in large infrastructure projects, there are technical, regulatory, and organisational dependencies that make these projects complex (Geraldi *et al.,* 2011). Complexity can be perceived as structural (i.e., size, variety), dynamic (changes), uncertainty, pace (urgency or criticality of time), and socio-political complexity (Geraldi *et al.,* 2011). Large infrastructure projects have a major societal impact and require both public and political support and often require public funding and ownership (Walsh *et al.,* 2022). Furthermore, the construction and maintenance of infrastructure is often expensive and has large environmental implications like CO2-emissions, pollution, and noise (Davies *et al.,* 2019). In many of these projects, there is a strong focus on sustainability and environmental requirements both during the construction but also after construction. While there is abundant literature on governance and project management of large and complex projects (Davies *et al.,* 2019), and research on sustainability assessment during and

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after infrastructure construction, there is hardly any research on how these projects organise their environmental work and how environmental professionals interact with production and construction client professionals.

The lack of research on environmental roles within highly environmentally complex projects poses a problem, as the delivery of such projects partly depends on clear role structures (Bechky 2006) that provide clarity into the responsibilities, routines, roles, and relationships of the actors involved. Existing research on environmental roles has found that these professionals often struggle with unclear responsibilities and ambiguous role expectations, which hinders their ability to drive meaningful change (Gluch and Bosch- Sijtsema 2016). For example, Akotia and Opoku (2018) found that sustainability professionals are often involved too late in the delivery process, even in projects explicitly framed as sustainable regeneration. Similarly, other studies have highlighted how environmental management frequently clashes with the more immediate demands of construction work (Gluch and Räisänen 2012), resulting in environmental experts struggling to find their place among more established roles in construction projects (Gluch 2009, Gluch and Bosch- Sijtsema 2016).

Given that sustainability and environmental requirements in infrastructure projects are likely to increase, and that clarity around responsibilities, routines, and roles is essential for delivering projects accordingly, this research aims to explore why environmental experts often have difficulty finding their place among other professionals in projects with high environmental ambitions. To explore this, we conducted a case study of a large-scale infrastructure project in Sweden, characterised by high environmental demands, complex construction processes, and a dense urban setting. More specifically, we ask the following research question: How do every day dynamics in construction projects shape environmental professionals' work expectations?

To address this question, we adopt a practice lens which emphasizes that environmental work is empirically grounded in what people do in practice rather than through formal documents and predefined descriptions. By centring on people's actions (practices), we gain insight into how everyday dynamics in construction projects shape environmental work expectations, and how these expectations, in turn shape the work environmental professionals do. A key advantage of a practice lens is that it allows us to highlight tensions and contradictions as they play out on the ground, offering a more nuanced understanding of why environmental professionals may struggle to establish themselves within projects. It also provides nuanced insights into how the industry might better organise environmental work in the future.

Practice Perspective on Role Expectations

By adopting a practice lens (Feldman and Orlikowski 2011), this study focuses on the micro-dynamics of everyday actions and interactions through which construction outcomes are produced. More specifically, we are interested in what individual actors do when working in projects (Blomquist *et al.,* 2010), and how these practices shape expectations around their work. Work expectations emerge through ongoing social interactions that are continuously shaped and negotiated in practice—using tools, discourse, and embodied engagement. It emphasizes that action is not merely individual or cognitive, but situated within social, material, and temporal contexts. Rather than viewing the work of professionals as fixed, we conceptualise it as enacted in ongoing practices, shaped by shared understandings, material artefacts (e.g., plans, schedules, tools, environmental requirements), and the relational dynamics of

construction projects. This implies a bottom-up analysis of actions and interactions in situ—that is, as they unfold in real time—along with the meanings and motivations that underpin them (Blomquist *et al.,* 2010).

Since projects involve multiple actors sharing time and space, we focused on how environmental work expectations are shaped by differing temporal and spatial understandings as actors work towards achieving the project's objectives. These are influenced by temporal and spatial norms, as well as related structures that orient the ongoing activities of project actors—such as activity plans, time schedules, deadlines, and spatial regulations. Actors in interorganisational projects often hold differing understandings of space and time (Maaninen-Olsson and Müllern 2009), which must be negotiated and aligned during project work (Dahlgren and Söderlund 2001, Stjerne *et al.,* 2019). From this follows that environmental work, in time and space, should be viewed as socially constructed and practiced, and not just managed.

METHOD

This study follows a qualitative research design. Data was collected through 20 semi-structured interviews with 18 project participants and 80 hours of field observations, conducted by shadowing an environmental manager within the contractor's environmental organisation, 40 hours in 2021 and an additional 40 hours in 2023.

The first phase of fieldwork involved shadowing the environmental manager full-time, for one week, to gain a comprehensive overview of the construction project and its organisational context. This initial period enabled the researcher to observe a wide range of daily activities, offering a broad understanding of the field. These early insights informed the selection of specific situations and interactions for more focused observations in the second phase. While the first round served as an immersive phase to familiarise the researcher with the overall context, culture, and dynamics of the project, the second round was more targeted, allowing for closer examination of specific practices and interactions identified as analytically relevant through earlier data collection.

Activities involving meetings or direct collaboration with either client representatives or the production team were prioritised for focused observation. During these sessions, detailed notes were recorded in a field notebook based on the following dimensions: (1) what was being done and said; (2) when it occurred; (3) where it occurred; (4) who was involved; (5) how it was done or communicated; and, later, (6) why it occurred—an aspect clarified through both informal and formal interviews.

The formal interviews were conducted in 2021 (n = 2) and 2023 (n = 18), involving members of the environmental team (n = 4), support staff (n = 3), site management (n = 4), production staff (n = 3), and representatives from the client organisation (n = 2). Participants were asked about their daily work in the project and their perceptions of collaboration around environmental issues. Each interview lasted approximately one hour, was audio-recorded, and transcribed verbatim. The transcripts provided detailed insights into the project context as well as the shared understandings and expectations surrounding environmental work in the construction project. All participants provided informed consent prior to their involvement in the study.

The combination of observations and interviews enabled a deeper understanding of how environmental work expectations were enacted and interpreted in practice. While the interviews offered reflective accounts and explanations, the observations captured everyday practices and assumptions that participants often took for granted or did not

articulate explicitly. In this way, the two methods complemented each other analytically. Both interview transcripts and field notes were included in the thematic analysis.

The data was analysed thematically (Braun and Clarke, 2006), meaning that patterns of activity and understandings related to environmental work were inductively grouped into themes through an iterative process, see table 1. This involved interpreting practices and the meanings that different project actors invested in them, with particular attention to how environmental work expectations were shaped by contrasting spatial and temporal understandings within the construction project. The analysis revealed a set of spatial and temporal tensions that environmental professionals must navigate, which in turn contribute to diverging environmental work expectations.

Table 1: Coding table

Empirical Examples	Code / Sub-theme	Theme
"Noise pollution regulations dictate when and how much construction work can be carried out." (*Observation*) "If you plan your activities in advance, then there's time—we can be involved as a kind of think tank." (*Interview*)	Time is "fixed"	Temporal tensions
"He answers the phone and runs out of the meeting to fix a problem." (*Observation*) "In a perfect world, we would know a month in advance… but the schedule changes." (*Interview*) "If the timing is wrong, then that's just how it is..." (*Interview*)	Time in flux	Temporal tension
"We moved through the site to ensure that materials were stored in their designated places, and that all chemicals and vehicles on the construction site were approved." (*Observations*)	Space is "fixed"	Spatial tensions
"The construction site was largely empty, except for one area where activity was in full swing." (*Observation*) "We have a wheel loader just to move things around." (*Interview*) "space on site follows 'djungelns lag'—the law of the djungle" (*Interview*)	Space in flux	Spatial tensions

Case Description

The case study examines a large-scale and highly environmentally complex infrastructure project in a dense Swedish city, valued at £300 million, involving bridge and railway construction. The project was subject to strict environmental requirements, partly due to an environmental court decision, and partly because the client—the Swedish Transport Administration—is expected to fulfil environmental goals set by the government. As a result, the contractor faced high demands regarding how to organise its environmental management.

For the contractor to meet these expectations, more resources to comply with the environmental requirements compared to previous projects were required. Two years into the construction phase, the environmental department expanded, appointing a dedicated manager to handle "softer" issues previously managed by the production manager. The environmental roles were also restructured: instead of having a single QHSE manager responsible for quality, occupational health and safety, and environment, the responsibilities were split into three distinct roles.

A new environmental manager was hired with extensive experience in managing environmental issues during the construction phase, supported by a deputy environmental manager and three environmental coordinators, who were working within the different production blocks. This restructuring clarified responsibilities: the environmental managers focused on overarching environmental issues at the project level, while the environmental coordinators handled day-to-day problem-solving at the construction site.

RESULTS

Our study of how everyday dynamics in construction projects shape environmental professionals' work expectations identifies several spatial and temporal tensions that contribute to diverging environmental work expectations. Here, "tension" refers to the different activities and meanings that project actors invest in the practices of space and time. Space refers to physical space—i.e., the construction site and its spatial boundaries—and time refers to temporal aspects—i.e., the pacing of activities. In the following sections, we examine how these tensions unfold in practice and how they shape the work expectations of environmental professionals.

Spatial Tensions

The first set of tensions is associated with the different activities and meanings that the client and the contractor invest in the use of space—i.e., the construction site. Here, the client practices space through controlling activities, which trickle down to the contractor's environmental professionals. For example, the client's environmental specialists conduct weekly environmental inspection rounds to ensure that the construction site complies with environmental requirements. In this way, the environmental specialists are auditing space—grounded in a legal environmental responsibility:

> "Our main task from the Swedish Transport Administration is to monitor our operator responsibility in environmental matters—to make sure we are fulfilling the responsibility we're required to take under environmental law and our permits and everything else we're bound by." (Environmental Specialist, Client)

For the contractor's environmental professionals, however, auditing space is a more delicate, day-to-day activity—one that involves ongoing interactions with colleagues in production. As one environmental coordinator reflected:

> "We're an internal auditing function… it's a pretty thankless role, and I think you really need to be the right kind of person to want to do it. Because it can easily feel like we're… putting spokes in the wheels for our colleagues, or that it's perceived that way. So it's always a bit of a balancing act in how you present things." (Environmental Coordinator, Contractor)

Part of this balancing act involves accommodating production and ensuring the continuity of the building process. For production, practicing space is not only about identifying problems, but also about being actively involved in solving them. As one site manager put it:

> "Like our environmental guy—he's out there looking at things. Like, how should we divert the water? And he'll go, 'Well, we could do it this way,' and bring other ideas—'Let's do this instead, what's the easiest way?' When I'm out on site and he's there, he brings other suggestions and shows that he's engaged in both progress and production." (Site Manager, Contractor)

In contrast to the client, who practices space through controlling activities, this quote also illustrates how the contractor's site managers practice space through construction activities, prioritising progress over order. As another manager described it, space on site follows "djungelns lag"—the law of the jungle—where space is up for grabs and must be claimed. Here, space becomes a resource for building—perceived as immediate and temporary—which significantly differs from the client's understanding of space as "fixed" and regulated.

These contrasting spatial understandings—between space as regulated and space as a resource—create tensions that environmental professionals must continuously navigate in their daily work.

Temporal Tensions

The second set of tensions is associated with the different activities and meanings that the client and the contractor invest in the use of time—i.e., the pacing of activities. Although construction activities are planned according to deadlines and the overall production schedule, they are often adjusted in practice due to unexpected events and discoveries that arise during the construction process. The contractor practices time through scheduling, which may or may not involve environmental professionals. Yet the overarching purpose remains the same: to create a continuous flow of construction activities on-site and to ensure that workers have the right conditions to do their jobs well. As one site manager explained:

> "I work in a very straightforward way in my role as site manager and with my scheduling, so that everything flows smoothly. It might not need to flow quite as well in here, but out there with the workers, it's important to ensure that things run without interruptions, so it doesn't become frustrating or irritating for them. If the workflow remains continuous and there are always tasks to be done, then everyone stays happy." (Site Manager, Contractor)

In contrast, much of the work of environmental professionals involves trying to keep up with the pace of production—by checking the three-month construction plan, asking around to find out what is happening, and being present on-site.

> "The schedule is also ever-changing, so whatever happens, happens. In a perfect world, of course, we would have such well-planned work that we would know a month in advance how to handle all the environmental issues that might arise. But often, documents arrive late, or... the schedule changes, and suddenly there is an opportunity to do something that was not initially planned, and then the focus is simply on solving that problem." (Environmental Coordinator, Contractor)

The client's environmental specialists, however, expect a more proactive approach from the contractor's environmental team and explained how this would improve collaboration. As one of them noted:

> "If you're proactive in your work—if you plan your activities, if you have clear working methods, and if you're not constantly chasing urgent issues or reacting at the last minute—then there's time. If you plan things in advance and present proposals, then we can always be involved as a kind of think tank." (Environmental Specialist, Client)

Moreover, they reported that they often feel they can only intervene once a mistake has already occurred—or is about to occur. Although they would prefer a more

collaborative role, they feel the structure of the contract limits their ability to engage earlier:

> "We probably would have preferred to serve as more of a sounding board over the years. That there had been more room for discussions on proposals and approaches instead of... simply pointing fingers. Saying: 'This is wrong. This requirement hasn't been met. We see a significant risk that this won't be fulfilled or that mistakes will happen.' We have essentially become just a compliance control function." (Environmental Specialist, Client)

The challenge for project work arises when certain environmental requirements dictate the pace of construction activities—for example, environmental tests that must be analysed before work can proceed, or noise regulations and permits that restrict operating hours and the use of machinery. For environmental professionals, it becomes a question of timing the construction process: "You constantly have to stay alert and actively look for potential problems"(Environmental Coordinator, Contractor). By delivering this kind of information, however, environmental professionals often become the ones who disrupt ongoing construction activities. As one interviewee described:

> "I rarely bring good news. It's not like people stand up and applaud when I point out issues that both cost money and take time." (Environmental Coordinator, Contractor)

For site managers, disruptions to the construction process can be a source of frustration, and they acknowledge that the environmental role can be a thankless one. While they recognise that environmental feedback is generally valid, they see timing as a critical factor. As one site manager reflected:

> "Sometimes, during particularly stressful periods, many probably perceive those in the environmental role as being difficult rather than as being there to help." (Site Manager, Contractor)

Upon further reflection, he added that the issue often lies not in the feedback itself, but in when it is delivered:

> "If the timing is wrong, then that's just how it is. But what they say is always wise. It's just that sometimes, it's the wrong moment. There are right and wrong times to receive information, depending on the phase we're in and so on." (Site Manager, Contractor)

These examples illustrate how temporal tensions in project work give rise to diverging expectations around environmental roles. While site managers prioritise maintaining a continuous production flow, environmental professionals must adapt to frequent changes while ensuring that environmental requirements are respected, often without fully knowing what is coming next. At the same time, the client expects the environmental team to act proactively, even when the conditions for doing so are limited.

DISCUSSION AND CONCLUSIONS

The aim of this paper was to explore how everyday dynamics in construction projects shape environmental professionals' work expectations. Our findings suggest that environmental professionals are acting between competing spatial and temporal understandings: one that values flexibility and immediate responsiveness, and another that demands foresight, planning, and control. Navigating these expectations requires not only technical competence, but also relational sensitivity and strategic timing. Consequently, the environmental professionals perceived their work as being both "the supportive hero who clears the way and lays the groundwork so we can build" and "the troublemaker who throws a wrench in the works for their colleagues".

As previous research on temporal and spatial tensions in projects has shown (e.g., Maaninen-Olsson and Müllern 2009, Stjerne *et al.,* 2019), different actors tend to have different temporal and spatial norms that must be negotiated to enable collaboration. In our case, however, the client and the contractor never seemed to fully reconcile their differing temporal and spatial understandings of environmental work. Instead, it was the environmental professionals in the project who acted as a bridge between production and the client organisation—shifting between being present and embedded in day-to-day production, and being distanced and aligned with external, formal environmental requirements. This dynamic contributed to diverging work expectations rather than clarity. For individuals, this meant trying to fulfil expectations that do not fully align, which in turn could lead to work ambiguity and role conflict.

While this paper has identified some of the tensions that shape environmental professionals' work expectations, future research could further explore how environmental professionals manage these tensions in practice—for example, through boundary work or boundary-spanning activities. Such studies could provide valuable insights into how environmental professionals are collaborating with other professionals in projects.

By shedding light on how environmental professionals' work expectations are shaped through spatial and temporal dynamics in construction projects, this paper contributes to a more nuanced understanding of interorganisational collaboration in environmentally complex construction projects—highlighting the need to better support environmental professionals in their work.

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CIRCULAR BUILDING GOING IN CIRCLES: CHALLENGES IN CIRCULAR BUSINESS MODEL IMPLEMENTATION IN THE DANISH CONSTRUCTION INDUSTRY

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Developing a circular built environment is essential for achieving climate goals, yet the Danish construction sector faces significant challenges in adopting this transformative production model. In this paper, we investigate how a major contractor in Denmark aims to tackle these challenges by combining internal strategies with innovative collaborations, ensuring both sustainability and business viability. Based on a longitudinal study, the findings reveal a multi-level approach to implementing circular initiatives, partially centrally coordinated to align with the company's strategy. The contractor assumes a dual role as both producer and consumer of circular materials, partially creating a closed loop to enhance resource efficiency. Strategic alliances with non-competitive partners are critical, enabling access to expertise, resources, and scaling opportunities. Furthermore, investments in a building material platform are made to facilitate the development of new markets and businesses, underlying the importance of collaboration in overcoming the sector's barriers and fostering industry-wide transitions to circularity. However, these collaborations do not deliver the expected financial results, and the circular business models tend to stay in the inner circle.

Keywords: circular business model; construction industry; implementation; silo effects; symbolic action

INTRODUCTION

Circularity in the building sector is progressing slower than anticipated. Despite over a decade of promotion from various stakeholders, including knowledge producers (Ellen MacArthur, 2015), regulators (EU, 2018), and consultants (Jensen *et al.,* 2016), recent evaluations reveal a rather bleak picture. Reports highlight a low overall degree of circularity (Circle Economy, 2024), inadequate regulatory frameworks, and the persistence of fragmented, isolated circular building projects (Teknologisk Institut, 2024; Boverket, 2024). This status remains far from what is required to meet the 2030 climate goals (Teknologisk Institut, 2024; Boverket, 2024).

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Several factors contribute to this stagnation. Firstly, the impact of European legislation has been overestimated, with policy measures proving insufficient to drive large-scale change. Secondly, the positioning of "circular construction" as a consultancy commodity has diluted interest, overshadowed by newer concepts and trends. Thirdly, there has been limited progress in developing platforms for the circulation of used building materials, coupled with inadequate digital infrastructure to support these efforts.

Within this challenging context, our study examines the journey of a particular contractor from 2021 to 2024, aiming to understand how a company navigates these persistent obstacles through a combination of internal strategies and innovative collaborations. Acknowledging the scope for firm-level strategising, we conducted an in-depth investigation of a Danish contractor, CDK, as it attempted to advance its circular business practices. Adopting as strategy as practice and process perspective (Burgelman et ala 2018).

CDK, a large-scale company with multi-100-million-euro revenue, experienced significant growth prior to the study period and maintained this scale throughout. However, rather than operating within a steadily evolving market, CDK's efforts unfolded in a fragmented and often resistant landscape where circularity remained elusive. Our study provides insights into how an established construction firm sought to adapt its practices while confronting structural, logistical, and regulatory barriers that continue to impede broader transitions toward circularity.

METHOD

To understand how circular business models develop over time, we build on a qualitative longitudinal research approach, tracking four companies from 2020 to 2024. This approach provides in-depth insights into how businesses formulate strategies, adapt to market conditions, and engage with stakeholders to implement circularity. By focusing on changes in a longitudinal manner, we hoped to explore the development of circular strategies, their challenges, and the adjustment process.

The case studies include four companies: A contractor, an architect, a civil engineering and a material supplier. Data was collected through two rounds of semi-structured interviews with key representatives from the four companies - 8 in 2022 and 14 in 2024 -. Additionally, four workshops were conducted to support collaboration and refine circular strategies. They involved representatives for the four companies. Workshop 1 (Autumn 2022) established a framework based on initial interviews to clarify visions and ambitions. Workshop 2 (Spring 2023) focused on identifying challenges, mapping networks, and defining key partners. Workshop 3 (2023) provided tailored sessions to refine circular business models. Workshop 4 (2024) validated findings, gathered feedback, and reflected on strategic progress.

The workshops created a collaborative learning environment where stakeholders could exchange ideas, test concepts, and refine their strategies. However, this paper focuses on how one specific company successfully navigated challenges, adapted its strategies, and built partnerships to promote circularity within its context. The choice of CDK as the main case is opportunistic, as it was the only one among the four studied companies to develop genuinely new business models. The architectural firm's circularity initiatives came to an end when the unit was dissolved as part of an organisational merger. The consulting engineering firm experienced significant employee turnover, which led to a shift in strategic priorities. Lastly, the material

producer made incremental improvements by optimising existing processes but did not engage in the development of entirely new solutions. The findings offer valuable insights into the practical steps and collaborative efforts required to achieve circularity in the construction industry.

Conceptual Framework

In our review of circular business model literature, we encountered various definitions and interpretations of circularity and the circular business models (Kirchherr *et al.,* 2017; Ludeke-Freund *et al.,* 2019).

Traditional literature often frames circularity through technical processes such as recycling, reuse, resource efficiency, and closed-loop systems. These approaches tend to focus on optimising material flows and minimising waste within predefined supply chains. Circular business models are typically described through strategies that prioritise resource recovery, product life extension, and the creation of secondary markets for reclaimed materials (Jayakodi *et al.,* 2024).

These models also imply that circular business models involve more than technical optimisation; they require a fundamental restructuring of supply chains. Moving away from linear models, circular approaches should build on demand interconnected and adaptive systems where suppliers, manufacturers, and clients are integrated within a continuous loop of material use. This restructuring should be facilitated by strategic alliances, joint ventures, take-back systems, leasing models, and collaborative networks aiming at enhancing resource efficiency and creating value from what would otherwise be considered waste (Rao *et al.,* 2025).

Theoretical background

The strategy-as-practice and process (SAPP) approach emerges out of an extension of the strategy-as-practice (SAP) perspective (Burgelman etal 2018). SAP and SAPP emphasise that strategy is not a static plan or a singular executive decision but is instead something people do. It focuses on the micro-level activities, routines, and interactions through which strategy is enacted by practitioners such as managers, employees, or even external actors (Johnson *et al.,* 2007). Strategy, in this view, is not merely something an organisation has, but something that is performed and negotiated in everyday organisational life (Mantere, 2005). The SAP approach centers around three key elements: practices (the tools and routines employed), practitioners (the actors involved), and praxis (the ongoing activities through which strategy unfolds).

By contrast, the strategy-as-practice and process (SAPP) approach extends the SAP view by incorporating a processual perspective on how strategy unfolds over time. It brings together both the practical actions of strategists and the longer-term, often unpredictable development of strategic change (Burgelman *et al.,* 2018). SAPP is concerned with both the micro-level activities emphasized by SAP and the macro-level dynamics of strategic evolution, power struggles, and organisational learning. In other words, SAPP examines how strategy is both practiced and processed, emerging through a complex interplay of decisions, actions, and contextual change.

As such, strategy rarely materialises through a linear plan or a single visionary blueprint (Mintzberg *et al.,* 1998). Instead, it unfolds as a dynamic, iterative process shaped by internal negotiations, external pressures, and continual reorientations (Burgelman *et al.,* 2018). Strategising occurs through the interactions between actors, organisational routines, and contextual shifts, making it an empirical question as to

which actors drive these processes—whether senior executives or more distributed, even informal, agents (Mantere, 2005).

This perspective resonates with critiques of the business model literature, which often treats business models, including circular business models, as static templates. In contrast, both SAP and SAPP highlight the fluidity and performativity of strategy and emphasize the mobilisation of ideas, tools, and alliances, whether drawn from within the firm or borrowed from external sources. Strategic episodes may be seen as critical moments (Clausen and Koch, 1999) or as evolving sequences of decisions and actions (Hendry and Seidl, 2003), each shaping how strategy is made and remade over time. Below we simply refer to "SAPP" appreciating the huge overlap between SAP and SA

The case of CDK

CDK is a nationwide construction company in Denmark with around 700 employees. The company positions itself as a market leader in renovating public housing, including schools, daycare centres, housing cooperatives, and homeowners' associations. Beyond renovations, CDK is also involved in constructing new residential buildings, public institutions, and commercial properties.

Our study revealed that CDK's journey toward developing a circular business model was gradual and complex, involving a series of strategic decisions, alliances, and practical challenges over time. From 2014 to 2016, CDK's parent company initiated its first circular economy project, aiming to explore the feasibility of integrating reused materials into their operations. This early effort laid foundational principles that would guide future circular practices. However, the initial project remained largely experimental, with limited structural integration into broader business strategies.

By 2016, CDK began to systematically incorporate circularity into their bids, reflecting an increasing awareness of sustainability as a marketable and strategic asset. Circularity was gradually integrated into renovation projects, where material reuse could be practically tested. This incorporation remained fragmented and project-specific, lacking broader cohesion within the company's strategic framework.

By 2020, CDK's engagement in several R&D projects focused on material reuse demonstrated a growing commitment to circular practices. These projects were often conducted in partnership with external research bodies, reflecting CDK's effort to leverage external expertise to refine and expand its approach to circularity. The R&D projects also aimed to establish legitimacy and credibility within an emerging market for circular building practices.

In 2022, CDK acquired a 20% stake in PRB (Platform for Reuse of Building Materials), a platform specialising in recycling and selling second-hand building materials. This acquisition marked a strategic shift from exploratory projects to more concrete and commercially integrated practices. Through PRB, CDK aimed to deliver resource-efficient, closed-loop material flows by supplying recycled materials for both new construction and renovation projects. Instead of incinerating materials, CDK sought to redirect them towards reuse, preserving their environmental and economic value.

The acquisition also opened new revenue streams, allowing CDK to position itself as a supplier of recycled materials rather than merely a user. This dual role—both a producer and consumer of recycled materials—was seen as a means to differentiate CDK from competitors. PRB provided a structured platform for integrating recycled

materials into CDK's existing projects, making circularity more than an aspirational goal but a concrete business proposition.

However, interviews revealed that scalability remained a persistent challenge. Procuring enough uniform materials for large-scale projects, such as acquiring 100 identical doors for a school, proved difficult. Limited access to standardised products was anticipated to become a significant bottleneck for PRB's ambitions to scale its operations. Without consistency in material availability, CDK found it challenging to integrate reused materials into larger, commercially viable projects.

Furthermore, the acquisition of PRB reflected CDK's broader strategy to increase the volume of recycled materials available in the market, thereby making circular practices more accessible and attractive within the industry. The strategy aimed at creating economies of scale by enhancing the visibility and availability of reused materials. CDK recognised that if recycled materials could be provided at scale, their appeal to other developers and contractors would increase, thereby normalising circularity within the construction industry.

Additionally, a retail partner acquired 20% of PRB in 2022, creating a three-way partnership. The retail partner's network of 22 wholesale centers across Denmark played a crucial role in raising awareness of CDK's circular profile among various market segments. These wholesale centers served as distribution points for PRB's recycled materials, enhancing accessibility for both professional contractors and private customers.

For private customers, value creation was primarily tied to reduced costs and the social capital associated with building sustainably. Recycled materials appealed mainly to those engaged in renovations or DIY projects who valued contributing to a greener lifestyle. The branding of PRB products often highlighted their environmental benefits, tapping into broader cultural narratives about responsible consumption and ethical building practices.

Additionally, the storytelling aspect of recycled products emerged as a strategic tool for engaging customers. Materials with unique histories, such as oak planks from the Opera House, added an element of authenticity and cultural value to CDK's offerings. This approach proved particularly effective for marketing to private consumers who valued the idea of incorporating historical or prestigious materials into their projects.

CDK's renovation activities further reflected their strategic focus on circular business models, particularly in leveraging materials derived from renovation projects. The study identified resource mapping, marketing of materials, resale, and integrating recycled materials into construction projects as CDK's core competencies. These activities were essential for establishing circular networks between companies and fostering collaborations that laid the groundwork for more complex and ambitious circular business models.

Despite these efforts, scaling CDK's circular model to professional projects did not meet expectations. A major obstacle was the lack of reliable documentation for the lifespan and quality of recycled materials, which acted as a barrier to integrating these materials into new projects. This issue was particularly problematic for projects requiring long-term durability or structural integrity. Without established standards for assessing the quality of recycled materials, CDK's attempts to integrate them into larger projects were often met with scepticism from clients and regulators.

Furthermore, the general shortage of recycled materials created additional difficulties in scaling CDK's business model. CDK's strategy of acquiring PRB, fostering partnerships, and emphasising resource mapping proved effective at a smaller scale but faced significant barriers when applied to larger projects.

The logistical challenges of managing warehouse functions also emerged as a significant barrier. Storing and sorting reclaimed materials required substantial investment, and the costs associated with these activities limited PRB's ability to scale effectively. Without adequate infrastructure for warehousing, the ambition to provide consistent supplies of recycled materials remained constrained.

Lastly, external regulatory frameworks and the broader consultancy-driven commodification of circularity added complexity to CDK's efforts. While CDK sought to build a cohesive strategy for circularity, the lack of comprehensive regulations and the fragmented nature of industry standards hindered their progress. As "circular construction" became increasingly commodified by external consultants, CDK struggled to differentiate its own practices from market-driven narratives.

Throughout this process, Adam, the sustainability manager, emerged as a critical champion within CDK, driving most of the changes during the time of our study. His role was not only operational but also strategic, as he actively shaped the company's circular business model through ongoing negotiation, coordination, and advocacy. Adam's efforts to establish PRB, facilitate partnerships, and promote storytelling around culturally significant materials were instrumental in CDK's progress. His capacity to bridge internal operations with external networks demonstrated how strategic agency within organisations often hinges on individual actors who push for change.

Adam's contributions also illustrate how strategy emerges through practice. Rather than adhering to a fixed blueprint, Adam continually adjusted CDK's approach based on feedback from partners, clients, and regulatory bodies. This iterative process reflected his ability to combine routine practices with experimental initiatives, facilitating a more adaptable and resilient approach to circularity. His engagement in navigating logistical, infrastructural, and regulatory challenges underlines the significance of practitioners in the construction of strategy.

Overall, CDK's journey toward a circular business model was marked by incremental progress, ongoing negotiation, and persistent obstacles. While Adam's role as a champion provided direction and coherence to CDK's strategy, external challenges and infrastructural limitations continued to constrain scalability. Nonetheless, CDK's strategy-making process demonstrates how circularity is enacted and constructed through a complex interplay of tools, interactions, and practices.

ANALYSIS AND DISCUSSION

From a Strategy as Practice and Process (SAPP) perspective, CDK's efforts to establish a circular business model can be understood as an ongoing process shaped by the actions, interactions, and tools employed by various practitioners within and outside the organisation. Rather than viewing strategy as a static plan, the SAPP approach reveals how strategy emerges through situated practices performed by key actors, particularly Adam, CDK's Sustainability Manager (Burgelman *et al.,* 2018, Jarzabkowski *et al.,* 2007; Whittington, 2006).

The incorporation of circularity into CDK's project bids from 2016 onwards illustrates how strategy was constructed through routinised practices. By embedding

sustainability principles into project bids, CDK began to formalise circularity within its everyday business operations. However, this routinisation was largely experimental and lacked coherence, reflecting the gradual and adaptive nature of strategy-making within CDK (Jarzabkowski and Spee, 2009; Nicolini, 2012).

Adam's leadership in initiating R&D projects on material reuse by 2020 highlights the role of non-routine practices in strategy formation processes. These projects functioned as experimental sites where alternative approaches to circularity were tested and refined. From a SAPP perspective, these efforts demonstrate how practitioners engage in strategic experimentation over time to explore new possibilities and overcome existing limitations. Adam's ability to connect internal efforts with external research bodies also shows how strategic agency involves bridging knowledge domains (Burgelman, 1991; Jarzabkowski, Balogun, and Seidl, 2007).

The establishment of PRB in 2022 marked a critical shift towards developing a formalised circular business model. The creation of PRB reflects how strategy is enacted through practices of institutionalisation, where experimental efforts are transformed into structured routines that can be scaled and commercialised (Golsorkhi *et al.,* 2010). By promoting PRB as both a platform for sourcing recycled materials and a marketplace for selling them, CDK sought to integrate circularity into a cohesive, market-facing strategy. However, from a business model perspective, the development of PRB also reveals significant limitations in CDK's capacity to challenge the existing supply chain structures. While CDK succeeded in creating a platform for recycling and reselling materials, the circular model largely remained internal to the company's own operations. Instead of reconfiguring external supply chains or fostering broader industry-level change, CDK primarily operated as both a client and provider of its own recycled materials (Whittington, 2006; Jarzabkowski and Kaplan, 2015). This self-contained approach restricted CDK's ability to scale its circular practices beyond its own organisational boundaries.

Despite efforts to institutionalise circularity through PRB, CDK's business model was characterised by a lack of engagement with external suppliers and clients beyond the retail partner. Rather than creating an open network where recycled materials could flow across various actors, CDK's model was primarily centered on circulating materials within its own projects. This reliance on internal systems illustrates how CDK's strategy was constrained by its inability to mobilise external supply chain partners or influence broader industry practices (Jarzabkowski and Kaplan, 2015; Vaara and Whittington, 2012). Partnerships were central to CDK's strategic efforts. The acquisition of 20% of PRB by a retail partner in 2022 expanded CDK's network, providing new distribution channels and enhancing visibility. From an SAPP perspective, these partnerships were not merely formal agreements, but ongoing negotiations shaped by interactions and adaptations. Adam's role in managing these relationships highlights the significance of building alliances as a way of advancing strategic goals. However, these alliances remained largely instrumental to CDK's own operations rather than facilitating a broader transformation of industry practices (Balogun and Johnson, 2004; Burgelman *et al.,* 2018, Rouleau, 2005).

A key aspect of CDK's approach to promoting circularity involved the use of storytelling as a branding tool. Adam championed the idea of marketing materials with unique histories, such as oak planks from the Opera House, to appeal to customers who valued authenticity and cultural heritage. By framing recycled

materials as products with stories, CDK enhanced its appeal to private consumers who associated sustainability with social capital and ethical behavior. This approach illustrates how strategy-making is not only about material practices but also about crafting narratives that resonate with stakeholders (Rouleau and Balogun, 2011; Vaara and Whittington, 2012).

From a SAPP perspective, the limitations of CDK's business model highlight how strategy-making is shaped by broader institutional and infrastructural constraints. Despite Adam's efforts to build partnerships and institutionalise circular practices, the company's circular model remained confined to its own operations. The lack of reliable documentation for recycled materials, regulatory fragmentation, and logistical difficulties with warehousing all contributed to CDK's inability to expand circularity beyond its own projects (Nicolini, 2012; Jarzabkowski and Kaplan, 2015).

Adam's role as a champion within CDK was central to the enactment of strategy. His engagement was visible in his efforts to establish PRB, facilitate partnerships, and promote storytelling as a strategic tool. However, Adam's efforts were not always supported by top management. While he worked to push circularity as a core strategic priority, he sometimes encountered indifference from leadership who remained focused on short-term profitability and conventional business practices. Adam's strategy-making involved not only working with top management but also working against them when necessary to advance his circular agenda. His ability to navigate these tensions, adapting strategies based on feedback from partners, customers, and regulators was a process of iterative learning (Mantere, 2005; Golsorkhi *et al.,* 2010).

However, from a business model standpoint, Adam's efforts primarily succeeded in consolidating circularity within CDK's own organisational framework rather than creating a broader network of material flows that could engage multiple actors across the industry. CDK's reliance on internal networks and partnerships with the retail partner suggests that its circular business model remained largely self-referential, without challenging or transforming external supply chains (Whittington, 2006; Vaara and Whittington, 2012).

Overall, CDK's journey toward a circular business model illustrates how strategy-making is constructed through a complex interplay of tools, interactions, and practices. Adam's role as a practitioner was critical to this process, but his efforts were continually shaped and constrained by broader institutional and infrastructural conditions. CDK's experience demonstrates how circular business models can be limited by their inability to extend beyond organisational boundaries and reconfigure supply chains to include broader networks of actors. While the SAP perspective highlights how CDK's strategy emerged through the situated actions of practitioners like Adam, the SAPP lens brings additional attention to the longer-term, emergent processes and structural shifts involved in institutionalising circularity. CDK's trajectory reflects the tensions between micro-level agency and broader organisational and industry-level constraints—illustrating how strategy is both enacted in the moment and shaped through unfolding processes, alignments, and path dependencies (Burgelman *et al.,* 2018; Whittington, 2006).

CONCLUSIONS

The analysis of CDK's circular business model development demonstrates how strategy-making is shaped by a complex interplay of practices, interactions, and constraints. From a Strategy as Practice and Process perspective, CDK's approach to

circularity involved efforts to institutionalise new practices through PRB, build partnerships, and enhance legitimacy through storytelling over a longer process in time.

Adam played a central role in driving these initiatives, sometimes working alongside top management and at other times pushing forward despite their passive resistance or reluctance to fully engage with the circular agenda. His strategic efforts were characterised by experimentation, negotiation, and adaptation, illustrating how practitioners actively shape strategy through their actions. However, CDK's reliance on internal structures and partnerships limited the scalability of its circular business model. The company's strategy-making process was further constrained by logistical challenges, fragmented regulatory frameworks, and an inability to effectively engage external supply chains. Rather than transforming broader industry practices, CDK's circularity efforts remained largely internalised and self-referential. While Adam's contributions were essential in advancing circularity within CDK, the broader system of material flows and partnerships necessary for genuine transformation remained underdeveloped. To mobilise such practices across the industry, future efforts could involve building shared platforms for traceable material exchange, forming precompetitive alliances, or introducing policy mechanisms that reward open innovation and collaborative circular practices. Without such collective infrastructure, the scalability of circular business models risks remaining confined to individual firms.

Ultimately, CDK's experience illustrates how circularity remains elusive when confined to organisational boundaries rather than integrated into broader networks. Despite substantial efforts, circular building appears to be going in circles.

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REVITALISING BUILDING PRODUCTION THROUGH REGENERATION: A POSITIONAL PAPER

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This paper explores regenerative building production as an approach that goes beyond minimising environmental harm to actively generating net-positive socio-ecological impacts. Grounding the discussion in sustainability transitions theory, we highlight how construction significantly contributes to global carbon emissions and waste. Using the phenomena construction methodology, a conceptual framework is proposed to integrate regenerative design principles with sociotechnical perspectives, framing the shift to regeneration as a transitional phenomenon and revealing how multilevel interactions among stakeholders, policies, and niche innovations can drive adoption. Practical steps for clients, designers, contractors, policymakers, and communities include revised procurement models, ecological design solutions, and policy incentives that support deeper collaboration and accountability. The paper underscores that achieving a regenerative transition requires shifting incentives, fostering collaboration, and effecting systemic change across the sector.

Keywords: regeneration; building production; construction management; net positive impact; planetary boundaries

INTRODUCTION

The mainstream construction industry accounts for around 40% of global CO_2 emissions (Burns *et al.,* 2024) and 40% of EU waste (Eurostat, 2024). A significant portion of this impact arises from building production—that is, on-site processes, supply chains, and management practices. Although measures such as emission-free sites, recycling, and lifecycle analyses have been introduced, entrenched norms still prioritise short-term cost reduction over long-term resource efficiency (Oyefusi *et al.,* 2024). Regeneration offers a pathway beyond sustainability and circularity by focusing on repairing damage, improving well-being, reversing environmental degradation, and restoring ecosystems for a net positive impact; it involves humans as key ecosystem contributors engaging and collaborating holistically (Mang *et al.,* 2016). However, regenerative measures, strategies and business models have not been widely adopted in building production. To examine how that can become

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regenerative, this paper employs a systematic literature review and the phenomena construction methodology (Alvesson and Sandberg, 2024), framed by sustainability transitions theory (Köhler *et al.,* 2019). We propose an early conceptual framework that positions regenerative building production within the sociotechnical system of construction and outlines practical steps for stakeholders to move from niche experiments to broader implementation.

Sustainability transitions theory aims at conceptualising how sociotechnical systems can be radically changed to address challenges incurred by unsustainable consumption and production - as it is considered that incremental improvements and technological fixes ultimately fail to address those (Köhler *et al.,* 2019). This theory is primarily grounded in the interplay of the sociotechnical concepts of the multilevel perspective (MLP), technological innovation systems (TIS), and strategic niche management (SNM) (Bergek *et al.,* 2008; Schot and Geels, 2008; Köhler *et al.,* 2019). Those concepts and their interaction are elaborated below and will later frame the integration of regeneration into building production as a systemic transition rather than a standalone technical fix.

MLP explains transitions as non-linear processes unfolding across three nested structuration levels: niches, socio-technical regimes, and the landscape (Köhler *et al.,* 2019). Niches are protected "incubation rooms" for radical innovations, where novelties can develop shielded from market selection (e.g., pilot projects for reuse). Regimes represent the dominant technologies, infrastructures, business models and institutions that are stabilised by incumbent actors and routines, leading to path-dependence and incremental change (Köhler *et al.,* 2019). The landscape denotes broader exogenous trends (e.g., climate targets, economic conditions, cultural values) pressuring the regime; transitions occur when niche innovations mature and align with landscape pressures to sufficiently destabilise existing regimes, thus becoming the new regimes (Köhler *et al.,* 2019). In MLP, stability and change interact; regimes are typically change-resistant, so niche breakthroughs often require both internal momentum and external landscape pressure (Geels and Schot, 2007).

Apart from MLP, the TIS framework focuses on the development of innovation systems around a specific technology or solution, and consists of actor networks (e.g., firms, users, policymakers), institutions (regulations, norms), and technological artifacts related to innovations (Bergek *et al.,* 2008). Rather than multilevel structures, TIS evaluates seven systemic functions - i.e., key processes that must be fulfilled to successfully develop and diffuse a novel technology: (1) knowledge development and diffusion; (2) entrepreneurial experimentation; (3) directionality of innovation efforts; (4) market formation; (5) sociopolitical acceptance and legitimation; (6) resource mobilisation; and (7) positive externalities (spillovers reinforcing the system) (Köhler *et al.,* 2019). By assessing functional strengths and weaknesses, systemic barriers hindering innovation can be pinpointed - e.g., a stagnation in thinking beyond sustainability and towards regeneration might reveal a lack of relevant business models, or insufficient legitimation (scepticism about quality or building code compliance). TIS is especially useful for understanding early-phase innovation dynamics and identifying policy or network interventions to strengthen the innovation system (Bergek *et al.,* 2008). It emphasizes the emergence and diffusion of novel innovations more than the active destabilisation of incumbent systems - which is MLP's focus (Köhler *et al.,* 2019).

Furthermore, SNM examines how to deliberately nurture niche innovations so they can grow and challenge the regime (Schot and Geels, 2008). It posits that radical innovations typically start in protective niches - e.g., subsidised demonstration projects, living labs, or specialised markets - where they are shielded from mainstream selection pressures (Köhler *et al.,* 2019). There, dedicated actors (e.g., ConTech startups or clients practicing social procurement for community buildings) invest in developing the innovation. SNM emphasizes three key processes for niche development: (1) first- and second-order learning about technical issues and broader societal impacts; (2) network building by forming broad stakeholder alliances to support the innovation; and (3) articulating compelling narratives to attract attention and resources (Köhler *et al.,* 2019). Through iterative cycles of experimentation and feedback, a niche innovation can improve on technical performance, reduce uncertainties, and build up a supportive coalition (Köhler *et al.,* 2019). Successful niches may then scale up and enter mainstream markets. SNM can thus guide experimental projects and strategically position innovations - which is highly relevant for adopting regeneration in building production.

In practice, MLP, TIS, and SNM are often seen as complementary; niche experiments can function as seeds for broader transition dynamics (Markard *et al.,* 2012). However, while all three concepts adopt a systemic perspective to capture the complexity of sociotechnical change (Köhler *et al.,* 2019), they differ in focal scale and analytical lens. MLP provides a broad structural overview of transition dynamics across levels, highlighting how landscape pressures and niche-regime interactions drive systemic change. TIS functionally analyses the innovation process for a given technology, identifying which system functions are blocking or enabling progress. SNM gives a process view for cultivating practical innovations through experiments and learning-by-doing. In short, MLP is useful for understanding the macro-context and timing of transitions, TIS for diagnosing innovation system weaknesses and crafting policy support for meso-level system building, and SNM for informing on-the-ground experimentation and micro-level innovation and stakeholder management. As such, to implement all three concepts in tandem, a positional framework needs to account for this variation in application levels, as well as their vertical interaction.

METHOD

We first conducted a systematic literature review (SLR) (Bell *et al.,* 2022) to explore the general application of regeneration in the built environment. We focused on 2016-2025 to capture the recent emergence of, primarily, regenerative design as a distinct paradigm (Cândido *et al.,* 2023). This is justified on the basis that the field is relatively nascent and rapidly evolving, with key definitions, frameworks, and examples solidifying only in recent years. We targeted peer-reviewed academic sources across Scopus and Web of Science, using keywords like “regenerative design”, “regenerative urban development”, “built environment”, and “circularity”. We prioritised literature from the Global North, given that much of the relevant discourse originates there, while also incorporating studies from the Global South when available to provide broader context. We applied standard systematic screening (Bell *et al.,* 2022), first by filtering by title/abstract relevance and followed with full-text review to identify sources that substantively discuss regeneration in the built environment. Grey literature (e.g., industry reports, guidelines) was consulted sparingly to illustrate practical applications (e.g., specific regenerative building projects) but did not dominate our source base. The SLR was conducted in iterations, at first broadly netting 1,800 hits; subsequently, after five systematic screening loops

and gradually more specific keywords (e.g., “regenerative construction cases”), we ended up with 20-25 references in the paper. Following the SLR, we synthesized our findings into the previously unutilised context of building production, by employing the phenomena construction methodology (Alvesson and Sandberg, 2024), which encourages researchers to actively construct the phenomenon of interest rather than simply accept established definitions. In our case, “regeneration in building production" is not an existing well-defined concept, so we iteratively built it by integrating insights from regenerative built environment literature framed within the previously expounded sociotechnical concepts of sustainability transition theory; reviewing the literature helped identify key attributes of regenerative practice, which we then re-conceptualised for building production to address our research question (Alvesson and Sandberg, 2024). We thus combined, e.g., regenerative design principles and sociotechnical transition factors, to establish regenerative building production as a new phenomenon.

