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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 - 38th Annual ARCOM Conference

Dr Apollo Tutesigensi, University of Leeds

It was a great privilege for me to edit these Proceedings of the 38th Annual ARCOM Conference. The Conference Organising Committee, Conference Secretary and I hope that these Proceedings provide readers with opportunity to improve and increase their knowledge and research and, altogether, contribute towards shaping construction management practice and/or research journeys.

In the process of organising the 38th Annual ARCOM Conference, we received abstracts and papers from a broad range of authors from a broad range of countries reporting research carried out over the last few years on a broad range of topics. The long-standing popular themes of sustainable construction; health, safety, and wellbeing; planning, productivity, and quality; and information management and technology continue to be areas of significant research activity.

However, in these Proceedings, we also see growing research in areas such as construction contracts; equality and diversity; construction technology; infrastructure development; pedagogic research in construction management and engineering; and human resources management. This suggests that despite the global challenges we faced in the last two or three years, construction management research continues to grow and thrive. May this continue to encourage us to seek to create knew knowledge wherever it may be required.

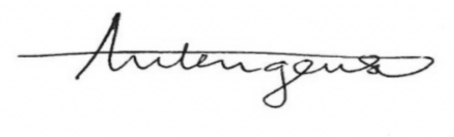
The conference theme of 'build back wiser' was conceived in the wake of global realisation of the need to accelerate our responses and readiness for global issues such as climate change, pandemics, and geopolitics. It was aimed at signposting the need to be reflective practitioners and challenge the often 'taken-for-granted' ideas in our quest to contributing towards innovations required to address the global issues. Many papers in these Proceedings have reflected on this theme in subtle ways. Yet, this theme is not for the 38th Annual ARCOM Conference only. It is a theme on which we should continue to reflect as we read the papers, critique the papers, and build on the papers in our future research, publications, or practice.

The Proceedings came together because of the work of many individuals. My co-editor, Dr Chris Neilson organised, liaised, copy-edited, and sometimes nudged. Cath O'Connell dealt with all IT matters ever so promptly. The Organising Committee reviewed all the 256 abstracts received and joined the Scientific Committee to review papers at both initial and final review. The 105 members of the Scientific Committee reviewed several papers at both initial and final review stage. Professor Libby Schweber, Dr Vivien Chow and Professor Paul Chan offered help at very short notice and got me out of pickles on several occasions.

Of course, we could not have papers or Proceedings without authors. The authors were determined to go through the multi-stage review processes and reflect on critical-friends' comments, questions, and suggestions – many of which were really challenging! A measure of our authors' resilience is in the fact that from 256 abstracts, we received 163 papers and, hopefully for our readers' pleasures, herein publish over

100 papers. I am indebted to all the above for making these Proceedings of the 38th Annual ARCOM Conference happen!

I wish everyone enjoyable reading!



Dr Apollo Tutesigensi

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The success of the Annual ARCOM Conference depends on the voluntary efforts of the members of both the ARCOM Committee and our international Scientific Committee. We are indebted to the members of both committees who together provided rigour and constructive feedback in the peer-review process.

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BUILDING INFORMATION MODELLING AND DIGITALISATION

ORGANISATIONAL CULTURE IN BUILDING INFORMATION MODELLING MATURITY RESEARCH: A BIBLIOMETRIC ANALYSIS

Sonali Alankarage[1], Nicholas Chileshe[1,2], Aparna Samaraweera[1], Raufdeen Rameezdeen[1] and David J Edwards[2,3]

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Building Information Modelling (BIM) has gained a traction in the construction industry, driven by the plethora of benefits of its usage. Because of the differences in BIM maturity, not all organisations benefit equally from BIM. Organisational culture is vital in stimulating the growth of BIM maturity and is frequently considered a critical element in BIM maturity model. This study takes a bibliometric approach to reveal the focus and emerging trends of BIM maturity and culture research. VOSviewer software was used to map keyword co-occurrence and Scopus database was searched for keywords related to culture and BIM. The number of publications in the discipline ascended between 2012 and 2021, with the UK producing majority of the articles. Keyword cluster analysis highlights five research themes: research on BIM adoption, basic management, safety culture, waste management, and pure culture. According to the content analysis of the papers organisational culture is considered either as a variable or a root metaphor.