Literature Review and Findings

Regeneration in the built environment has emerged as a paradigm that goes beyond traditional sustainability. While conventional “green” design aims to reduce harm (e.g., lower energy use), regenerative approaches strive for net-positive outcomes actively restoring and improving socio-ecological systems (De Wolf and Bocken, 2024). This marks a conceptual departure from more reductionist, mechanistic views on sustainability (Camrass, 2022). Regeneration embraces the interconnectedness of socioecological systems, viewing human development as part of nature (Mang *et al.,* 2016; Camrass, 2022), promoting co-evolution and mutual thriving through deeper integration and interdependence (Jones *et al.,* 2023).

In the built environment, regeneration contrasts the ecosystem degradation often associated with urban development, with regenerative practices seeking to renew soils, boost biodiversity, enhance community well-being, and restore the human-nature relationship (Toner *et al.,* 2023). It spans frameworks such as regenerative design, urban planning, and architecture by grounding them in the shared principles of systems thinking (situating projects within broader socioecological systems), place-based design (responding to local culture and ecology), co-evolution (adapting with natural systems), and net positivity (e.g., buildings enhancing ecosystem health and social footprint) (Camrass, 2022; Jones *et al.,* 2023). A regenerative building might generate renewable energy, clean more water than it consumes, increase biodiversity, and foster community ties. This approach redefines success, measuring outcomes like ecosystem services, community well-being, and cultural value in addition to resource efficiency (Sadat *et al.,* 2024; Oyefusi *et al.,* 2024). Recent research highlights both growing interest in putting regenerative ideals into practice and the challenges of doing so. While ambitions like net-positive energy, biodiversity, and social equity are well articulated, definitional and paradigmatic inconsistencies persist (Camrass, 2022). Still, moving “beyond sustainability” while rooted emerges as a shared emphasis (De Wolf and Bocken, 2024). This reflects a shift, where embracing complexity, long-term vision, and an ethic of care for living systems, is pronounced.

Regenerative principles can be applied across levels (Oyefusi *et al.,* 2024). Nonetheless, neighbourhood and district levels are often highlighted as ideal for intervention, based on balancing building integration, green infrastructure, community systems, and strong stakeholder engagement (Camrass, 2022). Precinct-scale projects (e.g., eco-districts) enable synergies like shared energy, water recycling, and

community gardens, fostering circular, closed-loop systems (Camrass, 2022). Moreover, place-based design and community involvement are repeatedly cited as keys to success (Toner *et al.,* 2023). Other examples occur at the master-planning scale (e.g., ecovillages, campuses) where architecture, landscape, and community can be integrated holistically (Toner *et al.,* 2023). Building-scale examples also exist, notably through the Living Building Challenge (LBC), with net-positive cases like the Bullitt Centre and the Phipps Centre (Cole, 2023). However, by early 2025, fewer than 25 projects worldwide had achieved full LBC certification, underscoring the gap between regenerative ideals and mainstream practice (Green Building Alliance, 2025).

While regenerative visions are often conceptually ambitious, translating them into building production practice remains challenging and underexplored (Camrass, 2022). There is limited guidance on how planning-stage ideals can be realised through conventional construction, supply chains, and contractor practices (Sadat *et al.,* 2024). Barriers include inadequate stakeholder engagement, entrenched industry norms, and lack of supportive incentives; for example, market valuations rarely reflect socio-ecological benefits, making regenerative investments hard to justify (Camrass, 2022; Cole, 2023). Moreover, regenerative building requires systems thinking, ecological literacy, and community facilitation - areas where many professionals lack training and skills (Toner *et al.,* 2023). A few pilots have attempted to foster such training; e.g., LENSES (Living Environments in Natural, Social and Economic Systems), a tool developed to help project teams conceptualise and implement regenerative design, was applied in an Australian development (Plaut *et al.,* 2016); and regenerative development was attempted in Chile and Mexico, through co-designing with local communities, restoring brownfield and degraded sites into healthy ecosystems, and creating local economic value (Gibbons *et al.,* 2018). Nonetheless, these sparse examples exemplify the gap in mainstream practice even more and highlight the need for capacity-building and education.

In summary, regeneration in the built environment is framed as a systems-based paradigm aiming at net positivity. Over the past decade, its principles and frameworks have been tested in selected projects, but mainstream adoption remains limited due to definitional ambiguities, unsupportive policies, entrenched industry norms, and coordination challenges across disciplines and scales (Cole, 2023). A key gap lies in integrating regeneration into building production, which largely depends on how its principles are implemented in material sourcing, construction methods, supply chains, and on-site management.

Positional Framework: Regenerative Building Production

Informed by the phenomena construction methodology, our proposed framework places our literature insights (i.e., principles, challenges, multiscale considerations) within building production using the previously expounded concepts of MLP, TIS, and SNM. Thus, it positions regenerative building production as an innovation to be nurtured and scaled within the sociotechnical system of construction. Specifically, our framework is delineated into: (a) a multilevel perspective on integrating regeneration into building production, and (b) proposals for practical implementation steps for key stakeholders aligned with this perspective.

MLP, TIS, and SNM on Regenerative Building Production

MLP can help identify landscape, regime, and niche factors shaping a regenerative transition in building production. At the landscape level, pressures such as the climate crisis, biodiversity loss, international policy shifts, and changing market expectations

can create momentum for a regime change (from "doing less harm" to "doing more good"). However, the current building regime is resistant: contractors prioritise cost and speed, regulations focus on minimum compliance, supply chains depend on high-carbon materials, and a risk-averse culture limits experimentation (Cole, 2023).

To drive regenerative building production, TIS points to niche innovations nurtured and connected to regime actors. Small-scale projects testing regenerative methods (e.g., biodegradable materials, zero-waste sites, habitat restoration, and community co-building) can act as "learning laboratories" for new practices. Finally, SNM incentives are essential, offering support through research funding, green procurement, and clients prioritising regenerative goals. As successful experiments accumulate, networks can then form to share knowledge and build momentum (Cândido *et al.,* 2023), like how LEED scaled sustainable practices. A feedback loop can emerge, where landscape pressures (e.g., climate targets) increase regime openness, enabling niche innovations to influence mainstream practice. As projects prove viable (e.g., restoring ecosystems within budget) larger actors can begin to adapt in the new regime; over time, building codes, standards, and financing tools can evolve to support regeneration, marking a sociotechnical transition from niche to norm.

In this process, intermediaries and coalitions are key - e.g., an alliance of architects, contractors, and environmental NGOs can develop guidelines for regeneration, acting as a bridge between niches and regime. This multilevel view informs our suggested practical steps (see below) by highlighting that change must happen at different levels: bottom-up innovation, top-down pressure, and lateral spread through networks.

Stakeholder Implementation Steps

Achieving regeneration during building production requires coordinated action from all relevant key stakeholders. Based on our multilevel perspective, we outline practical steps for each stakeholder category to advance regenerative building production.

Project developers/clients/owners: Setting ambitious goals and demanding innovation
Clients play a pivotal role in embedding regeneration by defining ambitious targets. Specifying goals such as zero waste, net-positive energy, or biodiversity gains in project briefs can provide mandates for design and construction teams (Cole, 2023). Adopting collaborative procurement models (e.g., integrated project delivery (IPD)) can further align stakeholders around regenerative outcomes. Clients must also invest with a long-term perspective, as regenerative features may not yield immediate profit but build resilient, future-proof assets. Incentives, pilot programs, and public-private partnerships can help offset initial costs. Ultimately, clients can drive change by championing the vision, committing resources, and creating demand that pulls niche innovations into mainstream practice.

Design professionals (architects, engineers, consultants): Translating regenerative principles into buildable solutions and guiding the team
Designers can translate regenerative principles into actionable plans - like specifying materials and methods that support regeneration (e.g., carbon-storing or pollution-absorbing materials) and designing for deconstruction and circularity (Remat, 2025). Engineers can then ensure the safety and feasibility of regenerative systems (e.g., rainwater harvesting). A practical tool is a Regenerative Construction Plan, outlining how site work will avoid harm and create positive impacts (e.g., reusing topsoil, preserving native vegetation). Workshops and value-engineering sessions can then

align design intent with construction methods and educate builders on regenerative goals. As "niche intermediaries," designers mediate between radical ideas and practical delivery, bridging vision and execution (Cole, 2023).

Construction managers and contractors: Implementing regenerative practices
Building production is where plans materialise, so it must evolve to meet regenerative goals. Contractors can consult the previously conceived Regenerative Construction Plan and adopt a "construction ecology" approach, treating the site as an ecosystem to be improved. This includes rigorous waste management (aiming for zero landfill), using low-emission or renewable-powered equipment, and protecting or enhancing habitats during construction (e.g., timing work to avoid disturbing wildlife, creating wetlands to treat runoff). Training site workers in regenerative practices (in continuation to the workshops) and appointing an ecological supervisor can reinforce these efforts. Contractors can also innovate through modular or prefabricated methods to reduce waste, prioritise early installation of green infrastructure, and try emerging materials like algal concrete or mushroom-based insulation (Remat, 2025). Participating in pilot programs and industry networks can also support knowledge exchange. From a sustainability transitions lens, contractors can scale niche innovations; once a method proves viable, they can refine, standardise, and replicate it. Sharing project data (e.g., on carbon sequestration, biodiversity gains, etc.) can then help build the business case and an industry-wide technical foundation.

Policy makers and regulators: Enabling and incentivising regenerative practices
Local and national governments can play a key role in advancing regenerative building production by shaping the regulatory regime. The first step is integrating regenerative criteria into building codes and approvals (e.g., requiring large projects to demonstrate net-positive environmental impact or contribute to urban ecological networks). While traditional codes focus on health, safety, and minimum standards, new performance-based criteria could reward outcomes like habitat restoration or surplus clean energy. Policymakers must also ensure regulations do not stifle innovation; overly prescriptive rules risk creating a compliance mentality that discourages experimentation (Cole, 2023). Innovation zones or pilot exemptions can provide flexibility for testing regenerative approaches. Financial tools, such as fast-track permitting, grants, and tax incentives, can offset upfront costs and de-risk pioneering projects. Public procurement can lead by example, setting regenerative requirements for government projects and creating market demand. Additionally, policy should build industry capacity through funding training, research, and knowledge-sharing (Cole, 2023). Incentivising niche innovation would mean moving from enforcing minimum standards to enabling transformation and gradually redefining standard practice.

Community and end-users: Participating in the building production processes for local value
Often overlooked in production, local communities and end-users can be key in regenerative outcomes. Participatory practices (e.g., involving residents tree planting or placemaking) can minimise disruptions and enhance local value. Community input, including indigenous ecological knowledge, can also improve project alignment with local ecosystems (Cole, 2023). Maintaining transparent dialogue throughout construction, e.g., by sharing updates on progress towards regenerative goals, can build trust and public support. Treating the site as part of the community can foster education through tours or workshops. Engaging future users during construction can

also improve the long-term success of regenerative goals, as those involved are more likely to sustain and advocate for them.

These proposed actions show that all stakeholders in building production can have a role in driving systemic change. Our positional framework places regenerative building production at the nexus of multilevel transformation and multi-actor participation: clients set the vision and fund it; designers translate it into plans; contractors deliver with suitable methods; policymakers enable the shift; and communities co-create and benefit. These roles align with sustainability transitions theory, where regime elements must align to enable a new configuration (Cole, 2023; Cândido *et al.,* 2023). The framework also emphasizes feedback loops, where early project outcomes should inform evolving policies and practices. The aim is to institutionalise regenerative approaches by moving from isolated experiments to mainstream norms. Building production can thereby scale from niche innovation to a catalyst for socioecological transformation in the built environment.

DISCUSSION

The proposed framework shows how insights from regenerative built environment literature can be practically applied to the construction phase through a sociotechnical sustainability transition lens. A key implication is that regenerative building production requires technical solutions, process innovation, and cultural change. Framing regeneration within a multilevel perspective reveals that green construction techniques, however advanced, will not drive systemic transition without aligned support from clients, supply chains, and regulations.

The framework's multi-stakeholder approach initiates the addressing of a key gap: how to operationalise regeneration in building production. It offers a proposal for a structured roadmap to translate high-level principles into construction practices. A key takeaway for practitioners is the need for early collaboration; regenerative outcomes like zero waste or habitat preservation depend on design-stage decisions being carried through to execution. Strategies such as IPD and early contractor involvement are therefore crucial. Similarly, policymakers can use the framework to identify leverage points (e.g., reforming procurement policies and introducing innovation-friendly codes).

A key consideration is the feasibility and pace of transition. Despite recent momentum (particularly through digital tools like BIM) and the specific attributes of different national contexts, the construction industry as such largely remains risk-averse and slow to change. Regenerative practices today are at a stage comparable to early green building efforts; emerging but lacking widespread institutional support. With only a few realised projects, regeneration remains a niche. Therefore, deep-seated regime inertias, like entrenched business models, education gaps, and short-term cost thinking, must be addressed. Our stakeholder recommendations target these barriers: realigning incentives to reward long-term regenerative value, recognising ecosystem services, and advancing professional education and knowledge exchange. Still, the transition will likely be gradual. Early successes should be celebrated but scaled thoughtfully to preserve quality and credibility.

Developing measurable indicators is also essential. While net-positive goals are conceptually clear, assessing biodiversity gains or social well-being is complex. Without clear metrics, it is difficult for industry and regulators to set targets or verify outcomes. Tools like the LBC certification have begun defining such metrics (e.g.,

net-positive energy, and habitat impact), but further refinement is needed. We can thus highlight the development of indicators like a construction biodiversity index, well-being metrics, or circularity scores to track progress and ground regenerative goals in practice, as a key area of future research. As another future direction, digital technologies could support this effort: AI-enabled digital twins might enable real-time monitoring of environmental performance, while blockchain could support transparent, collaborative tracking of regenerative criteria across stakeholders.

CONCLUSIONS

Integrating regeneration in building production represents a frontier for sustainable development that requires reimagining roles, retooling practices, and realigning incentives. While the vision of regenerative built environments is increasingly well-articulated, the implementation details, especially during building production, remain a challenge. We therefore propose a structured positional framework that can act as a conceptual bridge between theory and practice. In the long term, a transition to regenerative building production could significantly amplify the sector's contribution to moving from mitigating harm to actively healing and improving our ecosystems and societies. Such a shift would represent a profound sociotechnical transition where the construction industry could lead in demonstrating how human enterprise not only coexists with nature but helps it thrive.

Our positional framework is limited in that it is conceptual; however, it does carry practical significance, so we encourage stakeholders in research and practice to refine, test, and implement it. For industry actors, it provides a vision of a collaborative, multilevel effort for shifting building production towards regeneration. For academics, it demonstrates the combination of the sociotechnical aspects of sustainability transitions theory with regeneration concepts in the built environment to structure a complex problem. In that sense, we effectively constructed a new phenomenon: regenerative building production. We thus aspire to influence how future studies evaluate construction projects, i.e., looking at them in terms of regenerative contributions, or how construction-phase innovations diffuse.

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TRANSFORMING THE DESIGN OF RESOURCE-INTENSIVE LOAD-BEARING STRUCTURES INTO REGENERATIVE PRACTICES: AN INSTITUTIONAL ANALYSIS OF OPTIMISED DESIGN METHODS IN CONSTRUCTION

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Addressing over-dimensioning in construction, which leads to excessive resource use and CO2 emissions, is crucial for building regenerative cities. By integrating New Institutional Theory and Action Research, traditional design practices in the Danish construction industry can evolve to support regenerative sustainability. Current practices often prioritise cost over sustainability, resulting in over-dimensioned structures. A new digital design practice for load-bearing structures is proposed, aiming to balance structural integrity and environmental sustainability through optimisation principles. Practical applications of these principles are demonstrated through a simulation tool and design case. Stakeholders in the Danish construction industry collaborated through workshops and interviews to develop and evaluate the new design practice. This process identified institutional barriers and drivers, providing insights into the social and technological factors influencing the adoption of sustainable and regenerative design practices. The findings highlight the need for clear guidelines and supportive policies to foster innovation. Integrating digital tools and optimisation techniques, supported by collaboration and education, is essential for building regenerative cities, promoting a regenerative, resilient urban future.

Keywords: action research; digitalisation; institutional theory; over-dimensioning; sustainability

INTRODUCTION

The construction industry is a critical sector that significantly impacts global sustainability and resource management. As urbanisation and infrastructure development continue to expand, the need for innovative solutions to reduce environmental footprints becomes increasingly urgent. Traditional design practices have proven inadequate in addressing these challenges, particularly in reducing CO2 emissions and managing the complexity of conflicting design requirements (National Academies of Sciences, Engineering, and Medicine 2019). This study aims to address these challenges by developing new digital practices that can optimise both structural integrity and environmental sustainability (Deshvena 2024).

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Lange-Kornbak, D and Hassan, A K (2025) Transforming the Design of Resource-Intensive Load-Bearing Structures into Regenerative Practices: An Institutional Analysis of Optimised Design Methods in Construction, *In*: Thomson, C and Neilson, C J (Eds) Proceedings of the 41st Annual ARCOM Conference, 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 891-899.

The importance of this work lies in its potential to revolutionise the construction industry by integrating advanced digital tools and sustainable practices. The research is based on strategic guidelines for technology, sustainability, and business, which relate to competencies demanded in the future Danish construction industry (Danish Ministry of Interior and Housing 2021). By focusing on over-dimensioning in the design phase, which leads to unnecessarily high resource consumption and CO2 emissions (Wang *et al.,* 2024; Takser *et al.,* 2024), this research seeks to shift the industry's focus from cost optimisation to sustainability, thereby supporting the green transition (Petersen 2016).

The approach taken in this research is significant because it leverages digital tools to manage numerous and conflicting design requirements, avoiding the pitfalls of traditional practices that often result in over-dimensioning (Sawhney and Knight 2024). This research aims to develop a new digital design practice that can balance structural integrity and environmental sustainability. Additionally, the research will examine how over-dimensioning in the Danish construction industry is linked to ideas about buildability and how precise design affects buildability.

This work builds on previous research in the field by addressing the practical challenges of traditional design practices and exploring the possibilities for developing new digital solutions. The research questions are: 1) What issues characterise traditional design practices, and how can more sustainable, digital practices be developed; 2) How can sustainable and digital practices be theorised and legitimised to reassess traditional practices? These research questions are formulated to uncover both technological and social/institutional issues. The first question focuses on the practical challenges of traditional design practices and the possibilities for developing new digital solutions. The second question examines how these new practices can be theorised and legitimised to create broader acceptance and implementation in the construction industry.

Previous research has shown that traditional design practices often focus on cost optimisation rather than sustainability, leading to over-dimensioning and unnecessarily high resource consumption. The present work builds on this research by investigating how digital tools and optimisation techniques can be used to develop more sustainable design practices (Li *et al.,* 2025).

Strategic guidelines for integrating technology, sustainability, and business practices in the construction industry have been developed to address future competencies. These guidelines emphasize the need for organisational learning, innovation, and performance improvement to achieve sustainable development. Research has shown that these strategic frameworks can help construction companies adapt to changing market demands and regulatory requirements (Silalert *et al.,* 2021).

This study presents a conceptualisation of a new digital design practice focused on reducing over-dimensioning in load-bearing structures—an area with high potential for resource and climate impact reduction. The practice is defined by regenerative sustainability-oriented principles (e.g., minimising CO_2 emissions, maximising circularity) and the use of digital tools to manage complex design requirements. It is explored through workshops and simulations with industry stakeholders but is not yet developed into a quantitative tool. The contribution lies in framing the concept and analysing the institutional conditions for its future development and adoption.

Theory

To understand and develop new digital design practices that optimise both structural integrity and environmental sustainability, this study draws on New Institutional Theory (NIT). NIT examines how institutional structures—formal (e.g., laws, standards) and informal (e.g., routines, competencies)—influence the development and innovation of practices (Lounsbury and Crumley 2007). Here, NIT is used to identify these structures and understand how they shape adoption of optimisation-based design methods, particularly through institutional logics prioritising cost, safety, or sustainability. The theory reveals institutional barriers and drivers that support or hinder sustainable design. A socio-technical perspective also highlights technological factors influencing the shift toward more digitised, sustainable practices.

Lounsbury and Crumley (2007) highlight that new practices emerge through an interactive process where multiple actors contribute to change. They argue that practices are not simply adopted but shaped through complex interactions between actors and institutional structures. This includes theorisation and legitimation, where actors frame new practices—such as digital optimisation—as necessary and aligned with prevailing norms, increasing institutional acceptance. This perspective is especially relevant in construction, where diverse stakeholders are involved in design, and institutional barriers often impede innovation and sustainability.

Research within Action Research (AR) shows that involving key actors in the construction industry through cycles of action and reflection is effective for developing and implementing new practices (Azhar 2007). Azhar's study highlights AR's potential to improve collaboration between academic researchers and industry practitioners, enhancing the relevance and impact of research in real-world projects. This study draws on both NIT and AR to develop and implement digital design practices that optimise structural integrity and environmental sustainability in construction.

METHOD

To investigate how digital tools can manage numerous and conflicting design requirements and avoid over-dimensioning, the study used AR as both methodology and theoretical lens. AR was structured around identifying institutional and technological barriers and drivers, co-developing solutions with key industry actors (e.g., consultants, knowledge institutions), and iteratively reflecting through interviews and workshops. The research team took an embedded, facilitative role to enable participatory engagement and practice-oriented inquiry. Interview and workshop design drew on NIT concepts like institutional logics and legitimacy to explore how actors perceive and justify digital practices within existing norms. While the full AR cycle—including long-term implementation—was beyond scope, the study embodied core AR principles: collaboration, iteration, and contextual learning, supporting the development of sustainable digital design practices.

This process comprised three main methods. First, a qualitative content analysis of relevant articles and documents was conducted to identify barriers and drivers for new design practices. Next, four semi-structured interviews were conducted using an interview guide to elicit diverse perspectives on sustainability and institutional constraints. Finally, two workshops were held involving numerical tools. The first workshop used a simulation case with a timber beam to generate data and illustrate the concepts of a new, sustainable digital design practice. The second workshop

employed an optimisation design case—based on the minimisation and maximisation of objective functions expressed in terms of design variables—for a comparative analysis of traditional and new design practices. This formed the basis for discussing institutional barriers and opportunities for implementation.

Interviews and workshops were documented through audio recordings, transcriptions, and video. Results were presented via PowerPoint presentations and communicatively validated through interactive discussions in the workshops. This methodological approach ensured a comprehensive and systematic investigation of how digital tools can contribute to developing more sustainable design practices in the construction industry.

RESULTS AND ANALYSIS

Document Analysis

The main results of the document analysis are presented throughout this paper and served as the foundation for the interview guide.

Interviews

The four interviews provide an in-depth insight into the technological and social/institutional issues affecting sustainability in the Danish construction industry. The results show that there are several barriers and drivers influencing the implementation of sustainable design practices.

Technological and Social/Institutional Issues

- Interviewee 1 highlights that traditional design methods often lead to over-dimensioning, resulting in unnecessary material consumption and higher CO2 emissions. Additionally, it is pointed out that manufacturers have invested in standard products, making it difficult to adapt to new sustainable materials and methods. Social and institutional issues include resistance to innovation and complex building regulations, which create uncertainty among practitioners
- Interviewee 2 identifies time and economic pressures as obstacles to thorough analyses and optimisation of sustainability, which can lead to over-dimensioning and suboptimal solutions. Strict safety requirements can also lead to unnecessary over-dimensioning. There is a tendency to prioritise short-term economic gains over long-term sustainability improvements, and economic factors and lack of incentives from authorities can be barriers to adopting more sustainable methods
- Interviewee 3 criticises the construction industry for being conservative and reluctant to change established methods. The many requirements and standards can lead to over-dimensioning, and there is an economic advantage to using standard solutions, making it less attractive to invest in sustainable solutions. Lack of financial resources for innovation and resistance to change in the industry are also barriers
- Interviewee 4 emphasizes that the construction industry often sticks to known materials and methods, creating resistance to innovation. There is a general reluctance to take risks with new materials and methods, and the many requirements for construction can make the design process complex and overwhelming. Focusing on short-term costs rather than long-term sustainability gains can also hinder investments in new, more sustainable solutions

Drivers for New Practices

- Interviewee 1 sees digitalisation as an important driver, as the implementation of digital tools can improve design processes and enable better optimisation of sustainability. New optimisation methods can help manage complex design requirements and reduce over-dimensioning. Social and institutional drivers include stricter climate requirements from authorities and increased consumer awareness, which can drive innovation and adoption of new methods
- Interviewee 2 highlights the potential of using digital tools and AI to optimise the design process. Increased awareness of sustainability and stricter requirements from authorities can act as drivers for implementing more sustainable solutions
- Interviewee 3 sees digitalisation and the implementation of digital tools and simulations as important drivers. Increased focus on sustainability and involvement of various stakeholders in the development of new tools and methods can also promote innovation
- Interviewee 4 emphasizes Building Information Modelling (BIM) and parametric modelling as key technological drivers. Stricter CO2 requirements and taxes drive innovation, while collaboration between professional groups leads to synergies and new solutions

These results show that there are several technological and social/institutional barriers and drivers affecting the implementation of sustainable design practices. By applying NIT and AR, these challenges can be addressed, and new practices can be developed to promote sustainability in the construction industry.

Workshops

The workshops provided insights into technological and institutional barriers and drivers affecting sustainable design practices for load-bearing structures.

Workshop 1: Technological Issues
Participants discussed applying optimisation principles to develop sustainable design concepts. Key barriers include design complexity, leading to over-dimensioning and increased CO2 emissions. Shifting to optimisation techniques can balance cost, sustainability, and structural integrity. Digitalisation and software for design optimisation were highlighted as drivers.

Workshop 2: Social and Institutional Issues
Participants identified barriers like strict regulations limiting innovative materials, resistance to change due to traditions and norms, and economic considerations making builders reluctant to invest in new solutions.

Drivers for New Practices
Political support, such as stricter CO2 requirements, can drive regenerative sustainability. Collaboration among consultants, builders, and producers can promote new practices. Educational institutions and research projects can educate future engineers and architects in new technologies and materials.

Sustainability-Related Characteristics and Design Parameters
Key characteristics and design parameters for regenerative sustainability include:

- CO2 Emissions: Minimise the carbon footprint in all phases of construction
- Use of Renewable Materials: Integrate biogenic materials and ensure they are easy to recycle
- Design for Disassembly: Create structures easy to disassemble and reuse

- Flexibility: Adapt buildings to future needs without significant costs
- Durability: Ensure structures have a long lifespan with minimal maintenance
- Recyclability: Ensure materials and structures can be disassembled and reused
- Thermal Capacity: Design buildings to control temperatures effectively
- Biodiversity: Assess construction's impact on biodiversity and the environment
- Aesthetics: Create buildings that are visually appealing and therefore more likely to be preserved

Structural Processes

To develop sustainable dimensioning practices, focus on:

- Theorisation: Development and formulation of theories about regenerative sustainability in dimensioning practices. This involves understanding how it can be integrated into the design process and what principles should apply
- Legitimation: New practices must be legitimised through recognition from relevant institutions and actors. This can be achieved by demonstrating that sustainable solutions are both effective and economically advantageous
- Social Recognition: For new dimensioning practices to gain traction, it is important that they are recognised by the industry. This can be achieved through knowledge sharing, workshops, and collaboration between actors
- Negotiations: Stakeholders, including builders, consultants, and authorities, must negotiate to find common ground on implementing sustainability. This requires open dialogue and collaboration

Involved Actors

Effective and sustainable construction practices require involvement from:

- Builders: Builders play a central role as they make decisions about materials and methods. Their engagement is crucial to promoting sustainable solutions
- Consultants: Consultants, including engineers and architects, must have the necessary knowledge and competence to advise on sustainable solutions. They must also be able to communicate the benefits of these solutions to builders
- Knowledge Institutions: Educational and research institutions can contribute new knowledge and innovation. They can also play a role in educating future professionals in sustainable practices
- Producers: Producers of building materials must ensure sustainable materials are available, tested, and approved for construction
- Authorities: Public authorities can promote sustainability through regulations and incentives

DISCUSSION

Developing sustainable and digital design in construction requires integrating data, literature, and theory. NIT offers a framework for understanding how institutional structures shape emerging practices. It also shows how optimisation methods gain legitimacy by aligning with dominant logics and stakeholder expectations. Institutional entrepreneurs—engineers, consultants, and researchers—reframe regenerative sustainability as a core design value and foster acceptance. According to Lounsbury and Crumley (2007), new practices emerge through interaction among actors and institutions. This is especially relevant in construction where diverse stakeholders and institutional barriers often hinder innovation and sustainability.

Empirical data from interviews and workshops indicate significant technological and institutional barriers to promoting sustainability in the construction industry. These

include over-dimensioning, resistance to innovation, complex regulations, and economic factors. Over-dimensioning leads to excessive resource use and CO_2 emissions—critical issues for building regenerative cities. Concurrently, the data highlight several drivers, such as digitalisation, optimisation principles, stricter climate requirements, and growing consumer awareness, which can foster sustainable design practices.

Background literature supports these findings by highlighting the role of digital technologies in advancing sustainability in construction. A Royal Institution of Chartered Surveyors (RICS) report notes that digitalisation improves design and optimises sustainability (Sawhney and Knight 2024). Another study shows digital tools help manage complex requirements and reduce over-dimensioning (Deshvena 2024).

A crucial strategy is to promote collaboration among various stakeholders in the construction industry. This may include cooperation between engineers, architects, material researchers, and authorities to develop and implement new practices. AR can be an effective method to involve stakeholders in a cycle of actions and reflections that can lead to the development and implementation of sustainable design practices. This collaborative approach ensures that the perspectives of all key actors are considered, leading to more comprehensive and effective solutions.

Furthermore, it is essential to develop clear guidelines and standards for sustainability in the construction industry. This may include requirements for CO2 emissions, the use of renewable materials, and design for disassembly. Stricter climate requirements and economic incentives can also motivate actors to change their practices and adopt more sustainable methods. Danish Ministry of Interior and Housing (2021) emphasizes the need for strategic guidelines that integrate technology, sustainability, and business practices to address future competencies in the construction industry.

The findings highlight that over-dimensioning and complex regulations hinder buildability. Optimisation techniques and digital tools improve design precision, reducing material waste and simplifying construction. Collaboration among stakeholders and supportive policies are essential for enhancing buildability and promoting sustainable practices in the construction industry.

The findings from the interviews and workshops also highlight the importance of addressing both technological and social/institutional issues. For example, technological barriers such as the complexity of design and the need for optimisation techniques must be addressed to reduce over-dimensioning and CO2 emissions. Social and institutional barriers, including resistance to innovation and complex building regulations, must also be overcome to promote the adoption of sustainable practices.

Developing sustainable and digital design practices involves optimisation principles and traits such as minimising CO_2 emissions and load capacity, while maximising circularity i.e., disassembly, flexibility, and durability. This multi-criteria problem also considers biodiversity and aesthetics. Simulations and case studies confirm optimised designs meet safety and robustness standards. Structural integrity is evaluated through load-bearing simulations, and durability via lifecycle analysis. Interviews and workshops with stakeholders highlight digital tools and collaboration as key to practical, accepted solutions. Feedback confirms alignment with industry standards for safety, robustness, and long-term performance, supporting holistic acceptance.

Integrating these perspectives helps the construction industry create practices that foster sustainability and innovation. Stakeholder involvement, clear guidelines, and focus on key sustainability traits are essential. These efforts support a more resilient urban future.

CONCLUSIONS

This work has explored how digital tools can manage numerous and conflicting design requirements, avoiding over-dimensioning in the construction industry. By integrating New Institutional Theory and Action Research, the project has identified barriers and drivers influencing sustainable design practices.

Definition of traditional design, and development of sustainable, digital practices
Traditional design practices are characterised by over-dimensioning, resistance to innovation, complex regulations, and economic factors. These practices often prioritise cost over sustainability, leading to high resource consumption and CO2 emissions. To develop more sustainable practices, integrating digital tools and optimisation techniques is necessary. This integration can balance structural integrity and environmental sustainability. Collaboration among stakeholders is crucial. Stricter climate requirements and increased awareness drive sustainable solutions.

Reassessment: theorisation and legitimisation of sustainable, digital practices
Sustainable and digital practices can be theorised and legitimised by developing theories around sustainability in design practices. This involves understanding how sustainability can be integrated into the design process and what principles should apply. Applying optimisation techniques to manage complex design requirements and reduce over-dimensioning is essential. New practices must be legitimised through recognition from relevant institutions and actors by demonstrating that sustainable solutions are effective and economically advantageous. Social recognition and negotiations between stakeholders are essential for broader acceptance and implementation in the construction industry.

Final Remarks
The research underscores the need for clear sustainability guidelines in construction. Combining New Institutional Theory and Action Research enables innovative practices. These efforts support a more resilient urban future. The proposed design reduces over-dimensioning, uses digital tools, fosters stakeholder collaboration, and promotes regenerative construction that balances structural integrity with environmental and social benefits.

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MOTIVATIONAL FACTORS FOR CIRCULAR ECONOMY DESIGN KNOWLEDGE MANAGEMENT IN CONSTRUCTION AND DEMOLITION WASTE SECTOR

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Incorporating circular economy (CE) concepts during a construction project's design phase arguably reduces both construction and demolition waste (C&DW): ostensibly through the enabling of deconstruction, or timed replacement, over demolition. However, evidence suggests that the construction industry lacks the critical knowledge of CE design requisite to incorporating such practices. CE knowledge management has been identified as a potential mitigator of this challenge; however its implementation is also challenged through lack of motivation for knowledge management more generally. This study therefore sought to investigate the motivational influences around CE design knowledge management uptake through interviews of sixteen CE design experts within the construction sector. Their responses were then analysed through reflexive thematic analysis facilitated by NVivo software. The intrinsic and extrinsic motivational factors for CE design knowledge management uptake of individuals, organisations and government were thereby identified. The findings offer practical guidance to design professionals, organisations and policymakers in developing effective strategies for CE design knowledge management adoption across the industry.

Keywords: circular economy; construction and demolition waste; design stage; knowledge management; motivational factors

INTRODUCTION

Construction and demolition waste (C&DW) generation is a growing global issue due to the significant volume and embodied resources in it (Soto-Paz *et al.,* 2023). The C&DW refers to the unused resources created through the construction cycle, or the surplus of construction supplies generated during construction projects (Soyinka *et al.,* 2023). More than 40% of global solid waste is generated from construction activities (Oluleye *et al.,* 2022), and in addition to the generation, the treatment of C&DW is also a crucial problem in the world as construction industry is responsible for around 30% of global landfilling (Soto-Paz *et al.,* 2023; Zaman *et al.,* 2023). Circular Economy (CE) provides an alternative to the current linear economic model of "make, use, dispose": offering instead a closed-loop resource usage approach (De Marchi and Di Maria, 2020). It focused upon keeping material in use as long as possible through regenerative and restorative practices like reduce, rethink, and repurpose (Koralage *et*

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al., 2024) thereby managing C&DW effectively (Soto-Paz *et al.,* 2023; Zaman *et al.,* 2023).

Despite the potential of CE to reduce C&DW, its implementation is hindered by several barriers such as finance, technology, regulation and knowledge (Koralage *et al.,* 2024; Oluleye *et al.,* 2022; Zaman *et al.,* 2023). Among these, knowledge related barriers are particularly prominent in the literature, emphasising the need for CE knowledge management (KM) as a critical enabler for C&DW management (C&DWM) (De Marchi and Di Maria, 2020; Oluleye *et al.,* 2022). In general, KM is defined as a mechanism to convert data into useful information (Boamah *et al.,* 2022) to ensure unrestricted flow (Zhang *et al.,* 2021). This study holds KM to be a collection of actions, including: creation, acquisition, organisation and storage (documentation), distribution, application and evaluation of knowledge. In sum, referred to as the KM process (Shehzad *et al.,* 2024). Effective CE KM not only mitigates knowledge barriers but also plays a pivotal role in overcoming financial, technological, and regulatory constraints, thereby facilitating the broader adoption of CE principles in the sector (Koralage *et al.,* 2024; Oluleye *et al.,* 2022).

Design for CE in C&DWM is recognised as a highly effective approach, as it integrates CE strategies like design for long life, design out hazardous materials, climate resilient design and design for shared resources at the early stages of a construction project promoting resource efficiency and waste reduction (Zaman *et al.,* 2023). Existing studies highlight the necessity of systematically handling of knowledge related to CE design practices that enable material reuse, recycling, and waste reduction (Oluleye *et al.,* 2022). It involves capturing, sharing, evaluating and applying insights from circular design approaches to minimise waste generation and maximise resource efficiency (Koralage *et al.,* 2024) for several reasons: Firstly, it is held to facilitate both explicit and tacit knowledge transfer across a fragmented and multidisciplinary construction industry, ensuring the dissemination of best practices, lessons learned, and technological innovations among practitioners, policymakers, and researchers (Oluleye *et al.,* 2022; Soyinka *et al.,* 2023); secondly, it accelerates integration of CE principles into C&DWM by designers, contributing to reduced environmental impacts and enhanced resource efficiency (Shehzad *et al.,* 2024); lastly, it enables improved construction industry responses to evolving global regulatory requirements (Soto-Paz *et al.,* 2023), such as the Paris Agreement.

Despite the recognition of the importance of KM in CE it remains inadequate in the construction industry, hindering effective C&DWM (Koralage *et al.,* 2024; Soyinka *et al.,* 2023). The reasons leading to this include; lack of clarity around CE knowledge management processes; fragmented project structures that limit knowledge sharing; no standardised framework for CE knowledge integration; and, insufficient digital tools to facilitate knowledge transfer (De Marchi and Di Maria, 2020; Zaman *et al.,* 2023). Additionally, resistance to change, inadequate professional training, and misaligned incentives further impede the widespread adoption of CE design KM practices. Consequently, despite growing efforts to implement CE practices in construction, ineffective KM undermines CE adoption (Zhang *et al.,* 2021).

The mere availability of information does not ensure its effective management. It is necessary for stakeholders to actively engage in KM processes (Boamah *et al.,* 2022; Hung *et al.,* 2011) to facilitate CE implementation in managing C&DW. However, without a clear understanding of motivational factors for stakeholder participation in CE design KM, efforts to enhance KM may remain ineffective (Al Rawashdeh *et al.,*

2024). Motivation refers to the process of influencing someone's tendency to engage in a specific activity by stimulating interest, desire, or commitment through internal or external factors (Hung *et al.,* 2011). According to Deci and Ryan (2012), motivations are categorised as intrinsic or extrinsic based on their source. Intrinsic motivation stems from internal factors such as personal interest, curiosity, and the inherent enjoyment of an activity, while extrinsic motivation is influenced by external rewards, social recognition, monetary incentives, or compliance with external expectations.

While CE research has expanded across various domains, the motivations for managing CE design knowledge regarding C&DWM during the design stage remain underexplored. Al Rawashdeh *et al. (*2024) investigated how the small and medium enterprises drive CE adoption through organisational motivation. However, their study does not reflect the motivations for CE KM uptake and does not engage the C&DWM context. This study specifically aims, therefore, to identify the motivational factors influencing CE design KM in the C&DW sector. Addressing these motivational factors at different structural levels is also crucial; each level presenting unique drivers and constraints influencing its effective adoption. Thus, the study focuses upon CE design KM in commercial building projects, examining motivations at the individual, organisational, and governmental levels. This study treats individuals and organisations as separate analytical categories, recognising individual motivations as linked to personal development and organisational motivations as tied to collective performance. Additionally, given the construction sector's economic significance, government entities at national level play a pivotal role in advancing CE design KM in the C&DW sector through its management of economic and political structures.

METHOD

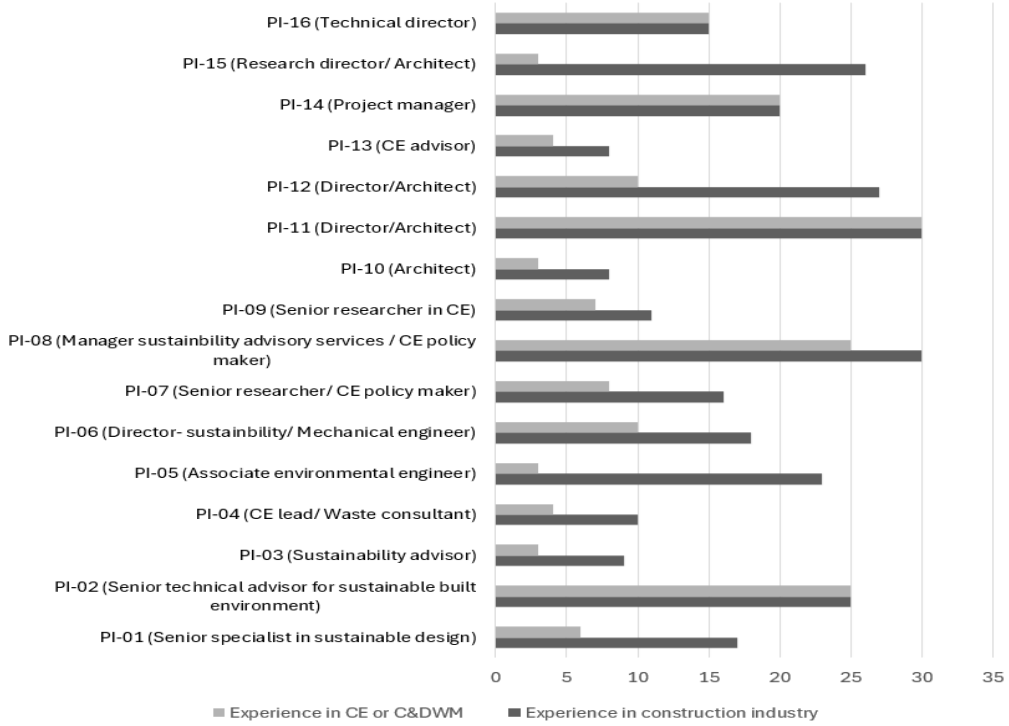
Qualitative research methods have been recognised as an appropriate approach for examining individuals' subjective experiences, opinions, and beliefs, which cannot be quantified through statistical measures (Mendivil, 2022). Thus, this study used a qualitative research design, to investigate motivational factors influencing CE design KM in the Australian C&DW sector. Interviews of identified experts was determined as the most appropriate data collection technique, premised on their ability to provide in-depth insights, capture domain-specific knowledge, and explore nuanced perspectives on industry practices and challenges (Sandelowski, 1998).

Accordingly, 16 semi-structured interviews were conducted via Zoom platform with CE experts who possess a minimum of five years of industry experience and at least two years of experience in CE or C&DWM. Judgemental sampling was used to select the potential participants who fulfil the above criteria from publicly available company websites, CE groups and LinkedIn profiles. The interviews were recorded with written consent from the respondents. Auto-generated Zoom transcripts were reviewed and manually verified against the recordings for accuracy. Following the studies by Boamah *et al. (*2022) and Al Rawashdeh *et al. (*2024), who identified the requirement to identify motivational factors driving KM, open-ended exploratory questions were designed to elicit insights from each respondent into the motivational factors influencing individuals, design organisations, and governmental bodies in managing CE design knowledge and respondents were encouraged to share their rationale behind responses. The expert profiles are presented in Figure 1. To ensure anonymity, respondents have been assigned codes ranging from PI-01 to PI-16, listed sequentially from the bottom to the top of Figure 1. The factors were categorised as

intrinsic or extrinsic based on respondents' explanations of the underlying reasons for their motivations associated with each factor and aligned them with the definitions of intrinsic and extrinsic.

The respondents' composition was determined to cover multiple professionals in design teams with the aim of obtaining multiple perspectives and ensuring validity and reliability of results. Reflexive thematic analysis was conducted to analyse the findings as it is a flexible, iterative, approach enabling systematic identification, organisation, and patterns of meaning interpretation within qualitative data, while simultaneously acknowledging the researcher's active role in the interpretative process (Braun and Clarke, 2019). It framed by the following steps: 1), Data familiarisation and writing notes; 2), Systematic data coding; 3), Generating initial themes; 4), Developing and reviewing themes; 5), Refining, defining and naming themes; and 6), Writing. The transcripts were manually reviewed and coded. NVivo was used as the coding interface, being user-friendly and helping in organising and analysing patterns (Mendivil, 2022) of the identified codes. The following section presents the findings of the study and situates them within the existing body of literature, offering a critical discussion that highlights their theoretical and practical implications.

Figure 1: Profile of respondents



FINDINGS AND DISCUSSION

Table 1 presents the identified motivational factors for CE design KM across individual, organisational and government level, categorising them based on the source of motivation as intrinsic and extrinsic. The numbers presented in each column indicate the frequency of respondents who expressed alignment with the corresponding view. The study identified 14 intrinsic and 16 extrinsic motivational factors, encompassing both common and level-specific factors. Among these, two factors were found to display different motivations (intrinsic and extrinsic) at various levels, as presented in Table 1.

The potential for risk reduction serves as a motivation for all levels to manage CE design knowledge. As PI-04 stated, "Internally, they need it to (…) understand the risk that motivates them to document what's happening, whether they do that or not is a completely different question." Accordingly, despite risk reduction ability is a motivation for a design organisation to manage CE design knowledge, it is not a widespread motivation in contemporary C&DW sector.

Table 1: Intrinsic and extrinsic motivations for CE design KM

	Individuals	Organisations	Government
Intrinsic			
To build capacity for risk mitigation	X (1)	X (1)	X (1)
Passion for CE	X (6)	X (4)	X (8)
Interest for exemplary leadership in CE initiatives	X (2)	X (8)	X (7)
To optimise use of time	X (2)	X (2)	X (3)
To achieve cost savings		X (2)	X (9)
To evaluate the impacts of their initiatives and refine performance targets		X (2)	X (11)
To enhance knowledge	X (4)		
Interest of acquiring certifications (eg: Green Star)		X (3)	
To obtain quality output #		X (1)	
To develop proprietary data management systems		X (3)	
To safeguard material values and facilitate resource reutilisation across other economic sectors		X (2)	
To preserve cultural and historical values of the built environment*			X (1)
To promote adoption and local development of CE products			X (2)
To formulate performance indicators for CE practices			X (2)
Extrinsic			
Reputation and social image	X (3)	X (5)	X (2)
Economic opportunities available	X (1)	X (5)	X (9)
To secure competitive advantage	X (2)	X (8)	X (1)
Requirements for environmental sustainability	X (4)	X (5)	X (3)
To preserve cultural and historical values of the built environment*	X (1)	X (1)	
External pressures	X (2)	X (4)	
To ensure continued adaptability to the industry	X (1)	X (1)	
Professional commitment to environmental stewardship	X (2)		
For reporting to relevant authorities		X (5)	
To comply with national and public based initiatives			X (11)
To increase quality of output #			X (1)
Limitations in existing policies			X (1)
To enhance community health and wellbeing			X (7)
To reinforce the capacity of small enterprises			X (3)
Liabilities arising from inadequate CE implementation (eg: compensation to disaster damages)			X (1)
To establish a standardised definition for CE within the building industry			X (2)

*,# indicates same motivation exhibits differently across levels

Instead, clients often perceive CE implementation as inherently risky of and within itself, and so are reluctant to invest in CE KM, viewing it as non-essential (PI-12) as highlighted similarly by Corvellec *et al. (*2022). Future research should therefore

focus upon in-depth investigations into the benefits of CE KM that outweigh the risks through uncertainty minimisation.

Passion for CE emerged as a common intrinsic motivation driving individuals, design organisations, and government to generate, acquire, evaluate, and share new CE knowledge, document best practices, and apply their knowledge in subsequent projects. For example, PI-14 characterised CE as a "progressive-thinking" approach that is "…essential for future generations…" thereby reinforcing the long-term significance of preserving CE design knowledge by individuals. Similarly, around half of the participants found it as a motivation at government level. For example, PI-04 and PI-15 indicate that governmental actors share this passion, driven by their aspirations to achieve specific waste reduction targets and resource conservation.

Though interest for exemplary leadership in CE initiatives is a common motivation for all levels to manage CE design knowledge, their output as leadership is specific. Few highlighted that leadership is evidenced at the individual level and PI-13 noted that aspirations to assert professional influence and drive CE design innovation whilst fostering a culture of proactive problem solving (PI-08) as motivations for leadership. Design professionals, therefore, demonstrate leadership by educating peers, promoting collaboration, and sharing best practices within their networks to accelerate CE adoption in C&DWM (PI-02, PI-15). In contrast, most of the respondents highlighted that developers and design organisations exhibit leadership by pioneering CE designs in construction projects that set industry benchmarks and inspire broader adoption of CE practices (PI-01, PI-07). Benchmarking, as highlighted by Mendivil (2022), is a critical facilitator of CE implementation, and this study uniquely identifies it as a key motivational driver for KM. Furthermore, design organisations demonstrate leadership through creating competitive environments that stimulate innovation and drive the continuous improvement of CE processes (PI-02, PI-07, PI-14), which is also revealed by (Al Rawashdeh *et al.,* 2024), particularly among small- and medium-sized enterprises. At the government level, leadership is demonstrated through development of progressive policies, regulatory frameworks and developing opportunities for CE incentives in the C&DWM sector (PI-05, PI-08, PI-13).

Few responded highlighted, potential time savings as an intrinsic motivation at all levels to engage in CE design KM. For example, it allows governments to expedite processes by leveraging existing knowledge and avoiding repetition of unsuccessful practices (PI-09). Furthermore, it enhances the productivity of both individuals and design organisations, thereby addressing the time constraints identified by Shehzad *et al. (*2024) as barriers to the successful adoption of CE. However, PI-02, PI-04, and PI-10 noted that CE KM in the C&DW sector is often perceived as time-consuming. Therefore, future research should explore project management strategies and best practices for optimising time efficiency in CE design KM, particularly in the short term, as long-term benefits alone may not sufficiently motivate widespread adoption in the sector.

Economic opportunities can be either intrinsic or extrinsic. This study identifies potential intrinsic cost savings through CE applications, including optimisation of resource utilisation by minimising material over-ordering for contingencies (PI-07, PI-16) and improvements in project constructability (PI-10) as motivational factors for organisations to create, evaluate and apply CE knowledge. Additionally, the reduced time required for component replacement compared to new design development further reinforces intrinsic economic benefits (PI-13), thus it is a motivation to

document material information. As per Al Rawashdeh *et al. (*2024), driving CE KM provides economic benefits for organisations, however this study uniquely identifies it as a key motivation for CE KM in the C&DW sector. Further, many respondents highlighted that the government ensures cost savings through CE design KM, as it helps them to reduce associated landfilling costs (PI-09) and strengthen their economic resilience in the long run (PI-07). Therefore, it motivates government to actively disseminate CE knowledge. This ability to reduce landfilling costs serves as a unique motivation for the C&DW sector, particularly given the sector's significant contribution to global solid waste. According to Soto-Paz *et al. (*2023), the C&DW sector is responsible for approximately 30% of global landfilling. In the Australian context, C&DW accounts for 38% of total waste generation, representing a considerable loss of materials with potential for reuse or repurpose (Zaman *et al.,* 2023). Thus, this motivation suggests both significant cost savings and environment benefits.

Few respondents highlighted that the motivation to preserve the culture and history of buildings extends beyond a passion for CE in reflecting a deliberate commitment to protecting architectural heritage and maintaining historical continuity, whilst perhaps only incidentally integrating cultural values into CE design practices. Hence, in the contemporary context, this motivation tends to act upon individuals and organisations as an extrinsic driver: preservation efforts being undertaken in response to heritage listing requirements (PI-10) or those of clients' determinations should no such obligations exist. Refining CE performance targets serves as a motivation for both organisations and government to manage CE design knowledge. While individuals may assess and revise their CE implementation performance, this practice is not currently prominent, highlighting the need for future research to develop specific CE performance criteria for individuals.

Requirement for a quality output identifies intrinsic for organisations, but extrinsic for governments. As explained by PI-14, the use of CE design concepts for regeneration, durability and modular structures can help in preventing mould and increase air tightness of buildings - reputational considerations alone making this an intrinsic motivator. Government motivation regarding quality, however, is framed around community engagement facilitation around CE (PI-02, PI-08) adoption in order to maintain public accountability (PI-14) - an extrinsic motivation. However, despite the potential for quality output being a motivational factor, CE is sometimes perceived as a barrier by clients who associate it with recycled products of lower quality (PI-13, PI-15), an idea also identified by Corvellec *et al. (*2022) in existing studies. Consequently, there is a clear need for more effective dissemination of knowledge regarding how CE can enhance building quality, thereby encouraging broader CE knowledge application. Professional commitment to environmental stewardship serves as a motivation for individuals to manage CE design knowledge (PI-08). However, few respondents highlighted this and mention that this commitment is more commonly observed among architects, sustainability consultants, environmental consultants, and CE specialists, rather than across other professional groups within the design teams of construction projects.

As shown in Table 1, four common extrinsic motivations for CE design KM have been identified across the three levels. Among them, reputation and social recognition emerge as a key motivation for CE design KM in the C&DW sector. Organisations seek to enhance their public image by showcasing their CE initiatives. As PI-09 highlights, they can gain a positive social image by demonstrating past achievements

and ongoing commitments to CE. Additionally, few highlighted that the individuals are benefitted from increased visibility through public speaking opportunities at national and international events and facilitating professional and collaborative engagements that elevate their social status. Government can also enhance their reputation through CE KM leadership, positioning themselves as pioneers in the global transition towards climate change mitigation (PI-05).

Extrinsic economic opportunities serve as a common motivation for all identified levels in CE KM, with specific benefits tailored to each party. For instance, most of the respondents explained that the government views CE KM as an economic opportunity, recognising its potential to minimise material downcycling (PI-08), "…accelerate CE implementation by preventing reinventing the wheel…" (PI-09), and promoting the localisation of CE practices to enhance regional money circulation (PI-06). Additionally, developers and organisations can generate income by selling waste materials as inputs to other industries (PI-08, PI-09), through tendering process advantages (PI-13) and in wining more business opportunities (PI-15). Moreover, CE design KM expand new market opportunities for individuals and organisations to develop products and services (e.g., establish new business ventures as CE consultants) (PI-13). This is consistent with Oluleye *et al. (*2022) who also highlights CE KM systems as a strategic avenue for economic benefits. Thus, industry should focus on CE KM systems from a financial perspective.

Yet securing competitive advantage through CE design KM extends beyond economic opportunities as it helps foster innovation, compliance with evolving regulations and strengthen market positioning of individuals and organisations (PI-01, PI-04, PI-05). As PI-06 noted organisations "…will start to win the jobs because they can show us that they can do it." Further, it enables governments to strengthen their resource security, build public trust (PI-09) and attract foreign investments by being CE leaders (PI-07). The role of competitive advantage in driving CE KM has also been emphasized in previous studies such as those by Al Rawashdeh *et al. (*2024) and Mendivil (2022). Consequently, these motivations lead organisations to systematically document and share knowledge, conduct rigorous evaluations and refine processes through continuous improvement practices. Such KM actions not only enhance operational efficiency but also reinforce the strategic positioning of design organisations within the competitive landscape.

All identified motivations inherently relate to the three pillars of sustainability (environment, social and economic), as the dimensions of the triple bottom line are interconnected. However, while contributing to environmental sustainability emerged as a common direct motivation, other aspects of sustainability are less explicitly referenced, reflecting the misperception that CE connects solely with environmental benefits (Corvellec *et al.,* 2022). As PI-13 explains, "…waste is a human construct like it's not an inevitability. It is something that happens because of poor processes, designs, business models, etc. So circular economy isn't about managing waste. It is about redesigning our economy so that waste doesn't happen in the first place. Because the circular economy is based off from nature, and in nature there is no waste. Everything has a place and a purpose.". Ultimately, these insights underscore the requirement for the C&DW sector to adopt a more holistic approach when motivating for CE design KM, one that fully integrates the environmental, social, and economic benefits. Overall, this study identifies the intrinsic and extrinsic motivations driving CE design KM in the C&DW sector for individuals, organisations

and governments: highlighting their distinct, yet interconnected, motivations in developing KM as a CE adoption enabling mechanism.

CONCLUSIONS

This study presents the first comprehensive exploration of motivations for CE design KM regarding C&DWM. A total of 14 intrinsic and 16 extrinsic motivational factors were identified, encompassing both common and level-specific motivations, which will aid in formulation of effective strategies to motivate design professionals for CE KM. Among these, two factors were found to exhibit different motivations (intrinsic and extrinsic) across various levels, as indicated in Table 1. Additionally, economic benefits were recognised as a factor encompassing both intrinsic, cost savings, and extrinsic, economic opportunities, motivations. Whilst the study's findings are limited to the Australian context, they can, however, serve as a guideline for investigating motivations in other settings. In addition, it is important to acknowledge that the same motivation for the same stakeholder can be driven by both intrinsic and extrinsic factors. For instance, individuals may engage in CE KM to promote environmental sustainability. However, this motivation may stem from either regulatory compliance requirements (extrinsic), or a personal commitment to environmental preservation (intrinsic). Further, these classifications are based on the current context of the Australian construction industry and may evolve, as the industry itself evolves, over time. This research is ongoing, the next phase will focus on ranking motivations based on their significance, examining their influence on various KM actions, and formulating strategies to strengthen such motivations. Additionally, a framework will be developed to enhance CE design KM in the C&DWM sector. Beyond this, future research should explore motivations for CE KM from diverse perspectives, considering variations in professional knowledge levels and discipline-specific factors that may influence engagement with CE KM.

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SUSTAINABLE LOW-CARBON HOUSING RETROFITTING IN THE UK: AN LCA-BASED ASSESSMENT FOR BUILDING REGENERATIVE CITIES

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The UK's housing sector needs to reduce embodied carbon in retrofitting to achieve net-zero targets, particularly in the context of building regenerative cities. While 80% of existing homes will remain in 2050, research predominantly examines operational carbon, neglecting embodied carbon associated with construction materials and processes. This paper addresses this gap through long-term sustainability analysis using cradle-to-grave Life Cycle Assessment (LCA), evaluating three retrofitting scenarios for a London-based semi-detached house over a 60-year lifespan using the One Click LCA tool. Results show that material selection and durability critically influence outcomes, with embodied carbon increases of 38-64%. These findings demonstrate key trade-offs between initial material choices and long-term emissions, providing essential evidence for LCA-integrated retrofitting planning. The research offers practical solutions to transform existing housing into sustainable urban assets through carbon-conscious material selection, directly supporting regenerative city development. By quantifying these relationships, the study presents a replicable framework for reducing embodied carbon in urban regeneration projects.

Keywords: embodied carbon; global warming potential; life cycle assessment; regenerative cities; retrofitting

INTRODUCTION

The global challenge of climate change has driven countries to create substantial targets for reducing their greenhouse gas emissions. Under the 2008 Climate Change Act, the UK aims to cut CO_2 emissions by 80% of 1990 rates before 2050 (Schwartz *et al.,* 2022). The built environment sector accounts for substantial emissions, with residential buildings alone consuming 30% of the UK's energy and contributing 27% of its CO_2 emissions (Davies *et al.,* 2011). Embodied carbon (EC) plays an important role because of the associated CO_2 emissions from materials and construction processes throughout a building's lifecycle (Asif *et al.,* 2007; Kim, 2019).

According to Vilches *et al. (*2017), retrofitting the ageing housing stock in the UK to improve energy efficiency often involves materials and activities that increase EC.

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Farhan, M, Tokbolat, S and Osorio Sandoval, C (2025) Sustainable Low-Carbon Housing Retrofitting in the UK: An LCA-Based Assessment for Building Regenerative Cities, *In*: Thomson, C and Neilson, C J (Eds) Proceedings of the 41st Annual ARCOM Conference, 1-3 September 2025, Abertay University, Dundee, UK, Association of Researchers in Construction Management, 910-920.

Therefore, retrofitting strategies need an evaluation tool, such as Life Cycle Assessment (LCA), to determine environmental impacts and reduce both EC and operational carbon (Schwartz *et al.,* 2022). However, the practical application of LCA in housing retrofitting faces several barriers: the complexity of housing stock, with diverse building types, ages, and construction methods complicating standardised approaches (Serrano *et al.,* 2022); data limitations, as detailed environmental impact data for materials and processes specific to retrofitting are often unavailable (Serrano *et al.,* 2022); regulatory gaps, with current policies prioritising operational energy efficiency over EC (Vilches *et al.,* 2017); knowledge and skill gaps, as many professionals lack expertise in LCA and its application to retrofitting (Kim, 2019); and economic constraints, as the cost and time required for LCA and low-carbon solutions can hinder stakeholders (Davies *et al.,* 2011).

This research addresses these gaps by applying LCA to minimise EC in housing retrofitting, focusing on the UK's existing housing stock. The study evaluates three retrofitting scenarios for a semi-detached house in London, using the One Click LCA tool to quantify EC over a 60-year lifespan. The research aims to review best practices for EC reduction in retrofitting; assess the suitability and limitations of LCA for UK housing; identify effective strategies for low-carbon retrofitting; investigate barriers and enablers for LCA adoption; and provide strategic recommendations for materials and construction practices for wider adoption of LCA in the UK housing retrofitting sector. The research incorporates a literature review with virtual and on-site case studies of a typical semi-detached house in London, and combines LCA with retrofitting to support informed decision-making, balancing energy efficiency with EC reduction. This study contributes to the growing body of knowledge on sustainable retrofitting by providing architects and engineers, as well as policymakers, with implementable guidance which helps transform homes into sustainable urban assets, aligning with the vision of building regenerative cities.

LITERATURE REVIEW

To reach net-zero carbon targets, reducing EC is very important in building retrofitting. Although much attention has been given to operational carbon, embodied carbon from construction materials and processes remains underexplored, mainly when it applies to retrofitting (Ibn-Mohammed *et al.,* 2013; Giesekam *et al.,* 2016). LCA provides a comprehensive framework to quantify environmental impacts across the building lifecycle. In applying LCA, one follows the procedures given in ISO 14040 and ISO 14044, which require you to complete four steps: goal and scope definition, inventory analysis, review impacts, and interpret the data (Sharma *et al.,* 2011). For the built environment, EN 15978 divides life cycle stages into Product Stage (A1-A3), Construction Stage (A4-A5), Use Stage (B1-B7), and End-of-Life Stage (C1-C4), making it possible to assess all kinds of carbon emissions (Fenner *et al.,* 2018; Orr *et al.,* 2020). Although there are different LCA models for buildings, applying them in retrofitting poses distinct methodological challenges compared to new construction. The first important issue to deal with is the lack of data. Many structures created before the current standards for buildings do not have specific information on what materials were used and how they were built, which introduces difficulties and some uncertainty into their LCA (Famuyibo *et al.,* 2013; Vilches *et al.,* 2017). Furthermore, residual values of existing materials, partial reuse, and the allocation of environmental burdens between old and new components create additional complexities for accurate inventory analysis (Vilches *et al.,* 2017).

The viability of LCA data used in retrofit assessments remains a concern across these studies. Even though databases such as ecoinvent, used in One Click LCA, and ICE contain extensive information, they lack specificity for older housing stock, vernacular materials, and traditional construction (Lis *et al.,* 2019; Vilches *et al.,* 2017). As a result, people working on such projects typically use proxy values, generic data, or assumptions, resulting in more uncertainty about the results. These uncertainties can significantly influence comparative outcomes between retrofit options and introduce variability into the decision-making process (Fenner *et al.,* 2018; Weiler *et al.,* 2017).

Several studies have explored these challenges through case studies. According to Famuyibo *et al. (*2013), stronger retrofits with enhanced insulation and ventilation were best at reducing lifecycle carbon emissions, but at the same time also highlighted the significant embodied carbon burden of retrofit materials. In their study, Gaspar *et al. (*2015) observed that retrofits having external insulation combining renewable technologies can lower lifecycle emissions by as much as 70%. However, embodied carbon still contributed nearly 30% of total emissions, revealing its growing significance as operational efficiencies improve. Petrovic *et al. (*2019) assessed embodied carbon impacts in UK housing retrofits and emphasized that while retrofitting can achieve substantial carbon reductions, material selection and replacement cycles significantly affect overall embodied carbon performance. Comparing retrofitting to demolition and new construction, Weiler *et al. (*2017) noted that advanced methods of retrofitting usually lead to lower emissions, which points to the importance of material conservation over replacement. In the same way, Serrano *et al. (*2022) point out that using traditional materials for restoration can outperform modern retrofitting in certain environmental categories while preserving heritage value. Despite growing recognition, LCA adoption in retrofitting remains limited due to the lack of Retrofit-specific tools, incomplete EPD databases, and insufficient industry expertise (Weiler *et al.,* 2017; Lis *et al.,* 2019; Fenner *et al.,* 2018). Economic constraints and weak regulatory drivers also discourage systematic integration of LCA (Davies *et al.,* 2011). However, policy frameworks like RICS Whole Life Carbon Assessment (RICS, 2024), UKGBC Net Zero Roadmap (UKGBC, 2021), and RIBA 2030 Climate Challenge are encouraging broader application, particularly in regenerative urban development.

Overall, the review examined the application of Life Cycle Assessment for retrofitting, trying to reduce embodied carbon and its relationship to operational carbon in housing in the UK and EU, to support the broader goal of building regenerative cities. Both the advantages and the challenges of this area are addressed in the literature, such as using informed decision making, low carbon materials, innovative technologies, and circular economy principles, but it also points out barriers such as data gaps, methodological uncertainties, and a lack of expertise. However, the development of new policies and modern LCA tools implies that LCA could greatly contribute to the transition towards low-carbon regenerative urban environments and achieving net-zero targets.

METHOD

The study applies the LCA framework from ISO 14040 and 14044, adapted through RICS whole life carbon assessment guidance (RICS WLCA, 2024), on a case study with system boundaries shown in Figure 1. LCA has four stages: goal and scope definition, inventory analysis, impact assessment, and interpretation (Sharma *et al.,* 2011). The goal was to quantify and compare the EC of three retrofitting scenarios for

a semi-detached house in London, focusing on fabric improvements for both exterior and interior and their long-term environmental implications. The functional unit was 1 m² of building area over a 60-year lifespan, enabling standardised comparisons across retrofitting scenarios (Cuellar *et al.,* 2012). The primary impact category is Global Warming Potential (GWP), measured in $kgCO_2e$.

The case study building is an 80 m² semi-detached house in London constructed in 1968, featuring brick cavity walls, concrete block internal walls, double-glazed windows, and a hipped roof with timber truss structure, which represents a significant portion of the UK's housing stock, and offers considerable potential for carbon reduction through retrofitting (Petrovic *et al.,* 2019). This house type was selected as it reflects the challenges and opportunities associated with retrofitting ageing housing stock, which is a key focus of regenerative cities.

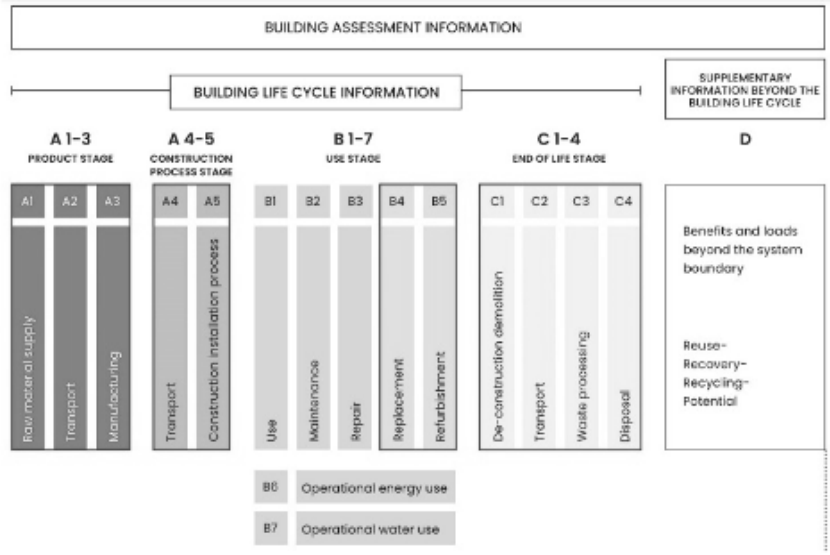


Figure 1: System Boundary Diagram showing included and excluded life cycle stages as adapted from EN 15804

Three retrofitting scenarios were developed:

1. Retrofitting-A: High-performance materials with long service lives, such as polyurethane (PUR) insulation and natural stone cladding.
2. Retrofitting-B: A balanced approach using sustainable materials, such as timber cladding and stone wool insulation.
3. Retrofitting-C: Low-carbon materials with shorter service lives, such as cellulose insulation and laminate flooring.

The scenarios represent typical British retrofit approaches by focusing on building fabric improvement of thermal optimisation, air tightness and moisture control in sync with the UK net zero whole life carbon roadmap (2021). Fabric-first determines building envelope upgrades as the initial step (Mohammadpourkarbasi *et al.,* 2023).

The life cycle inventory analysis involves data collection from multiple sources to ensure accuracy and reliability. Detailed information about the existing building was obtained through architectural plans, on-site surveys, and consultation of standard construction references. Appendix-1 shows a list of material selection and quantities for each scenario. The retrofitting scenarios focused exclusively on material additions and replacements. The material selection reflected UK construction trends of natural and composite components, with quantities calculated from standard specifications.

The analysis retrieved environmental data mainly from the One Click LCA database and Inventory of Carbon and Energy (ICE) while using UK-specific data as the top priority. Key assumptions included a 60-kilometre transportation radius for materials, construction emissions of 1,400 $kgCO_2e$ per £100k (RICS WLCA, 2024), and material wastage rates between 5% and 15% as per Environmental Product Declarations. Replacement cycles followed manufacturer specifications and industry benchmarks. End-of-life processes adhered to standard UK practices, with demolition energy data derived from One Click LCA's London case studies. The analysis fully incorporated material replacements during maintenance and their specified intervals as per the EPD or Manufacturer specification to ensure comprehensive lifecycle waste tracking.

The life cycle impact assessment used One Click LCA software to evaluate Global Warming Potential (GWP) in $kgCO_2e$, focusing on EC. Separate models compared the baseline building and the retrofitting scenarios, identifying hotspots. Inputs include UK-specific EPDs (with localisation adjustments), material quantities, and element breakdowns. Transportation impacts reflect defined distances and vehicle types, while replacement cycles and end-of-life scenarios (recycling, reuse, and landfill) ensure full lifecycle coverage. The software's process-based LCA generates detailed carbon breakdowns by material, element, and lifecycle stage, with results compared across scenarios (Figure 2), within defined system boundaries.

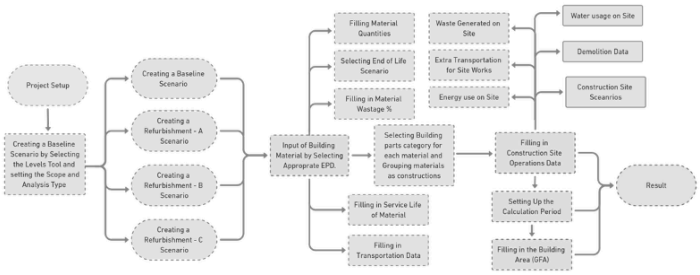


Figure 2: LCA Process Flowchart

RESULTS AND DISCUSSION

The Life Cycle Assessment of the existing building and three retrofitting scenarios revealed critical insights into GWP over a 60-year timeframe (Figure 3). The baseline recorded 42,940.14 $kgCO_2e$. Retrofitting-A (64% higher, 70,444.66 $kgCO_2e$) exhibited the highest carbon footprint due to high-impact materials like polyurethane insulation and high-performance glazing. Retrofitting-C (52% higher, 65,366.71 $kgCO_2e$) faced recurring EC from replacements (B4-B5 stages). Retrofitting-B (38% higher, 59,304.17 $kgCO_2e$) emerged as the most sustainable option by prioritising timber cladding and moderate replacement cycles. These findings highlight the role of material choices in reducing EC, aligning with the regenerative cities' goals of low-carbon resilience.

When standardised per square meter, Retrofitting-B outperformed others (741.3 $kgCO_2e/m^2$, 12.36 $kgCO_2e/m^2$/year), demonstrating efficiency in space utilisation and carbon mitigation. Retrofitting-A (880.56 $kgCO_2e/m^2$) and Retrofitting-C (817.08 $kgCO_2e/m^2$) highlighted trade-offs between material durability and upfront emissions. The results corroborate existing literature (e.g., Schwartz *et al.,* 2018), emphasising that retrofitting when paired with sustainable materials can significantly lower life cycle emissions compared to demolition and reconstruction. This analysis stresses the need for policies incentivising low-carbon material adoption (e.g., timber) to align urban regeneration with net-zero targets.

The results demonstrate significant variations in environmental impacts across lifecycle stages, highlighting how material choices influence EC. In A1-A3, Retrofitting-A generated the highest emissions (49,204.05 $kgCO_2e$, 86% above baseline) due to energy-intensive materials like PUR insulation and high-performance glazing.

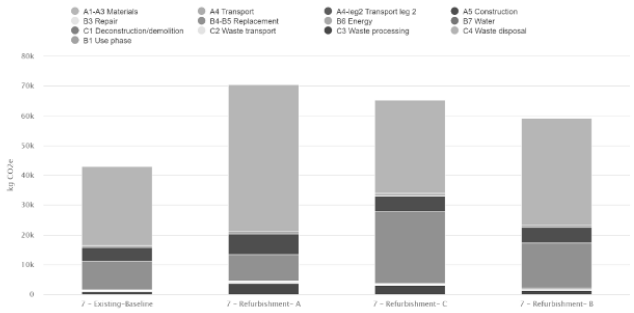


Figure 3: A comparison of total embodied carbon across different Life cycle stages over the 60-year lifespan

Retrofitting-B (35,867.51 $kgCO_2e$, +36%) and Retrofitting-C (31,522.73 $kgCO_2e$, +19%) achieved lower impacts through timber and natural stone prioritisation. A4-A5 contributed modestly, with Retrofitting-A's complex logistics (7,914.44 $kgCO_2e$) exceeding timber-based Retrofitting-B (6,056.82 $kgCO_2e$) and Retrofitting-C (5,897.26 $kgCO_2e$). B4-B5 revealed divergent trends: Retrofitting-A's durable materials (e.g., stone cladding) cut recurring emissions (-9.1%, 8,804.16 $kgCO_2e$), while Retrofitting-C's frequent replacements spiked impacts (+150%, 24,291.71 $kgCO_2e$). Retrofitting-B balances these extremes (+58%, 15,280.67 $kgCO_2e$). C1-C4 impacts peaked for Retrofitting-A's non-recyclable PUR (+200%, 4,522.01 $kgCO_2e$) but were minimised by Retrofitting-B's biodegradable timber (+39%, 2,099.17 $kgCO_2e$). These findings underscore the importance of material selection in reducing life cycle carbon, aligning with regenerative urban goals by prioritising durable, low-carbon solutions.

The walls and façade treatments significantly impacted EC across all scenarios, with Retrofitting-A's PUR insulation and natural stone cladding yielding the highest emissions (19,674.9 $kgCO_2e$, primarily in A1-A3). Retrofitting-B's composite panels reduced emissions by 3,496.88 $kgCO_2e$, while Retrofitting-C's mineral plaster and cellulose insulation offered lower initial carbon but higher recurring impacts due to shorter lifespans. Flooring choices revealed similar trade-offs: Retrofitting-A's natural stone had high initial emissions (15,730.43 $kgCO_2e$) but low long-term impacts, Retrofitting-B's timber balanced sustainability and durability (11,661.56 $kgCO_2e$), and Retrofitting-C's laminate/carpet doubled long-term emissions (22,868.42 $kgCO_2e$) through frequent replacements. For roofing and openings, Retrofitting-A's aluminium windows and ceramic tiles incurred high upfront carbon (8,923.65 $kgCO_2e$) but provided durability, whereas Retrofitting-B's uPVC and fibre cement reduced initial impacts but required more maintenance. Retrofitting-C achieved the lowest lifecycle carbon (12,868.61 $kgCO_2e$) despite periodic insulation replacements. These results, summarised in Figure 4, underscore the balance between material durability and EC, demonstrating how strategic selection can advance regenerative urban objectives.

Evaluation of Retrofitting Strategies

The assessment of the three retrofitting strategies A, B, and C reveals distinct trade-offs between initial and recurring EC, material choices, and long-term sustainability

across a 60-year building lifespan. Scenario-A records the highest total EC at 70,444.66 $kgCO_2e$, largely due to high-carbon materials like PUR insulation and natural stone cladding.

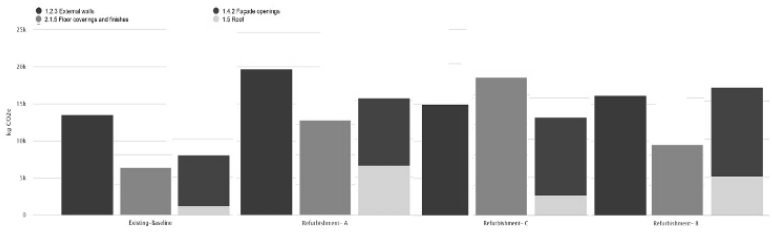


Figure 4: GWP contribution due to building elements across different LCA stages in all scenarios

While these materials significantly increase initial EC (A1-A5), their durability reduces recurring impacts to 8,804.16 $kgCO_2e$ (B4), aligning with Ibn-Mohammed *et al. (*2013), and Schwartz *et al. (*2018), who support using robust materials in projects targeting long-term structural efficiency as well as supporting Stephan *et al. (*2013) findings that durable materials yield lower lifecycle emissions despite higher upfront costs. This approach enhances operational performance but limits adaptability for future retrofitting. Scenario-B emerges as the most balanced strategy with the lowest total EC of 59,304.17 $kgCO_2e$. It combines timber cladding and composite panels to lower initial EC, while offering manageable recurring emissions of 15,280.67 $kgCO_2e$. Timber's carbon-sequestering properties (Soust-Verdaguer *et al.,* 2017) and the low energy demand of uPVC windows contribute to an effective trade-off between embodied impacts and longevity. This aligns with research by Blengini *et al. (*2010) and Schwartz *et al. (*2018) that promotes the use of low-carbon, durable materials that offer long-term operational advantages. Scenario-C, though achieving the lowest initial EC through organic cellulose insulation, paint finishes, and laminate flooring, results in higher recurring EC (24,291.71 $kgCO_2e$), bringing its total to 65,366.71 $kgCO_2e$. The frequent need for replacement compromises its sustainability over time, underlining the findings of Ibn-Mohammed *et al. (*2013) on the drawbacks of having short-lived materials in long-term carbon strategies.

These findings form the basis for a replicable framework aimed at reducing embodied carbon in urban regeneration projects by prioritising low-impact durable materials, balancing initial and recurring emissions across the full lifecycle, integrating material service life into early LCA modelling and adapting strategies to building typologies. Although the case study focuses on a small semi-detached house, its results offer transferable insights that can be implemented in wider urban regeneration efforts. This comparative LCA fills a critical gap in the literature, as the majority of existing studies emphasize operational carbon and post-construction mechanical efficiency, embodied carbon linked to construction methods, material choices, and replacement cycles remains underexplored. By quantifying and comparing these outcomes, the study provides practical guidance for embedding LCA into retrofit design, planning, and policy.

LIMITATIONS AND FUTURE WORKS

This study has several limitations. First, it focuses solely on embodied carbon, excluding operational emissions and other environmental impacts such as water consumption and resource depletion. Second, the use of generic data and assumptions in the LCA, particularly for materials lacking specific EPD which may lead to some

uncertainty in the results (Lis *et al.,* 2019). Third, the cost of the materials is not considered while selecting the materials. However, such limitations are common in early-stage retrofit assessments, and the comparative scenario-based approach still offers valuable insights for identifying the most sustainable solutions by building different design strategies based on material selection and intervention levels for maximum embodied carbon reduction. Lastly, the analysis is limited to a single case study, which may not reflect the full diversity of housing typologies or regional conditions.

Future research should incorporate operational carbon and life cycle cost analysis (LCC) to provide a more holistic evaluation of retrofitting strategies (Schwartz *et al.,* 2022). Expanding the study across multiple building types and regions is needed to validate the findings and develop benchmarks for different building types and regions. Additionally, the development of simplified LCA tools and databases tailored to retrofitting projects could enhance the accessibility and accuracy of embodied carbon assessments (Vilches *et al.,* 2017).

CONCLUSIONS

The research successfully applied Life Cycle Assessment to evaluate the embodied carbon of a typical semi-detached house in London under three Retrofitting scenarios, providing insights into material selection and life cycle environmental performance. The results demonstrate that embodied carbon varies significantly depending on material choices and replacement frequency across a 60-year lifespan. Retrofitting-A, while thermally efficient, resulted in the highest emissions due to energy-intensive materials (70,444.66 $kgCO_2e$). Retrofitting-C, despite using low-carbon materials initially, led to increased recurring emissions (65,366.71 $kgCO_2e$) due to shorter material lifespans. Retrofitting-B emerged as the most sustainable option (59,304.17 $kgCO_2e$), highlighting the importance of balancing durability with low embodied impact.

These findings reinforce the necessity of balancing immediate carbon costs with long-term sustainability, which is a key principle in regenerative urban development. Additionally, the research suggests that innovative materials, such as phase change materials or low-carbon concrete with longer service life, could contribute to further reducing emissions in future retrofitting projects. Integrating LCA into decision making for the sustainable retrofitting, this study offers actionable guidance to architects, engineers, and policymakers to decarbonise the UK's housing stock. Furthermore, the necessity of including embodied and operational carbon in a carbon reduction equation is emphasized, which is a key first step to regenerative cities that restore rather than deplete natural systems. Future research should consider emerging technologies and full life cycle carbon assessments to improve urban regeneration strategies for a sustainable future, supporting the UK's transition to a net-zero future.

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APPENDIX

List of the material selection and quantities for each scenario

Scenarios	Retrofitting- A		Retrofitting- B		Retrofitting - C	
Building Parts	**Components**	**Qty**	**Components**	**Qty**	**Components**	**Qty**
Foundation & Footings	PU Insulation Spray Foam 40kg/m3	2.8 m3	Rockwool Insulation-55kg/m3	2.8 m3	Cellulose Insulation, Blown	2.8 m3
External Cavity Walls	PU Insulation Spray Foam 40kg/m3	12 m3			Cellulose Insulation, Blown	12 m3
Intermediate Floor	PU Insulation Panels	3 m3	Stonewool/mineral wool Insulation	3 m3	Cellulose Insulation	3 m3
First Floor	Plasterboard	37 m2	Plasterboard	37 m2	Plasterboard	37 m2
	MDF	40 m2	MDF	40 m2	MDF	40 m2
	Glass Wool insulation Panels	30 m2	Glass Wool insulation Panels	30 m2	Glass Wool insulation Panels	30 m2
	PU Insulation Panels	6 m3	Stonewool/mineral wool Insulation	6 m3	Cellulose Insulation	6 m3
Roof	Bitumen Felt	70 m2	Bitumen Felt	70 m2	Bitumen Felt	70 m2
	Concrete Roof Tiles	62 m2	Concrete Roof Tiles	62 m2	Concrete Roof Tiles	62 m2
	PU Insulation Panels	12.4 m3	Stonewool/mineral wool Insulation	12.4 m3	Cellulose Insulation	12.4 m3
	Plastic Waterproofing membrane	70 m2	Plastic Waterproofing membrane	70 m2	Plastic Waterproofing membrane	70 m2
	Roofing Tile- Ceramic	70 m2	Roofing Tile- Fibre Cement	65 m2	Roofing Tile- Slate	65 m2
	Gypsum Plasterboard	78 m2	Gypsum Plasterboard	78 m2	Gypsum Plasterboard	78 m2
Loft Floor - Structure	Softwood Timber Joists and Beams	450 kg	Softwood Timber Joists and Beams	450 kg	Softwood Timber Joists and Beams	450 kg
	Softwood Timber Floor Boards	450 kg	Softwood Timber Floor Boards	450 kg	Softwood Timber Floor Boards	450 kg
Finishes	Ceiling gypsum Plaster	192 kg	Ceiling gypsum Plaster	192 kg	Ceiling gypsum Plaster	192 kg
	Ceiling Paint	75 m2	Ceiling Paint	75 m2	Ceiling Paint	75 m2
	Wall Gypsum Plaster	600 kg	Wall Gypsum Plaster	600 kg	Wall Gypsum Plaster	600 kg
	Wall Paint	225.5 m2	Wall Paint	225.5 m2	Wall Paint	225.5 m2
	Ceramic Tiles- Unglazed (Kitchen)	8.3 m2	Ceramic Tiles- Unglazed (Kitchen)	8.3 m2	Ceramic Tiles- Unglazed (Kitchen)	8.3 m2
	Laminate Flooring	30 m2	Laminate Flooring	30 m2	Laminate Flooring	30 m2
	Broadloom Carpet	28 m2	Broadloom Carpet	28 m2	Broadloom Carpet	28 m2
	Ceramic Tiles Unglazed- Floor(Toilet)	4.3 m2	Ceramic Tiles Unglazed- Floor(Toilet)	4.3 m2	Ceramic Tiles Unglazed- Floor(Toilet)	4.3 m2
	Ceramic Tiles Unglazed- Wall(Toilet)	17 m2	Ceramic Tiles Unglazed- Wall(Toilet)	17 m2	Ceramic Tiles Unglazed- Wall(Toilet)	17 m2
Finishes - Toilet	Porcelain Stoneware Tiles - Floor	4.3 m2	Ceramic Tiles	4.3 m2	Engineered wood Flooring	4.3 m2
	Porcelain Glazed Tiles - Walls	17 m2	Ceramic Glazed Tiles - Walls	17 m2	PVC interior wall covering	17 m2
	Adhesive	100 kg	Tile Adhesive	105 kg	Silicon Sealant	4 kg
	Silicon Sealant	2 kg	Silicon Sealant	1 kg		
Finishes - Interior Area	Natural Stone Flooring	38 m2	Solid Wood Floorig – Ground Floor	30 m2	Laminated Flooring- Ground Floor	38 m2
	Gypsum Plasterboard	37 m2	Solid Wood Floorig – First Floor	30 m2	Broadloom Carpet- First Floor	32 m2
	Natural Stone Floor Tiles	32 m2	Ceramic Tiles - Kitchen	4.3 m2	Gypsum board – Ceiling	75 m2
	Joint Grout for Stone	25 kg	Joint Sealant	1 kg	Gypsum Plaster on Ceiling	195 kg
	Decorative gypsum board – Ceiling	75 m2	Tile Adhesive	85kg	Gypsum Plaster on walls & Loft	795 kg
	Gypsum Plaster on walls & Loft	795 kg	Gypsum Board- Ceiling	795 kg	Emulsion Matt paint- Ceiling	75 m2
	Satin sheen finish Paint- walls	225.5 m2	Wall Paper Interior- Walls & Loft	303.5 m2	Emulsion Matt paint- Walls & Loft	303.5 m2
	Satin Sheen Finish Paint – Loft	78 m2	Wall Paper Interior- Ceiling	75 m2		
Exterior Cladding	Natural Stone Slab	90 m2	Façade Insulation Panel System	90 m2	Mineral Plastering	90 m2
	Adhesive Mortar	450 kg			Emulsion Paint- Exterior	90 m2
	Joint Grout	25 kg				
Loft Flooring	Gypsum Plasterboard	40 m2	Solid Wood Flooring- Loft	40 m2	Laminate Flooring	40 m2
	Ceramic tiles – Unglazed	40 m2				
	Tile Adhesive	2 kg				
	Silicone Sealant	200 kg				
Windows/Doors	Aluminium Window	16 m2	Aluminium Window	16 m2	Aluminium Window	16 m2
	Wooden Window Sill	10.5 m	Wooden Window Sill	10.5 m	Wooden Window Sill	10.5 m
	Wooden Doors, Hatch Door, Wooden Frame Glass Door	23.76 m2	Wooden Doors, Hatch Door, Wooden Frame Glass Door	23.76 m2	Wooden Doors, Hatch Door, Wooden Frame Glass Door	23.76 m2
	Aluminium Frme Sliding Patio Door	4 m2	Aluminium Frme Sliding Patio Door	4 m2	Aluminium Frme Sliding Patio Door	4 m2
	Aluminium Triple glazed window	16 m2	uPVC window – Triple Glazed	16 m2	Wooden Frame Window- Triple Glazed	16 m2
	Aluminium Sliding Patio Door	4 m2	uPVC frame External Doors – Triple Glazed	3.7 m2	External Wooden Door	4.2 m2
	Acoustic Wooden Door with Frame	19.7 m2	uPVC Frame- Sliding Patio Door	4 m2	Thermal insulating Internal Doors	19.7 m2
	Aluminium Security door- Entrance	3.7 m2	Interior Solid Core Wooden Door	19.7 m2	Security door for entrance	3.7 m2
	Aluminium Frame Skylight	1.5 m2	uPVC Skylight	1.5 m2	Wooden Skylight	1.5 m2
LEGEND						
	Material Removed/Replaced			**Additional Materials**		

CONSTRUCTS AND INDICATORS FOR ASSESSING STAKEHOLDER BEHAVIOUR IN ADOPTING THE CIRCULAR ECONOMY IN CONSTRUCTION AND DEMOLITION WASTE MANAGEMENT: EXPERTS' PERCEPTIONS

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Construction and demolition waste is the world's largest waste source, and it constitutes over 30% of global waste. Researchers have argued that it can be significantly reduced by adopting Circular Economy (CE) principles. However, stakeholder behaviour presents a significant barrier to CE adoption in Construction and Demolition Waste Management (CDWM), and it has not been explored in depth. To address this gap, this study aims to identify and verify a set of constructs and related indicators to assess the behaviour of stakeholders. These were identified through a systematic literature review and verified by 11 experts in Australia. Seven constructs were identified using the Theory of Planned Behaviour (TPB) and the Norm Activation Model (NAM), and 19 related indicators were derived from identified barriers. In addition to this, 12 indicators were suggested by the experts. By focusing on validated indicators, this research equips policymakers, industry practitioners, and researchers to assess the behaviour of stakeholders when implementing circular economy principles in CDWM.

Keywords: circular economy; construction and demolition waste management; constructs; indicators; stakeholder behaviour

INTRODUCTION

The CE is a system where materials never become waste and nature is regenerated (Ellen MacArthur Foundation, 2015). In a CE, products and materials are kept in circulation through processes like maintenance, reuse, refurbishment, remanufacture, recycling, and composting. This approach aims to keep materials in use for as long as possible, thereby lowering the reliance on natural resources in construction projects (Kirchherr *et al.,* 2017). Despite increasing acceptance of CE by various countries, CE has not been fully implemented in CDWM, mainly due to several underlying barriers. The previous studies have established that the behaviour of stakeholders is one of the key barriers to adopting CE in CDWM. To highlight few, obstacles such as perceived higher costs (Tura *et al.,* 2019; Bilal *et al.,* 2020; Urbinati *et al.,* 2021) and

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lack of awareness of ecological benefits related to CE practices (Siringo *et al.,* 2020; Charef *et al.,* 2021) reflect stakeholders' attitudes. Ajzen (1991) noted that cost and benefit perceptions are key factors influencing individual attitudes, which is considered as one of the variables in determining an individual behaviour. Moreover, barriers like a lack of skilled employees (Campbell-Johnston *et al.,* 2019), insufficient financial incentives (Tura *et al.,* 2019; Salmenperä *et al.,* 2021), inadequate infrastructure (Adams *et al.,* 2017), and limited waste regulations (Dunant *et al.,* 2017) are closely related to perceived behavioural control, which is shaped by resources and opportunities, including time, money, space, and policy support (Ajzen, 1991) and influence the behaviour of an individual.

Thus, it is evident that stakeholder behaviour significantly impacts CE adoption in CDWM. To overcome these obstacles, it is required to understand and address the fundamental constructs influencing behaviour of construction stakeholders (Geissdoerfer., 2017). A construct is a theoretical concept, theme, or idea based on empirical observations. However, constructs are usually not directly measurable (Bhandari, 2022). Therefore, indicators that are a measurable representation of constructs need to be derived (Bhattacherjee, n.d.).

However, the absence of clearly defined constructs and indicators makes it difficult to assess the behaviour of stakeholders. In addition, the constructs and indicators should be more closely aligned with stakeholders involved in the design phase, as this stage offers a prime opportunity to reduce waste at its source (Ajayi and Oyedele, 2018). To address this gap, this study aims to identify and validate a set of critical key constructs and indicators to assess stakeholders' behaviour towards CE adoption in CDWM. The constructs and indicators are identified through literature review and validated using the expert interviews. Thereby, this study facilitates the assessment of stakeholder behaviour and enables the formulation of targeted actions to enhance the adoption of CE principles.

LITERATURE REVIEW

Javid *et al. (*2021) defined behaviour as "Behaviour is the approach in which one performs certain actions in a given scenario concerning a set of targets." Studies have shown that both rational and moral factors significantly influence behaviour, particularly in contexts requiring sustainable decision-making (Ding *et al.,* 2023). Rational behaviour is the practice of making choices that result in the most optimal level of utility or benefit for the individual, based on logical evaluation and consistent with their self-interest and goals" (Becker, 1976). Moral behaviour is the conduct that is by accepted principles of right and wrong, and is often driven by ethical standards, societal norms, and the desire to act in a way that is valuable to others and society as a whole" (Schwartz, 1977).

Several inter-disciplinary research highlights the importance of incorporating rational and moral dimensions since the behaviour of the environment is a combination of altruistic concern and self-interest (Shi *et al.,* 2017). The CE adoption is considered environmentally friendly since it intends to minimise the usage of resources, waste reduction, and foster the reusing, recycling, and re-manufacturing of products and materials. By reducing environmental degradation, pollution, and resource waste, CE contributes to the well-being of the ecosystem and future generations (Ellen MacArthur Foundation, 2015). As a result, CE adoption has a characteristic of altruism and self-interest. Hence, it is required to assess both the rational and moral behaviour of an individual. Most research to date has focused on the rational

behavioural perspective, and, the moral behavioural perspective, has been comparatively underexplored. Ozaki (2011) described cognitive behavioural theories involves a rational assessment. On the other hand, Schwartz (1977) developed normative behavioural theories that emphasize personal norms and moral obligations. The TPB, developed by Ajzen (1991), is a cognitive theory explains behaviour through attitude, subjective norms, and perceived behavioural control. While TPB effectively models intentional decision-making, it has been criticised for neglecting moral and altruistic influences (Shi *et al.,* 2017). In contrast, the NAM, introduced by Schwartz (1977), focuses on moral obligations, personal norms, and awareness of consequences in shaping behaviour. However, NAM does not account for rational factors such as perceived behavioural control, social influences, and situational constraints (Fang *et al.,* 2021), limiting its applicability in complex decision-making environments like CE adoption.

Studies suggest that combining TPB and NAM can overcome these limitations, as it integrates both self-interest and altruistic motivations (De Groot and Steg, 2009). Therefore, integrating both rational and moral perspectives provides a comprehensive understanding of stakeholder behaviour. Ding *et al. (*2023) developed a behavioural assessment framework by integrating the TPB and the NAM. However, their study was limited to examining the behaviour of a single stakeholder group; contractors and focused exclusively on one CE principle; recycling. This narrow scope overlooks the broader array of CE principles, which are equally critical to comprehensive CE adoption. Furthermore, the effective implementation of CE in CDWM necessitates the participation and behavioural change of multiple stakeholder groups across the project lifecycle. Although some studies have discussed behavioural indicators in construction sector, there is a lack of comprehensive and validated indicators specifically designed to measure the constructs underpinning CE adoption in CDWM. This gap is particularly pronounced in the Australian context, where such indicators have not been empirically tested or contextualised to local industry practices.

METHOD

The TPB and the NAM are used as the theoretical underpinnings and identified through the systematic literature review as the most relevant theoretical frameworks to understand stakeholder behaviour in the context of CE adoption for CDWM. Based on these theories, a total of seven behavioural constructs were derived, four from TPB and three from NAM. Furthermore, the specific indicators used to assess each of these constructs were also identified through the literature review. These indicators were developed by analysing the behavioural barriers frequently reported in the literature. For example, according to the TPB, attitude is a key construct influencing behavioural intention. As noted by Ajzen (1991), cost is one of the factors that can significantly shape an individual's attitude. As stated by Curado *et al. (*2024), the perception of higher costs has been identified as a barrier to the adoption of CE, and from this, perceived cost has been derived as an important indicator influencing stakeholder attitude. The PRISMA methodology (Moher *et al.,* 2009) was employed for a structured and transparent review process, using Web of Science and Scopus, to source relevant studies published in the last ten years (Geissdoerfer *et al.,* 2017) concerning CE and CDWM. After applying inclusion and exclusion criteria, 26 articles were selected. The identified constructs and indicators are verified through semi-structured expert interviews. Purposive sampling was used to select experts from Australia to verify the context-specified constructs and indicators, and interviews were conducted with 11 experts. This non-probability sampling method is especially

appropriate because it enables the intentional selection of individuals who possess specific expertise and experience pertinent to the research topic (Palinkas *et al.,* 2015). The profile of the experts is provided in Table 1.

Table 1: Profile of Experts

Category	Designation, Code and Experience (years)
Industry	Design specialist (E01, >15), Non-executive director and company secretary (E02, >25), Urban planner (E03, 10), CE consultant and Civil engineer (E04, 10), Principal and consultant (E05, 20), CE specialist (E06, 10), CE pioneer and head of CE (E07, >30), Project leader (E08, >26), Environmental Sustainability Lead (E09, 10)
Policy	Policy designer (E10, >25), Senior environmental advisor and officer of the CEO (E11, 18)
Academia	Lecturer (E01, >15), Lecturer (E02, >25)

The participants in this study, with industry experience ranging from 10 to 30 years, possess the depth and breadth of knowledge required to validate the indicators for CE adoption in CDWM. Their experience aligns with the evolution of CE principles over the past decade, during which CE gained global recognition and became embedded in policies such as Australia's National Waste Policy Action Plan (2019) and Victoria's Recycling Victoria Policy (2020). Out of the 11 participants, 8 have expertise in CDWM and CE, while 3 specialise solely in CE. This distribution ensures that the study benefits from insights directly related to industry practices and the broader sustainability framework. Additionally, 2 participants have experience spanning both academia and industry, allowing for a balanced perspective between theoretical research and practical application. Furthermore, 2 participants are involved in policymaking, bringing an understanding of regulatory frameworks and government-driven initiatives. In comparison, the remaining 7 participants come from industry backgrounds, contributing firsthand knowledge of challenges and opportunities in CE implementation within real-world projects. This diverse mix of expertise ensures the study is grounded in both practical application and policy relevance, making the findings robust and applicable to the sector. The frequency analysis is employed as the analysis technique to identify the most stated indicators to measure each construct.

FINDINGS AND DISCUSSION

Seven key constructs have been identified by integrating TPB and NAM, including attitude, subjective norms, perceived behavioural control, and behavioural intention from TPB. The first three constructs are antecedents of the behavioural intention (Ding *et al.,* 202), and the intention can be derived by assessing those 3 constructs. On the other hand, personal norms, awareness of consequences, and ascribed responsibilities are derived from NAM. Further, as suggested by Marsh *et al. (*1998), a minimum of three indicators was used to measure each construct in this study. These indicators were derived from the identified behavioural barriers. The findings as illustrated in Table 2, will be discussed, focusing on the validation of these indicators and insights into their applicability in the context of Victoria. The table comprises the constructs, indicators, number of expert respondents who validated the indicators, and the agreed percentage, reflecting the extent of expert consensus obtained using the following formulae.

Percentage agreed = (Number of respondents who agreed/ total number of respondents) * 100

Rational Behaviour (TPB)

Attitude is an individual's favourable or unfavourable assessment of engaging in a particular behaviour (Ajzen, 1991). To measure stakeholder attitudes toward CE adoption, three indicators were developed from the literature by translating key

behavioural barriers into measurable elements. First, the barrier related to the perception of higher costs (Curado *et al.,* 2024) was captured as the indicator perceived cost, reflecting stakeholders' concerns that CE practices require more financial investment.

Table 2: Validation of Constructs and Indicators

Constructs	Indicators and agreed %	Definition of indicators
Theory of Planned Behaviour (Rational behaviour)		
Attitude (A)	Perceived cost (100)	Monetary cost that the user thinks he/she incur by adopting CE
	Perceived environmental benefits (100)	Beliefs about the positive outcomes associated with adopting CE in response to a real or perceived threat
	Policy objectives (81.82)	A set of ideas or plans that is used as a basis for making decisions to adopt CE
	*Education/ Knowledge (9.09)	Stakeholders' awareness, understanding, and technical literacy around CE principles, practices, and outcomes
	*Procurement and contract models (9.09)	Structure, conditions, and requirements embedded in procurement processes and contractual agreements that influence whether and how CE practices are adopted
Subjective Norms (SN)	Peer influence (81.82)	Process by which peers affect one another's behaviour to adopt CE
	Government pressure (100)	Formal mechanisms, such as laws and regulations, that authorities employ to influence individuals and group to adopt CE to align with societal norms and objectives
	Public pressure (100)	The influence that people feel from others in their social circle or society at large to act, think, or behave in a certain way
	*Leadership/ hierarchical influence (9.09)	Describes how organisational leaders or supervisors directly shape employee behaviours and norms, especially in hierarchical industries like construction
	*Company vision/ internal culture (9.09)	The degree to which a company's purpose or sustainability values influence individual decision-making
	*Shareholder and reputational pressure (9.09)	The external pressure from investors which influences organisations to adopt sustainable practices
Perceived Behavioural Control (PBC)	Skills (100)	The ability to retrieve knowledge and apply it to a task in a proficient manner
	Training (100)	The process of learning the skills you need to do a particular job or activity
	Financial incentives (100)	Monetary benefit paid by an organisation to motivate and encourage people to adopt CE
	Infrastructure accessibility (100)	The basic physical and organisational systems that enable people to adopt CE
	*Digital platforms (9.09)	Presence of digital systems that enable transparency, traceability, and operational ease in CE implementation
Norm Activation Model (Moral behaviour)		
Personal Norms (PN)	Personal commitment (100)	Individuals feel a sense of moral duty to engage in CE practices
	Environmental perception (100)	Stakeholders' views of environmental issues shape their sense of personal responsibility
	Balance of short-term and long-term considerations (100)	Consideration of long-term benefits over short-term costs in adopting CE
	*Social motivation and values (9.09)	individual's sense of responsibility or drive that arises from broader societal concerns rather than purely environmental or economic incentives.
	*Morality (9.09)	Internal ethical framework that guides decisions about what is right or wrong
Awareness of Consequences (AC)	Environmental benefits (100)	Knowledge among decision-makers about CE's ecological benefits
	Economic advantages (100)	Awareness of CE's economic potential
	Social implications (100)	Social outcomes of CE adoption
	*Existential threat and climate anxiety (18.18)	Awareness driven by emotional responses to environmental crises, including fear of collapse or concern for future generations
	*Consequences of inaction (9.09)	Understanding not just the benefits of CE, but the risks of continuing with business-as-usual practices.
Ascribed Responsibility (AR)	Guidelines (100)	A command or authorisation to act in a particular way on a public issue given by the electorate to its representative
	Mandates (100)	A command or authorisation to act in a particular way on a public issue given by the electorate to its representative
	Resource depletion (81.82)	Reduction of available natural resources due to unsustainable extraction and consumption.
	*Local impact awareness (9.09)	Feeling responsible when the consequences of their actions are tied to their immediate environment or community
	*Future harm and fear, and shame (18.18)	Emotional states that can trigger or strengthen one's sense of moral obligation to act sustainably.

*New indicators () Agreed %

Second, the barrier lack of awareness or appreciation for environmental benefits (Munaro and Tavares, 2023) informed the indicator perceived environmental benefits, which aimed to assess whether stakeholders recognise the environmental value of CE implementation. Finally, the lack of coherent policies and the persistence of regulatory frameworks that favour linear models (Mubarik *et al.,* 2024) led to the indicator policy objectives, intended to reflect how existing policies influence stakeholders' perceptions of CE.

Most experts agreed with these indicators and emphasized their continued relevance in practical settings. However, the policy objectives indicator received the most critical feedback. While acknowledged as important, several experts questioned its real-world effectiveness. Rather than viewing it as a stand-alone motivator, they believed its value lay in the way policy drives market incentives or procurement strategies. To highlight a few, "Policies should create market value and financial incentives, not just set guidelines (E10)." One expert noted that without enforcement, policy lacks behavioural power: "Having a policy is good… but actioning it is where we want them to get to (E03)." Apart from these indicators, several additional indicators were highlighted. Education/ knowledge of environmental benefits is highlighted by E03, and the expert emphasized that without understanding the benefits of CE, people may not develop a positive attitude towards its adoption. In addition, E06 emphasized procurement and contracting models as a possible indicator to measure attitude. The expert emphasized that CE adoption is heavily influenced by regulatory changes like mandatory Building Information Modelling use and how procurement is structured, especially in large projects where financial motivations override sustainability goals.

The social influences that individuals experience from others who hold significance for them when they are making decisions about their behaviour are defined as the subjective norms (Ajzen, 1991). To assess the influence of social pressure on stakeholder behaviour in CE adoption, three indicators were developed based on barriers identified in the literature. The barrier of resistance or scepticism from peers (Sajid *et al.,* 2024) informed the indicator peer influence, acknowledging the role of professional networks in shaping behaviour. The lack of support or endorsement from authoritative bodies (Mahpour, 2018) was translated into the government pressure indicator, reflecting the importance of top-down regulation and guidance. Lastly, the negative public perception of construction waste (Curado *et al.,* 2024) led to the public pressure indicator, which captures the broader societal expectations toward sustainable waste management. Although the government pressure and public pressure were acknowledged by all the participants, peer influence received mixed responses. While some experts agreed that colleagues and industry norms play a role, others disagreed or offered a reframing of this indicator. For example: "I don't think I would add pressure from peers… maybe more around the goal of your company as a whole (E02)." "Construction is a very hierarchical exercise... if your boss doesn't care about it, well, you won't care about it (E05)." Apart from this leadership or hierarchical influence (E05), company vision or internal culture (E06), and shareholder and reputational pressure (E04) are added by the experts.

The perceived behavioural control is the perceived difficulty or ease of carrying out the behaviour (Ajzen, 1991). The construct of PBC was conceptualised through three key indicators derived from barriers identified in the literature. The lack of skilled employees (Munaro and Tavares, 2023) informed the indicator skills and training,

highlighting the need for stakeholders to possess the necessary knowledge and competencies to implement CE effectively. The absence of financial incentives or supportive regulatory frameworks (Debnath and Sarkar, 2023) was translated into the indicator of financial incentives, acknowledging the influence of economic motivators in empowering sustainable decisions. Finally, the inadequacy of infrastructure for sorting, recycling, or reusing materials led to the indicator accessibility of infrastructure, reflecting how logistical and physical constraints limit behavioural control. Across the expert interviews, there was strong and consistent agreement on these indicators. The interviews also surfaced several important indicators such as technological tools and tracking systems, internal values and beliefs and logistics to measure the PBC. E03 recommended including tools like digital platforms, material passports, or product tracking systems to improve visibility and coordination across the supply chain by stating, "It would be great if we had platforms or systems… that allowed people to know where materials are going or how to reuse them".

Moral Behaviour (NAM)

Personal norms are the moral responsibility to carry out or refrain from activities, which is the prerequisite to behavioural intention (Schwartz, 1977). PN is defined using three indicators derived from literature on behavioural barriers to CE adoption. The lack of personal commitment to sustainability (Takacs *et al.,* 2022) was addressed through the indicator personal sustainability commitment, capturing whether individuals feel a sense of moral duty to engage in CE practices. The barrier related to prioritisation of short-term gains over long-term environmental goals (Bertolotti and Roman, 2024) led to the indicator short- and long-term consideration, reflecting the internal conflict between immediate rewards and sustainable outcomes. Lastly, poor environmental perceptions or beliefs (Chrispim *et al.,* 2024) informed the environmental perception indicator, which examines how stakeholders' views of environmental issues shape their sense of personal responsibility. These indicators were broadly supported by experts during interviews, yet they also revealed deeper insights into the drivers of personal norms. Experts offered meaningful additions to the indicators, which include social motivation and values, and financially rooted morality. E011 highlighted that "Circular isn't just environmental, it's social… you have to think about small business, lower cost for end-users, and job creation."

Awareness of the negative impacts on others or valued aspects when failing to act pro-socially is defined as the awareness of consequences (Schwartz, 1977). The barrier lack of knowledge among decision-makers about CE's ecological benefits (Kirchherr *et al.,* 2017) informed the indicator knowledge of environmental benefits. The limited awareness of CE's economic potential (Nujen *et al.,* 2023) led to the indicator economic advantages, and the overlooked social outcomes of CE adoption (Chakraborty *et al.,* 2022) were translated into the indicator social implications. These indicators were broadly endorsed by expert participants, who agreed that awareness of consequences is fundamental to changing stakeholder behaviour. However, interviews revealed that awareness is often lacking, particularly around the non-environmental impacts of CE. Existential threat and climate anxiety, and the consequences of inaction are mentioned as additional indicators. Particularly noted in interviews 06 and 07, experts emphasized that stakeholders especially younger generations, are increasingly influenced by fear-based awareness of global environmental collapse, where E06 stated that "Existential threat means the fear of dying… the global crisis has created anxiety amongst young people."

A sense of accountability for the adverse effects resulting from not engaging in pro-social behaviour is defined as the ascribed responsibility (Schwartz, 1977). To measure this, three indicators were developed based on the barriers identified in the literature. The lack of understanding among political decision-makers about CE's ecological impacts (Kirchherr *et al.,* 2017) informed the indicator mandates and guidelines, highlighting the role of formal frameworks in assigning responsibility. Most experts agreed with these indicators in principle, affirming that stakeholders are more likely to engage with CE when they perceive it as part of their role or obligation. However, the indicator resource depletion (part of social and environmental implications) was seen by some as too abstract or removed from people's daily experience. E05 reflected: "You talk about indicators of resource depletion. I kind of feel that they're too much for most people." Experts recommended local impact awareness, narrative of future harm and fear, and shame as drivers as additional indicators to measure AR.

CONCLUSION

This study identifies the key constructs and indicators necessary for assessing stakeholder behaviour in the adoption of CE principles in CDWM. The research systematically develops these constructs and identifies suitable indicators to measure each of them. Since the study was conducted in Australia, the identified indicators were validated through expert interviews to ensure contextual relevance. The findings confirm that attitude, subjective norms, perceived behavioural control, personal norms, awareness of consequences, and ascribed responsibility are crucial constructs influencing CE adoption. Experts unanimously validated the 19 key indicators identified in the literature, highlighting their importance in shaping stakeholder behaviour. Additionally, education/ knowledge of environmental benefits, procurement, and contracting models to measure attitude; leadership or hierarchical influence, company vision or internal culture, and shareholder and reputational pressure to measure subjective norms; technological tools and tracking systems, internal values and beliefs and logistics to measure the PBC; social motivation and values, and financially rooted morality to measure personal norms; existential threat and climate anxiety, and the consequences of inaction to measure awareness of consequences; local impact awareness, narrative of future harm and fear, and shame as drivers to measure ascribed responsibility are identified as additional indicators through expert interviews. The study contributes to existing knowledge by providing an empirically validated constructs and indicators for assessing stakeholder behaviour in CE adoption. Future research can be done to assess the behaviour of stakeholders to adopt CE in CDWM by using the validated constructs and indicators from this study. Also, studies can be conducted on how to change the behaviour of stakeholders to accelerate the adoption of CE in CDWM.

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PUBLIC CLIENTS' TRANSITION TOWARDS CIRCULAR PRACTISES IN INFRASTRUCTURE PROJECTS

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Transforming the resource intensive construction sector is vital for the transition to circular economy. Incorporating changes to transition from linear to a circular way of working place significant demands on client organisations. The primary objective of our study is to develop a conceptual change model that provides recommendations on what internal changes can be implemented within public clients, to accelerate their transition to circular practises in infrastructure projects. A literature review indicates that models incorporating both process and content aspects are most effective in addressing comprehensive organisational change. Empirical data was gathered through case studies among public clients, being Dutch regional water authorities. The initial organisational change framework was validated and refined through expert interviews. The developed change model serves as a guiding tool for facilitating public clients' transition from their current state to the desired state through structured and achievable steps. The framework identifies four key areas of change: people, work process, structure, and external. For each of these four aspects, change measures are presented in the unfreeze-transition-refreeze steps, adopted from Lewin's change model for planned organisational change.

Keywords: change model; circularity; organisational change; public client; water authority

INTRODUCTION

In 2016, the government-wide program for a circular economy identified 'construction' as one of the five priority areas to be addressed first, given the sector's resource-intensive nature (Ministry of Infrastructure and the Environment and Ministry of Economic Affairs, 2016). The transition agenda 'Circular Construction Economy,' crafted collaboratively by various public and private stakeholders, outlines the Dutch strategy to achieve full circularity in the built environment by the year 2050.

Infrastructure projects are majorly procured by public entities. Public clients can directly shape market demand for circular products and services through the implementation of strategic purchasing policies (Hanemaaijer et al., 2023). Nevertheless, changes like the transition to circular construction practices place great demand on client organisations. Many circular initiatives are still in their initial phases, with limited scaling up or break- through activities. At this point, substantial market demand for and supply of circular products and services is still lacking

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(Hanemaaijer et al., 2023). This might indicate that public clients need to alter their strategic, tactical, or operational approaches to facilitate the transition.

One significant group of Dutch public client organisations is the Dutch Regional Water Authorities (water boards), responsible for regional water management. The 21 Dutch Regional Water Authorities build and manage huge numbers of infrastructure works like flood defenses, navigable waterways, pumping stations, and wastewater treatment plants. These authorities hold an independent position in the democratic system in the Netherlands with autonomous governance over the activities assigned to them (Havekes et al., 2017).

Lately, the water boards have been busy tackling climate change and shifting towards sustainability mainly in three areas: climate adaptation, energy neutrality, and circular economy (Unie van Waterschappen, 2021). While the water boards have set targets of achieving 50% circularity by 2030 and 100% circularity by 2050, the specific actions required to shape these goals have not yet been completed or crystallised (Besseling *et al.,* 2020). The Union of Water Boards indicates that the water boards have made progress in the circular economy domain. All 21 water boards have developed a circularity policy, with over 17 of them having already adopted it administratively. However, it remains largely experimental and exploratory (Unie van Waterschappen, 2021). Given the nature of their work, water authorities understand employing a linear approach to material usage is unsustainable. They directly deal with the consequences of climate change such as heavier rains and prolonged periods of drought. Being major clients in the infrastructure sector, they have the resources and opportunities to make a substantial difference in the transition to a circular economy.

While the urgency for change is present, the water boards struggle to progress beyond pilot projects, increase maturity levels throughout the organisation, and align new policies with daily practices. It is currently perceived as an additional task for a select few within the organisation but rather should evolve into a norm for the entire organisation of the water boards. This transition brings about a change in decision-making, design, purchasing, use and logistics, among other things. To achieve a rapid and significant transition to circular construction practices, public client organisations, such as water boards, must move beyond standardised, traditional methods of working. Thus, for the implementation of such transitions, these organisations must adapt their internal organisation to incorporate the changes.

This study explores the pressing need for robust strategies related to the internal organisation of public clients, aiming to facilitate the transition to a circular way of working. This was achieved by examining Dutch regional water boards. The guiding research question is: What changes in the internal organisation of a public infrastructure client could facilitate the transition to circular construction practices?

LITERATURE REVIEW

Organisational change is defined as the empirical transformation observed in the form, quality, or long-term state of an organisational entity. This change typically arises from the introduction of new styles of thinking, acting, or operational approaches, aimed at adapting to the environment or enhancing performance (Pardo-del Val *et al.,* 2012: 1845). According to Errida and Lotfi (2021), change management models support and act as guiding frameworks to facilitate change efforts by outlining specific processes or steps that can be followed. It also depicts the various factors influencing

change and identifies the levers necessary for success in the change management process.

Transition to circular constructions is often initiated deliberately. Planned organisational changes are deliberate activities to move an organisation from its current state to the desired state (Stouten *et al.,* 2018: 752). While reviewing the existing literature, it can be found that several planned organisational change models are available. For instance, Joseph Galli (2018) did a comparative analysis of five major change models and identified the advantages and disadvantages of each. Errida and Lotfi (2021) identified 37 change models through extensive literature reviews and analysed the selected models to identify the factors influencing change management success. Planned organisational change models mainly fall into two categories: (1) processual and (2) descriptive models (Parry *et al.,* 2014; Errida and Lotfi, 2021).

Processual change models outline the unfolding of the change process and determine the steps for conducting and managing change. Some renowned processual change models include Lewin's 3- stage model, Kotter's 8-step model and Prosci's ADKAR model. (Parry *et al.,* 2014; Errida and Lotfi, 2021). While there are several other processual models available, many of them are variations of Lewin's 3-stage model, often dividing the three stages into more steps (Errida and Lotfi, 2021). Within the three most used change models mentioned above, the ADKAR model focuses on an individual's change adaptation, while Lewin's and Kotter's approach guides and facilitates organisation-wide change (Joseph Galli, 2018). In this study, since the focus is on organisational change, Lewin's and Kotter's models are explored further. Lewin's 3-stage model of change is called the classical model by some authors (Talmaciu, 2014) and widely regarded as the cornerstone of planned change management (Errida and Lotfi, 2021). Most subsequent theories and models are founded on Lewin's fundamental principles (Yli- Kerttula and Varis, 2023). This model splits the process of change into three stages or phases, namely: unfreeze, moving and refreeze (Talmaciu, 2014). Kotter's 8-Step Change Model builds upon Lewin's initial change theory, giving an expanded view to managing organisational change (Joseph Galli, 2018).

While processual models refer to 'how' change can occur, descriptive models focus on content and describe 'what' changes in the organisation. Some common descriptive change models include Burke and Litwin's model of organisational change and Nadler and Tushman's congruence model (Errida and Lotfi, 2021). There is disagreement in the literature regarding the selection of the most suitable model to steer change within an organisation (Errida and Lotfi, 2021). Several authors think that using a single model may not provide a full description and may neglect certain important factors. Besides, one model for all cases may be inappropriate to the particularity of the change (Joseph Galli (2018); Al-Haddad and Kotnour (2015)). While literature may provide some direction, it is ultimately the organisational environment that should determine a suitable change framework that fits (Joseph Galli (2018); Al-Haddad and Kotnour (2015)). Existing change management models are not specific enough for the needed transitions to circular practises by public construction clients. Therefore, this research intends to develop a tailor-made framework for organisational change that addresses circular transitions in public client organisations such as the Dutch regional water boards.

METHOD

The first phase of the study consists of a literature review, document review, and three unstructured exploratory interviews. The objective of this phase is to identify the essentials for a change framework that comprehensively captures the different aspects of change that need to be addressed in the organisation for circular transitions. For this purpose, it was imperative to initially understand the current ways of working at the organisation under consideration. This is done by commencing with a review of documents available within the organisation on governance aspects. The understanding is further solidified through exploratory interviews. This procedure helped understand what areas of internal organisation should be prioritised in the change framework in later parts of the study. The subsequent step was a thorough literature review on available organisational change literature. Considering the inputs from the previous step, this step involved the identification of some components essential in a change framework. These findings formed the theoretical basis for the rest of the research. Next, a specific set of goals are defined according to the desired state post-change for each organisational aspect. For this purpose, a detailed literature survey was conducted as extant literature is fragmented on how a 'circular' organisation should function.

The second phase of the study focuses on empirical investigation. Since the extant literature on internal organisational change to transition to circular construction practices is scarce, analysis of multiple case studies was an apt methodology for this part. The multiple case study is a qualitative research methodology that enables us to attain substantial, contextual, and in-depth insights into the subject of focus (Yin, 2017). A minimum of two case studies were utilised to eliminate the possibility of deductive theory confirmation. The individual case studies must predict similar results (literal replication) to allow the possibility to generalise findings (Yin, 2017).

The following criteria were used to identify suitable water boards for the study: (1) Water boards with recognisable initiatives for transitioning towards circular constructions. The first and crucial criterion for selection was to check if a water board had already formulated its own goals and translated them into policies. Furthermore, it should had taken actionable steps towards achieving these ambitions like implementing pilot projects, steps for sustainable commissioning, or other ongoing initiatives; (2) Water boards with an established organisational structure and process maturity. This criterion emphasizes the importance of selecting water boards that possess a mature organisational structure and well-defined processes, as these characteristics are conducive to effectively implementing organisational change strategies related to transitioning to circular construction practices; (3) Water boards of varying sizes and scope of tasks.

Based on the criteria listed above, two Dutch regional water authorities were chosen, both front-runners in sustainability transitions. A background study into these organisations, their working and their circular initiatives was done prior to semi-structured interviews through documents retrieved from publicly available websites. Criteria that were set for the selection of interviewees are: (1) Role and position. The interviewee should hold a position relevant to infrastructure management, strategic planning or change management within the organisation. They must have varying positions to bring as many perspectives as possible. (2) Experience. Professionals with substantial experience (min. 5 years) and must have participated in completed/ongoing circular construction initiatives of the organisation.

Following to the above criteria, three to five interviewees were selected for each case. Case A: department manager, policy advisor (asset management), asset manager, program manager sustainability and circularity and technical manager. Case B: project leader, advisor circular economy and manager sustainable innovation.

In-depth analyses of the data collected during the case studies were performed to identify the emerging themes and perspectives discussed, using both deductive and inductive approaches. The guiding theoretical framework was utilised to categorise the findings into four main aspects, namely, people, work process, structure and external. The data collection and analysis within a predetermined framework gives the analysis a deductive nature. At the same time, themes and patterns within these categories emerged directly from the data through thematic analysis, without any preconceived notions, thereby giving it an inductive nature.

In the third phase of the research an organisational change framework for transition to circular construction practises was developed based on the empirical findings from Phase 2. This framework was validated and refined for improving its applicability through expert interviews with three interviewees from prominent Dutch public infrastructure client organisations. These experts were: Advisor circular economy, policy advisor circular economy and senior advisor circular economy and innovation.

FINDINGS

Multiple change models could be combined to align with the specific needs of a change initiative or the context of an organisation (Errida and Lotfi, 2021). It is found that models that incorporate both process and content aspects demonstrate the most promise in addressing the change holistically (Barnett and Carroll, 1995). Keeping this in mind, the change model for this study includes components of a processual model as well as organisational-specific variables and factors from descriptive models.

Figure 1 provides a visual representation of the theoretical framework used in the study. This model primarily consists of two parts. First, it adopts one of the most utilised processual models, namely, Lewin's 3-stage model consisting of unfreeze-transition-refreeze steps. The Kotter's 8-step model is often seen as a detailed version of Lewin's model. The second part involves the variables or factors targeted for change within the organisation as found in various descriptive change models. The four content aspects identified are people, work process, structure and external. The initial three aspects, or their modified forms, are present in various descriptive models such as Burke-Litwin's model, Nadler-Tushman's congruence model, and McKinsey's 7S Framework. The fourth aspect -external -was identified during validation interviews of this model framework. 'People' relates to the different individuals who are part of the organisation. The main aspect that could be considered in this component is the organisational culture. According to Bertassini *et al. (*2021), organisational culture to support the transition to a circular economy consists of five building blocks- mindsets, values, behaviours, capabilities and competences. 'Work Process' relates to the operations of the organisation and how they are performed. It includes aspects related to the adaptability of the processes in place and its financial management. It also includes how strategies are devised and formed into work assignments. 'Structure' refers to the way the organisational structure is set up, the span of control of the roles and functions, accountability, and management practices to name a few. For changing to circular ways of functioning, organisations must also learn from the external environment. Absorbing technological

advancements, collaborating with external stakeholders, knowledge sharing and policy development are some crucial aspects of this component.

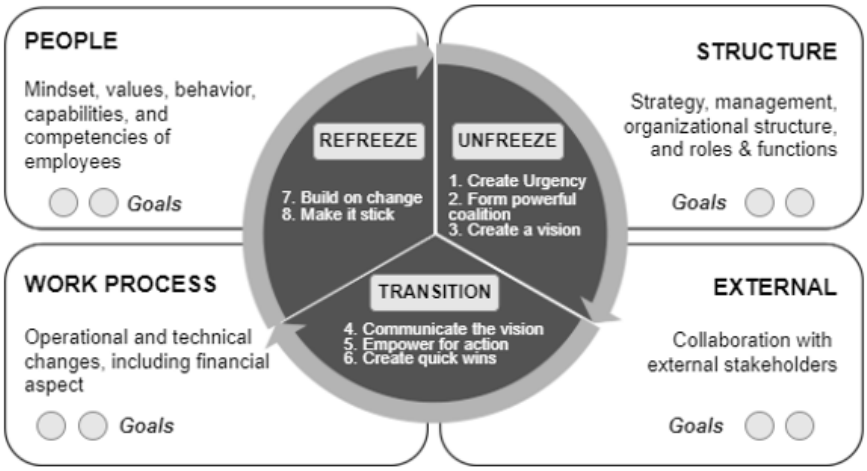


Figure 1: Theoretical framework showing the essential components for an effective organisational change framework (own work)

A critical gap in the existing literature was the absence of insights into the internal functioning of a 'circular' public organisation. It was thus necessary to identify a set of goals that define 'circular' functioning and communicate the desired state of functioning of the organisation post-change. Defining these goals, in turn, would help identifying the procedural changes required to achieve the desired organisational state. A literature review was conducted to identify relevant goals, resulting in the selection of eight goals across four change aspects. These goals were derived from academic sources on general circular business transitions and a review of documents from the Union of Water Boards.

Table 1: Desired goals for a 'circular' organisation for each change aspect

Goal	Literature	Interviewees
People		
i. Exhibit a supportive and shared mindset	(1) (2) (3)	A2, A4, A5
ii. Possess capacity essential for transition	(3) (4)	A1
iii. Institute a culture for innovations		
Work Process		
i. Make decisions using value cases in place of business cases	(3) (11)	
ii. Have redesigned processes that incorporate circular practices	(5) (6)	
Structure		
i. Improved intra-organisational collaboration and accountability	(5) (7) (1) (8)	A2,B2
ii. Ensure managerial commitment (leadership and political)		
External		
i. Establish best practices in knowledge sharing	(3) (10)	
ii. Effectively collaborate with external stakeholders	(3) (9)(10)	

von Kolpinski et al., (2023), Diercks et al., (2023), (3) Unie van Waterschappen (2021), (4) Bertassini et al., (2021), (5) Graessler et al., (2024), (6) Barros et al., (2021), (7) Hofmann and Jaeger-Erben (2020), (8) Unal et al., (2019), (9) Salvioni and Almici (2020), (10) Jäger-Roschko and Petersen (2022), (11) Hoogheemraadschap van Delfland (2022)

Subsequently, case study interviews were conducted to validate these goals within the context of public organisations. This validation process assessed their applicability, leading to the identification of additional goals and modifications to the initial set, as detailed in Table 1.

The interviewees pointed out common barriers and drivers for change. A main barrier is that a linear way of working is ingrained within the water boards' tasks. Tasks that have been performed for 40-50 years have undergone extensive optimisation in design and engineering to achieve maximum effectiveness. Another main barrier is the risk-averse nature of water board. The tasks of the water boards are crucial to keep the inhabitants safe. When new work processes are adopted to transition to circular practices, the effects of the changes are (partly) unknown. This includes aspects such as safety requirements, quality guarantees for circular products, availability of circular materials and components, and their costs. How employees manage these risks is crucial during transitions. The literature review identified eight goals across four key aspects of change, outlining how a 'circular' water board should ideally operate. Interviewees were asked whether they found these goals particularly necessary for accelerating the transition to circular practices. The interviewees acknowledged the importance of all eight goals in facilitating the organisation's transition to circular practices. Furthermore, they proposed additional goals and modifications to the existing ones.

Overall, the interviewees found it hard to clearly outline the steps for achieving each goal. This difficulty is likely because of the ongoing nature of circular economy transitions, which cannot yet be delineated as a straightforward, black-and-white blueprint. The impacts of different processes in these transitions are still unclear. Therefore, the key themes that emerged from interviews were analysed and classified into 'unfreeze-transition-refreeze' steps for each of the four change aspects.

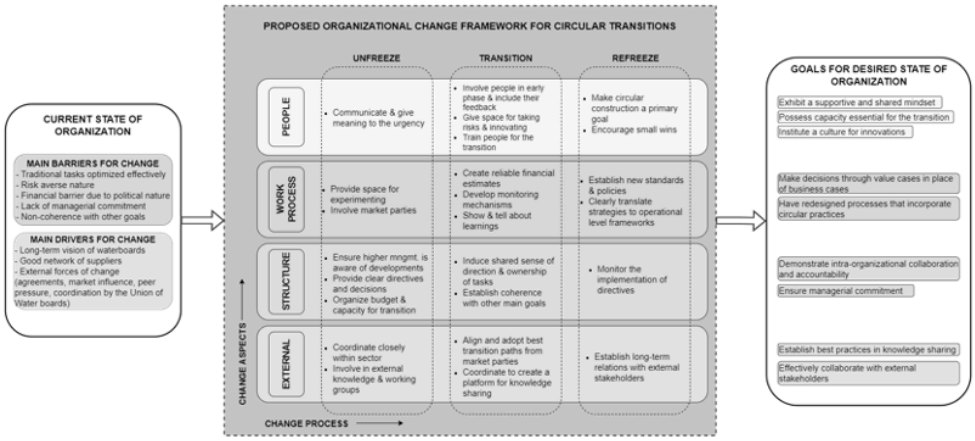


Figure 2: Organisational change framework for transition to circular construction practises (own work)

The validation process that followed confirmed the applicability of the identified themes and provided additional change measures. It also allowed for re-arranging identified measures within 'unfreeze-transition-refreeze' steps. The final change framework was developed by incorporating these changes for all four change aspects. See Figure 2. The change framework assists organisations to transition from its current linear working to a desired state of circular working by addressing the four key aspects. By including both the areas of change and the process for change, the framework becomes an effective tool to negotiate change.

CONCLUSIONS

The objective of this research was to develop measures for adjusting the internal functioning of public clients, such as Dutch regional water boards, to enable the

integration of circular construction practices in the management of their infrastructure assets. The proposed change framework outlines the internal organisational changes that public infrastructure clients like the water boards, can implement. These changes, if implemented proactively, are intended to facilitate the transition to circular infrastructure. The validation process, which included expert interviews, was crucial for confirming the initial findings and refining the framework, ensuring the proposed measures are both effective and feasible. This makes the framework a valuable tool for public construction clients.

The framework makes a significant scientific contribution by focusing on change management specifically for public construction clients aiming to transition to a circular economy, a focus that is absent in existing change management models. The study's focus on organisational change aspects that can be integrated into the daily operations of water boards makes it particularly novel. Internal organisational dynamics of circular economy transitions for public clients have been less explored but are now recognised as a high-priority issue. This framework provides a structured approach to navigating these organisational complexities.

It is recommended that the change measures specified for the four areas within the organisation be proactively implemented by change managers, programme managers, and/or the lead sustainability team. The framework enables them to adopt change measures to meet the specific needs of their organisational environment by considering the most significant barriers faced by their team or organisation.

Traditionally, water boards focus on technical solutions for issues due to their technical nature. However, further technical advancements in circular transitions are already possible than what is currently incorporated in the water boards. Therefore, water boards should emphasize managerial and organisational strategies to overcome human barriers to transition. The framework's change measures support this shift.

This study has certain limitations that should be acknowledged. The proposed framework has been developed and evaluated within the context of water boards, and its applicability to other public organisations remains untested. Further research is necessary to assess its relevance across different institutional settings, considering potential contextual differences.

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PRIORITISING SUSTAINABLE AND LOW-CARBON TRANSPORT INDICATORS IN INFRASTRUCTURE TRANSITION USING PAIRWISE COMPARISONS

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Renewing transport infrastructure for net-zero emissions is a critical priority that requires aligning emission reduction targets with broader sustainability objectives; however, this alignment involves navigating potential trade-offs between the two. This study employs pairwise comparisons within the Analytical Hierarchy Process (AHP) as a research method to explore how the selected transport indicators are relatively prioritised by experts under two decision contexts: Achieving sustainable transport and pursuing decarbonisation. Insights were gathered from 20 professionals across urban planning, public transport operations, infrastructure development, and academia, ensuring a diverse and cross-sectoral perspective. Results reveal context-sensitive shifts in priorities: indicators such as 'social equity' and 'accessibility' were prioritised under sustainable transport, while 'energy-transport' and 'planning' gained prominence under the decarbonisation context. Subgroup analysis of public transport providers and infrastructure planners further highlighted variations in prioritisation. Findings were interpreted within the AHP framework and mapped against SDG-linked principles. The study offers actionable insights to guide low-carbon infrastructure transitions aligned with regenerative urban futures and inform strategies influencing the construction sector and built environment.

Keywords: Analytical Hierarchy Process; decarbonisation; low-carbon transport; sustainable transport; sustainability indicators

INTRODUCTION

Building regenerative cities requires reimagining transport infrastructure not merely as a means of mobility, but as a catalyst for environmental restoration, social inclusion, and long-term urban resilience. This transformation involves shifting away from fossil fuel-reliant systems towards sustainable, equitable, and low-carbon transportation networks. The global transition to sustainable and low-carbon transportation systems has become a pressing priority as the sector is a major contributor to greenhouse gas emissions, accounting for approximately 24% of global CO2 emissions (IEA, 2021). Sustainable transport and decarbonisation of transport are often seen as complementary intentions, but can, at times, produce tensions if pursued in isolation (Almeida and García-Sánches, 2017). While decarbonisation focuses primarily on reducing greenhouse gas emissions, typically through electrification, fuel shifts, and energy efficiency, sustainable transport encompasses

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broader social, environmental, and institutional objectives such as accessibility, equity, safety, and resilience (United Nations, 2015). The Intergovernmental Panel on Climate Change (IPCC)'s Sixth Assessment Report (2022) highlights that although climate mitigation is essential, it must be pursued in a way that strengthens, rather than undermines, sustainable development goals, noting that "synergies and trade-offs between mitigation and the SDGs are context-specific and highly scale-dependent" (IPCC, 2022; Ch 7). When decarbonisation efforts disregard social and equity concerns, they risk entrenching disparities or producing unintended consequences such as reduced accessibility or affordability for vulnerable groups (Creutzig *et al.,* 2015; Soergel *et al.,* 2021; SLoCaT, 2021). Kostetckaia and Hametner, (2022) also highlight those countries experiencing significant trade-offs often struggle to advance SDGs, stressing the need for integrated policy approaches.

The process of "Pairwise Comparison" is a key foundation of the Analytical Hierarchy Process (AHP), a multi-criteria decision-making method developed by Saaty, (1980) to derive priority weights by evaluating criteria relative to one another. Using Saaty's 1-9 scale, experts assess indicators two at a time within a defined decision context. These judgments are then synthesized to calculate weights, enabling a transparent, expert-informed ranking of factors. A key feature is the Consistency Ratio (CR), which evaluates the coherence of judgments, with a CR below 0.1 indicating acceptable consistency (Saaty, 1990)

While AHP has been applied in infrastructure planning to support sustainability assessments particularly in developing contexts (for example, Abou-Shady and El-Sawy, 2013; Abdullah and Pang, 2016), this study does not adopt AHP as a prescriptive tool for planning or policy formulation. Rather, Pairwise Comparison is used here as a structured method for eliciting expert judgments on the relative importance of transport indicators under different strategic goals. Kraus, (2021) confirms that integrating sustainability criteria into transport decision-making improves alignment with broader development objectives.

While studies propose SDG integration across various sectors, a critical evaluation of the synergies and trade-offs in transport decarbonisation is lacking (Sabet and Farooq, 2025). Despite vast research in the field of transportation, the literature reveals a limited exploration of how prioritisation shifts when the focus transitions from broad sustainability goals to specific decarbonisation targets. This study addresses this gap by asking the research question: How does the prioritisation of key indicators differ when transport planning shifts from a sustainability-oriented agenda to a decarbonisation-focused one?

Contribution of the work is twofold: field and practice. It is intended to advance the understanding of decision making in transport planning and the tensions between the climate and sustainable goals. In practice, the study's insights will guide decision makers in planning for low carbon infrastructure delivery, which is a core component of the construction sector.

METHOD

A set of indicators from our unpublished work presented in Table 1 has been adopted for this study. These indicators have been selected following systematic literature review to assess decarbonisation of transport with Sustainable Development Goals at the core. As previously introduced, pairwise comparisons and AHP weights were used to analyse expert prioritisation of transport indicators while aiming for broad

goals of sustainability and decarbonisation. Expert responses for pairwise comparisons were collected using AHP-OS (Goepel, 2018), an open-access online tool chosen for its convenience and efficiency.

Key transport stakeholders were selected through purposive sampling to ensure relevant expertise in the prioritisation process. Participants were recruited in two phases: initially through snowball sampling, which yielded ten responses, followed by targeted LinkedIn outreach to expand the sample. In total, 20 transport experts were engaged, representing four key sectors: planning consultancies (30%), public transport operators (30%), infrastructure development authorities (25%), and academia/research/NGOs (15%). Participants were primarily based in Central Scotland and Southeast England, with additional representation from the East and Southwest of England. Their professional roles ranged from planners, engineers, and managers to directors and professors.

Participants were provided with the project context, a codebook of terms, and a consent form. Upon confirming participation, meetings were scheduled, and the AHP-OS web tool was used to collect pairwise comparisons. Experts assessed the relative importance of indicator pairs under two distinct decision contexts: (1) Sustainable Transport (ST) and (2) Decarbonisation of Transport (DT).

Table 1: Quadrants and list of indicators derived from Systematic literature review. SDGs (with indicative name of the goal) that are influenced by the performance of transport infrastructure

Quadrant	Indicators	Indicator codes	SDGs Impacted
Equitability	Accessibility	E1	SDG 1(Poverty), 2(Hunger), 4(Education) and 11(Cities)
	Social equity	E2	SDG 4,5(Equality), 8(Jobs and Growth) and 16(Institutions)
Health	Road safety	H1	SDG 3(Health) &11
	Health and well-being	H2	SDG 3, 4 and 11
	Efficiency of public transit	H3	SDG 11
	Walking and cycling	H4	SDG 11
Greener Thinking	Energy-transport	G1	SDG 7(Clean Energy)
	Planning	G2	SDG 8, 12(Consumption)&13(Climate)
	Traffic conditions	G3	SDG11
	Economic aspects	G4	SDG 8
Resilience	Robustness	R1	SDG 1, 9(Infrastructure) and 11
	Redundancy	R2	SDG 13
	Response time	R3	SDG 13

The Relative importance of quadrants and indicators was assessed through pairwise comparisons, and weights were calculated using the Weighted Geometric Mean Aggregation of Individual Judgments (WGM-AIJ). Each criterion was assigned a normalised priority weight (summing to 1), representing its proportional importance. Higher scores indicate greater relevance in the decision context, while lower scores reflect lesser priority.

FINDINGS AND DISCUSSION

The indicator prioritisation results are presented separately for the ST and DT scenarios, reflecting the unique emphasis and trade-offs under each goal. To support this, two distinct AHP decision structures were developed to independently capture expert judgments within each scenario. Figure 1 and Figure 2 represents the decision structure used to prioritise indicators under the ST and DT contexts respectively.

Figure 1: AHP Hierarchy for Sustainable Transport (ST) Goals

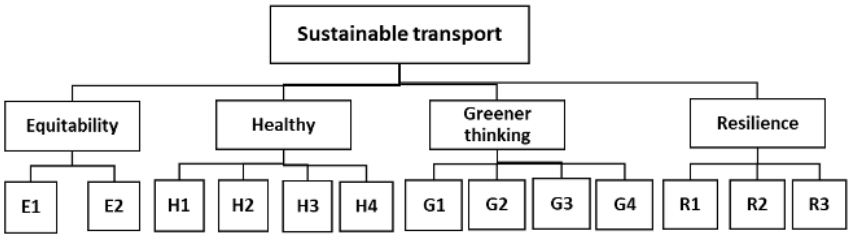
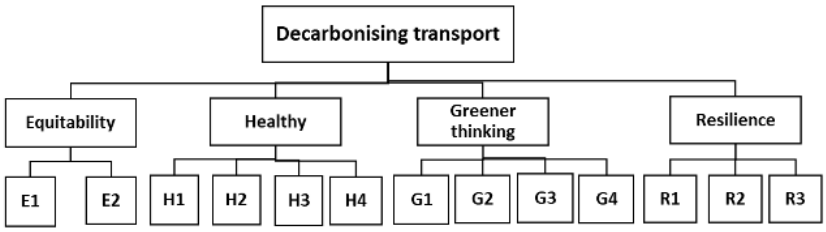


Figure 2: AHP Hierarchy for Decarbonisation of Transport (DT) Goals



Group results - Top Ranked Indicators for Each Context

Table 2 presents the aggregated AHP weights for each quadrant, highlighting how expert priorities shift between the goals of sustainable transport and decarbonisation, while health-related outcomes remained consistently important in both contexts, the relative weight of Greener Thinking increased (from 0.261 to 0.331) and Equitability declined (from 0.210 to 0.159) under DT, indicating a potential trade-off between environmental ambitions and social inclusion. Table 3 displays AHP-

derived weights and ranks for individual indicators within each strategic quadrant, further illustrating how expert prioritisation differs across the two scenarios.

Table 2: Comparison of Quadrant-Level Priorities under Sustainable Transport (ST) and Decarbonisation Transport (DT) Goals

Quadrant	Weight (ST)	Weight (DT)	Change
Equitability	0.210	0.159	▼ Reduced emphasis in DT
Healthy	0.289	0.299	▲ Consistently high
Greener Thinking	0.261	0.331	▲ Increased emphasis in DT
Resilience	0.241	0.211	▼ Slight decline

Key Indicators: Robustness (0.114), Accessibility (0.112), and Social Equity (0.098). These indicators emphasize the importance of resilience, ease of access, and equity in creating a sustainable transport system aligned with SDG goals, reflecting a holistic approach that incorporates social and infrastructural robustness.

Priorities under context 2: For Decarbonisation of Transport

Key Indicators: Planning (0.109), Walking and Cycling (0.097), and Energy-Transport (0.097).

The emphasis here is on forward-looking planning and encouraging active, low-carbon modes of transport, such as walking and cycling, which reduce emissions directly and encourage clean energy usage and efficiency.

Table 3: Indicator-Level Weighting and Ranking Shifts between Sustainable Transport (ST) and Decarbonisation Transport (DT) Goals

Quadrant	Indicators	ST Group result	Rank	DT Group result	Rank	Change in ranking
Equitability	Accessibility (E1)	0.112	2	0.079	7	▼ Decline
	Social Equity (E2)	0.098	3	0.080	6	▼ Decline
Healthy	Road Safety (H1)	0.049	12	0.048	13	≈ No Change
	Health and well-being (H2)	0.078	6	0.081	5	≈ Slight Increase
	Efficiency of public transit (H3)	0.076	8	0.072	8	≈ No Change
	Walking and cycling (H4)	0.087	5	0.097	2	▲ Moderate Increase
Greener Thinking	Energy-transport (G1)	0.053	10	0.096	3	▲ Sharp Increase
	Planning (G2)	0.092	4	0.109	1	▲ Major Increase
	Traffic conditions (G3)	0.048	13	0.060	11	▲ Slight Increase
	Economic aspects (G4)	0.068	9	0.065	10	≈ Slight Decline
Resilience	Robustness (R1)	0.114	1	0.090	4	▼ Decline
	Redundancy (R2)	0.076	7	0.070	9	▼ Slight Decline
	Response time (R3)	0.051	11	0.051	12	≈ No Change

Priorities under context 1: Sustainable Transport

Validation and Sensitivity analysis

All pairwise comparison matrices had consistency ratios below the accepted 10% threshold, confirming the logical coherence and reliability of expert judgments in line with AHP's theoretical framework.

A dynamic sensitivity analysis was done and visualised the ranking shifts between the ST and DT perspectives as shown in Figure 3. Positive values represent indicators gaining importance under the decarbonisation lens, while negative values indicate reduced prioritisation, highlighting the nuanced trade-offs and synergies between the two policy goals.

Trade-offs Between Accessibility, Social Equity, and Decarbonisation

The findings suggest a clear trade-off between equity and access in decarbonisation strategies. In ST prioritisation, accessibility ranked second, but in DT, it dropped to seventh place. Similarly, social equity, which held the third position in ST, fell to sixth place in DT. These shifts indicate that while decarbonisation strategies focus on reducing emissions, they may overlook crucial social factors such as accessibility and equity. The pursuit of low-carbon transport must not compromise accessibility, as this can deepen existing inequalities by limiting economic opportunities for marginalised communities. Evidence from Pönkänen *et al. (*2025) shows that transport systems often favour wealthier populations, reinforcing socio-economic disparities. To prevent this, decarbonisation strategies must ensure reliable and affordable mobility for transit-dependent communities.

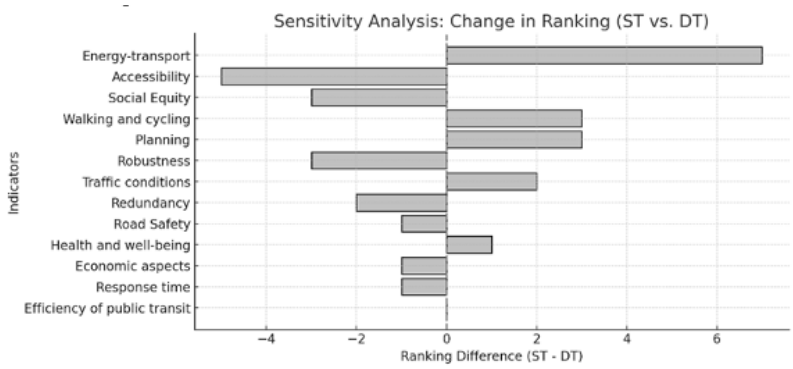


Figure 3: Sensitivity analysis of indicator ranking among context 1 (Sustainable transport) concerning context 2 (Decarbonising transport)

The Role of Planning in Achieving Decarbonisation Goals

Planning plays a crucial role in enabling decarbonisation, ranking first in the DT context with an 18.5% increase in score compared to ST. This highlights the importance of strong urban and transport planning in achieving decarbonisation.

Integrating land-use planning with transport policies ensures emission reductions without sacrificing accessibility. Czepkiewicz *et al. (*2024) highlight how urban density and land-use policies play a critical role in reducing transport emissions, reinforcing the need for integrated strategies. Policies that promote compact, walkable cities with accessible transit options can enhance both environmental and social sustainability.

Prioritising Active Mobility for Decarbonisation

The results show that 'walking and cycling' have gained greater prominence in DT, rising from the fifth position in ST to the second position in DT. This shift reflects the growing recognition of active mobility in reducing transport emissions. Encouraging walking and cycling not only lowers emissions but also offers public health benefits and well-being.

Pedestrian-friendly design, extensive cycling networks, and mixed-use developments encourage short-distance travel. Expanding shared micro-mobility options like bike-sharing can further support decarbonisation, but equitable access across all socio-economic groups is crucial.

Categorising participants under public transport providers and planners and advisors

For this AHP analysis, experts were initially selected for their broad transport-related expertise rather than specific roles. However, a post-hoc categorisation into public transit providers and other transport infrastructure planners was carried out to explore potential differences in prioritisation. While not part of the original sampling strategy and not statistically conclusive, this grouping provided useful qualitative insights into varying expert perspectives.

Context 1: Sustainable Transport Priorities

Key Priorities

Public Transport Providers Prioritise robustness (18.9%), accessibility (10%), and efficiency (9.1%). This indicates a continued focus on system reliability, while also increasing the emphasis on accessibility for diverse users.

Planners and advisors on accessibility (11.7%), planning (11.3%), and social equity (9.5%). Compared to decarbonisation, sustainable transport places greater importance on accessibility and equity.

Context 2: Decarbonising Transport Priorities

Key Priorities
Public Transport Providers emphasize system robustness (15.2%), redundancy (9.6%), and efficiency of public transit (9.5%). These indicators reflect a strong focus on ensuring a reliable transit network that can withstand disruptions and operate efficiently with minimal energy waste.

Planners and advisors Prioritise planning, energy-transport, and walking/cycling. Planning (17.5%) has the highest weight showing the importance of long-term strategies for decarbonisation. Energy-transport (13.1%) suggests an active shift toward cleaner transportation technologies and policies.

Comparative Analysis: Public Transport Providers vs. Planners

Planning vs Robustness
The strategic vs. operational divide remains evident. Planners rank indicators planning and energy transport highest, advocating for transformative, long-term infrastructure strategies. Meanwhile, Public Transit providers emphasize robustness and redundancy, highlighting concerns over day-to-day operational reliability.

Accessibility and Walking/cycling
Interestingly, both groups rank accessibility and walking/cycling in the top five priorities, reflecting a shared recognition of active transport's role in urban sustainability.

Social equity
It is recognised by both groups but is ranked higher by planners. This indicates that planners place greater emphasis on a policy-driven orientation towards inclusivity, whereas transit operators focus more on maintaining functional reliability.

RECOMMENDATIONS

Based on these findings, the following policy recommendations aim to maximise the synergies between sustainability and decarbonisation while mitigating potential trade-offs

Promote Inclusive Low-Carbon Transport Systems
One key finding is the potential trade-off between emissions reduction and accessibility. While decarbonisation is vital, low-carbon systems must remain accessible and affordable for everyone.

Subsidising low-carbon public transport options: This supports SDG10.2 by ensuring that vulnerable population can access affordable and sustainable transport options. Research by Serebrisky *et al. (*2009), and Bongardt *et al. (*2010) note that well-designed subsidies help reduce financial barriers, though their effectiveness depends on careful policy design.

Investing in infrastructure for active transport modes: Bakker *et al. (*2019) emphasize that integrating bike lanes and pedestrian pathways into urban planning enhances both affordability and sustainability aligning with SDG 11.7 and SDG 3.4. Public transport integration with active mobility infrastructure creates equitable and multimodal systems.

Enhancing public transit systems: Improving the reliability and convenience of public transit systems ensures they serve as a viable, low-carbon alternative to private vehicles (Arsenio *et al.,* 2016) contributing to SDG9.

Fostering Synergies Between Energy Efficiency and Decarbonisation
The analysis showed that Energy-Transport efficiency is a key indicator for both sustainable and low-carbon transport. Improving energy efficiency in transport along with Electric vehicle promotion is crucial for achieving decarbonisation and cost savings. Key strategies include:

Encouraging Modal Shifts: Policies like congestion pricing and low-emission zones can shift reliance from cars to public transit, cycling, or walking, aligning with SDGs 11.2 and 13.

Public-Private Partnerships: Collaboration with private sectors can drive investment in energy-efficient technologies, supporting innovations necessary for clean transport and advancing SDG 9.

Integrating Equity into Decarbonisation Policies
Decarbonisation often overlooks equity, necessitating inclusive policy design:
Participatory Planning: Involving marginalised groups in transport policy development ensures inclusive low-carbon systems, supporting SDGs 16 and 10.

Equity-Focused Subsidies: To counteract the disproportionate impacts of carbon taxes on low-income populations, targeted subsidies for public transit and EVs are essential, aligning with SDGs 1 and 10.

Expanding Access: Investing in transport infrastructure for rural and suburban areas promotes social equity, supporting SDG 11.

Adopting a Holistic Transport Policy Approach
To address complex interactions in transport policies:

Long-Term Prioritisation: Prioritise sustainability over immediate cost savings for substantial emissions and health benefits.

Integrated Policies: Align transport with urban planning to reduce commutes and support public transit access, furthering SDG 11.

Cross-Sector Collaboration: Ensure transport policies align with climate goals through collaboration across transport, energy, urban planning, and finance sectors

CONCLUSIONS

This study provides a structured analysis of transport decarbonisation priorities by leveraging pair wise comparisons and AHP weights to capture expert perspectives on key transport indicators. The findings highlight critical trade-offs and synergies among transport planning priorities, revealing that while social equity and accessibility are central to sustainable transport objectives, energy-transport considerations receive lower prioritisation in this context. In contrast, when the focus shifts to decarbonisation, significant sectoral discrepancies emerge, with public transport providers emphasising resilience and efficiency over vehicle transition, whereas other transport infrastructure planners Prioritise energy transition.

By examining these trade-offs, the study highlights the complex relationship between decarbonisation efforts and Sustainable Development Goals (SDGs). Notably, accessibility and social equity indicators align with SDGs related to poverty reduction,

quality education, and sustainable cities, whereas energy transition and efficiency strategies align more closely with climate action and economic growth objectives. These insights reinforce the importance of integrated policy approaches that balance environmental, social, and economic considerations in transport decarbonisation strategies. By identifying key decision-making patterns and sectoral perspectives, this study enhances understanding and provides valuable guidance on alignment of decarbonising efforts with broader sustainability goals and infrastructure planning. The findings suggest important downstream implications for the construction sector, as shifts in transport priorities influence investment toward sustainable and resilient building practices.

To acknowledge the limitations of any study is important to ensure a reasonable interpretation of the findings. First, expert judgments for pairwise comparisons, introducing subjectivity and potential biases based on individual backgrounds, policy orientations, and sectoral priorities. Although the method ensures structured decision-making, the ranking of indicators may still reflect personal or institutional perspectives. Second, the sample size of prioritisation is relatively small, though from broad expert base offers a holistic perspective, yet a more specialised expert group could enhance certainty in sector-specific insights. Future research could explore larger sample sizes, comparative regional analyses, or develop sector-specific models where expert selection is stratified by transport mode to ensure context-relevant policy recommendations. AHP assumes that decision criteria(indicators) are independent, it may oversimplify the interdependencies among transport sectors. Hence future studies could integrate AHP with the Analytic Network Process (ANP) to capture the interconnected dynamics.

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DEVELOPING A CONCEPTUAL FRAMEWORK TO EMBED THE SOCIAL COST OF CARBON IN COST ESTIMATION FOR COMMERCIAL BUILDINGS

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Cost estimation for commercial buildings predominantly focuses on financial metrics, neglecting societal impacts of carbon emissions. The Social Cost of Carbon (SCC), monetising long-term damage of carbon dioxides, offers a mechanism to integrate environmental and social externalities. This study develops a conceptual framework for embedding SCC into building cost estimation. A critical review of 23 academic studies and 8 semi-structured interviews with sustainability consultants, cost managers, policymakers are conducted. Findings reveal 3 primary carbon cost drivers from literature and 4 key integration themes from industry, the need for granular carbon data, stakeholder interest alignment, supportive policy incentives, and tools compatible with existing cost software. The proposed framework integrates SCC throughout the building lifecycle, from feasibility and design to procurement and operation, expanding Whole Life Costing to incorporate societal costs. This enables cost professionals to account for long-term climate and social impacts alongside traditional expenditure. Future research should pilot the framework and develop digital tools (e.g., BIM-based platforms) For SCC-informed decision-making.

Keywords: social cost of carbon; cost estimation; commercial buildings; sustainability; whole life costing

INTRODUCTION

The commercial building sector is under growing pressure to address not only the environmental consequences of construction (e.g., greenhouse gas emissions) But also the social impacts of buildings on communities and public well-being. Buildings are responsible for nearly 40% of global energy-related carbon dioxide emissions (Gao *et al.,* 2023; Myint *et al.,* 2025), contributing significantly to climate change. At the same time, construction activities and building operations affect public health, safety, and social equity - for instance through air pollution, resource depletion, and community disruption (Lu *et al.,* 2020). These externalities impose monetised societal damage that is usually borne by society at large rather than by project proponents. The Social Cost of Carbon is a financial estimate of the long-term harm caused by emitting one extra tonne of carbon dioxide into the atmosphere. It represents the monetary value of future damages to society, such as negative impacts on public health, farming, and infrastructure, for every additional tonne of CO_2 released. Unlike

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conventional market-based carbon prices, e.g., carbon taxes or emission trading permit prices, SCC attempts to quantify all externalities borne by society, such as the cost of climate-related disasters or health care burdens from pollution (Rennert *et al.,* 2022). Department for Energy Security and Net Zero publish carbon valuation guidelines for UK government policy appraisal that SCC is used in cost-benefit analyses to inform regulations (Rennert *et al.,* 2022); however, it remains contentious due to uncertainties in climate-economic models, e.g., discount rates, damage functions, and ethical debates about intergenerational impacts (Khabarov *et al.,* 2020; Dong *et al.,* 2024). Notwithstanding these debates, SCC provides a useful framework to evaluate the broader societal costs of emissions in monetary terms, effectively translating environmental and social harm into project-relevant cost figures.

Traditionally, cost estimation in commercial building projects has focused on capital expenditure and straightforward lifecycle costs including maintenance, operation, disposal, emphasising the financial viability of projects. Standards like Publicly Available Specification (PAS) 2080 and International Organisation for Standardisation (ISO) 14000 promote sustainability considerations, but their influence on everyday cost planning has been fragmented and indirect (Huang *et al.,* 2018; Cui *et al.,* 2019). As a result, early project decisions often omit the full spectrum of carbon costs, leading to suboptimal choices that perpetuate environmental damage and social harm (Othman and Mohamed, 2016). For example, a design alternative with lower upfront cost may incur higher emissions and future societal costs yet be favoured if those external costs are invisible in the budget. This gap between sustainability goals and cost methods means that the true societal impact of design and material choices is rarely factored into business cases. Even Whole Life Costing (WLC) Frameworks, which attempt to account for costs over a building's life, seldom quantify societal externalities like public health effects or climate damages (Wong, 2010; Tokede *et al.,* 2013). There is a clear need to bridge conventional cost estimation with sustainability metrics so that decisions at the planning and design stages internalise carbon emission costs (Wu *et al.,* 2021). In other words, cost models must evolve to explicitly include the SCC, effectively embedding monetised environmental and social impacts into project appraisal.

This paper addresses the above gap by developing a conceptual framework that embeds the SCC into cost estimation practices for commercial buildings. The research is guided by the following objectives: (1) Identify key cost drivers across a building's lifecycle that significantly contribute to carbon-related societal costs; (2) Explore industry perspectives on the challenges and enablers of integrating SCC into current cost estimation through expert interviews; and (3) Formulate a practical framework that links these cost drivers and industry insights, operationalising SCC inclusion at each project stage. By clearly defining these objectives, we focus the study on both the technical factors from literature and the stakeholder/context factors from practice needed to incorporate SCC. In pursuing these objectives, the study aims to demonstrate how expanding cost estimation to include monetised societal damage can encourage more sustainable decision-making in building projects.

LITERATURE REVIEW

Efforts to integrate sustainability into construction cost management reveal limitations in existing approaches, particularly the neglect of broader societal costs like carbon emissions. Traditional cost estimation focuses on direct financial costs, overlooking environmental degradation and social impacts (Sadliwala and Gogate, 2022;

Samarasekara *et al.,* 2024). Although frameworks like Whole Life Costing and Lifecycle Costing extend beyond initial capital expenditure, they rarely monetise societal externalities such as climate damage or public health effects (Wong, 2010; Tokede *et al.,* 2013).

Consequently, sustainable initiatives struggle to justify green choices economically. SCC, originating from environmental economics, addresses this by assigning monetary value to comprehensive carbon damage, encompassing infrastructure risks, agricultural losses, ecosystem degradation, and health impacts (Ackerman and Stanton, 2010; Livermore, 2016). Despite its policy use, SCC adoption in construction faces challenges: complex valuation debates, e.g., discount rates, climate sensitivity; Khabarov *et al.,* 2020, lack of sector-specific data (Wu *et al.,* 2021), and stakeholder misalignment favouring short-term budgets over long-term liabilities (Kamaruddin *et al.,* 2024; Kolk and Pinkse, 2006). Practitioners often perceive SCC as an added complication without mandates (Kita, 2017).

Nevertheless, integrating SCC holds promise for driving low-carbon innovation, offering holistic externality valuation beyond direct carbon pricing. Recent advances, such as OpenBIM tools for monetary carbon assessment (Lu and Deng, 2023) And multi-stakeholder frameworks (Wu *et al.,* 2021), demonstrate growing efforts to quantify sustainability within cost models. The literature thus identifies a clear gap between conventional cost estimation and carbon accountability, motivating this research to bridge financial metrics with societal impacts through a unified SCC framework.

METHODS

This study employed a qualitative mixed-methods approach, combining a critical review with thematic analysis of expert interviews, to triangulate theoretical and practical insights for robust framework development. A critical review of 23 academic publications (2010-2024) Sourced from Scopus and Web of Science identified key carbon cost drivers and SCC integration methods. Selection criteria prioritised studies on lifecycle carbon accounting, SCC valuation, sustainable cost methods, and building WLC. Publications like Wong (2010) And Plebankiewicz *et al. (*2019) Provided foundational concepts, with analysis synthesising insights across construction management, environmental economics, and sustainability science. This yielded initial cost drivers for framework development.

Complementing this, semi-structured interviews were conducted with eight UK-based professionals, e.g., sustainability consultants, cost managers, policymakers, selected via purposive sampling to capture diverse stakeholder perspectives in commercial building projects. Interviews, lasting 45-60 minutes, explored current cost practices, SCC awareness, and integration barriers. Saturation was achieved by the eighth interview. To transform this rich interview data into substantive findings, the verbatim transcripts were subjected to a rigorous thematic analysis using NVivo software. The process began with open coding, where foundational concepts were identified directly from the practitioners' narratives, such as the recurring challenge of "data availability." Through an iterative analytical process, these initial concepts were then compared and grouped to build robust, higher-order themes. For example, concepts like "data availability" and "data security" were consolidated into the overarching theme of " data granularity". This systematic approach ensured that the core findings presented in this study are directly and demonstrably grounded in the expressed experiences and perspectives of the participants. Trustworthiness was

ensured through researcher cross-checking and disconfirming evidence consideration. Integrating literature-derived drivers and interview themes enabled the development of a theoretically grounded, practically relevant SCC integration framework.

RESULTS

Key Carbon Cost Drivers from Literature

The critical review identified three primary cost drivers significantly determining a commercial building's carbon footprint and associated societal costs over its lifecycle: (1) Embodied carbon in materials production, (2) Operational energy consumption, and (3) End-of-life decommissioning emissions. These drivers represent the largest contributors to a building's total carbon emissions and thus its monetised societal impact, making their integration crucial for effective SCC application in cost estimation (Lu *et al.,* 2023; Plebankiewicz *et al.,* 2019). The proposed framework explicitly centres on these drivers, mapping each to relevant project lifecycle stages and specific cost-estimating relationships (CERs) That incorporate SCC to translate carbon impacts into monetary terms. Figure 1 presents a novel conceptual framework designed to embed carbon cost considerations directly into the building lifecycle. It aligns with Royal Institute of British Architects (RIBA) Plan of Work, a definitive model for the design and construction process of buildings. It illustrates how three principal carbon cost drivers intersect with critical project stages, including Feasibility (RIBA 1-2), Design Development (RIBA 3-4), Procurement (RIBA 4-5), and Operational Planning (RIBA 6-7). However, cross-cutting dimensions of Data Transparency and Stakeholder Engagement are essential supports for successfully managing a project's whole-life carbon impact.



Figure 1: Main structure of the SCC-integrated cost estimation framework

In detail, Feasibility (RIBA 1-2) Establishes a project's viability and strategic brief, setting the foundational carbon footprint for the building's entire lifecycle. Design Development (RIBA 3-4) Refines the concept into a detailed technical design, making critical decisions on materials and systems that determine the building's final embodied and operational carbon performance. Procurement (RIBA 4-5) Involves appointing a contractor to construct the building, providing a crucial opportunity to enforce carbon reduction targets through contractual agreements and partner selection. Operational Planning (RIBA 6-7) Prepares for the building's handover and long-term use, establishing the management and monitoring strategies essential for achieving its designed energy performance throughout its life.

Table 1 details the framework for embedding the Social Cost of Carbon (SCC) At each lifecycle stage, augmenting traditional cost processes with specific actions or cost-estimating relationships (CERs).

Table 1: Breakdown of SCC integration across lifecycle stages in the conceptual framework

Project Stage	SCC Component	Further Task
Feasibility	Carbon Scenario Analysis	Estimate emissions for various site/design options; monetise using SCC values (Wu *et al.,* 2021).
	Site and Typology Comparison	Compare alternative locations and typologies with embodied emissions impact (Wu *et al.,* 2021).
	Carbon-Adjusted Financial Appraisal	Include SCC in financial appraisals and NPV modelling of lifetime project costs (Wu *et al.,* 2021).
Design Development	Material and Component Evaluation	Evaluate low-carbon material choices using embodied carbon and SCC metrics (Lu and Deng, 2023).
	Systems and Operational Strategy Analysis	Assess systems based on carbon-cost trade-offs; simulate energy performance (Lu and Deng, 2023).
	Iterative Design Feedback	Use SCC feedback to guide design decisions during early development stages (Wolf *et al.,* 2016).
Procurement	SCC-Integrated Tender Criteria	Integrate SCC into contractor selection and bid evaluation criteria (Xue *et al.,* 2018).
	Supplier and Manufacturer Declarations	Require EPDs and carbon costing from suppliers and manufacturers (Xue *et al.,* 2018).
	Contractual Mechanisms	Implement incentives or penalties tied to construction-phase emissions (Xue *et al.,* 2018).
Operational Planning	Long-Term Emissions Forecasting	Forecast emissions across asset life; inform energy and capital planning (Wolf *et al.,* 2016).
	Maintenance and Retrofit Planning	Plan for upgrades or replacements with SCC-informed decision tools (Wolf *et al.,* 2016).
	End-of-Life Emissions and Circularity	Include carbon value of demolition and promote reuse and recycling (Wolf *et al.,* 2016).
All Stages	Data Transparency and Documentation	Maintain traceability of SCC inputs via digital tools and documentation (Lu and Deng, 2023).
	Stakeholder Engagement	Align stakeholders on SCC importance through engagement and training (Kamaruddin *et al.,* 2024).
	Policy and Regulatory Integration	Integrate SCC with carbon pricing policies and building regulations (Kolk and Pinkse, 2006).

During the Feasibility (RIBA 1-2) Stage, carbon scenario analysis is used to estimate and monetise projected emissions from early design or site options, enabling comparisons based on societal carbon costs (Wu *et al.,* 2021). This includes evaluating the embodied carbon impacts of different sites or building typologies. Concurrently, carbon-adjusted financial appraisals integrate SCC into metrics like Net Present Value (NPV), explicitly factoring future carbon liabilities into investment evaluations (Wu *et al.,* 2021).

In the Design Development (RIBA 3-4) Stage, SCC is incorporated into material selection by adjusting purchase prices based on embodied carbon, facilitating comparisons between alternatives as formalised in Equation (1):

$$\text{Adjusted Unit Rate} = \text{Material Cost (£)} + (\text{Embodied Carbon (tonnes)} \times \text{SCC (£/tonne)}) \quad (1)$$

Analyses of systems and operational strategies also use SCC to assess long-term emissions from design options, guiding choices towards energy-efficient solutions.

This involves iterative feedback loops where designs are recalculated for lifecycle carbon impacts to ensure alignment with targets (Wolf *et al.,* 2016).

At the Procurement (RIBA 4-5) Stage, SCC is integrated into tender evaluation criteria, where proposals are assessed on both financial cost and anticipated construction-phase emissions (Xue *et al.,* 2018; Sloan *et al.,* 2014). Bids are evaluated to include societal carbon costs, calculated as a carbon liability using Equation (2):

$$\text{Carbon liability} = \text{SCC (£/tonne)} \times \text{Projected operational emissions (tonnes)} \quad (2)$$

Supply-chain transparency, through mandatory Environmental Product Declarations (EPDs), and contractual clauses with carbon-related incentives or penalties ensure robust data and accountability (Xue *et al.,* 2018).

During Operational Planning (RIBA 6-7), long-term operational emissions forecasts are informed by SCC to guide maintenance and retrofitting decisions, monetising the avoided societal costs of efficiency improvements (Wolf *et al.,* 2016). The end-of-life strategy also monetises the carbon implications of demolition and disposal. Factoring SCC into these decisions encourages designs that support material reuse and circular economy principles, with the end-of-life liability evaluated using Equation (3):

$$\text{End-of-life liability} = \text{SCC (£/tonne)} \times \text{Estimated end-of-life emissions (tonnes)} \quad (3)$$

Finally, two universal elements are critical. First, data transparency and documentation, requiring consistent carbon data and SCC values, often facilitated by digital platforms and robust local datasets. Second, stakeholder engagement and policy integration are essential to foster alignment among clients, contractors, and regulators. Communicating SCC's necessity, reinforced by mandates or policies, is crucial for effective adoption (Kamaruddin *et al.,* 2024; Kolk and Pinkse, 2006).

Themes from Expert Interviews

The expert interviews substantiated and enriched the framework by highlighting four key themes essential to effectively embedding SCC into cost estimation practices. These themes represent practical considerations crucial for the framework's successful implementation. The first theme identified was data granularity, emphasising the need for detailed, region-specific carbon data to reliably integrate SCC into cost estimation. Industry practitioners across sustainability consultancy and cost management roles highlighted the critical importance of accurate, localised datasets. For instance, a costing manager in the energy sector explained: "Developing the carbon cost estimation, you need to have a good database. If you don't have a good database, the indicators you use in the planning phase could be different from the reality in execution". This underscores the necessity of high-quality local carbon data as the foundation for credible SCC integration.

The second prominent theme, stakeholder alignment, pointed to the prevalent challenge of short-term financial considerations overshadowing long-term carbon liabilities. A professional in project controls within the infrastructure sector highlighted this tension, noting: "Most companies…look at it short term - what's this going to cost to build - and disregard the OpEx costs. Looking at whole life cycle costs is quite unusual". This observation illustrates a significant barrier: organisations' predominant short-term outlook conflicts with the long-term perspective required to

effectively integrate SCC. Achieving stakeholder alignment thus requires clearly communicating the value of incorporating SCC into long-term decision-making and proactively educating stakeholders on its benefits.

Regulatory drivers emerged as the third key theme, with interviewees stressing the crucial role external mandates or incentives play in facilitating SCC adoption. Interviewees from cost consultancy and project management backgrounds agreed that clear regulatory requirements or strong client-driven mandates are essential. A cost consultant emphasized their role's limitations, stating: "All we can do is price what we're asked to price… If we want to price in additional scope to make social value gains, we will do it because we are told to". Similarly, a project management expert pointed to the effectiveness of mandatory procurement requirements for carbon reporting: "In the bid process, you must provide [carbon impact] information. Then they have to do it... people who don't provide it will not be considered". These statements illustrate that explicit regulatory expectations are powerful motivators for incorporating carbon accountability into industry practices.

The final theme, tool interoperability, highlighted the necessity for integrating SCC calculations seamlessly into existing cost estimation tools and workflows. Cost consultants and sustainability professionals emphasized that effective implementation requires minimal disruption to established estimation practices. One expert, experienced in sustainability-focused cost planning, noted ongoing industry efforts to enhance compatibility with widely used estimation software: "We're working with [software] companies that have tried-and-tested systems and advising them on what we need… to move those systems forward". Another professional specialising in aviation cost planning described the technical feasibility enabled by structured data systems: "If the data's structured correctly, you can easily apply the carbon factor… a lot of it comes down to the structure of your data". These insights confirm that integrating carbon-cost calculation modules into familiar cost-estimation tools significantly enhances practicality and likelihood of adoption.

Collectively, these four themes, including granular data, stakeholder alignment, regulatory support, and tool compatibility, highlight critical factors determining the successful adoption of SCC methodologies. Addressing these aspects ensures the practical relevance and feasibility of the proposed SCC-integrated framework, bridging the gap between theoretical sustainability objectives and real-world cost management practices in construction.

DISCUSSION

Integrating SCC into building cost estimation bridges the critical gap between financial planning and environmental accountability. The framework quantitatively monetises carbon externalities within standard cost analysis, moving beyond traditional Whole Life Costing's qualitative treatment of environmental factors (Huang *et al.,* 2018; Wu *et al.,* 2021). This operationalises SCC into specific cost-estimating relationships, incentivising socially optimal choices alongside cost-effectiveness. Findings align with stakeholder and policy realities: cost professionals operate within client directives and market norms, perceiving SCC integration as a potential complication unless mandated or value-adding (Kita, 2017). The framework's success thus hinges on demonstrating value (e.g., life-cycle savings, risk reduction) And aligning with regulatory drivers. Policy mandates, such as emerging climate disclosure rules, are pivotal catalysts for adoption (Kamaruddin *et al.,* 2024;

Kolk and Pinkse, 2006). Robust methods like this framework can, in turn, support policymakers by demonstrating industry capability.

Data quality and tool interoperability are key implementation bottlenecks. While digital innovations like BIM facilitate embedding carbon values (Lu and Deng, 2023), data uncertainty, e.g., SCC value ranges, emission factors, remains a challenge. Transparency in reporting ranges and using uncertainty buffers is advocated to manage this (Dong *et al.,* 2024). Seamless integration with existing cost software and workflows is essential for practitioner uptake. Potential benefits include improved decision-making accounting for long-term risks and externalities, potentially revealing win-win scenarios where carbon efficiency aligns with cost efficiency (Porter's hypothesis). However, limitations exist: The framework's conceptual nature requires empirical validation; SCC values and impact factors evolve with science and policy (Rennert *et al.,* 2022); and it specifically targets carbon externalities, acknowledging that monetising other social impacts, e.g., community cohesion remains complex and outside its scope. Future research should pilot the framework in real projects, develop interoperable digital tools, explore sensitivity to SCC values, and consider integrating other environmental indicators.

CONCLUSIONS

This research developed a conceptual framework embedding the SCC into commercial building cost estimation across the lifecycle. It addresses the disconnect between financial decisions and the societal costs of carbon by monetising emissions. Key findings underpinning the framework are three primary carbon cost drivers including embodied emissions, operational energy, end-of-life emissions and four cross-cutting themes containing data granularity, stakeholder alignment, regulatory drivers, and tool interoperability. Expert interviews highlighted both challenges, e.g., prevalent short-termism and opportunities, e.g., data-driven win-wins (Kolk and Pinkse, 2006).

For practice, the framework provides cost consultants and project managers a structured method to quantify carbon impacts monetarily, enabling more sustainable decisions and clearer societal cost pictures. For policy and standards, it offers a template for operationalising carbon reporting or pricing within projects, potentially accelerating compliance with standards like PAS 2080. Limitations include the framework's conceptual stage, reliance on evolving SCC/data, its specific focus on carbon externalities and UK-centric interview insights. Future work must prioritise testing and refining the framework in real projects through pilot studies, developing user-friendly digital tools or plugins for seamless implementation, and maintaining updated regional carbon cost databases. Collaborating on standard SCC values for construction could enhance consistency. This framework provides a foundational step towards holistic cost models that integrate environmental and societal accountability into construction economics.

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THE ROLE OF DIGITAL TECHNOLOGIES IN ADVANCING CIRCULAR ECONOMY PRACTICES IN THE AUSTRALIAN CONSTRUCTION INDUSTRY

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The construction industry's ongoing environmental impact demands urgent improvement, driving a strong emphasis on adopting circular economy (CE) principles for their ecological benefits. There is a growing recognition of Digital Technologies (DTs) as facilitators of circular practices. However, the construction industry is known for its slow adoption of technology, primarily due to the resistance of professionals to change. Thus, this research investigates how professionals in the Australian construction and CE sectors perceive the role of DTs in enabling circular practices. Data from 16 semi-structured interviews were analysed using code-based content analysis with NVivo 15. The findings reveal nine key roles of DTs—including acting as guiding platforms, facilitating data collection, tracking materials, optimising design, reducing material usage, enabling material reuse, and improving material flow—supported by technologies such as AI, Additive Manufacturing, Big Data Analytics, BIM, GIS, Digital Twin, Blockchain, IoT, RFID, and Cloud Computing. The identified roles of DTs were mapped against existing CE barriers within the construction industry. This study demonstrates how DT solutions address key CE challenges and provide practical insights for construction stakeholders to advance circular initiatives.

Keywords: circular economy; construction industry; digital technologies; data management; material tracking

INTRODUCTION

The construction industry's resource-intensive operations harm the environment through high energy use, carbon emissions, resource depletion, and excessive waste (Ababio and Lu, 2023). Maintaining current practices risks compromising the environment's ability to support future generations and exacerbates existing environmental issues (Osei-Tutu *et al.,* 2023). The Linear Economy (LE) model in construction covers resource acquisition, material conversion, use, and disposal at End of Life (EOL) (Illankoon and Vithanage, 2023). However, it mainly focuses on material lifespan, often overlooking the post-consumption phase (Cimen, 2021). In contrast, the circular economy (CE) emphasizes maximising material flow and resource efficiency while reducing waste through modularity, regenerative systems, adaptability, reuse, recycling, remanufacturing, and designing for longevity (Ellen

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Macarthur Foundation 2012). The construction industry values the CE for its significant environmental benefits and potential (Pomponi and Moncaster 2017).

A smooth transition to CE depends on key enablers such as industry digitalisation, R&D, stakeholder education, regulatory support, and financial incentives (Shooshtarian *et al.,* 2023). In this context, the complex nature of construction projects, along with the demands of technology, legal frameworks, manufacturing procedures, service outsourcing, and supply chains, has led to the emergence of digital ecosystems (Kovacic, Honic and Sreckovic, 2020). These digital ecosystems have become essential enablers of cooperation, value creation, and the implementation of circular principles. Despite recognising the value of DTs for circular practices, the industry faces slow adoption, primarily due to professionals' resistance to change (Thirumal *et al.,* 2024a). There is growing interest in addressing the slow uptake of DTs in CE practices by grounding research in theories of technology and innovation. In particular, the Diffusion of Innovation (DoI) theory outlines five phases of adoption: knowledge, persuasion, decision, implementation, and confirmation. Specifically, knowledge of utilising DTs for CE practices acts as the precursor, followed by persuasion, where individuals form perceptions based on their understanding, ultimately leading to the decision to adopt or reject it (Thirumal *et al.,* 2024b). However, many studies overlook how such knowledge is reflected in professionals' perceptions, failing to capture nuanced industry perspectives. This slow uptake also raises critical questions about whether current digital solutions truly address the practical challenges of CE implementation. Existing research often overgeneralises the potential of DTs without linking them to specific CE barriers, with limited empirical evidence, especially in Australian construction, on how professionals perceive their role in overcoming these challenges. This study addresses that gap by exploring how industry professionals interpret and engage with DTs in the context of CE implementation.

LITERATURE REVIEW

The importance of DTs to CE adoption in construction projects

DTs are tools or systems that utilise digital processes to create, store, process, and communicate information, thereby enhancing and transforming human and industrial activities through digital data and computation (Puolitaival, Kestle, and Kähkönen, 2018, p. 254). The construction industry is gradually started to adopt DTs, including Geographic Information Systems (GIS), Radio Frequency Identification (RFID) (Yu *et al.,* 2022), Additive Manufacturing (AM), Cloud computing (CC) (Jemal *et al.,* 2023), Building Information Modelling (BIM), Artificial Intelligence (AI), Big data analytics (BDA), Blockchain (BCT), Internet of Things (IoT) and Digital Twins (D/Twins) (Rodrigo *et al.,* 2023) to preserve the built environment's integrity, safety, productivity and circularity. These DTs are vital to the industry's digital transformation, facilitated by technological advancements (Setaki and van Timmeren,2022). DTs can significantly ease the complex, challenging, and diverse shift to circular practices in the industry (Yu *et al.,* 2022).

It is vital to explore whether DTs can help advance the CE by tackling the existing barriers. For instance, the industry faces significant barriers to effective recycling and material reuse due to inadequate tracking mechanisms (Oluleye *et al.,* 2023). If such tracking is lacking, accountability is compromised due to the challenges associated with identifying and obtaining resources from buildings that have been modified or demolished. In addition to tracking issues, the industry is hindered by insufficient

waste segregation and surveillance facilities (Oluleye *et al.,* 2023). Current technologies often fall short of efficiently recycling materials, hampered by inadequate material segregation, management barriers, and a lack of disassembly (Osei-Tutu *et al.,* 2023).

Additionally, a lack of a proper data management system exacerbates the challenges associated with circular building practices (Munaro and Tavares, 2023). Existing material databases and modelling tools are limited in their efficacy due to the deficiency of openness and accessibility of technical information regarding building components (Oluleye, Chan, and Antwi-Afari, 2023). Due to these limitations, stakeholders frequently disregard recycling goals or legal obligations. Thus, integrating strategies facilitating the shift to CE remains difficult for construction organisations and key stakeholders (Ababio and Lu, 2023).

Another significant barrier is the absence of integrated methods, instruments, and procedures for managing CDW (Munaro and Tavares, 2023). The industry lacks extensive instruments for identifying, classifying, and verifying recovered or reclaimed materials. The issue of circularity in product design further complicates the implementation of CE practices (Munaro and Tavares, 2023). Thus, the industry suffers from a dearth of material alternatives and complexity in supply chains, which impedes the growth of circular product design (Ababio and Lu, 2023). Moreover, the real-world application of DfD is inhibited by the absence of standardised visualisation tools and spatial geometries (Munaro and Tavares, 2023).

Integrating DTs could bridge the identified challenges by providing real-time, detailed tracking of materials and CDW, thus enhancing the efficiency of reuse and recycling processes and supporting data-driven decision-making regarding waste reduction and resource allocation (Munaro and Tavares, 2023). Moreover, DTs can offer advanced circular design and simulation capabilities, thereby improving the lifecycle management of resources (Cimen 2021). These DTs facilitate the generation and management of data and information required for circular business models. Consequently, digitalisation enables closed material loops and provides precise information regarding the location, state, and accessibility of resources, aiding the transition to a more sustainable CE (Antikainen, Uusitalo, and Kivikytö-Reponen,2018). Recognising this potential, the European Circular Economy Action Plan (2020) emphasizes digitalisation as a key enabler of CE, aiming to reduce material intensity and dependency on virgin resources. In Australia, the CE Interim Report (DCCEEW, 2024) highlights the need for a diverse range of engineering and digital skills to capitalise on CE opportunities fully. However, findings from the Victorian Circular Activator (2022) reveal that many SMEs in the construction sector still rely on conventional waste management methods, with limited integration of DTs in CE initiatives.

METHOD

A comprehensive literature review was conducted to establish theory-based knowledge and identify the potential of DTs in implementing CE practices in construction. Following this, 16 semi-structured interviews were conducted with professionals selected through purposive sampling. All participants had a minimum of two years of experience in CE or DTs within Australian commercial construction projects. They were asked to share their perspectives on the role of DTs in enabling circular practices in construction. This approach ensured a focused and cohesive sample of industry professionals whose insights were most relevant to the research

objectives. NVivo 15 was used to open-code the transcripts and conduct code-based content analysis. The codes were then grouped into themes for synthesis and comparison across participants.

FINDINGS AND DISCUSSION

The respondents' years of experience in the construction industry, circular economy, sustainability, and digital technologies are shown in Figure 1.

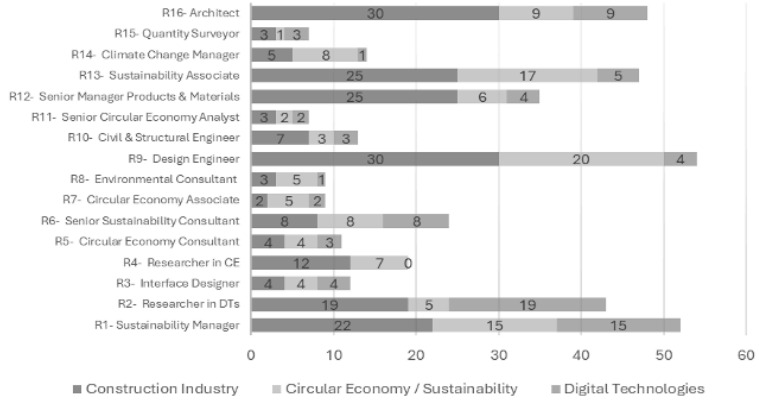
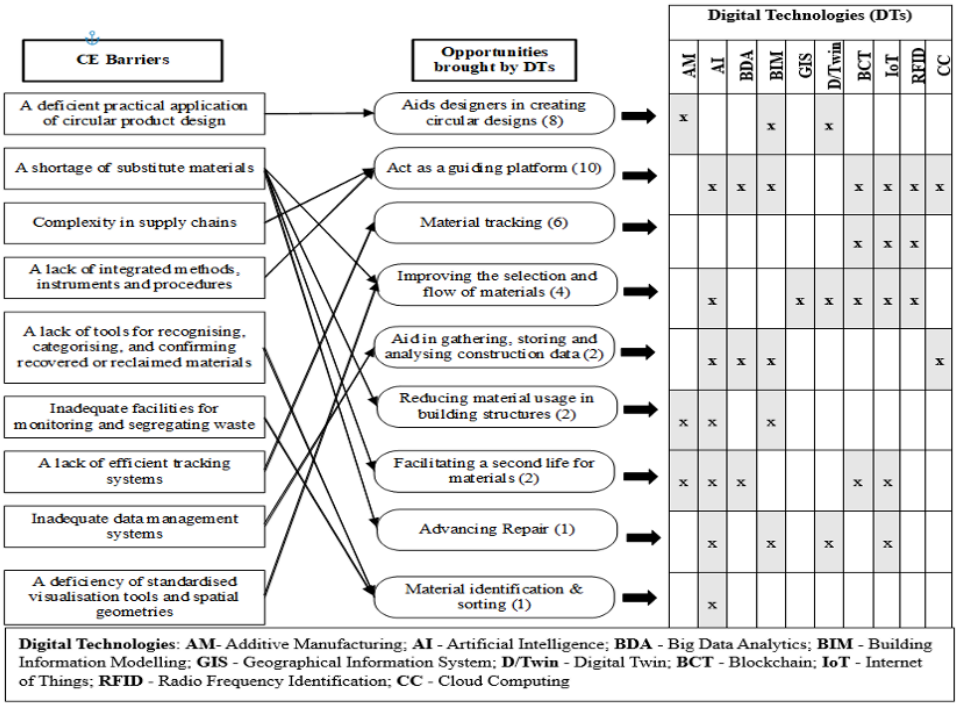


Figure 1: Respondents' years of experience in the construction industry, circular economy or sustainability, and digital technologies

The role of DTs in advancing CE practices in construction, along with the specific DTs enabling them, is presented in Figure 2.

Figure 2: Role of DTs in advancing CE practices in the construction industry



Note: Numbers at the end of each statement indicate the number of respondents who agreed on points.

All respondents consider DTs as an enabler that can aid in implementing CE practices. They believe DTs offer tools for better tracking, managing, and optimising materials, helping reduce waste and improve resource efficiency. The following section outlines the varied perspectives of Australian construction professionals on the role of DTs in

advancing CE practices, the barriers they face in implementing or utilising these technologies and their current ability to fully leverage these tools.

Aids designers in creating circular designs

DTs play a key role in helping designers create circular buildings, with early design decisions being crucial to achieving circular outcomes (Banihashemi *et al.,* 2024). This aligns with the views of R1, R4, R9, and R16, who emphasized that developing circular designs supported by DTs can optimise material use while minimising waste. Similarly, R5, R10 and R13 highlighted how DTs facilitate real-time updates to 3D building models whenever modifications are needed. However, insufficient integration of circular principles in product design poses an additional barrier to adopting CE practices (Munaro and Tavares, 2023), suggesting that broader design reforms must complement digital tools to be truly effective. Collectively, these insights underscore the potential of DTs to support circular practices through improved design processes, progress monitoring and evaluation of alternative solutions. Additionally, respondents noted that DTs could support the Design for Disassembly (DfD) principle by facilitating more deliberate sourcing of materials for future projects. It is well established that existing buildings adhere to a traditional cradle-to-grave lifecycle and are not designed to accommodate disassembly or deconstruction. However, R12 noted that such considerations are still not commonly integrated into BIM in current practice, primarily due to limited funding during the design phase. This highlights that while DTs offer potential, financial constraints remain, restricting their practical application. Moreover, all respondents agreed that circular design is rarely considered early and is often addressed only at the end of a building's life. Although DTs such as AM, D/Twins, and BIM can facilitate innovative CE solutions, respondents criticised their limited application, noting that BIM is still primarily used for clash detection rather than more advanced functions. This indicates that shifting towards circular buildings takes time, as it involves aligning models with traditional approaches and enabling design teams to utilise these models to develop more efficient designs.

Act as a guiding platform

DTs have significant potential to streamline construction processes and applications, thereby enhancing efficiency. However, a considerable barrier remains, the absence of integrated instruments, and procedures for implementing CE practices (Munaro and Tavares, 2023). This lack of integration contributes to the complexity of construction supply chains, further hindering efforts to close material loops and achieve circularity (Ababio and Lu, 2023). Addressing these interconnected challenges, R11 emphasized that DTs can act as foundational platforms by enabling the development, integration, and access to a range of supportive tools, functions, and services. R16 further noted that effectively deploying these technologies demands a whole-systems approach that aligns digital innovation with CE goals to reduce fragmentation and enhance material flow. Respondents particularly underscored applications such as the Digital Marketplace, Material Passports, and Digital Product Passports.

Specifically, R7 described the Digital Marketplace as a platform where materials, whether excess, available, or in demand, can be listed, and R5 noted its usefulness in facilitating the supply and demand of materials. These platforms hold significant potential to enhance material exchange and supply chain connectivity; however, current limitations, such as the lack of scheduling for demolition components (Çetin, De Wolf, and Bocken, 2021), hinder their ability to support effective material reuse. In addition, Material Passports (MPs) are static documents exemplified by projects

such as the Building as Material Banks (BAMB-EU) and trials conducted by Kennett Builders in Australia. While MPs can aid CE practices, limitations remain, including the lack of a centralised system for material data storage and standardised formats for organising information. This fragmentation highlights data governance and coordination challenges that may limit MPs' effectiveness in promoting circularity. In contrast, Digital Product Passports (DPPs) are designed as dynamic, detailed tools for tracking materials and managing their lifecycle. They are expected to have wider adoption, particularly in response to upcoming EU regulations between 2026 and 2030. The Australian pilot at Rosella Street exemplifies localised efforts to trial these systems. However, as R12 observed, such initiatives remain exceptions rather than the norm, indicating slow diffusion and potential resistance within the Australian construction industry. Respondents agreed that DTs, including AI, BDA, BIM, BCT, IoT, and RFID, can collectively support the development and integration of Digital Marketplaces, MPs, and DPPs. Further respondents indicated a tendency to procure materials directly from manufacturers, viewing guiding platforms as less dependable or efficient in fulfilling project requirements.

Material tracking

Material tracking is becoming crucial in the CE context for effective resource management and optimisation throughout their lifecycle. This approach ensures that materials are sourced, utilised, and disposed of in alignment with CE principles. However, the Australian construction industry faces significant barriers to recycling and material reuse, mainly stemming from inadequate end-of-life (EOL) tracking mechanisms (Oluleye *et al.,* 2023). Addressing this, respondents (R5, R6, R7, R9, and R12) emphasized that effective tracking allows future building owners to access essential data, particularly during the deconstruction phase. This approach allows for real-time monitoring of the materials. It supplies crucial data on their condition, which is frequently overlooked until the building approaches its EOL. R7 and R9 further highlighted that, without DTs, it is challenging to track this information and make informed decisions moving forward, which compromises environmental accountability. Furthermore, R16 emphasized that a closed-loop system depends on the commitment of both buyers and sellers, via take-back schemes or recycling. This commitment is underpinned by DTs such as BCT, IoT, and RFID, which enable effective tracking of materials and products. While all respondents recognised the importance of material tracking within the CE context, some were unfamiliar with the specific technologies available to support it. However, R5 noted that there are ongoing discussions about the effectiveness of tracking technologies in overseeing the long-term lifecycle of materials within a circular economy.

Improving the selection and flow of material

The circular economy maximises material flow and resource efficiency while minimising waste (Ellen MacArthur Foundation, 2012), which can be achieved by optimising the selection, sourcing, and utilisation of materials in construction, manufacturing, and other production processes. R4 and R5 emphasized that design and material handling are key in a CE, requiring innovative approaches for effective management. Digitalisation supports closed material loops here by providing precise resource information (Antikainen, Uusitalo and Kivikytö-Reponen, 2018). For instance, R3 noted that DTs facilitate provenance tracking and lifecycle management, allowing materials to be reintegrated into the CE at the end of their life. Furthermore, R12 highlighted the potential of Material Flow Analysis (MFA) as a systematic approach to monitor circularity across a building's lifecycle. Nevertheless, applying

MFA in practice is constrained by the lack of standardised visualisation tools and spatial geometries, which Munaro and Tavares (2023) recognise as major technical obstacles. Thus, the industry suffers from a dearth of material alternatives (Ababio and Lu, 2023). Technologies like AI, GIS, BCT, IoT, D/Twin, and RFID provide real-time resource flow insights; their effectiveness depends on resolving standardisation challenges and achieving interoperability. Respondents noted that systemic and financial limitations restrict the effectiveness of MFA in promoting circularity in construction.

Aid in gathering, storing, and analysing data Although construction project data is essential for supporting CE practices, collecting, storing, and analysing this data poses significant challenges. Munaro and Tavares (2023) highlight that the lack of effective data management systems significantly impedes circularity initiatives, a concern also emphasized by R7, who points out the inefficiency of using mental or paper-based data storage. This reliance complicates decision-making and raises the risk of data loss and inconsistencies. In contrast, DTs enable proactive risk detection and real-time data analysis for improved site impact management, as noted by R15. The ability of DTs to capture and share data throughout a building's lifecycle (Charef, 2024) presents an ideal framework to support CE goals. R7 further emphasized that comprehensive data capture enables stakeholders to make more informed decisions about costs, carbon reduction, and material reuse. Despite implementation challenges, R14 notes current databases suffer from limited openness, access, and unreliable predictions, reducing their usefulness. This illustrates a broader systemic problem in which data silos and inconsistent standards hinder the ability of Data Trusts to promote circularity. Additionally, although respondents recognised BIM, AI, cloud computing, and big data analytics as helpful in managing data, concerns persist regarding their integration and scalability in industry applications.

Reducing material usage in building structures

Minimising material use in building structures is essential for advancing CE practices, focusing on enhancing manufacturing and design efficiency by tightening resource loops (Talla and McIlwaine, 2024). R1 highlighted that DTs can significantly reduce material use to the minimum required for a building, while R8 emphasized their ability to predict material needs, quantities and timing, thus enhancing inventory management. Additionally, R8 stated that integrating DTs supports assessing materials like used timber for potential reuse in future projects. They can help identify whether certain project elements can be retrofitted instead of discarded, thereby reducing waste and encouraging material reuse. DTs such as AM, AI, and BIM can be utilised to optimise building design, reducing material usage in building structures. However, the use of decreasing materials in construction remains a debated topic within the industry. While respondents acknowledged its theoretical value for promoting circularity, they were hesitant to adopt it in practice due to concerns about compromising the quality of outcomes.

Facilitating a second life for materials

Reusing and repurposing materials to extend their lifecycle is a core principle of the CE, aimed at reducing resource extraction, environmental impact, and waste generation (Ellen MacArthur Foundation, 2012). DTs offer promising support, but their impact is limited by several challenges. R1 emphasized that DTs have the potential to develop comprehensive databases of material properties, theoretically enabling improved reuse decisions. Pilot initiatives, such as the Legacy Living Lab (L3) in Western Australia, showcase how the use of reused components and

recyclable materials can substantially reduce waste and embodied carbon (Minunno *et al.,* 2018). This facilitates the identification of effective repurposing or reuse strategies once materials reach the EOL. For instance, BIM models provide detailed information about a building's structure, materials, and components, essential for creating a disassembly plan. In addition to structural data, BIM can store videos, manuals, and visual resources to guide demolition teams in safely dismantling the building and recovering valuable materials. Other than BIM, DTs such as AM, AI, BDA, BCT and IoT can facilitate material reuse and recycling. Nonetheless, such cases remain rare due to limited data infrastructure and incentives in most construction projects.

Advancing Repair

Monitoring the state of buildings enables timely and coordinated maintenance and repair operations, thereby extending their lifespan and reducing the flow of materials through the loop (Tsui, Wuyts, and Berghe, 2024). However, the primary focus in construction is on retrofitting and redesigning buildings, with a strong emphasis on recycling and repurposing materials. R8 emphasized that the importance of repair in CE practices is frequently neglected in the Australian construction industry. Additionally, R8 mentioned that DTs have a considerable opportunity to investigate and incorporate reparative practices within the next five to ten years, offering a more sustainable construction approach and supporting the broader objectives of circularity. DTs, such as D/Twin and IoT, enable real-time management through continuous monitoring and predictive analysis, while BIM supports precise repair planning and AI facilitates data-driven repair decisions. According to the respondents, DTs enable more accurate and timely repairs, which help reduce construction waste and extend the lifespan of buildings. However, the practice of undertaking such repairs remains relatively uncommon in the Australian construction industry.

Material identification and sorting

It is essential to identify and sort out various materials used in construction, typically during demolition, renovation, or at EOL. This is a crucial practice for promoting circularity and reducing waste in the industry. However, reusing and recycling practices in the industry are currently hindered by insufficient waste material segregation and surveillance facilities (Oluleye *et al.,* 2023). Additionally, the sector lacks comprehensive tools for identifying, classifying, and verifying recovered or reclaimed materials (Osei-Tutu *et al.,* 2023). Thus, a significant obstacle to material reuse and recycling is managing complex materials, often composed of a mix of ingredients from demolition projects. R8 claimed that if DTs are adequately implemented to identify and sort materials, they could help the industry transition from costly recycling options to reuse. AI algorithms can be trained on extensive datasets of waste samples to find patterns, predict the characteristics and composition of different waste types, and enhance sorting and disposal processes (Rodrigo *et al.,* 2023). Respondents are aware of the emergence of material identification and sorting mechanisms; however, the industry still lacks effective implementation due to limited technological adoption and insufficient regulatory support.

CONCLUSIONS

DTs are critical for implementing CE practices in the construction sector. However, their adoption remains low in the Australian construction industry due to professionals' resistance to change. According to DOI theory, perceptions lead to the decision to adopt or reject an innovation. Thus, this research investigates how

professionals in the Australian construction and CE sectors perceive the role of DTs in enabling circular practices. The findings highlight that technologies like AM, BIM, D/Twins, AI, GIS, BCT, IoT, RFID, and IoT hold significant potential to advance CE practices through design optimisation, advanced repair, material tracking, reuse, real-time monitoring, lifecycle monitoring, standardising MFA, Their current application remains limited due to a lack of awareness, low utilisation, reluctance, scalability challenges, insufficient data infrastructure and incentives, and inadequate regulatory support. This underscores the need for broader adoption and integration to realise the benefits of CE practices in construction fully. Comparing these roles to CE barriers, the study shows how DTs can address issues like material inefficiency, limited reuse, and poor data integration. It offers policymakers evidence-based recommendations to support informed decisions promoting DTs in construction. As a qualitative study, the findings offer in-depth insights, but they do not include statistical evidence that would allow for broader generalisation or comparison. A valuable future study could involve a quantitative investigation assessing the adoption level and impact of specific DTs commercial construction projects.

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REUSED OR USED UP? UPSCALING MATERIAL AND COMPONENT REUSE IN THE SWEDISH CONSTRUCTION SECTOR

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Material and component reuse is seen as vital for circularity in construction; but practical adoption remains relatively slow in Sweden. This paper examines how such reuse can catalyse a transition from linear to circular construction. Drawing on sociotechnical concepts in the sustainability transitions theory (multi-level perspective; technological innovation systems; and strategic niche management); it reviews national research on reuse in Sweden. The findings reveal institutional and cultural lock-ins; weak policy incentives; and inadequate market infrastructure; all contributing to stagnation. A cohesive framework is proposed to address these barriers through multi-actor coalitions (e.g., policy bodies; major construction firms; demolition contractors; and environmental NGOs); demonstration projects; digital platforms; regulatory reforms; and strategic public procurement. The study expands the understanding of construction sector's circular transformation and offers guidance on embedding reuse to improve resource efficiency while maintaining performance.

Keywords: material and component reuse; building production; upscaling; climate footprint; circular economy

INTRODUCTION AND BACKGROUND

In Sweden, construction activities generate approx. 22% of the country's total CO_2 emissions (ACAN, 2024) - therefore, decreasing those emissions can strongly contribute to Swedish climate neutrality goals by 2050. Such a decrease requires the reduction of the emissions embodied within building production (Burns *et al.,* 2024), as they represent approx. 20% of construction-related CO_2 emissions in Sweden (Karlsson, 2024). Product reuse in building production can contribute to Sweden's 2050 net neutrality goals (e.g., by reducing embodied emissions and enhanced resource efficiency) and create new forms of environmental, social and economic value within the built environment (Lundgren *et al.,* 2024; Riuttala *et al.,* 2024).

However, despite a growing research interest on material and component reuse, as well as its critical importance in achieving circularity in the built environment, practically implementing it in Swedish building production seems to be stagnating (Boverket, 2024). In this paper, we refer to stagnation as a condition in which reuse initiatives have emerged but fail to scale or integrate into standard building production processes. Rather than a complete absence of activity, stagnation describes a state of

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partial uptake where interest, policy ambitions, and isolated experiments exist, but structural barriers prevent broader adoption. In the Swedish context, this is evident in the disconnect between national circularity strategies and the limited reuse observed in practice - particularly in large-scale building production (Mjörnell, 2025; Boverket, 2024), as well as in how very few construction materials and components are recycled or reused in Sweden, with most being redirected to secondary construction uses instead of building production (Andersson and Buser, 2022). Therefore, in this paper, we attempt to diagnose why such a stagnation exists, and how it can be overcome towards upscaling material and component reuse in Swedish building production.

First, we conceive a theoretical framework of sustainability transitions by combining key sociotechnical concepts. Given the complexity of upscaling reuse in construction - a process shaped by actors, rules, practices, infrastructures, and markets - drawing on the sustainability transitions literature provides a foundation for understanding structural dynamics, innovation processes, and niche development, respectively. This approach allows us to analyse not only how reuse could emerge and spread, but also why it currently stagnates despite policy support. Then, by utilising the phenomena construction methodology, we use this framework to analyse recent empirical results of nationally funded research projects about circularity and sustainability in construction and ultimately propose implementation steps for upscaling material and component reuse in Swedish building production.

Theory - Sustainability Transitions

To understand why reuse in Sweden remains marginal despite rising interest and policy support, we turn to sustainability transitions theory; this will help unpack not only innovation emergence but also systemic inertia, institutional lock-ins, and governance challenges that shape the trajectory of change. Sustainability transitions theory aims at conceptualising how sociotechnical systems can be radically changed to address challenges incurred by unsustainable consumption and production patterns - as it is considered that incremental improvements and technological fixes ultimately fail to address those (Köhler *et al.,* 2019). Specific sociotechnical concepts are particularly prominent in this theory; however, power relations, everyday practices, and institutional structures also critically shape sustainable transitions (especially for understanding contextual barriers and enablers). Below, the key sociotechnical concepts in sustainability transitions are detailed, and will later be utilised to understand reuse in Swedish building production as a transitional phenomenon.

Key Sociotechnical Concepts in Sustainability Transitions

The multi-level perspective (MLP) explains transitions as non-linear processes unfolding across three nested structuration levels: niches, socio-technical regimes, and the landscape (Köhler *et al.,* 2019). Niches are protected "incubation rooms" for radical innovations, where novelties can develop shielded from market selection (e.g., pilot projects for reuse); regimes represent the dominant technologies, infrastructures, business models and institutions stabilised by incumbent actors and routines, leading to path-dependence and incremental change; and the landscape denotes broader exogenous trends (e.g., climate targets, economic conditions, cultural values) pressuring the regime (Köhler *et al.,* 2019). Transitions occur when niche innovations mature and align with landscape pressures to sufficiently destabilise existing regimes, allowing for niches to upscale into new regimes (Geels, 2002). In MLP, stability and change interact; regimes are typically change-resistant, so niche breakthroughs require both internal momentum and external landscape pressure (Geels and Schot, 2007).

Apart from MLP, the technological innovation systems (TIS) framework focuses on the development of innovation systems around a specific technology or solution; it consists of actor networks (e.g., firms, users, policymakers), institutions (regulations, norms), and technological artifacts related to innovations (Bergek *et al.,* 2008). Rather than multi-level structures, TIS evaluates seven systemic functions - i.e., key processes that must be fulfilled to successfully develop and diffuse a novel technology: (1) knowledge development and diffusion; (2) entrepreneurial experimentation; (3) directionality of innovation efforts; (4) market formation; (5) sociopolitical acceptance and legitimation; (6) resource mobilisation; and (7) positive externalities (spillovers reinforcing the system) (Köhler *et al.,* 2019). By assessing functional strengths and weaknesses, systemic barriers hindering innovation can be pinpointed - e.g., a stagnation in reusing building materials might reveal a lack of relevant marketplaces or business models, or insufficient legitimation (scepticism about quality or code compliance). TIS is especially useful for understanding early-phase innovation dynamics and identifying policy or network interventions to strengthen the innovation system (Bergek *et al.,* 2008) and tends to emphasize the emergence and diffusion of novel innovations more than the active destabilisation of incumbent systems - which is MLP's focus (Köhler *et al.,* 2019).

Furthermore, strategic niche management (SNM) examines how to deliberately nurture niche innovations so they can grow and challenge the regime (Schot and Geels, 2008). It posits that radical innovations typically start in protective niches - e.g., subsidised demonstration projects, living labs, or specialised markets - where they are shielded from mainstream selection pressures (Köhler *et al.,* 2019). In these niches, dedicated actors (often startups or social entrepreneurs) invest in developing the innovation. SNM emphasizes three key processes for niche development: first- and second-order learning about both technical issues and broader societal impacts, network building by forming broad stakeholder alliances to support the innovation) and managing expectations and visions by articulating compelling narratives to attract attention and resources (Köhler *et al.,* 2019). Through iterative cycles of experimentation and feedback, a niche innovation can improve on technical performance, reduce uncertainties, and build up a supportive coalition (Köhler *et al.,* 2019). Successful niches may then scale up and enter mainstream markets. SNM thus provides a methodology for guiding experimental projects and strategically positioning innovations - which is highly relevant for building material and component reuse. In practice, SNM is often combined with MLP and TIS; niche experiments are seen as seeds for broader transition dynamics (Markard *et al.,* 2012).

Comparing the Sociotechnical Concepts

All three concepts (MLP, TIS, and SNM) adopt a systems perspective to capture the complexity of sociotechnical change (Köhler *et al.,* 2019), but they differ in focal scale and analytic lens. MLP is useful for understanding the timing of transitions in the macro-context, TIS for diagnosing innovation system weaknesses and crafting policy support for meso-level system building, and SNM for informing on-the-ground experimentation and micro-level innovation and stakeholder management. MLP, TIS, and SNM are often seen as complementary (Markard *et al.,* 2012), but they are widely applied in construction and circular economy research, few studies integrate them to construct a phenomenon-specific framework tailored to the context of reuse upscaling. Moreover, the theoretical implications of applying these frameworks to stagnated circularity efforts - rather than successful transitions - remain underexplored.

METHOD

In our research, we first implemented the qualitative abductive loop (Bell *et al.,* 2022) to work iteratively between the insights gained from a targeted literature review, the dimensions of our theoretical framework, and the second-hand learnings retrieved from a comprehensive meta-analysis. The empirical foundation of this paper is a meta-analysis conducted by Mjörnell (2025), which synthesizes findings from more than a dozen Swedish research projects funded between 2021 and 2025, all focused on reuse and circularity in construction. While this report is a secondary source, it functions as a second-order aggregation of empirical insights, drawing from diverse project contexts, stakeholder groups, and methodological approaches. As such, it provides a rich, composite overview of the current state of research and practice on reuse in Sweden, making it a suitable basis for our theory-led analysis.

The targeted literature review method was chosen based on the study's precise focus on a narrow topic positioned in a specific context (that of Sweden) (Bell *et al.,* 2022). For the references supporting the background in the Introduction, we focused on the past five years (2021-2025) to flag the temporal insight where the state-of-art corroborates that reuse in Swedish building production is currently stagnating. For the references on the different perspectives of sustainability transitions in Theory, we focused on the relevant developments of the last 20 years (2006-2025), as a reading of the pertinent literature revealed that this period showcased a more concentrated effort in synthesising and synergising those perspectives; however, some earlier seminal works (e.g., Rotmans *et al.,* 2001) were still included, as the conceptual foundations they helped us explain our theoretical framework. We targeted peer-reviewed academic sources mostly across Scopus and Web of Science, using keywords such as “material and component reuse”, “sustainability transitions theory”, “sociotechnical systems”, and “institutions”. We applied standard screening (Bell *et al.,* 2022), first by filtering by title/abstract relevance, followed by full-text review to identify sources and gain relevant insights. Grey literature (e.g., industry case studies, guidelines) was consulted sparingly to obtain additional insights, without dominating our source base.

Mjörnell's (2025) report, featuring a meta-analysis of the results of Swedish sustainability- and circularity-related research projects in 2021-2025, provided us with second-level intensive an extensive qualitative data (Pink *et al.,* 2013) that “closed off” our abductive loop (Bell *et al.,* 2022) and helped understand where recent Swedish advancements fit in the sustainability transitions discourse we implemented, as well as corroborate the current stagnation of reuse in Swedish building production. This meta-analysis thus serves as our empirical material. We add to the meta-analysis, which is mainly descriptive, by applying the concepts of MLP, TIS, and SNM in a combined way to construct a cohesive framework that allows us to interpret stagnation and propose practical and theoretical steps for system reconfiguration.

Rather than aiming for empirical generalisation, our goal is to conceptually understand “reuse upscaling” as a transitional phenomenon. Drawing on Alvesson and Sandberg’s (2024) phenomena construction methodology, we use the aggregated empirical material to generate theoretical insights about system-level stagnation and pathways for reconfiguration. This approach allows us to move beyond fragmented case descriptions and instead synthesize structural dynamics across projects, using theory to reinterpret the current limitations and opportunities in the Swedish context.

FINDINGS

By implementing the phenomena construction methodology, we utilise our theoretical insights to analyse the compiled results in the meta-analysis by Mjörnell (2025). Based on this, we identify the sustainable transition characteristics for reuse in Swedish building production, as well as the current situation and need for change.

Sustainability transition characteristics for reuse in Swedish building production
Building production involves a complex sociotechnical system of technologies, markets, user practices, infrastructures, policies, and stakeholders (e.g., contractors, suppliers, and end-users). It faces tensions between long-standing practice norms and the increasing adoption of new tools (e.g., digital ones like BIM and digital twins) demanding new competencies. The buildings' lengthy operational life also makes it difficult to predict which emerging innovations will ultimately prevail.

Transition pathways are often contested: dominant industry players guard their market positions (e.g., contractors focusing on new construction, suppliers on new products), while smaller firms specialising in deconstruction or reuse struggle to influence the broader shift. Since sustainability is a public good, businesses have few incentives to invest in reuse without regulatory support. Accordingly, public policies—e.g., taxes, subsidies, environmental regulations, and innovation strategies—play a key role in guiding transitions. In Sweden, policymakers could increase climate-footprint thresholds for both new and existing building materials or promote lower taxes on reuse and the relevant labour—making refurbishment more competitive than new construction. Having outlined the general characteristics and systemic tensions surrounding reuse in Swedish building production, we now turn to one of the key institutional dimensions shaping these dynamics: policy and power. This includes the role of legislation, regulatory gaps, and political signals influencing reuse adoption.

Policy and power in transition
The Swedish Planning and Building Act (PBL) currently lacks mechanisms to enforce reuse. Detailed building permit requirements allow minimal flexibility for reused materials, and there are no oversight policies for material inventories or verified waste quantities. Stronger legal and policy measures are needed to drive reuse adoption, including flexible permits and detailed plans supporting building conversion, alongside incentives such as VAT relief and tax deductions for reuse-oriented renovation. Municipalities should also be allowed to conduct reuse initiatives beyond their own jurisdictions. Rigorous oversight is crucial to document material inventories and consistently track reuse and waste quantities. While policy frameworks provide the formal scaffolding for reuse, governance mechanisms - such as data infrastructure and oversight systems - determine how reuse is coordinated and monitored in practice. The next section explores these operational dimensions.

Governing transitions
Information on reusable products is scarce and hard to access, obscuring availability, location, and ownership. The Swedish utility value principle for rent control further encourages new products by justifying higher rents. Strengthening the reuse market therefore requires increased digitalisation and efficiency, such as digital inventories, demolition permits, and shared databases detailing material availability and quality. A unified data environment can facilitate oversight, faster feedback, and new digital services, also aiding municipalities in monitoring reuse and demolition waste. Finally, clear traceability of reused products could benefit resource management. In addition

to formal systems, societal values and cultural perceptions can be critical in enabling transitions, as described below in the influence of civic attitudes and norms.

Civic society, culture and social movements in transition
Linear construction and renovation practices remain the prevailing norm, with new materials and products often perceived as more valuable than existing ones - even though those are sometimes of higher quality. Notably, surveys show that 2/3 of tenants support increased reuse (Mjörnell, 2025). Therefore, greater awareness of reuse's value - emphasising the tangible quality and functionality of reclaimed materials - can help towards making reuse the standard approach. Nonetheless, cultural attitudes are not only embedded in civil society but also influence industry practices, therefore shaping reuse dynamics as shown in the following.

Businesses and industries in sustainability transitions
Few incentives currently encourage businesses to use reused materials and products; buying new items is simpler and less labour-intensive, with discounts on new products reinforcing this norm. As a result, reused products typically appear in renovations rather than new construction, and supply constraints hinder broader adoption. Heavy building components, like structural elements, are rarely reclaimed due to perceived risks and uncertainties around cost, warranties, and technical lifespans.

Though independent digital platforms facilitate sales of reused materials in Sweden, logistical hurdles (transport, storage) persist. Manufacturers often operate in mono-material flows, making sourcing reused components time-consuming. Therefore, the sector must link reuse to green loans and insurance, adopt iterative design processes that incorporate reuse options from the start, and establish procurement procedures allowing contractors to find appropriate reused products. Discount structures favouring new materials should be re-evaluated, and standardised assessment and quality-assurance methods (e.g., warranties and certifications) must be developed.

To integrate reuse into core offerings, building material suppliers could introduce warehouses and resale facilities - potentially supported by a "construction bank" for reused frames. Manufacturers should design recyclable products and assume responsibility for reclaiming them. Such strategies require deeper expertise in building production, including new roles like inventory specialists, dismantlers, and refurbishers who can certify quality and guarantees, as well as coordinating transportation and logistics for handling both new and reclaimed materials. While business practices shape the supply of reused materials, their uptake also depends on consumer demand and acceptance. In the following, the focus shifts from industry actors to end-users, examining how everyday preferences, perceptions, and price expectations influence reuse in building production.

Transitions in practice and everyday life (consumer perspective)
From a consumer standpoint, new products currently remain the default choice, and there is limited acceptance for paying the same price for reused products. This mindset reinforces a linear consumption model valuing novelty over sustainability. For reuse to become the new norm, consumers must actively seek out and prefer reused products, recognising that their quality and performance can rival - or even exceed - those of new materials. To support this shift in perception, the utility value principle should be revised, allowing rent increases for properties that incorporate reused elements, thus acknowledging their equal or greater worth. Consumer preferences and norms are not uniform across the country; they are shaped by spatial

context, infrastructure availability, and local policy conditions. We therefore explore next how location, scale, and place-specific initiatives affect transition dynamics.

Geography of transitions; space, scale and places
Currently, reusing building products in Sweden is primarily driven by occasional, often temporary, municipal initiatives, which pave the way for private-sector participation and the growth of reuse-related services. Most existing reuse hubs cater to individual consumers, selling single items rather than supporting large-scale commercial adoption. Although some property owners maintain their own storage facilities, there is currently limited infrastructure for broader efforts. Change would require local and regional authorities to establish or expand reuse hubs and streamline their logistics. Such hubs would allow public and private actors to adopt reuse, providing a central point for collecting, sorting, refurbishing and delivering materials on-time and cost-effectively. However, spatial variation in reuse practices reveals issues of access, equity, and environmental responsibility, which are addressed below.

Ethical aspects of transition: Distribution, justice, poverty
Renovation projects in Sweden do not require climate declarations, and there is no systematic carbon taxation on new building production. Additionally, there are no established methods for placing tangible value on reused materials, hindering comparisons with new alternatives. Moving forward, mandatory climate declarations for renovation projects, supported by a standardised methodology for including reused products, are essential. Carbon taxation on new items should be introduced to reflect their environmental impact and incentivise reuse. Beyond climate considerations, clear procedures for assessing reused materials - also considering quality, aesthetics, and historical significance - are necessary to encourage broader acceptance.

DISCUSSION

Building on the systemic challenges identified in the findings, the discussion now proposes a set of coordinated steps for enabling reuse to scale — grounded in the theoretical logic of transition pathways and institutional transformation. While some of the patterns outlined above — such as lock-ins and institutional misalignment — may appear familiar, this study contributes by analysing them as mutually reinforcing across niche, regime, and institutional levels. Rather than offering general policy advice, we conceptualise reuse stagnation as a system-wide coordination failure, where niche efforts lack sufficient alignment with existing rules, routines, and responsibilities. This adds to construction management literature by diagnosing how partial experimentation without structural support can stall transitions — a dynamic often overlooked in more success-oriented circularity studies. So, considering the dimensions described in the findings, we outline five steps for upscaling reuse in Swedish building production. Consistent with transition management, these steps should be placed in iterations of envisioning, experimenting, evaluating, and learning.

Step 1: Stakeholder coalition - Bringing together key stakeholders (e.g., the Swedish National Board of Housing, Building and Planning, major contractors, NGOs)
This coalition should develop a shared vision and targets for upscaling reuse (e.g., a roadmap to increase reused content in building production by 2030). A common vision can help align efforts across levels and create a mandate for change. Sweden's policy backdrop (fossil-free ambitions and circular economy strategy) can serve as guiding context, but this step translates high-level goals into a sector-specific mission. It also sets up governance for the transition: defining roles, forming working groups, and securing initial funding commitments for subsequent steps.

Step 2: Niche development - Launching a series of well-resourced pilot projects to demonstrate reuse in practice
These should vary by project type and geography across Sweden to explore different reuse aspects. For each pilot, SNM should be applied to identify and secure protections (e.g., regulatory sandbox arrangements or grants to cover extra costs), involve a broad participant network (e.g., contractors, suppliers of salvaged materials, approval authorities, end-users), and set clear learning objectives. By rigorous documentation and monitoring of technical performance of reused elements, cost and time impacts, and user satisfaction, an evidence base can be accumulated and best practices refined. These pilots should also serve as training grounds for professionals, help shift mindsets (seeing that reuse is feasible and can meet quality expectations), and the results disseminated through industry forums and media to build legitimation.

Step 3: Developing, in parallel with pilots, the supporting infrastructure and knowledge networks for a reuse market
This could involve creating a digital marketplace platform for secondary products (with government support or as a public-private partnership), so that supply (from demolitions) can meet demand (building production) efficiently. Private sector participation should be incentivised - by, e.g., encouraging startups to offer deconstruction services, refurbishing, auditing and certifying salvaged components for resale. To tackle information and skill gaps, a national knowledge centre on circular construction (collecting data, publishing guidelines, and offering training modules) should be established, and regular workshops or "community of practice" meetings where project teams share lessons from reuse projects should be held. This step is about ensuring the TIS functions are fulfilled: connecting actors, spreading know-how, and lowering transaction costs to use reused components. Success can thus be measured by growth in the number of companies dealing with reuse, their turnover and increased listings or transactions on the marketplace over time.

Step 4: Policy and regulatory reform using insights from pilots and system analysis
The coalition (from Step 1) should work closely with policymakers to update standards and regulations in favour of reuse - e.g., by developing technical standards for reused structural elements, clarifying building code provisions to explicitly allow reused materials if certain criteria are met, and creating streamlined permitting processes for projects with high reused content. Moreover, potential economic measures can be introduced, including tax credits or grants for projects that incorporate reuse (both products and labour), reduced fees or faster permits as incentives, and higher landfill fees or stricter quotas for demolition waste diversion. Public procurement rules at the municipal and national levels should include evaluation criteria for circularity - making reuse a competitive advantage in bidding. These institutional changes can embed reuse and move it from niche to a normal option. It is important that reforms are designed collaboratively (with input from industry to ensure practicality) and are communicated clearly to avoid uncertainty. Over time, regulatory support increases the legitimacy of reuse and gives developers confidence that investing in it will pay off. This step addresses the institutional and political barriers systematically, turning enabling conditions into formal requirements.

Step 5: Scaling-up, monitoring, and adapting
As multiple pilots succeed and market infrastructure grows, the focus shifts to upscaling and continuous improvement. Larger-scale adoption should be encouraged, by, e.g., requiring that all publicly funded building projects in Sweden incorporate at least 30% (by value or volume) of reused or recycled components by a certain date,

gradually raising this threshold as the industry's capacity expands. Private developers can be engaged through green building certification systems (updating tools like Miljöbyggnad (environmental certification system for buildings in Sweden) or BREEAM-SE to reward reuse). Establishing metrics and monitoring for the transition will help track the building material and components reused annually, emissions or waste reductions achieved, etc. An independent review board (with academic experts and industry) can periodically assess progress against the vision and targets set in Step 1. Based on monitoring, adaptation measures should be taken - if some barriers persist (e.g., certain materials are still rarely reused, or unexpected safety issues arise), expert groups should adjust policies. This echoes the iterative, reflexive governance advocated in transition management (Rotmans *et al.,* 2001), for keeping the strategy on track. Finally, success stories should be communicated clearly - e.g., if a major new building is completed using mostly reclaimed materials, it should be publicised as a showcase of Swedish innovation. This helps maintain public and stakeholder support, which is crucial for long-term transition processes (Markard *et al.,* 2012).

These five steps form an actionable strategy for addressing stagnation and enabling a system-wide shift toward reuse. Next, we conclude by reflecting on how these findings contribute to both transitions theory and the construction management field.

CONCLUSIONS

Our findings suggest that stagnation is a distinct phase in sustainability transitions, where niche activity and political rhetoric exist, but fail to destabilise the regime or attract sufficient structural support. Recognising and diagnosing stagnation can help avoid "pilot fatigue" and redirect efforts toward systemic realignment. In this paper, we have formulated a theoretical framework and outlined five steps for upscaling reuse in Swedish building production: (1) forming a multi-actor stakeholder coalition to overcome fragmented governance, (2) conducting structured niche experiments to generate practical evidence and stakeholder confidence, (3) building essential digital and knowledge infrastructures to address transaction cost and coordination barriers, (4) reforming regulatory frameworks that currently inhibit reuse, and (5) establishing iterative monitoring mechanisms to ensure ongoing alignment and scalability. This systematic approach provides clear, actionable pathways for embedding reuse into Swedish building production, advancing theoretical understanding of stagnation phases, and offering practical guidance for achieving a circular built environment.

This paper contributes to transitions theory by illustrating how upscaling reuse requires simultaneous action across niche, regime, and institutional layers. We show that transition stagnation can occur even under favourable landscape pressures (e.g., circular economy policies), if niche innovations lack legitimation, institutional alignment, and clear role distributions. The proposed five-step approach implements this insight into a roadmap for stalled transitions. A key limitation is our study's reliance on a single meta-analytical source rather than first-hand empirical data. While Mjörnell (2025) offers a valuable synthesis of research and practice across Sweden, future work should validate and extend our findings through primary data collection, (e.g., ethnographic studies, project case research). Such follow-ups could also explore the transferability of our roadmap to other national or sectoral contexts.

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EVALUATING 1960S-1970S AGEING CONCRETE BUILDINGS THROUGH DOCUMENTARY ANALYSIS FOR RENOVATION AND DEMOLITION DECISIONS

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This paper explores the challenges and opportunities of managing mid-century concrete buildings through a techno-historical analysis of construction methods and contemporary retrofit options. Using the University of Melbourne's John Medley Building—a controversial structure slated for demolition—as a case study, the research assesses how evolving building codes from the 1960s to the 2020s shape the feasibility of adaptive reuse. In the context of regenerative cities, the study highlights the broader value of preservation beyond carbon reduction, addressing embodied energy, cultural significance, and social networks. The paper identifies key regulatory transitions through a desktop analysis of architectural and engineering documentation. It examines the building's compliance with modern standards related to concrete durability, fire safety, sustainability, and accessibility. The findings inform a broader methodology that integrates documentary research with non-destructive onsite assessment techniques, offering a framework for evaluating ageing concrete buildings. Although grounded in the Australian university context, the study has broader relevance for global urban renewal strategies.

Keywords: aging concrete buildings; historical construction; retrofit assessment

INTRODUCTION

Managing mid-century concrete buildings presents one of the most pressing challenges in contemporary urban development (Hu 2025; Loschke and Easthope 2016; 2022). As concrete structures built during the post-World War II construction boom near the end of their intended lifespans, stakeholders face difficult decisions on how to proceed with them (Barnett, 2023). This tension is particularly evident in Australia, where a substantial stock of concrete buildings from the 1960s and 1970s requires critical assessment for conservation, adaptation, or replacement (Moore and Doyon 2024). The University of Melbourne's 2023 Estate Master Plan addressed the challenge of transforming ageing infrastructure through strategic renewal. This comprehensive plan focused on improving the quality of buildings within the estate, particularly older concrete structures that fell short of modern sustainability,

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accessibility, and functionality standards (University of Melbourne, 2023a). Similarly, the Victorian State Government proposes demolishing forty-four public housing towers by 2051, mirroring public housing renewal debates occurring across developed nations from Singapore's Housing Development Board estates to UK council housing stock, starting with five by 2031. Initially regarded as cost-effective, these 1960s-70s structures are now overcrowded and do not meet contemporary standards (Kolovos, 2024). These parallel cases highlight a dilemma: while these buildings often require significant costs to upgrade current standards, demolition incurs substantial environmental and social costs. The built environment represents a critical intervention point for regenerative urban development, not only through reducing operational emissions but by recognising existing buildings as valuable material banks with embodied resources that can be preserved and enhanced through adaptive reuse rather than demolition and replacement (UN Environment Programme, 2023). This paper examines the feasibility of preserving and retrofitting ageing concrete buildings through a case study of the John Medley Building at the University of Melbourne, addressing social, environmental and health safety arguments for adaptive reuse over demolition.

Completed in 1971, the John Medley Building is a six-story reinforced concrete structure on the University of Melbourne's Parkville campus. Designed by Australian architect Roy Grounds (in association with John Scarborough), it was intended to house the Faculty of Arts and was named after Sir John Medley, Vice-Chancellor (1938- 1951). The building exemplifies late modernist architecture, distinctive from the historic neo-Gothic and classical revival styles of the university campus at that time. It features brutalist elements with exposed concrete, deep banded windows, and prominent stairwells, reflecting mid-twentieth-century functionalist ideals (Jencks 2002).

As of 2023, the building remains in use but is slated for demolition as part of the University's Estate Master Plan (University of Melbourne 2023a). The reasons include outdated mechanical systems, poor thermal performance due to insufficient insulation, and accessibility issues. Inspections reveal concerns about the concrete envelope, spalling, and water ingress in stairwells and façades. Despite these challenges, the building holds cultural and historical significance as a mid-century landmark and a rare example of Grounds' institutional designs (Tibbits, 2003). This heritage and deterioration raise critical questions about adaptation, compliance, and the long-term viability of Australia's mid-century concrete architecture (Bullen and Love 2011; Yeung 2004).

The study is beneficial because it establishes a techno-historical methodology that compares building regulations with construction documentation, providing a basis for onsite technical assessments and offering cross-disciplinary practical assessment protocols and theoretical foundations for the forthcoming wave of mid-century building lifecycle decisions.

METHOD

This paper presents the initial phase of a two-part research project that utilises a techno-historical approach, integrating archival research with contemporary building regulations (Alves, 2014). We examine the influence of historical design intentions on current regulatory frameworks and the future of concrete constructions, focusing on the John Medley Building at the University of Melbourne as a case study of mid-century institutional architecture in Australia. Comparisons within Australia's federal

regulatory system, where states implement national building codes with local variations, are like regulatory frameworks in Canada, Germany, and other federal systems. Additionally, archival research establishes a robust documentary foundation for the subsequent onsite investigations in the project's second phase. This desk-based analysis utilises policy comparisons within Australia's federal regulatory system, where states implement national building codes with local variations, akin to regulatory frameworks in Canada, Germany, and other federal systems, alongside archival research to establish a solid documentary foundation for the subsequent onsite investigations in the project's second phase.

Historical records, including drawings, specifications, photographs, site instructions, and correspondence from the University of Melbourne Archives and the Public Records Office of Victoria, were reviewed using thematic content analysis. However, records were incomplete, with archival collections prioritising architectural drawings over other construction design documents.

Thematic content analysis was selected for three key reasons: the incomplete and heterogeneous nature of archival records required interpretive synthesis across diverse document types (drawings, specifications, correspondence, site instructions); the need to extract implicit design assumptions and regulatory contexts embedded within but not explicitly documented in historical materials; and the requirement to trace how building performance expectations evolved from the 1960s to the 2020s across different periods and document types, enabling identification of critical transitions in regulatory thinking and construction practices.

Documents were analysed through a two-phase coding process:

We conducted comparative policy analysis of three regulatory instruments: Building Regulations Victoria 1969, Victorian Building Regulations 2018, and University of Melbourne Campus Building Design Standards (2023), employing clause-by-clause comparison to analyse changes in structural, fire, accessibility, material, and sustainability requirements. The extraction and alignment process required subjective decisions about comparable provisions across these frameworks, reflecting our professional judgment about regulatory intent and application. We maintained analytical transparency through independent coding by three authors, collaborative finalisation, and clear documentation of decision-making criteria.

We then conducted a comprehensive review of archival drawings and documentation to identify technical specifications, material standards, and construction procedures from 1971, before synthesising these insights with contemporary regulatory requirements to assess adaptation potential. This integrated approach identified areas where historical design practices diverge from current standards and demonstrated how evolving regulatory frameworks influence institutional decision-making for mid-century concrete building management, retention, or repurposing.

The Evolution of Victoria Building Regulation

Victoria, Australia's second-most populous state, encompassing Melbourne, provides a representative case study of how building regulations have evolved in developed nations facing similar post-war construction challenges. The regulatory transitions observed in Victoria reflect broader international trends toward performance-based building codes and increased sustainability requirements.

In Victoria, the National Construction Code (NCC), Australia's unified national building standards, including the Building Code of Australia (BCA), govern building

regulations under the authority of the Building Act 1993 and the Building Regulations 2018. While the NCC provides consistent technical standards, Victoria implements state-specific provisions to address local climate, policy priorities, and urban challenges administered by the Victorian Building Authority (VBA). However, many existing buildings, including the John Medley Building, were built under earlier codes and do not meet current standards after years of evolution.

Victoria's regulatory environment has undergone four key changes, culminating in the performance-based regulation of 2018. Building Regulations 121 (fire performance solutions), 124 (a registered building practitioner or endorsed building engineer must document performance solutions in certificate of compliance), and 236 (access to buildings for persons with disability) permit compliance through performance solutions, providing flexible alternatives to rigid rules. While this approach fosters innovation, it also raises concerns regarding inconsistent enforcement and construction quality (Vaz Serra *et al.,* 2024). This flexibility enables adaptive reuse based on performance rather than strict compliance for existing buildings, facilitating retrofitting. Then, the shift from local to state and national oversight is apparent, with Regulation 10 aligning codes with the BCA and Regulations 47 and 47A mandating detailed reporting to the VBA. Local councils retain limited roles within a centralised compliance structure, such as managing designated area maps (Regulations 148-149).

Contemporary regulations reflect societal goals by addressing safety, liveability, sustainability, and urban amenity. For example, environmental performance mandates minimum garden areas (Reg. 76A), site permeability (Reg. 77), and stormwater management (Reg. 133). Quality-of-life standards guarantee access to daylight, visual privacy, and private open space (Regs. 84-86). Accessibility is considered under Part 5, aligning with modern expectations for equitable access. These factors increasingly influence how older buildings are evaluated, not only for compliance but also for their relevance in contemporary educational and institutional contexts.

A major regulatory change is the professionalisation of compliance established in Part 18, which creates frameworks for practitioner registration, integrity, and discipline, shifting responsibility from councils to building professionals. Inspection and testing standards are specified (Regs. 120, 173-174), and private building surveyors can now perform functions previously held by municipal surveyors (Regs. 67, 230, 232). A practitioner register (Reg. 256B) and probity standards (Div. 3A, Part 18) enhance accountability. Property owners are now directly accountable for certain safety measures (Regs. 144-147), indicating a shared duty-of-care model. In universities, internal standards further guide regulation application and interpretation. As a facility of the University of Melbourne, the John Medley Building must adhere to statutory requirements and the University's Campus Building Design Standards (University of Melbourne 2023b). They serve as a vital interface between general regulation and the specific operational needs of higher education infrastructure.

Table 1 presents the University of Melbourne's design standards across eleven major categories, aligning institutional requirements with evolving regulatory contexts to provide a structured framework for campus construction and renovation projects. These standards encompass essential safety considerations, detailed technical specifications for specialised spaces (laboratories, audio-visual systems), and sustainability requirements etc.

Table 1: Comparison between the Transitions of Victorian Building Regulation and the new UoM Building Design Standards

Space Type	Regulatory Transition	Victoria Building Regulation 2018	UoM Design Standards Requirements
Learning Spaces	From Minimum Safety to Broader Concerns	• Reg. 81-82: Daylight and solar access • Reg. 83: Overshadowing protections • Reg. 84: Overlooking provisions	• Room Types: Collaborative Learning Spaces, Event Space/Major Lecture Theatres, Lecture Spaces, Flexible Learning Spaces • Digital AV Systems: Projection systems, flat panel displays, video switching, sound reinforcement, hearing augmentation • Noise Limits: Lecture theatres (40 dB(A)), Teaching spaces (45 dB(A)) • Integration with University monitoring platforms (Crestron XiO and Fusion, etc.)
Circulation and Access	From Local to State/National	• Reg. 73-74: Street setback requirements • Reg. 78: Accessibility regulations • Reg. 10: Direct reference to Building Code of Australia • Reg. 152: Local designations in state framework	• Corridor widths ranging from 1000-2700mm based on importance • Doors and Handles: Max 20N opening force, D-type lever handles (30-50mm circumference), glazed panels in high-traffic doors • Door dimensions must allow equipment movement with appropriate hardware • Compliance with University's Master Keying system • Minimum circulation spaces exceeding code requirements (800mm between equipment) • Office Layout: 1500mm minimum between heads; 2000mm between desk rows
Structural and Building Elements	From Council Oversight to Professional Accountability	• Part 18: Building Practitioners registration • Reg. 174: Professional qualification requirements • Reg. 120-123: Compliance certification (AS CA2-1973 Working Stress design -> AS3600-2018 Limit state design with serviceability)	• 50-year design life for all structural elements with defined professional accountability • Concrete safety: 500MPa reinforcement with enhanced performance profiles • Floor loadings and vibration specifications exceeding minimum code requirements • 12-month defect liability period with documented responsibilities • Façade materials compliant with state regulations (e.g., ACP not supported) • Testing and commissioning documentation with clear professional accountability • Design to convey 5% AEP (20-year ARI) with 20% climate change allowance
Sustainability and Comfort	From Minimum Safety to Broader Concerns	• Reg. 81-82: Daylight and solar access • Reg. 84-85: Ventilation and light requirements • Reg. 133: Stormwater drainage • Reg. 76A: Garden area requirements • Reg. 77: Permeability requirements • Reg. 133: Stormwater drainage • Reg. 75: Building height restrictions • Reg. 76: Site coverage limitations	• Green Star certification (minimum 5 Star, stretch target 6 Star) • Climate Active certification and sustainability dashboard reporting • Climate Leadership: EV charging for 15% of parking spaces (infrastructure for 25%) • All-electric buildings (no gas permitted) exceeding minimum requirements • Office temperature 20-25°C with proper air flow (0.1-0.2m/s) • Lighting designed for specific tasks with glare avoidance • Compliance with Australian Standards (e.g., AS/NZS 1680 for lighting) • Stormwater Drainage: Design for 5% AEP with 20% climate change allowance • Water Management: 40% reduction in annual stormwater discharge • Tracking biodiversity metrics, including areas suitable for planting and existing tree canopy coverage • Biodiversity: No net loss by 2025, nature positive by 2030 • Ergonomic requirements: Electric height-adjustable desks (620-1250mm)
Documentation and Compliance	From Prescriptive to Performance-Based	• Reg. 124: Documentation requirements • Reg. 173-174: Professional record-keeping • Reg. 233(3): Allows for 'partial compliance' • Reg. 256B: Register of Building Practitioners	• SiD reviews throughout project phases with risk assessments documented in risk register • Identification of hazards for building use, maintenance, and construction • Any deviations require formal modification requests and written approval • Complete documentation package including operational manuals and as-built drawings • Control system source codes and configuration files become University property

Source: by the authors

John Medley Building Historical Documentation

The historical architectural drawings and construction specialisations were reviewed to evaluate the building's potential for retrofitting. Initially constructed in 1971, this seven-story building is a mixed-use space comprising offices, classrooms and a library. In 2020, the building underwent refurbishment, yet the overall condition reflects its age. While the building is generally functional, several aspects require attention to align with contemporary standards, particularly regarding accessibility, fire safety, sustainability, and user well-being. The following considerations inform the adaptation process.

The building's layout may need adjustments to meet accessibility requirements. Circulation spaces and corridor widths might not fully comply with standards, requiring specific clearances for safe movement. It's important to assess circulation

spaces around workstations and storage units for accessibility compliance, enhancing inclusivity for mobility-challenged users. The University guidelines specify a minimum clear circulation space of 800 mm, with corridors needing to meet AS1428.**1(**2009) Design for Accessibility and Mobility standards. Despite the building size, the layout does not meet the criteria in high-traffic areas like classrooms and libraries. Clearances in front of storage units and workstations should be 1000 mm and need to be reviewed for compliance. Making these adjustments will improve usability and safety.

The building materials, mainly concrete sunshades, may risk durability. Exposed reinforcement bars and deteriorating grout might compromise the façade's structural integrity. To align with the University of Melbourne's sustainability goals, these issues could be addressed through retrofitting or replacing affected elements to meet modern durability standards. The flooring materials, consisting of carpet and linoleum overlays, should be re-evaluated to meet the guidelines' requirements for slip resistance, particularly in high-traffic areas. Floors must be durable and easy to clean while supporting accessibility needs. Designers should prioritise noise reduction in shared spaces like classrooms. Selecting materials with suitable slip resistance and soundproofing properties enhances user safety and comfort.

While the building has basic fire safety measures, such as extinguishers and illuminated exit signs, the guidelines specify the need for more comprehensive provisions, including fire doors, sprinklers, and defined escape routes that meet accessibility requirements. The building should undergo a thorough fire safety audit and upgrade its systems to ensure compliance with the latest standards, safeguarding the health and safety of its occupants. A thorough fire safety audit and system upgrades must bring the building into compliance with contemporary standards, focusing on reinforcement cover adequacy, compartmentation, and the integration of active fire suppression systems that the original design did not mandate.

Thermal comfort and air quality are essential for user well-being. University guidelines require maintaining indoor temperatures between 20-25°C, with controlled airflow and minimised radiant heat. The building's current HVAC system may not meet the standards, particularly regarding classroom windows. Updating thermal insulation or considering green roof solutions would enhance energy efficiency and user comfort, aligning with sustainability objectives and ensuring compliance with the guidelines.

Regarding sustainability, the building necessitates an energy efficiency audit, given its age and potential inefficiencies in heating, cooling, and insulation systems. Over time, windows have been replaced; however, visible gaps remain between the new frames and the concrete windowsills, posing potential waterproofing issues. These gaps could allow drafts, leading to heat loss and discomfort, while moisture intrusion might compromise indoor air quality and negatively impact user well-being. Enhancing thermal insulation, sealing window gaps, or considering green roofing solutions could elevate energy efficiency and occupant comfort, aligning with the University's sustainability and well-being objectives. While accommodating potential green initiatives like solar panels or insulation upgrades, the building's flat roof may require structural adjustments to support such retrofits.

Concrete building methodologies have evolved significantly from the 1970s to 2020s, representing a fundamental shift in structural design philosophy. The John Medley Building was constructed according to ASCA2-1973 standards, which utilised

working stress design focusing on elastic behaviour under service loads, producing conservative structures but failing to account for material non-linearity and ultimate load capacities. In contrast, contemporary AS3600 (2018) employs limit state design principles that address both serviceability and ultimate limit states, offering comprehensive technical standards for enhanced structural integrity, safety, and durability (Table 1). When evaluating the building's adaptation potential against current standards, assessors must consider this philosophical shift, as the original conservative methodology may have over-designed some concrete elements while lacking consideration for ultimate load conditions that contemporary assessment requires. Detailed analysis is necessary to verify performance under limit state conditions not anticipated in the original 1970s design approach.

The original reinforcement of the building, likely designed with a yield strength of 230MPa (230P) under the AS1302 standards from 1973, represents less than half the capacity of contemporary reinforcement, which is 500MPa under AS/NZS 4671. This significant difference in material strength has direct implications for assessing the building's current load-bearing capacity and retrofit potential. Engineers must consider this historical material specification when evaluating structural modifications or adaptation options. The lower-strength reinforcement may necessitate supplementary strengthening systems for any renovation that increases loads beyond the original design parameters. The building, designed under AS1170.1 (1971), was created using load calculation methodologies and safety factors that have been substantially revised in the current AS1170.1 (R2016). Of particular concern is the building's response to environmental loads. Initially designed according to CA 34.2 (1971) for wind loads and AS2121 (1979) for earthquake considerations, the structure predates significant advancements in understanding environmental forces, which are captured in contemporary standards AS1170.2 (2021) and AS1170.4 (2024). Given the University of Melbourne's location and the building's height profile, these updated wind and seismic standards could significantly impact the assessment of its structural adequacy.

DISCUSSION

The challenges of assessing mid-century concrete buildings exist globally. The techno-historical approach of comparing original construction standards with contemporary regulatory requirements can be adapted to different national building code frameworks, making this research relevant to the thousands of similar structures facing assessment decisions worldwide as post-war construction reaches end-of-intended-lifespan.

Assessors must thoroughly evaluate existing buildings to help decision-makers understand their value, not only as assets but also for their potential reuse, either in whole or in part. Although practices for reusing and recycling demolition materials have improved, objective assessments of entire buildings remain limited. These assessments need to extend beyond the current condition to consider the historical evolution of the building, including its initial design, construction methods and materials, modifications throughout its life, and external factors that may impact its overall performance.

Design codes and construction regulations also evolve over time, adding complexity to the assessment process and reinforcing the need for further research. Furthermore, the involvement of multiple stakeholders and specialised fields in the delivery and maintenance of a building underscores the importance of treating buildings as systems

of systems. This research calls for a multidisciplinary approach to inform architects, engineers, and policymakers engaged in sustainable urban redevelopment and future decision-making.

The research team for this project includes experienced architects, engineers, builders and urban planners from academia with strong industry backgrounds. The aim is to map and implement an appropriate research methodology to develop a meaningful assessment framework to guide future decisions (Table 2).

Table 2 presents our comprehensive assessment framework for the second phase of research, which transitions from historical documentation analysis to targeted on-site technical evaluation. This framework systematically addresses the key vulnerabilities and adaptation challenges identified through our techno-historical analysis of the John Medley Building.

Table 2 Framework for Phase 2 Targeted On-Site Technical Assessment

Assessment Category	Key Assessment Methods
Building Structure	• Concrete strength verification against AS 3600 requirements
	• Reinforcement testing (230MPa vs. modern 500MPa capacity)
	• Load-bearing capacity evaluation under contemporary standards
	• Environmental load resistance assessment (wind and seismic)
Building Fabric	• Concrete carbonation depth measurement
	• Façade condition assessment
	• Thermal envelope performance testing
	• Window-wall interface integrity examination
Compliance	• Fire safety audit against contemporary standards
	• Circulation and access assessment (minimum 800mm clearances)
	• HVAC performance testing (20-25°C temperature range)
	• Compliance with University of Melbourne Design Standards (Space and digital technologies integration)
Sustainability and Comfort	• Embodied carbon quantification• Green Star criteria assessment
	• Stormwater management evaluation
	• Indoor environmental quality measurement (i.e., hazardous material assessment; indoor air quality etc)

Source: by the authors

The framework is structured across four interconnected assessment categories, each designed to evaluate specific aspects of the building's performance against contemporary standards. The Building Structure category focuses on the quantitative evaluation of structural integrity, including concrete strength verification against current AS 3600 requirements and testing of reinforcement to determine the implications of the historical 230MPa yield strength compared to modern 500MPa standards. This category directly addresses the fundamental shift from working stress to limit state design principles identified in our regulatory analysis.

Building Fabric assessment methods target the durability and condition of the building envelope, with particular emphasis on concrete carbonation depth measurement to evaluate long-term performance and weathering resistance. The Compliance category highlights fire safety provisions that have evolved substantially since the building's construction, and spatial requirements are defined in the University of Melbourne's contemporary design standards. Finally, the Sustainability and Comfort category establishes methods to quantify environmental performance and adaptation potential, recognising the expansion of building regulations beyond basic safety to encompass broader societal and environmental concerns.

Preliminary findings highlighted the potential for concrete ageing and retrofitting, supporting the need for evidence-based assessments when deciding whether to demolish, disassemble for reuse, or preserve buildings. The research considers the limitations for future use based on current regulations and codes. The study focused

on one location and building type. Future research should view buildings as interconnected systems over time, considering preservation, external impacts, and broader social and economic contexts. New AI technologies can analyse data to support early project feasibility decisions by integrating all building components into a comprehensive picture.

CONCLUSIONS

This study establishes a techno-historical methodology that evaluates mid-century concrete buildings for adaptive reuse potential, addressing the gap between recognised preservation benefits and practical assessment tools for evidence-based decision-making. The methodology provides dual contributions: A replicable framework for distinguishing viable adaptive reuse candidates from buildings requiring demolition, potentially preventing unnecessary carbon emissions across thousands of similar structures globally, while establishing comprehensive assessment protocols that integrate historical construction practices with contemporary performance requirements. Financial constraints limited this phase to non-destructive testing (NDT) equipment and available documents at the University of Melbourne. Future studies using advanced scanning and simulation tools will improve data accuracy and completeness, enhancing the assessment framework.

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A MODEL OF SOCIAL VALUE MATURITY FOR BENCHMARKING CONSTRUCTION CONTRACTORS

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The increase in Social Value (SV) prominence has resulted in the availability of a diverse range of tools claiming to measure and compare SV. Public procurement often requires the subjective concept of SV to be quantified for comparison to be undertaken. Yet this reductionist approach arguably offers the illusion of comparison due to the inconsistencies between measurement tools. Such an illusion prevents robust SV comparison occurring and instead furthers the commercial agenda of reductionist SV measurement tools. Tools that prioritise immediate promises over longer term capability. A gap exists for an impartial comparison method that acknowledges the subjectivity of SV and allows comparison to extend beyond simple quantifiable actions to include organisational ability and strategic intention. Through twenty interviews an SV maturity model was developed. The model allows the SV capabilities of organisations to be compared beyond immediately quantifiable outputs and provides a benchmark for best practice. The wider contribution of the model includes providing the construction industry a method of analysing and comparing broad, nuanced, and often diverse SV performance.

Keywords: procurement; corporate social responsibility; sustainability; measurement; maturity

INTRODUCTION

Social value is increasing in importance in UK construction. Since the introduction of the Public Services (Social Value) Act (2012). The Act places a legal obligation on public sector organisations to consider social value as part of their procurement criteria. Construction contractors therefore need to evidence social value to increase their chance of securing public sector works (Watts and Higham, 2021). To help public sector clients transparently evidence their social value comparisons and assist contractors in articulating intended social value delivery, a diverse range of social value quantification tools are available (Skidmore, 2021). Many of these allocate financial proxy values to social value activity essentially assigning objectivist principles to a constructivist concept. Whilst this allows comparison of tender returns to occur, this reductionist approach serves to focus only on the social value contractors claim they can deliver and does not consider contractor capabilities. Nor are these approaches aligned, with different tools assigning different proxy values to the same social value activity (UKGBC, 2020). A gap exists for an impartial reflection and comparison method that acknowledges the subjectivity of social value whilst allowing comparison to extend beyond simple quantifiable actions and include organisational

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capability. A failure to address this gap allows current social value quantification tools to be 'gamed' resulting in unrealistic social value totals that contractors are then unable to achieve. There is also a risk contractors will be successful in procurement based on social value delivery claimed, even if they have no capability, experience (or intention) in doing so.

To address this industry problem and research gap, first this paper introduces the UK construction industry and its procurement requirements. The perspectives of social value from clients, quantification tool providers, and contractors are then explored. Extensive semi structured interviews with industry practitioners result in the proposal of a Social Value Maturity Model (SVMM). The model is then validated in a facilitated practitioner workshop. The contributions of this research are then outlined, along with limitations, proposed recommendations, and next steps.

UK Construction Procurement Requirements

The UK construction industry is one of the most important sectors for employment, infrastructure, and GDP contributions (Nguyen and Luong Le, 2022). In 2023 the value of new construction work was £139,029 million, an increase of 4.2% over 2022 figures (ONS, 2024). The procurement activity undertaken in the industry is therefore of considerable significance. Whilst procurement used to revolve around the criteria of time, cost, and quality, it has been described as the ideal mechanism through which social value metrics can be delivered (Selviaridis *et al.,* 2023). The introduction of the Social Value Act (2012) served to legitimise social value focused procurement criterion. Research has illustrated how since the introduction of the Act, social value has become the difference between procurement success and failure (Watts *et al.,* 2019). The Act is applicable to public sector works, which account for approximately 25% UK construction output (ONS, 2024). Although research has shown that private sector procurement is often influenced by public sector practices (Simcoe and Toffel, 2014). Public sector procurement practices can therefore serve as best practice guidance for the rest of the construction industry.

The successful ability of legislation to drive procurement practices aiding social value delivery has been illustrated by an in depth Northern Irish study of fifty construction contractors (Murphy and Eadie, 2019). However, the difficulty the industry faces is how to compare the social value that contractors can claim to create as part of their project works. The pressure of procurement has forced the subjective phenomena of social value to be considered as an objectivist concept to be quantified and compared. This arguably fits the agenda of public sector clients who need to transparently illustrate their procurement decisions.

A Client's Perspective of Social Value

The Social Value Act (2012) mandated procurement-based requests for social value activity. From a public procurement perspective this serves to empower clients in their request for social value to be included in all tenders. As public sector clients have accountability and transparency requirements, social value tenders need to be easily understandable and comparable (Craven, 2020). As social value is a fundamentally subjective concept, including it within procurement criteria is often problematic.

One study argues that the lack of standardised procurement practices further perpetuates the barriers to embracing social value in procurement (Bernal *et al.,* 2019). Another finds that procurement professionals are sometimes reluctant to

include social value criterion due to its ambiguous nature and potential of legal challenges (Wontner *et al.,* 2020). Quantification allows for comparison, but it has been argued that trying to compare unrelated social value-based initiatives is almost impossible (Kroeger and Weber, 2014). Yet due to the introduction of the Social Value Act, the need for quantification persists.

It is also claimed that the Social Value Act was never intended as an exhaustive regulation of procurement but as guided encouragement for organisations to consider social value (Boeger, 2017). However, it is arguably this light tough approach that has allowed ambiguity to flourish in how the Act is utilised. Procuring organisations therefore require a method of quantifying and comparing social value to discharge their legally mandated procurement obligations. To support such public sector procurement obligations, private sector entrepreneurship has resulted in numerous competing methods of quantifying social value (Skidmore, 2021).

Those Who (Claim to) Quantify and Compare Social Value

A wealth of toolkits and frameworks have emerged since the launch of the Social Value Act. An optimistic view is that all have been launched to help organisations compare and communicate previously difficult to articulate concepts. A pessimistic view is that social value quantification tools are not built upon sound data science yet remain a lucrative market as their use is the difference between procurement success and failure. The usage of such quantification tools is now widespread with it reported that there are over 300 different measurement tools available (Skidmore, 2021). Examples include the Greater Manchester Economy Unt Cost Database (GMEUCD), Social Return on Investment (SROI), Housing Associations Charitable Trust (HACT), Themes Outcomes Measures (TOMS), and Measure Up (UKGBC, 2020). Each utilises financial proxy data that is attributed to different social value outcomes. In essence, they all attempt to provide objectivist solutions to subjectivist initiatives through reductionist approaches. Research has illustrated how such approaches, whilst claiming to allow comparison, serve to limit and restrict the development of social value (Watts and Higham, 2021). However, the reductionist objectivist nature itself is not necessarily a negative, in that such approaches do allow for a common language through which social value can be discussed. However, it is the large areas of inconsistency amongst the leading tools that undermines such tools. For example, TOMS offers a financial proxy value for employing an apprentice as £309.73 per week yet Measure Up attributes the proxy value of £32,700 for each apprentice hired (MeasureUp, 2025). TOMS states that employing a 'local person' would result in £45,722 of social value (Social Value Portal, 2025), yet according to Measure Up this financial proxy value is £42,000, and according to the Manchester Economy Unit Cost Database this proxy value is £45,620 (Manchester Community Central, 2025). TOMS values the upskilling of employees at £13.02 per person per week, Measure Up at £1,100 per year, and GMEUCD at £443.00 per person if the training results in a Level 2 qualification. Such discrepancies raise questions pertaining to the validity of all tools. However, despite such a varied range of values for the same activities, the use of social value quantification tools has increased dramatically over recent years (Skidmore, 2021).

A Contractor's Perspective of Social Value

Most leading contractors now employ social value quantification tools for both procurement and annual reporting purposes (Watts *et al.,* 2024). However, research has shown that different approaches to quantification are being adopted for different

projects (Daniel and Pasquire, 2018). Construction contractors have a central role in maximising social value during project delivery (Raiden and King, 2021). However, earlier work has questioned the authenticity of construction contractors in their social value strategies and communications and posited that some may only engage with social value to gain legitimacy in the eyes of stakeholders (Watts *et al.,* 2019). If this is the case, then accuracy of social value quantification is arguably of lesser importance than the use of a tool itself. Equally, it could be posited that contactors could be more inclined to favour the use of social value quantification tools that attribute higher proxy financial values to social value activity. Somewhat irrespective of proxy accuracy, all quantification tools fail to assess contractor delivery capability. Therefore, a need exists for a more holistic method of social value comparison across organisational behaviours to reflect contractor ability and experience.

Comparisons are currently made on financially quantifiable, yet arguably questionable future promises of social value performance. The comparisons do not consider contractor capabilities and performance, or the inaccuracies of the data used. This leaves a clear gap in both current knowledge and industry practice with the need for the social value performance and organisational behaviours of contractors to be held accountable and comparable. A model may be of benefit to illustrate the social value maturity of organisations. This would aid procurement as clients could stipulate a minimum level of contractor social value maturity. Contributing to this gap will supplement current social value quantification tools and allow for a deeper consideration of contractor performance.

RESEARCH DESIGN

To better understand the current uses and problems of social value quantification tools, the insights of social value practitioners are needed. Purpose sampling was utilised with professionals identified and requested to participate based on their ability to inform the research. A desktop review of company websites was undertaken to identify those with a strong social value presence. Professionals from these organisations were then identified through a search on LinkedIn. Twenty semi-structured interviews were undertaken from across four contractors and two consultants (Table 1).

Participant	Job Role	Experience (years)	Organisation
A1	Social Value Manager	5	Contractor 1
A2	Social Value Manager	2	Contractor 1
A3	Social Value Manager	5	Contractor 1
B1	Social Value Lead	3	Contractor 2
B2	Social Value Co-ordinator	4	Contractor 2
B3	Social Value Co-ordinator	3	Contractor 2
C1	Sustainability Manager	3	Contractor 3
C2	Sustainability Manager	6	Contractor 3
C3	Sustainability Manager	5	Contractor 3
D1	Head of Social Value	7	Contractor 4
D2	Social Value Manager	7	Contractor 4
D3	Social Value Manager	5	Contractor 4
D4	Social Value Manager	1	Contractor 4
D5	Social Value Administrator	1	Contractor 4
E1	Social Value Director	7	Consultant 1
E2	Social Value Consultant	10	Consultant 1
E3	Social Value Consultant	10	Consultant 1
F1	Social Value Director	6	Consultant 2
F2	Social Value Consultant	2	Consultant 2
F3	Social Value Consultant	2	Consultant 2

Table 1: Interview Participants

Each interview was conducted via Teams and lasted between 30 and 60 minutes. Narrative analysis was utilised to structure the interviews. This allowed for questions to be asked from the perspective of a story request, allowing respondents to answer with examples of previous experiences, with information extracted from these stories to elicit a deeper understanding of the topics (Sandelowski, 1991). The interview

questions included "what makes one company stronger than another when it comes to social value?", "can you provide any stories of when you have witnessed companies promising more social value than they can deliver", "how do you currently measure social value", and "have you encountered any problems with social value measurement?". A thematic analysis was then undertaken where the data was reviewed in a systematic manner for identification of emerging patterns helping inform the research (Gray, 2018).

Themes emerged such as 'ability to measure social value', 'awareness of national and international agenda's', 'what good looks like', and 'social value training'. These themes were then mapped out and ranked based on the participant attributed significance. The data was used to understand what experience and ability a contractor needs to effectively deliver social value, and helped construct a model to classify contractor behaviours with regards to social value competency. A draft Social Value Maturity Model (SVMM) was then developed before being validated in a workshop containing three of the interview participants (table 2.0).

Interview Participant	Job Role	Experience (years)	Organisation
A1	Social Value Manager	5	Contractor 1
E2	Social Value Consultant	10	Consultant 1
F2	Social Value Consultant	2	Consultant 2

Table 2: Workshop Participants

All original participants were invited to attend the 60-minute online workshop. The questions asked at the workshop included "does this SVMM accurately reflect organisational maturity levels?", "would this SVMM assist you in comparing yourself and others?" and "where would you place your own organisation on the SVMM?".

FINDINGS AND DISCUSSION

Analysis of the findings revealed several key themes:

The Difficulties and Consistencies of Social Value Quantification Tools
Difficulties have been encountered when trying to measure, communicate, and compare social value by all participants. Participant F3 stated:

> "We often help different clients' draft procurement documents, and analyse received tenders, and without stating exactly what you want for social value, comparing the tenders received is a nightmare".

This was echoed by Participant E1 who commented:

> "Clients often find it difficult to ask for the social value they want so I've seen them leave it up to contractors to propose what they think is best, but without measuring social value, it's impossible to compare what contractors submit".

Such problems were reinforced from a contractor's perspective by participant E2 who argued:

> "I've written loads of tender responses for contractors and a lot of the social value questions asked are so ambiguous it's really hard to know what the client actually wants".

This was also echoed by participant A2 who stated, "trying to complete tenders is always difficult…social value more so…". These points reinforce those in existing literature regarding the variety of approaches social value adopts (Danie and Pasquire, 2018). The findings also confirm studies that illustrated how the lack of standardised procurement practices can hinder social value (Bernal *et al.,* 2019).

Participant F1 reported one method of overcoming any barriers encountered relating to social value comparison was "asking for a financial total the social value they [contractors] will create". This was echoed by participant B3 who revealed:

> "We just stick to numbers and figures…how many apprentices we'll hire, how many schools we'll visit…".

Such findings also confirm that social value initiatives are difficult to compare (Kroeger and Weber, 2014) and align with arguments that quantification tools allow social value initiatives to be communicated and compared (Skidmore, 2021). However, the findings also build further on how contractors purposefully use ambiguous social value terminology in communications to obfuscate inauthentic practices (Watts *et al.,* 2019). Without clear guidance, specific direction, and a severe restriction in social value autonomy, there remains a difficulty in comparing organisations based on their social value practices. The findings also confirmed a gap exists around determining the authenticity and honesty of social value tender submissions as participant D4 revealed:

> "On my current projects I've no idea how we're going to deliver the social value we promised".

This was reinforced by participant 3 who confirmed they had worked on "…many projects where we've not been able to deliver the social value agreed". When discussed further, it was found this was due to the contractor tendering behaviours as participant 3 confirmed:

> "We (Sustainability Managers) feed into the bidding team, but they finalise the bid…often this involves increasing our social value targets in order to win the work".

Any Social Value Maturity Model will therefore need to look beyond potentially superficial and tender based quantified social value responses to the organisational level practices and capabilities of social value.

The Development of a Social Value Maturity Model (SVMM)

The results of the thematic analysis served to inform the development of a social value maturity model (SVMM). The SVMM reconciles the need for social value to evolve, whilst also recognising the 'consistent' of social value across different organisations. The thematic analysis revealed the emergence of several consistent themes, these included education, measurement, and links to broader agendas. All themes were then structured based on their attributed significance in illustrating an organisations social value effectiveness and leadership. Figure 1 illustrates the proposed SVMM. The broad yet detailed nature of the SVMM attempts to overcome the previously articulated reductionist approaches to social value quantification that serve to hinder and limit the concept (Watts and Higham, 2021). Whilst simultaneously allowing a non-reductionist method of social value comparison that helps overcome the described impossibility of comparing organisational social value (Kroeger and Weber, 2014).

The SVMM can serve to address the current gap in knowledge and practice around contractors overclaiming on the social value they can deliver. As in the workshop, participant E2 stated:

> "This would be an ideal model to help clients compare social value [tender] returns…they could specify a minimum [SVMM] level as part of PQQs (Pre-Qualification Questionnaires)".

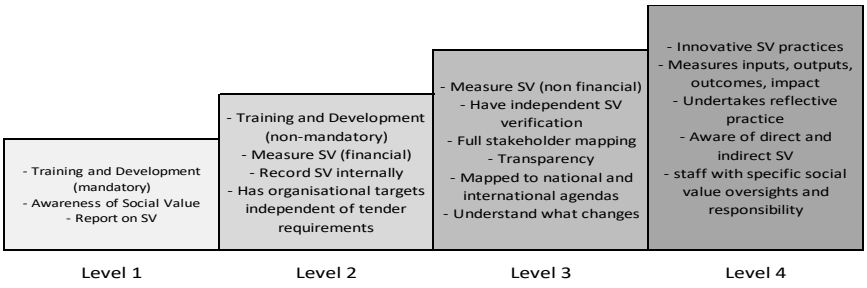


Figure 1: Social Value Maturity Model

Participant F2 also believed that the SVMM could help address the inconsistencies in social value measurement tools:

> "Clients are becoming smarter when it comes to social value…they have less faith in pounds and pence [social value measurement] and are more concerned with actual outputs …the SVMM would help clients…deliver the outputs they want".

How a SVMM Addresses Current Industry Needs

An ongoing evolution in social value was reported by all participants. It was reported that social value had evolved since its introduction, and all participants believed the concept will continue to evolve. Interestingly, whilst initiatives may evolve, the perception of what constituted good and bad social value organisations remained consistent for all participants. This revealed further disdain for current quantification tools as participant B1 stated:

> "Our views of social value have definitely changed over the years… the measurement tools available don't allow us to measure any new or innovative initiatives".

Participant A3 illustrated the changing nature of social value activity:

> "We used to focus on charity donations before my time, then it was hiring students, but now it's all about hiring the unemployed".

The proposed SVMM addresses this by allowing evolution and flexibility of practices if all actions are underpinned by best practice so social value can be effectively delivered. Participant F2 added to this understanding by stating:

> "I have seen contractors change their social value focus…not just to win work, it's also because social value itself changes in response to the needs of people and places".

The SVMM therefore meets the needs of both contractors and clients in allowing a reflection of social value ability to occur, as well as a comparison of contractors' social value capabilities and experience. By setting minimum SVMM levels that must be achieved, the SVMM serves as an effective companion to current social value tender comparisons. This should also reduce social value as a barrier to procurement participation (Bernal *et al.,* 2019), meet the needs of being easily understandable (Craven, 2020) and prevent clients relying on potentially untrustworthy quantification tools in assessing contractor capabilities. The SVMM also answers calls in the literature for a more holistic method of assessing organisational capability of delivering social value impacts and outcomes (Murphy and Eadie, 2019).

CONCLUSION

Social value is fundamentally a constructivist concept, and therefore it can be difficult to compare contractor procurement submissions. To aid such comparisons a range of social value quantification tools are now commercially available that assign proxy financial values to different initiatives. However, such approaches provide an unconvincing reductionist method to social value measurement that prioritises

inconsistent and immediate social value claims over longer term organisational social value capability. A gap exists for an impartial comparison method that acknowledges the subjectivity of social value and allows comparison to extend beyond quantifiable actions to include organisational ability and strategic intention.

Through practitioner interviews and a validation workshop, a Social Value Maturity Model (SVMM) is developed. The model consists of 4 levels that assess and reflect the maturity of a contractor in relation to their social value experience and capabilities. These levels serve as a benchmark of best practice and allow clients to better understand a contractor's ability to deliver social value. The SVMM was well received and addresses the gap of depending upon inconsistent quantification tools in procurement comparisons. It is recommended that the SVMM is piloted in assessing contractor capabilities and utilised in public-sector procurement to better understand its real-world industrial application.

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FROM STRATEGY TO SITE: ADVANCING SOCIAL SUSTAINABILITY IN INFRASTRUCTURE PROJECTS

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This paper investigates how social sustainability is organised and advanced in infrastructure projects, by drawing on 11 interviews and document analyses of a major Scandinavian contractor. The paper applies, and to some extent revises, a social sustainability framework by Valdes-Vasquez and Klotz (2013). Findings highlight strong commitments to safety but reveal gaps in inclusive team formation, stakeholder engagement, and evaluations of social impacts. This paper contributes to the broader discourse on sustainable infrastructure development by stressing the need to tighten governance to curb subcontracting risks and labour abuses, granting project managers greater influence over team selection to boost cohesion and decision quality, engaging communities earlier and more systematically to secure lasting benefits, embedding explicit responsibility for workers and stakeholders in corporate strategy, and replacing ad-hoc practices with rigorous, methodical social-impact assessments.

Keywords: case study; infrastructure; social sustainability; Sweden

INTRODUCTION

Social sustainability issues in the Architecture, Construction, and Engineering (ACE) industry are well-documented, yet persistent, issues that needs continuous addressing from research and practice (Alhammadi *et al.,* 2022). Social sustainability development in relation to infrastructure projects can be especially interesting to study, considering infrastructure's considerable impact on social well-being, in terms of external social sustainability like regional development, accessibility to amenities, equitable travel possibilities, and community cohesion (Sierra *et al.,* 2017), as well as internal social sustainability like work-life balance, job site remoteness, and equality (Alhammadi *et al.,* 2022). Infrastructure projects can ensure equity, accessibility, and decent work, so that every road, bridge, or rail link regenerate community well-being (Thomson and Newman, 2020; Vijayakumar *et al.,* 2024). Infrastructure projects thus play a vital role in contributing to socially sustainable communities and can be a catalyst for wider social sustainability development, such as regenerative cities. Therefore, this paper seeks to understand how social sustainability work can be organised and advanced in infrastructure projects. The purpose is addressed through a single case study of a major Scandinavian contractor's infrastructure division. The paper applies, and to some extent revises, a social sustainability framework by Valdes-

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Vasquez and Klotz (2013), which is useful for contactors to develop their social sustainability work.

Valdes-Vasquez and Klotz (2013) conducted multidimensional scaling and hierarchical cluster analyses of social sustainability parameters, as suggested by experts in academia, industry and government. By doing so they consolidated many disparate processes into one cohesive framework that outlines key social sustainability considerations for the ACE sector. They identified six distinct clusters aimed at increasing practitioners' awareness and guiding them in adopting a more integrated approach to social sustainability: A) Stakeholder engagement; B) User considerations; C) Team formation; D) Management considerations; E) Impact assessment; and F) Place context. Valdes-Vasquez and Klotz (2013) propose that future research should develop this framework to specific empirical conditions. As such, for the purpose of this paper, an extended literature review has been conducted to adapt the framework considering current construction management research, and for the specific nuances relating to the Scandinavian infrastructure context.

The first cluster, Stakeholder Engagement, aims to foster early integration and collaboration among the client, contractor, and public. Despite often viewed as a government duty, businesses are called to take social and environmental responsibility, which requires a structured intervention to sustain continuous participation and communication (Valdes-Vasquez and Klotz, 2013; Vanclay, 2020). Building on interviews and workshops with clients, contractors and sub-contractors, Duryan *et al. (*2020) explain how managing stakeholder expectations and aligning the temporary nature of projects with long-term impacts in construction is challenging due to conflicting interests, and a lack of stakeholder engagement and knowledge transfer. Similarly, in their review of social impact assessment (SIA) research, Vanclay (2020) argues that addressing community concerns early fosters collaboration and long-term project success, but that corporations, like contractors, mainly engage in Corporate Social Responsibility (CSR) and invest in social initiatives to gain public trust and often prioritise corporate benefits over stakeholder welfare.

The second cluster, User Considerations, discusses productivity, safety, health, and security for end users, alongside the necessity of a demonstrably reliable project design. Additionally, attention must be given to the broader community during construction, mitigating disruptions and corruption through structured oversight and intervention. Addressing demographic, gender, and diversity-related issues is essential to promote inclusivity within surrounding communities (Valdes-Vasquez and Klotz, 2013). In a multiple case study of Italian and Swedish bridge projects, Sebastian *et al. (*2013) found that infrastructure projects can significantly disturb surrounding communities, in terms of lack of accessibility and decreased safety, cause noise and dust pollution, traffic disruptions, congestion, delays, and accidents. Infrastructure-related disturbances must be actively managed through planning and communication.

The third cluster, Team Formation, underscores the need for project teams to reflect the diverse composition of the community. The inclusion of local firms and interdisciplinary expertise is important, and Valdes-Vasquez and Klotz, (2013) emphasize how diversity—across dimensions such as profession, gender, ethnicity, and sustainability expertise—enhance adaptability, problem-solving, and ultimately project outcomes. In a systematic literature review that resulted in a classification of 82 sustainability indicators, Stanitsas *et al. (*2021) concluded that sustainable project

management in the ACE sector depends on aligning teams across disciplines and incorporating sustainability project indicators. In a literature review where Owen *et al. (*2010) tried to map the current state and possible future of integrated design and delivery solutions, they contend that early contractor involvement enhances project coherence by leveraging expertise during planning. However, broader adoption of integrated design and delivery solutions remains limited due to challenges in collaboration, workforce skills, and knowledge management. In a cross-national study including interviews with 70 construction workers from different countries, Caro *et al. (*2015) found that temporary labour migration, which has increased since Eastern European countries joined the EU, increase possibilities for diversity in Scandinavian construction projects. However, this has also led to worker exploitation, where migrant workers frequently face social segregation, leading to workplace tensions.

The fourth cluster, Management Considerations, pertains to processes that enhance health, safety, and productivity for temporary and permanent users. These objectives can be achieved by implementing management plans and adopting safety measures (Valdes-Vasquez and Klotz, 2013). In an extensive literature review, Eisenberg and Jabareen (2017) constructed a conceptual framework of social sustainability where they argue that a safe and ethical work environment requires proactive management strategies to mitigate risks, such as negative impacts on individuals and communities, including social polarisation, urban poverty, and climate-related disruptions. Similar, in their conceptual paper, Zwetsloot *et al. (*2017) found that risk assessment is vital for identifying safety hazards and vulnerabilities, and a zero-accident target reinforces the idea that all accidents are preventable, thereby promoting continuous improvement in workplace safety. However, fragmented subcontracting structures, language barriers, and disengagement between office staff and site workers pose challenges. Managers must foster a positive safety culture, where accountability is encouraged, and workers feel empowered to halt unsafe work (Duryan *et al.,* 2020). Stock *et al. (*2018), in their assessment of current Industry 4.0 industrial cases, argue that digitalisation advancements can offer risk management benefits, including improved efficiency and accuracy, but potential risks of such tools must also be acknowledged.

The fifth cluster, Impact Assessments, help identify social issues and risks for affected communities and end users and serves as a tool to identify various challenges associated with the project. SIAs evaluate physical factors, resource distribution, and population shifts that contribute to socio-economic effects (Valdes-Vasquez and Klotz, 2013). Impact assessments promote sustainability by holding projects accountable for their broader effects, but Vanclay (2020) explain that SIAs are often treated as secondary add-ons in projects, limiting their potential. SIAs should be present already in the early phases of any project, as communities are impacted by projects as soon as speculation begins. In a critical review resulting in a conceptual, and quantitatively assessable, definition of social acceptance of energy infrastructure, Cohen *et al. (*2014) propose that while economic and compensatory measures can improve acceptance if projects cause opposition, social considerations—such as public accessibility, mobility, and quality of life—should be integrated early in the project life cycle, so potential impacts to the community can be foreseen.

The sixth cluster, Place Context, emphasizes the significance of the project's specific location, advocating for deliberate design choices. These decisions should foster a sense of ownership, encourage social interaction, and minimise social vulnerabilities for the community, with continuous monitoring to ensure these goals are met (Valdes-

Vasquez and Klotz, 2013). Communities should therefore be actively involved in decision-making to ensure legitimate and accepted project outcomes (Vanclay 2020). However, Yu's and Leung's (2018) survey of stakeholders who participated in public engagement activities, found that engagement is often limited, as project developers focus on approval rather than meaningful participation, which can lead to opposition, participant fatigue, and unresolved community concerns.

METHOD

This study employs a case study approach to capture the lived experiences of professionals working with social sustainability in the ACE sector (Baxter and Jack, 2008). The case organisation, a major Scandinavian contractor, was selected for its strong outspoken social sustainability agenda and industry influence. Researchers were granted workspace access to observe daily operations. The data collection included a document analysis and semi-structured interviews. The document analysis covered publicly available corporate materials, including corporate narratives, governing documents, and sustainability reports, focusing on themes such as labour practices, inclusion, diversity, health and safety, and community outreach. Interviews were conducted in the company's infrastructure division, with six project managers (PM1-6), and five members of the project support function (SF1-5). Participants were purposefully selected for their direct experience with social sustainability work. Thus, the interviewees drew their recollections based on their wide experience working in many different projects rather than a few specific projects chosen by the researchers. These projects ranged from small to large-scale road, tunnel and energy infrastructure projects. Explicitly stating a focus on social sustainability, the interviews focused on team formation and management considerations, strategy and communication, stakeholder engagement, and social impact assessments, emphasising personal experiences over corporate statements. Interviews were conducted either online or in person (March-April 2024), lasted ~1 hour each, and were recorded, transcribed, and analysed. Open-ended questions allowed for exploratory responses (Kvale, 2007).

A thematic analysis was used to identify patterns within the data (Braun and Clarke, 2006). Initial inductive coding, where common patterns of themes were identified, followed the Gioia method (Gioia *et al.,* 2013). After a first coding round where patterns from the empirical data had been identified, the framework by Valdes-Vasquez and Klotz (2013) was applied. At this point it became clear that the clusters proposed by Vasquez and Klotz (2013) could only help to explain part of what was found, but that a consolidation and rearrangement of the clusters helped to further the analysis. The findings helped to group issues together in a way not previously done by the framework, and helped to streamline what issues were tackled jointly, and which were seen as separate issues. The analysis thus progressed through iterative rounds toward more conceptually informed themes and a revised framework. The research team jointly validated coding to ensure rigor. Based on the data analysis, the six clusters from Valdes-Vasquez and Klotz (2013) were rearranged and consolidated into four clusters that better reflected and helped to explain the study's specific context.

FINDINGS

The interviewees emphasized risk mitigation as a core management concern, particularly in health, safety and environment (HSE), which is strictly legislated in Sweden. Proactive risk assessments tailored to site-specific conditions were deemed essential for worker and public safety. In addition, vetting subcontractors and

suppliers is prioritised, with strict pre-qualification requirements on tax compliance, union adherence, and health insurance. While effective, SF2 noted that bureaucracy disadvantages small businesses: “Many are alone in their own company, and they are not running construction machines because they like paperwork” The company’s corporate approach aligns with these concerns, limiting subcontracting to two levels to improve transparency, reduce delays, and curb corruption.

In terms of HSE, interviewees stressed clear communication between project phases, given the hazardous nature of infrastructure projects. While the company promotes worker involvement in safety decisions, final decisions rest with managers. Most respondents saw the company’s corporate vision as clear regarding people-first values, linking success to employee well-being. However, some felt the social sustainability strategy was fragmented, spread across different practices rather than forming a cohesive framework. SF3 described the company’s approach: “We don’t have formal, written procedures for everything. It’s more about taking ownership and ensuring tasks are completed. That approach is both our strength and our weakness”.

Safety policies, while well-intended, are not always effectively communicated, with on-site workers engaging with them less frequently than office staff. While onboarding safety briefings exist, tracking whether workers understand protocols remains a challenge. Safety messages are reinforced emotionally, emphasising: "Make sure everyone can go home at the end of the day!". But cultural differences and language barriers create complications in terms of translation of safety policies and norms, communication, and feedback loops. In response, the company mandates work environment training (OSA) for employees and subcontractors. However, the physical distance between offices and remote sites remains a challenge. Ongoing anonymous surveys now supplement annual feedback meetings to improve communication.

Issues with sexism or racism are said to be continuously decreasing as younger, more socially aware employees join the company. Instead, concerns about workload and work-life balance were more commonly noted, with employees citing excessive hours, disproportionately affecting female employees and those with children. Although post-pandemic flexibility introduced remote work options, it has limited feasibility for location-dependent roles in infrastructure projects. While digital tools like building information modelling (BIM) act as game-changers for accuracy and efficiency, client demand remains low. Digitalisation was also noted to decrease work-life balance, demanding constant availability: “They are working in three shifts, eight hours each. When [someone] is going home for the night and the next guy comes in, [notifications] come at night, in the morning and on the weekend.” (PM3).

Interviewees emphasized that effective teams require diversity, complementarity, and strong interpersonal skills. While technical qualifications are essential, cultural awareness and teamwork were equally valued. However, frustration was expressed over the lack of involvement in team selection. PM5 stressed the importance of ensuring equal participation: “If everyone is a 45-year-old white Swedish-born male, and think roughly the same way, then you won't get the best result. […] It requires a little more when we are a little different, but it will be better if we dare to talk through it.” A lack of women in the ACE sector, especially among craftsmen, was widely acknowledged. Gender-diverse teams were associated with better workplace culture and project outcomes. Interviewees emphasized the need for inclusive job descriptions and a welcoming work environment. While younger generations are

driving a cultural shift, industry norms still present barriers for women. PM3 noted: "It is easier to be a man in this sector, like it is everywhere else as well."

Foreign labour migration was identified as a potential risk, particularly when subcontractors exclusively hire foreign workers. Compliance issues are difficult to track, and incorrect wage payments are more common. SF2 noted: "We have at least one case where the workers didn't get their performance bonus […] They [Many foreign companies] sign the collective bargaining agreement in Sweden, but they don't really understand it." Though often using subcontractors, the company enforces its values strictly, issuing warnings or terminating employment when necessary.

The project-based nature of the sector creates social sustainability difficulties. Because each project is a clean slate, this makes team-building crucial but time-consuming. Managers called for more structured guidance, as current processes rely heavily on individual efforts. Moreover, the mobile nature of infrastructure work creates recruitment challenges, particularly for workers with families. Relocation demands make it difficult for single parents, an issue that has worsened over the past two decades. Some flexibility measures, such as early departures before weekends, have been introduced. Therefore, using local suppliers and subcontractors was seen as beneficial, particularly for remote projects, further improving efficiency. However, local engagement is prioritised only when quality and cost-efficiency are maintained.

Government and local authorities, often represented by clients, play a crucial role in infrastructure projects. While social sustainability criteria are increasingly included in tenders, environmental concerns still dominate. The interviewees noted that costs stemming from social sustainability work are not accounted for, making it difficult to justify beyond contract requirements, in comparison to environmental considerations which more easily justify higher costs. The interviewees acknowledged the challenge of balancing sustainability with competitiveness: "We must still compete with other companies that do not prioritise sustainability and social sustainability as highly as we want to, and we must still compete with them on the lowest price." (PM5).

Community engagement was largely seen as the client's responsibility, with contractors only engaging once the project begins. Clients typically handle pre-project communication, meaning there was a general lack of proactive engagement from the contractor, making it reactive rather than strategic. Internal stakeholder management and communication was also lacking. Although structured communication between office staff and site teams was seen as crucial to reducing project-level stress and workload, project-specific challenges remain isolated, lacking support from upper management. There was also concern over disconnects between design, planning, and execution teams, with calls for improved communication to improve workload distribution. Project follow-ups were considered insufficient, and interviewees felt that knowledge-sharing should be driven by senior management rather than left to project teams. Furthermore, while technical knowledge transfer is being prioritised due to its financial benefits, distribution of social sustainability knowledge remains a challenge. Safety advancements were attributed to effective knowledge transfer, but some interviewees criticised the overemphasis on negative incidents, arguing that positive lessons should be equally acknowledged. Instead, casual discussions among team members are critical to recognise successful practices and areas for improvement.

Despite existing guidelines, structured impact assessments are inconsistently required or practiced. Decision-making on-site is often based on experience and intuition, as

PM3 described: “Normally, your gut feeling is a good guideline if […] you can do it. Of course, we have papers [and] lots of guidelines, and some read them, but some do not”. Corporate-level recruitment goals, especially regarding gender diversity, were defined but lacked consistent tracking. SF1 noted an absence of a cohesive company-wide strategy, with each region operating independently. While environmental impacts are meticulously calculated, social considerations remain secondary, often relegated to community concerns about noise, pollution, and accessibility. An example of this was a local farmer who had a pregnant horse. A member of the team would call the owner before any blasting, so they could take proper precautions for their horse. This was said to provide much goodwill from the local community.

DISCUSSION

Albeit that the purpose of this paper was not to revise Valdes-Vasquez' and Klotz' (2013) framework, this became inevitable as the findings, that are context-specific to infrastructure projects, highlight what facets of the framework is useful and what aspects can be adapted to better fit the nuances of the specific empirical conditions. As such, some clusters have been reorganised and consolidated where relevant, to enhance applicability in this specific context, much like Valdes-Vasquez and Klotz (2013) themselves have asked for. As such, the revised framework has been developed with the support of the empirical data, resulting in four consolidated clusters. In the extended literature review and in the data analysis it became clear that the six clusters proposed by Valdes-Vasquez and Klotz (2013) have many overlaps and common denominators, making distinction between certain clusters difficult. As such, a consolidation and thereby simplification of the clusters into four new, more comprehensive and easily distinguishable clusters is a fruitful development.

The analysis also supports a rearrangement of the clusters, where management considerations come first, as formal work practices and sustainability goals are formulated on the management level. Then follows team formation, as every project is driven by an expedient unique team of people. Then follows stakeholder management, as no project is constructed in a vacuum, but within a community. This cluster also encompasses most aspects found within the 'user consideration' and 'place context' cluster, which thematically relates strongly to stakeholder management and community engagement. Lastly follows impact assessment, which happens in the closing of a project. The revised framework contributes an more context-sensitive and practical guide for contractors, that mirrors the life cycle of a typical project.

In terms of management considerations, the company’s proactive risk assessments and strict subcontractor vetting align with Valdes-Vasquez' and Klotz' (2013) call for thorough management plans to safeguard health, safety, and ethical practices. By assigning clear responsibilities and emphasising continuous communication the organisation reflects a zero accidents ambition, much like Zwetsloot *et al. (*2017) explain. At the same time, interviewees reveal ongoing challenges with language barriers and fragmented site-to-office communication, echoing the need for managers to remain engaged and ensure employees across multiple subcontracting levels feel empowered to report hazards. As such, much like Duryan *et al. (*2020) argue, although safety remains a core priority, the existing gap between office staff and on-site personnel in HSE engagement needs to be addressed. Strengthening on-site management’s role in safety culture would ensure better integration of HSE principles. Although the company’s OSA training is a positive step, its isolated approach to issues like stress and workload limits its impact. Like Stock *et al. (*2018) argue,

digital tools, such as BIM, promise improvements in efficiency and accuracy. Yet employees describe an "always-on" environment that threatens work-life balance, meaning that poorly managed digitalisation may instead undermine well-being. Adding to Eisenberg and Jabareen (2017), stringent administrative demands, which are not necessarily lessened by digital tools, can inadvertently exclude smaller firms, underscoring potential marginalisation. While the company's people-centric philosophy aims to foster inclusion, interviewees suggest that more cohesive procedures might enhance consistency. Thus, tensions remain between robust oversight and inclusivity, as well as between efficiency and overwork. Continued refinement—through transparent communication and balanced technological integration—is thus needed to uphold safe and sustainable conditions.

In terms of team formation, effective teams require socially competent leadership, diversity, and shared goals (Valdes-Vasquez and Klotz, 2013; Stanitsas *et al.,* 2021). Yet, project managers have little influence over team selection, despite being responsible for team dynamics. Allowing them to contribute to team formation would improve collaboration. This aligns with Owen *et al. (*2010), highlighting the challenges of interdisciplinary collaboration and workforce integration in construction. Subcontractors employing entirely foreign workforces pose a risk in relation to safety, social exclusion, wage disparities, and communication, highlighting the need for better integration measures beyond safety (Duryan *et al.,* 2020). This adds to Caro *et al. (*2015) conclusions, that temporary labour migration often results in exploitation. The temporary and mobile nature of infrastructure projects add further complexity to team formation and negatively impacts gender diversity. Gender diversity is linked to better workplace culture and project performance, though infrastructure projects, especially remote ones, still present major barriers for women. These findings echo broader research on the challenges of increasing representation in male-dominated sectors (Stanitsas *et al.,* 2021). Moreover, local engagement is mainly prioritised when it aligns with cost and quality standards. Therefore, more strategic workforce planning, clearer recruitment policies, and stronger labour protections could enhance team cohesion and wellbeing.

In terms of stakeholder management, Owen *et al. (*2010), highlight how early contractor involvement is important for team formation, and the same can be said for stakeholder management. Since only the client is involved in local stakeholder communication in the early stages means that the contractor may fail to garner support and build trust for the project, resulting in limited acceptance of disturbances and higher opposition. This reactive approach contrasts with Vanclay's (2020) best practices, emphasising early and continuous stakeholder involvement to foster long-term project success, reinforcing concerns that stakeholder participation is often treated as a procedural formality rather than a meaningful process (Yu and Leung, 2018). Expanding social impact reporting could perhaps help to mitigate this issue to force more in-depth community engagement. The company's annual reports primarily focus on workforce well-being, suggesting that they assume responsibility for internal benefits rather than wider social responsibility. However, internal stakeholder communication within the company was also identified as an area for improvement. The disconnect between office staff and site teams, as well as between design, planning, and execution teams, created inefficiencies and stress. This reflects Duryan's *et al. (*2020) findings that knowledge transfer in the ACE sector is often fragmented, particularly on social sustainability aspects. Improved knowledge transfer mechanisms could reduce project-based fatigue and strengthen collaboration.

In terms of impact assessments, the company's approach reflects broader challenges in integrating social considerations into project planning. While environmental impacts are systematically evaluated, social impact assessments (SIA) remain secondary, aligning with research that finds SIA often treated as an add-on rather than a core component (Vanclay, 2020). Despite existing guidelines, structured impact assessments are inconsistently applied, with decision-making on-site frequently based on intuition rather than formalised processes. This reinforces Valdes-Vasquez' and Klotz' (2013) concerns that social considerations are often overlooked in early project stages, despite their long-term significance. Since public opposition can begin before projects start (Vanclay, 2020), integrating social assessments in early planning could improve public relations, mitigate resistance (Cohen *et al.,* 2014), and decrease disturbances (Sebastian *et al.,* 2013). While some regional initiatives exist, such as notifying a horse owner before blasting, these efforts are largely ad hoc rather than systematically embedded in project planning. Both Vanclay (2020) and Cohen *et al. (*2014) suggest that early engagement and compensatory measures can improve project acceptance and social integration, yet current company practices appear to be driven more by individual initiative than strategic policy. Tailored, yet systematised, communication strategies and assessment methods could help reduce opposition by explaining project benefits and identifying disturbance mitigation measures.

For contributions, the paper empirically details how social sustainability work is performed within a Scandinavian infrastructure context and illustrates what areas are currently underdeveloped in practice. By answering Valdes-Vasquez' and Klotz' (2013) call to adapt the framework to different empirical contexts, the paper revises the framework accordingly and thereby identifies context-specific challenges and areas of improvement. Areas of improvement include: A) addressing subcontracting challenges, labour exploitation risks, and ethical concerns through more robust governance measures; b) allowing project managers greater influence over team selection to enhance cohesion and improve decision-making, c) encouraging earlier and more structured involvement with affected communities and other stakeholders to ensure long-term benefits beyond compliance-driven initiatives; d) revising corporate strategies to acknowledge responsibility for employees and affected communities and other stakeholders who are often overlooked; and e) shifting from intuitive, ad hoc decision-making towards methodical social impact assessments.

CONCLUSIONS

This paper has exemplified how social sustainability is currently organised within Swedish infrastructure projects and applied and subsequently revised the social sustainability framework by Valdes-Vasquez and Klotz (2013). Comparing the adapted framework with the empirical case highlights context-specific areas of improvement. Future research should consider comparative studies across cases to help identify common factors and develop country-specific frameworks. Also, as this paper excludes perspectives from subcontractors, craftsmen, clients, and the public, future research should explore their perspectives as well.

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ASSESSING THE SALVAGE VALUE OF GREEN COMPONENTS IN MALAYSIAN BUILDINGS

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As the market increasingly values green projects and shows a willingness to pay a premium for sustainable development, developers are leveraging green construction as a competitive advantage. However, most studies have focused on the overall value of green buildings, overlooking the salvage value of green components as an important factor in life cycle costing. This study aims to identify the green office building components best suited to Malaysia's climate and assess the key factors that contribute to the condition of their salvage value not only determined by their performance during the building's operation but also by their salvageable value at the end of its service life. Using questionnaires distributed to quantity surveyors, estate agents, and property valuers, the findings reveal that passive daylighting and natural ventilation are the most suitable components, while service life duration and proximity to disposal regulations are the most critical factors affecting salvage value. This study underscores the role of circular economy strategies in extending the lifespan and reuse of building components, thereby supporting urban development that restores ecological systems and promotes long-term sustainability.

Keywords: green building; green components; life cycle cost; salvage value; sustainable

INTRODUCTION

Building green components involves integrating sustainable design elements and technologies to enhance energy efficiency, reduce environmental impact, and improve indoor comfort. These components utilise natural resources like sunlight and wind while minimising reliance on non-renewable energy sources. Malaysia has been actively promoting sustainable architecture through green buildings that incorporate environmentally friendly components. The Green Building Index (GBI), the country's national green certification system, plays a crucial role in encouraging energy-efficient and eco-friendly construction. Various green components, including passive design strategies, energy-efficient materials, renewable energy systems, water conservation techniques, and smart technologies, have been successfully implemented in Malaysian green buildings to minimise environmental impact and improve occupant comfort.

One of the most effective green components in Malaysia's tropical climate is passive design, which optimises daylighting and natural ventilation to reduce reliance on artificial lighting and air conditioning. The Energy Commission Diamond Building in Putrajaya exemplifies this approach with its diamond-shaped facade, light shelves, and

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double-glazed windows, which enhance daylight penetration while minimising heat gain. This showcases the effectiveness of passive design in achieving substantial energy savings (Suhaimi et al., 2019). Similarly, Menara Mesiniaga in Subang Jaya integrates natural ventilation, vertical gardens, and sun-shading devices, effectively lowering cooling energy demand while improving indoor air quality.

The inclusion of salvage value in Life Cycle Cost (LCC) analysis for green components is a crucial element, as it reflects the potential residual value of the components at the end of their life cycle. While often overlooked, the salvage value can offer significant insights into the overall cost-effectiveness of green technologies. Recent studies have emphasized the importance of incorporating salvage value into LCC assessments to provide a more comprehensive understanding of the financial implications of sustainable solutions (Björklund and Steger, 2022; Branca and Antonucci, 2023). By considering salvage value, decision-makers can better assess the long-term benefits of green technologies and make more informed choices regarding their economic viability (Van Oort and Weijer, 2021; Zhang and Zhao, 2020).

Salvage Value in Building Construction

Salvage value is a critical factor in building construction, affecting both financial and environmental outcomes. In building construction, salvage value refers to the estimated residual worth of a structure or its materials at the end of its useful life. When a building is demolished, renovated, or repurposed, various components such as steel, concrete, wood, and fixtures can retain market value and be resold, reused, or recycled. The demand for reclaimed wood, bricks, and fixtures affects their resale potential, while well-maintained structures with modular components offer more reusable materials (Densley Tingley *et al.,* 2017).

Accurately estimating salvage value plays a crucial role in sustainable construction by helping developers make informed investment decisions, reduce waste, and promote circular economy principles. Ajayi *et al. (*2022) emphasize that assessing salvage value enables cost savings and minimises landfill waste, supporting sustainable construction practices. Similarly, Wang, Li, and Tam (2023) explore salvage value estimation from a circular economy perspective, demonstrating how recovered materials can retain financial worth and be reintegrated into new construction projects. A strategic deconstruction enhances salvage value by increasing material recovery, offering both economic and environmental benefits (Turner *et al.,* 2023; Zaman and Lehmann, 2021). Collectively, these studies underscore that precise salvage value estimation not only enhances financial returns for developers but also significantly reduces construction waste and promotes sustainability in the built environment. Therefore, this study aims to assess the salvage value of green components in Malaysia's green buildings.

METHOD

To investigate the green building components, a factor that contribute to the condition of the salvage value of green building components, and to identify the degree of deterioration of the salvage value of green components, this study adopted a quantitative research approach using a questionnaire survey method. The study targeted professionals involved in the construction, deconstruction, and management of green buildings in Malaysia. A purposive sampling method was used to ensure the

participation of individuals with expertise in green building and material reuse including property valuers, estate agents, and quantity surveyors.

To explore the perceptions and agreement of professionals toward the salvage value of green components in office buildings, a set of structured questions was developed. The questionnaire was designed based on literature, ensuring the data were thoroughly explored. The questionnaire was structured into two main sections. The first section collected demographic information about the respondents on job roles, experience, and involvement in green building projects. The second section of the questionnaire is made up of three questions that are all related to the first, the second, and the third objective. Firstly, respondents were asked to provide a rating scale ranging from 1 (Not Important) to 5 (Very Important) for the building green components. This question aims to obtain professional opinions and practical relevance, enabling more appropriate and effective green building strategies in reducing energy consumption, improving occupant comfort, and supporting the long-term environmental and economic performance of office buildings in Malaysia. Secondly, respondents were asked to rate the factors that contribute to the conditions of the salvage value of the green components of office buildings based on a scale from 1 (Strongly Disagree) to 5 (Strongly Agree). Finally, the study identified the degree of deterioration of green components that have been influenced by several factors. Respondents were asked to rate the percentage of deterioration using a predefined range. This approach allows for the mapping of deterioration trajectories and offers a practical benchmark for predicting service life and planning for reuse or replacement.

A sample size of respondents was determined using Krejcie and Morgan's (1970) sample size determination table. Data was collected through Google e-Forms online survey platform ensuring efficient and wide distribution. A Likert scale of 5 scales (1 = Strongly Disagree to 5 = Strongly Agree) was used to quantify responses, enabling statistical analysis.

All levels of frequency of usage, level of importance, and level of agreement to the statement asked in Likert scale questions and analysed by using SPSS software to generate the result. Cronbach's Alpha Reliability test is to test the data reliability, descriptive analysis and Relative Importance Index (RII) were used to determine the relative importance of each component and factor and, to confirm the ranking from the mean analysis.

DISCUSSION AND FINDINGS

A total of 213 sets of questionnaires were sent out to respondents and 166 were received with complete answers. 56 responses were received from property agents, 30 from estate agents, 63 from quantity surveyors, and 17 from others. Among the respondents, 20 % had 1 year of experience in green building construction, 78% experienced within 1 to 5 years, and 2% of the respondents had 6 to 10 years of experience.

Cronbach's alpha is used to assess the data's reliability after it has been collected and to determine the cohesiveness of a series of elements in a group's relationship by measuring the internal consistency and quality of data.

The reliability of questions regarding the use of green components in Malaysia's green buildings and the evaluation of their condition is 0.780, which is considered more than acceptable since it is higher than 0.7. With 30 components being reliable, this indicates that the questionnaires are valid and dependable for the study.

Table 1: Reliability Test on Identification of green components and evaluation of its condition

Reliability Statistic	
Cronbach's Alpha	Number of Items
0.780	30

Frequency of Use of Green Components

Mean Analysis

Table 2 presents the results of the mean ranking of frequencies of use and importance index (II) of green components in Malaysia's green office buildings based on the project experience of the respondents in Malaysia. The higher the mean value, the higher the frequency of green components being adopted.

Table 2: Frequency of use of green components in Malaysia's green office buildings

Code	Green Component	Frequency (Mean Score)	Importance Index (RII)	Rank
I2	Sufficient daylighting	3.84	0.768	1
I1	Natural ventilation	3.54	0.708	2
E5	Green roof	3.51	0.702	3
W2	Rainwater harvesting	3.48	0.696	4
E3	Wall insulation	3.43	0.686	5
E2	Solar shading	3.41	0.682	6
E1	High-performance glazing	3.32	0.664	7
O1	Passive cooling design	3.20	0.640	8
E4	Solar photovoltaic	3.20	0.640	9
W1	Water efficient fittings	3.20	0.640	10
I3	Sound insulation	3.02	0.604	11

In short, sufficient daylighting was ranked first. It was followed by natural ventilation, green roof, rainwater harvesting, wall insulation, solar shading, high-performance glazing, building passive cooling design, solar photovoltaic, and water efficient fitting. Sound insulation was ranked last.

Relative Importance Index (RII) Analysis

Relative Importance Index (RII) offers a more significant understanding of green component frequency of use. By referring to Table 2's insight:

Top Tier:

I2 - Sufficient Daylighting (RII 0.768): Ranking first, efficient daylight utilisation stands as a widely embraced practice as Malaysia experiences abundant sunlight throughout the year. This contributes to cost-effectiveness, natural aesthetic appeal, and the ability to enhance occupant well-being. Studies in Malaysia have shown that well-designed daylighting reduces electricity consumption by up to 30% in office buildings (Aziz *et al.,* 2022). I1 - Natural Ventilation (RII 0.708): Following closely, natural ventilation underscores the industry's commitment to passive strategies for energy reduction and indoor air quality improvement. Suitable cross-ventilation and passive cooling can improve indoor comfort and reduce dependency on air conditioning, which accounts for nearly 60% of energy use in Malaysian buildings (Zhai *et al.,* 2023). E5 - Green Roofs (RII 0.702): The third in ranking is green roofs. Green roofs are gaining attention in Malaysia as they help mitigate the urban heat island effect, improve insulation, and manage stormwater runoff during heavy rains (Li *et al.,* 2022) in Kuala Lumpur in particular has been promoting green roof adoption to address overheating in high-density areas.

Promising Mid-Range:

W2 - Rainwater Harvesting (RII 0.696): Rainwater harvesting is also highly relevant due to Malaysia's frequent rainfall, making it a practical solution to reduce dependence on treated water and promote water conservation, especially in urban-centre facing water shortages (Ghaffarian Hoseini *et al.,* 2023).E3 - Wall Insulation (RII 0.686): Its critical role in reducing energy demand for heating and cooling reinforces its adoption. Wall insulation is crucial in tropical climates to reduce heat transfer, thereby improving thermal comfort and reducing air conditioning loads (Fabbri and Tronchin, 2023). E2 - Solar Shading (RII 0.668): Solar shading is widely used in Malaysia to limit solar heat gain, particularly in office buildings and high-rise residences.

Balance and Context:

The remaining components, with RII values between 0.664 and 0.604, highlight the importance of balanced decision-making. High-performance glazing plays a similar role by minimising heat gain while allowing natural light, making it essential for commercial buildings in Malaysia's urban areas (Tadeu *et al.,* 2022). Solar photovoltaic (PV) systems rank lower due to the high initial investment and space constraints, despite Malaysia's strong solar potential. Water-efficient fittings, though beneficial, have a lower impact on energy savings compared to other measures. However, Malaysia's Green Building Index (GBI) promotes their use in sustainable building certifications (Zhang *et al.,* 2023). Sound insulation, ranked last, is important for occupant comfort but does not directly impact energy efficiency, which is a higher priority in Malaysia's sustainability efforts (Park and Lee, 2023). Overall, the ranking reflects Malaysia's climate conditions, energy challenges, and the increasing emphasis on sustainable building practices.

Factors Contribute to the Condition of Green Components' Salvage Value

Assessing the salvage value of green office building components is crucial for sustainability, cost efficiency, and circular economy practices. This study focuses on five key factors that contribute to the conditions of green office building components' salvage value in Malaysia. Those factors usage years, frequency of usage, maintenance needs, hazardous material, and disposal limits as they directly influence a component's resale potential and reuse viability.

Table 3 shows the result of the factors contributing to the condition of green components' salvage value through mean ranking and relative importance index (RII). The degree of agreement among respondents increases with an increased mean value.

Relative Importance Index (RII) Analysis
The Relative Importance Index (RII) values ranging from 0.638 to 0.696 indicate that these factors have a moderate level of importance in influencing the studied outcome. While they are not among the most critical factors (RII $\geq$ 0.80), they still play a significant role. Values closer to 0.696 suggest a stronger influence within this range, whereas those near 0.638 indicate a lower but still notable impact.

Usage years (F1) (RII 0.696), take the top spot in the list of the factors. Longer operation equates to greater wear and tear, diminishing value. Condition determines structural integrity and refurbishment costs (Akinade *et al.,* 2017), while age affects durability, although it is a high-quality material (Chileshe *et al.,* 2022). Second is disposal limit (F5) (RII 0.690), approaching disposal restrictions lowers a component's desirability and marketability, impacting its potential worth. Conversely, premature disposal of components before they reach their optimal end-of-life can lead to

increased waste and reduced salvage opportunities. Therefore, strategic planning of disposal limits is essential for maximising the economic and environmental benefits associated with green building components. Followed by hazardous material generation (F4) (RII 0.666), as the presence of hazardous materials complicates handling and disposal, deters buyers, accelerates deterioration, and lowers overall value (Nasir *et al.,* 2021). The frequency of usage (F2) (RII 0.640) also influences wear, with low-usage components, such as solar panels, retaining higher resale potential (Giorgi *et al.,* 2023). Lastly, maintenance (F3) (RII 0.638) plays a crucial role in determining the salvage value of green components, as a well-documented maintenance history enhances salvageability by minimising refurbishment needs (Nußholz *et al.,* 2019). By focusing on these factors, the study provides a practical, data-driven approach to maximising financial returns, minimising waste, and promoting sustainable construction.

Table 3: Factors Contribute to the Condition of Green Components' Salvage Value

Code	Factors	Frequency (Mean Score)	Importance Index (RII)	Rank
F1	The condition of the green component will decline as its usage years increase.	3.48	0.696	1
F5	The condition of the green component will decline as its disposal limit increases.	3.45	0.690	2
F4	The condition of the green component will decline as it starts to generate hazardous material.	3.33	0.666	3
F2	The condition of the green component will decline as its use frequency increases.	3.20	0.640	4
F3	The condition of the green component will decline as its need for maintenance increases.	3.19	0.638	5

The Degree of Deterioration of Salvage Value of Green Components with the Impact of Above-Mentioned Factors

Identifying the degree of deterioration in green building components involves comparing their current condition against their original (as-installed) condition. The respondents were asked to quantify in percentage how much total deterioration occurs in the salvage value of green building components by considering all contributing factors (above mentioned). This is important because the green components are possible to be reused, recycled, or resold if their condition and value are still viable. This allows asset managers, quantity surveyors, and sustainability consultants to better predict the component value, decide for the replacement or reuse, and estimate life cycle cost. The respondents were asked to rate the deterioration percentage based on the condition description in Table 4.

Table 4: Deterioration Condition Description

% Deterioration	Condition Description
1% to less than 5%	Like new, minimal signs of wear
5% to less than 10%	Minor wear, still fully functional
10% to less than 15%	Moderate wear, early signs of inefficiency
15% to less than 20%	Functional decline, possible repair needed
20% and above	Major deterioration, likely replacement required

Relative Importance Index (RII) Analysis

The analysis uses the RII cut-off value (Holt, 2014) as shown in Table 5 to determine the level of impact of factors on the salvage value of green components.

Table 5: RII Cutting Values

RII Range	Interpretation
0.80 -1.00	Very High Impact
0.60 - 0.79	High Impact
0.40 - 0.59	Moderate Impact
0.20 - 0.39	Low Impact
0.00 - 0.19	Very Low Impact

The results of the analysis in Table 6 show that components that have experienced a deterioration of 15% to less than 20% (C5) (RII = 0.610) are under the very high impact category. This means that the component has a significant decrease in salvage value. Deterioration of 20% and above (C6) (RII = 0.586) are included in the high-impact category and this supports the fact that deterioration exceeding 15% means that the component is at a critical level. On the other hand, components that have no change (C1) (RII = 0.325) are in the low-impact category and thus have a minimal impact on their salvage value. This category of factor impact levels can help in identifying the priorities and needs to maintain green components at a level below the 15% deterioration mark to maintain their economic and environmental value. Confirming that components in original condition retain maximum salvage value and pose minimal environmental disposal concerns (Zhou *et al.,* 2019).

Results show a clear relationship between the condition of green components and their salvage value. The physical and functional condition of these green components will gradually deteriorate, which will be influenced by factors such as due to aging, frequency of use, or inadequate maintenance. The study shows that when the component deterioration reaches 15-20% and above, there is a significant decrease in salvage value. At this stage, green components show the beginning of serious wear and tear, such as corrosion of metal fittings, cracks in cladding panels, or reduction in energy efficiency in insulation materials. Supported by Tam *et al. (*2020) stated that this reflects a tipping point where the material's performance, safety, and reuse potential are significantly affected. This means that the potential for reuse or resale is decreasing. This is because the components have started to show physical and functional deterioration, reducing performance, aesthetic value, and lack of potential for reuse. This reflects the point at which recovery and reuse become less economically viable. In addition, by this stage, components may be nearing end-of-life, with diminished recovery or recycling prospects (Ghosh *et al.,* 2021). Therefore, components in this condition are more likely to be discarded or recycled as scrap items. This clearly shows that it is important to manage the condition of green components over time and maintenance strategies to maintain their economic value at the end of life. Furthermore, factors such as the generation of hazardous materials and disposal constraints further exacerbate the decline in salvage value. In the context of a circular economy, preventing components from degrading into this range is essential to extend product life and maintain residual value.

Table 6: Degree of Deterioration of Salvage Value of Green Components with the Impact of Above-Mentioned Factors

Code	Condition	Frequency (Mean Score)	Importance Index (RII)	Rank
C5	Condition of green components declines from 15% to less than 20%	3.66	0.610	1
C6	Condition of green components declines at 20% and above	3.52	0.586	2
C4	Condition of green components declines from 10% to less than 15%	3.37	0.561	3
C3	Condition of green components declines from 5% to less than 10%	2.70	0.450	4
C2	Condition of green components declines from 1% to less than 5%	2.20	0.366	5
C1	Condition of green components remain the same.	1.95	0.325	6

CONCLUSION

In conclusion, the use of passive daylighting and natural ventilation has been identified as key components of green office buildings in Malaysia. It is an important step towards improving sustainability in the construction industry. These components are well-suited to the Malaysian climate, where abundant sunlight and natural airflow can be harnessed to reduce energy consumption, improve indoor air quality, and enhance occupant comfort. Passive daylighting minimises the need for artificial lighting, reduces energy demand, and reduces operating costs, while natural ventilation reduces the reliance on mechanical air conditioning systems, leading to energy savings and a more comfortable and healthier indoor environment. More importantly, the long-term sustainability of these components is closely linked to their salvage value, which plays an important role in advancing the principles of the circular economy. This study has found that several factors influence the condition of these green components to maximise their effectiveness and salvage value. Therefore, it is important to consider factors, including component age, disposal limits, potential for hazardous material generation, frequency of use, and maintenance costs. These components should be prioritised in both new construction and renovation projects to increase life cycle value and promote resource efficiency. With continuous innovation, supportive policies, and sustainable design practices, Malaysia's commitment to a greener construction industry is strengthened by implementing a circular economy strategy.

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Index of Authors

A

Abadi, M, 743, 753
Abdullahi, A, 19
Abdullahi, M, 19
Abdulrahman, R S, 19
Abiodun, O, 753
Aboagye-Nimo, E, 309, 792
Adah, C, 369
Aderibigbe, A, 181
Adinyira, E, 319
Agoi, O, 763
Agyemang, E A, 319
Ahn, C, 409
Aigbavboa, C, 297
Alex, S, 931
Alghaseb, M, 461
Ali, A, 1011
Ali, A S, 772
Allinson, M, 617
Aminian, E, 701
Amoah-Korsah, A, 597
Ansari, A, 399
Aravindakshan, A K, 222
Ashokkumar, A D R, 921
Asnaashari, E, 79
Ayer, S, 159
Ayhan, M, 617
Ayinla, K, 557

B

Baguley, P, 951
Ballal, T, 267
Belayutham, S, 419
Bosch-Sijtsema, P, 862
Bowen, P, 329
Boyd, P, 29
Bradley, J G, 200, 277, 359, 589, 721
Bradley, James G, 629
Brett, R, 287
Bridgeman, J, 711
Bronke, J, 782
Brooks, T, 169
Bruce, C, 339
Bruce, P, 339
Bui, N, 89, 99
Buser, M, 822, 871

C

Cevikbas, M, 69
Che Ibrahim, C K I, 419
Chen, Y, 210
Cheung, C M, 409, 419, 448
Chevrier, Q, 39
Chigangacha, S, 89
Chileshe, N, 49
Chinyio, E, 369
Chiponde, D B, 309, 792
Chow, V, 349
Christensen, C C, 782
Çidik, M S, 349
Coenen, T, 577
Costin, G, 900
Curran, M R, 359, 567

D

Daniel, E I, 369
Darvish, A, 802
Dasandara, M, 232
Davletbayeva, D, 59
Day, K, 981
de Gier, A, 822, 871
De Marco, A, 512
di Napoli, C, 512
Dickson, D, 535, 812
Dikmen, I, 69
Dini, A, 79
Donchev, T, 639

E

Edwards, D J, 429
Ejohwomu, O, 753, 951
Elghaish, F, 169
Emuze, F, 369

F

Fagerlund, B F, 1000
Faiz, Z, 772
Farhan, M, 910

Fatourehchi, D, 981
Fenn, P, 701
Filtane, A, 369
Fong, D, 210
Franz, B, 159
Frederiksen, N, 782, 822, 871
Fredslund, L, 190
G
Geekiyanage, D, 832
Ghansah, F, 597
Giddings, B, 842
Gilmour, S, 379
Gledson, B, 792
Goodier, C, 557
Gottlieb, S C, 822, 871
Govender, R, 329
Greenwood, D, 792
Grosse, H, 852
H
Haines, S, 409
Harding, D, 29
Harrison, A, 277
Hartmann, A, 577
Hasan, A A B A, 701
Hassan, A K, 891
Hellsvik, S, 862
Henjewele, C, 89, 99
Herath, N, 981
Holmegaard, R, 822, 871
Hrymak, V, 339
Huang, J, 743
Hunter, G, 639
Hussain, A, 419
Huynh-Xuan, T, 99
I
Ibrahim, H A, 89
Ismail, S, 419
Iyiola, C, 369
J
Jade, M, 49
Jain, M, 309
Jefferies, M, 842
Jeong, J, 409
Jeppesen, R D, 129
Johnston, J, 339
Jørsfeldt, L M, 129
Justesen, L, 129
K
Kaima, A, 503
Kajewski, S, 731
Karunasena, G, 648, 900, 921, 961
Kavishe, K, 503
Keane, C, 389
Kifokeris, D, 971
Kim, D, 409
Kissi, E, 297
Kiwia, N, 222
Klitgaard, A, 129
Koch, C, 547, 822, 871
Köhler, J, 522
Konanahalli, A, 59
L
Lange-Kornbak, D, 891
Laustsen, C, 190
Lee, D, 409
Liu, C, 921
Liyanage, A, 832
M
Ma, X, 981
Madsen, H K, 782
Mahamadu, A-M, 419
Mahmud, A T, 222
Manege, S L, 222
Mangvwat, J S, 721
Manu, P, 409, 419, 753
Maqbool, R, 951
Maxwell, D, 232
Maytorena-Sanchez, E, 242
McElwee, A, 200, 629
McMahon, E, 589
Mendis, P, 981
Mireku, E K, 297
Mjörnell, K, 971
Moda, H M, 399
Moghayedi, A, 39
Mohamad, M Z, 419
Mohammadkhani, R, 639
Mohandes, S R, 139, 149, 409, 448
Moloney, D, 359
Morgan, J, 557
Moyo, T, 120
N
Nadeetharu, M B K, 900
Nazif, A, 597
Ngo-Thanh, T, 99

Norhanim, Z, 772
O
O'Connell, K, 277
O'Neill, A D, 567
O'Neill, T, 471, 481
Oguntade, A, 763
Okafo, C, 399
olde Scholtenhuis, L, 109, 577
Oshodi, O, 369
Osorio-Sandoval, C, 910
P
Papadopoulou, T, 639
Perez, P, 419
Prabhakaran, A, 419
Q
Qazi, K, 149
R
Rahbarimanesh, A, 149, 448
Raliile, M, 438
Ramabodu, M S, 120
Ramadhan, Y, 688
Rangarajan, R, 399
Rashidi, A, 232
Rasool, S, 210
Rebuglio, M, 512
Redmond, C, 129
Rillie, I, 429
Riyadh, A-A, 961
Rogerson, R, 842
Rong, X, 139
Rose, T, 731
S
Samsudin, S, 419
Samuel, D, 617
Sarvari, H, 429
Schmidt III, R, 557
Sedevich-Fons, L, 658
Seidu, R, 597
Selman, A D, 607
Senarath, N B, 648
Sepehri, M, 617, 802
Serra, P V, 981
Sheng, Y, 149
Sherratt, F, 159
Sherratt, S, 159
Shooshtarian, S, 648
Smallwood, J, 438
Smith, S D, 379, 941
Sobowale, M, 169
Soltani, S, 232
Soman, R K, 109
Spillane, J P, 200, 277, 359, 389, 471, 481, 491, 567, 589, 629, 721
Strachan, S, 287
Straub, A, 931
Sunkari, S R, 941
T
Tao, Z, 951
Temby, E, 49
Tennant, S, 59
ter Huurne, R, 577
Thirumal, S, 961
Thuesen, C, 522
Tokbolat, S, 910
Tracey, M, 491
Tree, M, 287
Troje, D, 971
Troye, D, 1000
Truong, H Q, 99
Tuuli, M M, 668
U
Udawatta, N, 648, 900, 921, 961
Udeaja, C, 210
Umeokafor, N, 181
Umi-Kalsum, Z, 772
Upadhyay, Y, 181
Urquhart, S, 678
V
Verdonck, E, 607
Vohmann, B, 287
W
Wade, F, 379
Watts, G, 991
Webb, L, 349
Wheeler, D, 731
Whyte, A, 678, 688
Windapo, A, 369
Wisse, S E, 1000
Woodier, D, 522
Y
Yaghoubzadehfard, A, 981
Yakubu, K, 329
Yeow, J, 743
Young, B, 597
Yunusa-Kaltungo, A, 409, 419

Z

Zakaria, N, 1011
Zhang, L, 242
Zhao, Y, 242
Zolkafli, U K, 1011
Zou, J, 139, 448
Zulu, S, 503
Zungu, Z, 255

Index of Keywords

A

action research, 534, 933
active blended learning, 642
adversarialism, 187
affordable housing, 590
aging concrete buildings, 1028
AI adoption, 61
algorithm, 92
Analytical Hierarchy Process, 985
apprenticeship completion, 613
artificial intelligence, 50, 61, 72, 82, 92, 165
Australian Securities Exchange, 708
authentic assessment, 642
autoethnography, 893
autonomy, 763
auto-scheduling, 92
awareness, 50

B

benchmarking, 708
big five inventory, 501
blame culture, 417
blockchain technology, 124
BREEAM, 839
buildability, 655
building design, 243
building information modelling, 19, 40, 61, 144
building materials, 777
building obsolescence, 807
building production, 922, 1016
buildings, 882
built environment, 396, 613
bureaucracy, 893

C

case study, 448, 1047
categorisations, 665
causal loop diagramming, 871
causality, 697
cause of incidents, 448
challenges, 458, 829
ChatGPT, 82
circular business model, 913
circular economy, 777, 798, 942, 964, 1005, 1016
city centre, 882
civil engineering, 396
classification, 600
climate change, 829
climate footprint, 1016
collaboration, 187, 197, 438
collective action, 860
collective institutional entrepreneurship, 860
commercial buildings, 995
community, 882
community engagement, 752
complex product-service systems, 253
condom use, 343
conflict, 501
conflict management, 675
construction, 134, 233, 309, 438, 458, 481, 491, 621
Construction 4.0, 102
construction and demolition waste, 942
construction and demolition waste management, 964
construction circular economy, 144
construction contract, 187
construction contract risk management, 219
construction industry, 19, 50, 61, 279, 289, 731, 798, 913, 1005
construction management, 922
construction manager, 354
construction pedagogy, 632
construction planning, 72, 208, 534, 655
construction practices, 187
construction project management, 92
construction project management education, 642

construction projects, 675
construction safety, 428
construction safety management, 468
construction sector, 386
constructs, 964
context, 113
contract law, 850
contract management, 197
contracting, 267, 655
contractor selection, 731
contracts, 219
control, 686
corporate social responsibility, 1038
cost, 124
cost estimation, 995
cost management, 19
course evaluation, 632
critical race theory, 279
critical success factors, 697
cross-border, 233
cross-national comparison, 428
D
data analytics, 19
data management, 1005
data readiness, 61
decarbonisation, 985
decoupling, 818
defects, 665
demolition, 807
Denmark, 134
design decision-making, 243
Design for Safety, 438
design framework, 243
design stage, 942
developing countries, 102
diffusion of innovation, 102
digital technologies, 102, 468, 1005
digital technology, 72, 144, 386
digital transformation, 787
digital transition, 124
digital twin, 19, 113, 154, 175
digitalisation, 30, 40, 428, 933
digitalization, 197
disability inclusivity, 309
disagreement, 491
dispute, 491, 501
diversity and inclusion, 279
Drive-In Drive-Out, 374
E
EDI, 289
education, 299
embodied carbon, 953
emerging technologies, 309
employee wellbeing, 374
energy-yield, 718
environmental product declarations, 839
environmental professional, 903
environmental work, 903
Erasmus+, 632
errors, 665
ethical frameworks, 30
ethnic females, 279
EU regulation, 818
F
failure-modes, 718
functions, 481
G
GenAI, 30
gender, 299
gender balance, 289
generative AI, 82
Germany, 893
global warming potential, 953
good faith, 187
governance, 708
governmentality, 742
grand challenge, 860
green building, 850, 1059
green building law, 557
green components, 1059
green transition, 299
H
health and safety, 386, 458
historical construction, 1028
HIV/AIDS, 343
house building, 579
houses, 579
housing, 569
housing for all, 590
I
implementation, 913
incident, 417
India, 233, 323
indicators, 964
Indonesia, 718

industrialisation, 569
industry 4.0, 468
Industry 4.0, 134, 787
informal training, 323
infrastructure, 1047
innovative pedagogies, 642
insolvency, 708
institutional demand, 818
institutional entrepreneurship, 829
institutional theory, 197, 933
integration, 600
interaction, 406
interdisciplinary collaboration, 632
inter-firm conflict, 731
International Joint Venture, 686
intragroup conflicts, 675
Ireland, 374
K
knowledge management, 512, 942
L
leadership, 279, 364
leadership transition, 512
legal frameworks, 557
legal text analysis, 219
levels of detail, 40
life cycle assessment, 839, 953
life cycle cost, 1059
literature review, 600
low tender pricing, 731
low-carbon transport, 985
M
maintenance, 175
maintenance planning, 807
Malaysia, 438
male clients of female sex workers, 343
male construction workers, 343
management information systems, 534
material and component reuse, 1016
material tracking, 1005
maturity, 113, 1038
maturity model, 787
measurement, 1038
measurement workshop, 621
measures, 448
mental health, 406
mereology, 600
misalignment, 491
miscommunication, 82
MMC, 579
modular construction, 590
modularity, 544
motivational factors, 942
N
narrative, 267
natural language processing, 219, 839
nature, 882
near miss, 417
necessity, 697
necessity conditions analysis, 697
net positive impact, 922
net zero buildings, 154
net zero energy buildings, 154
O
O&M-framework, 718
occupational safety and health, 428
operational feedback, 243
opportunities, 829
organisational change, 364
organisational collective, 860
organisational culture, 208
organisational resilience, 267
organisational response, 818
OSH, 428
over-dimensioning, 933
P
pedagogy, 621
performance, 458, 686
personality traits, 501
placemaking, 396
planetary boundaries, 922
planning, 544
plasterboard, 777
PMO, 481
policy, 396, 579
policymakers, 579
positive discrimination, 289
practice, 903
predictive, 175
procurement, 1038
productivity, 208, 655
professional practices, 30
project cost management, 124
project governance, 763
project management, 208, 534, 655
project manager capability, 763
project performance, 697
project planning, 731

project stakeholders, 675
project success, 697
project type, 763
project-based organisation, 829
public private partnership, 525
PV-power, 718
Q
Qatar, 233
quality, 665
quantity surveying, 621
R
readiness, 50
refurbishment, 544
regeneration, 922
regenerative cities, 871, 953
regulatory adaption, 364
reporting culture, 417
reporting hesitancy, 354
research methods, 850
researcher bias, 613
responsible project management, 253
retrofit assessment, 1028
retrofitting, 953
reuse, 777
rework, 665
risk, 534, 850
S
safety culture, 323
safety management, 448
salvage value, 1059
Saudi Arabia, 481
science mapping, 144, 468
scientometric analysis, 219
semantic similarity, 839
silo effects, 913
site control, 113
skills shortage, 299
small businesses, 893
smart hospital system, 253
SME, 481
social cost of carbon, 995
social housing, 590
social sustainability, 1047
social value, 742, 752
socio-technical, 175
South Africa, 267, 386
South Australia, 50
spaces, 882
stakeholder behaviour, 964
stakeholder salience, 675
stakeholders, 655, 798
standardisation, 655
steel, 777
strategic management, 512
strategic planning, 512
strategy-as-practice, 267
student co-creation, 642
sufficiency, 697
sustainability, 102, 396, 590, 798, 807, 818, 850, 860, 933, 995, 1038
sustainability education, 632
sustainability governance, 557
sustainability indicators, 985
sustainable, 1059
sustainable certification, 893
sustainable design, 253
sustainable procurement, 752, 839
sustainable transport, 985
Sweden, 569, 1047
symbolic action, 913
synthesis, 600
systematic literature review, 92, 144, 406, 468, 525
systems thinking, 871
T
technical competencies, 30
technology, 165
technology innovation system, 569
technology integration, 92
technology transfer, 134
temporary accommodation, 374
tendering, 208, 708
tendering process, 731
tensions, 903
time, 72, 124
training, 613
tripartite, 438
trust, 686
tunnel construction, 40
U
UK construction law, 557
unskilled labourers, 323
upscaling, 1016
urban planning, 871
urban resilience, 871
use case, 165
utilities, 113
utility strike, 448

V

value for money, 525
Virtual Reality, 233
virtual twin, 154
vocational education, 613
VR, 233

W

Wales, 798
well-being, 406
well-being goals, 742
whole life costing, 995
work expectations, 903
worker welfare, 752
workers, 165
work-life balance, 374
workplace accident, 417
workplace stress, 354
written communication, 82

Z

zero carbon buildings, 154