Keywords: bibliometric analysis; BIM; maturity; organisational culture; VOSviewer

INTRODUCTION

Building Information Modelling (BIM) is a collection of interconnected policies, processes, and technologies that produce a methodology for managing critical building project and design data in digital format throughout the building's life cycle (Succar, 2009). The potential of BIM extends beyond technological aspects and fosters new ways of thinking along with a shift in the way processes and activities are carried out across all phases of construction projects (Sebastian and Van Berlo, 2010). Given BIM in Construction is a fast-growing area, still, its full utilisation in construction organisations remains limited. Despite the benefits of cost reductions, improved productivity, and collaborations, the level of improvement in BIM deliverables and services varies from organisation to organisation, as does their BIM

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Alankarage, S, Chileshe, N, Samaraweera, A, Rameezdeen, R and Edwards, D J (2022) Organisational Culture in Building Information Modelling Maturity Research: A Bibliometric Analysis *In:* Tutesigensi, A and Neilson, C J (Eds) *Proceedings of the 38th Annual ARCOM Conference,* 5-7 September 2022, Glasgow, UK, Association of Researchers in Construction Management, 14-23.

maturity (BIMM) (Smits, *et al.,* 2017). In terms of BIMM, BIM implementation in organisations mature from a basic level of to a more advanced level in terms of policies, processes, and technologies (Alankarage *et al.,* 2022). While some organisations have higher levels of BIMM than others, others are struggling with lower levels of BIMM (Saka and Chan, 2019). Fragmented views of the BIM users have caused this differentiation as the extent of BIM use largely depends on the users' perceptions (Afifuddin *et al.,* 2018). Similarly, Davies *et al.,* (2017) emphasise that the defensive and adverse nature of the thinking of BIM users is a significant hurdle to achieving desired levels of BIM uptake in organisations. Changing these perspectives and thinking is changing the culture of an organisation.

The BIM survey conducted by the UK BIM Alliance in 2021 highlights that changing the deeply held beliefs of BIM users to facilitate needed culture change is the most significant barrier of all in BIM implementation. Organisational culture has been identified as an important factor in defining BIMM level, making it a component in recently developed BIMM models that assess BIMM in organisations (Siebelink *et al.,* 2018). However, earlier BIMM models were more process-oriented and neglected the people-oriented factors (Wu *et al.,* 2017). Recent growing attention on human-related softer aspects like culture justifies the need for maturity in cultural elements to achieve BIMM in organisations. Organisational culture is explained by Schein (2004) as a set of fundamental, deeply held beliefs of people which distinguishes one organisation's members from another. Beliefs are anchored in an organisation and determine the rational and irrational behaviour of people in the BIM environment. Even if an organisation's BIM technology is advanced but not its culture, its BIMM suffers from a lack (Siebelink *et al.,* 2018). Even though culture is becoming a popular topic in BIMM related research, co-themed research is still relatively new and has not been thoroughly investigated. This paper follows a bibliometric approach to find emerging trends and the role of culture in the BIMM domain.

METHOD

A bibliometric analysis allows identifying the depth of knowledge of a particular research topic through examining the research front and producing networking structures of the interested scientific community (El Baz and Iddik, 2021). Scholars have commonly accepted this method to understand BIM-related research work. For example, Santos *et al.,* (2017) highlighted emerging fields in BIM by conducting a bibliometric analysis using literature published from 2005 to 2015 and the bibliometric analysis by Oraee *et al.,* (2017) reviewed collaboration in BIM-based construction networks. This study adopts a bibliometric approach to ascertain major research areas and emerging organisational culture- BIMM research trends.

Scopus was chosen as the database due to its more comprehensive range of coverage in scientific publications compared to other literature databases and its use in literature reviews in the BIM research field (Alankarage *et al.,* 2021). Peer-reviewed journal and conference papers were chosen as the sources of knowledge due to their reliability and conciseness in information (Aghimien *et al.,* 2020). Publications in English were used, and no starting year was established for data retrieval, and 2021 was set as the end of the time span. A two-stage search was carried out in with separate search strings linked by Boolean connectors. The combinations were queried in the database using the function TITLE-ABS-KEY (title, abstract and keywords). First stage of search located 481 articles using the keywords ("BIM" OR "Building Information modelling" OR "Building information modelling") AND ("maturity" OR "maturity model"). Next, using the terms ("Culture" OR "Cultur*") 103 articles were separated for further analysis. A similar strategy of two-stage searching was adopted by many previous studies, such as Guo and Feng, (2019). Later, results were analysed using the software called Visualisation of Similarities (VOS) viewer (van Eck and Waltman, 2010) - a software for reviewing literature that provides the fundamental functionality required for easily visualising bibliometric networks and avoids challenges in analysing papers manually (Aghimien *et al.,* 2020). The collected papers were descriptively analysed to identify research trends in publications from around the world over the years. Then, using a keyword co-occurrence analysis, clusters of studies covered in the filtered set of publications were identified. Leading articles in each cluster with the highest number of citations were identified to further analyse these clusters. To strengthen the bibliometric analysis, an analysis was carried out accounting the content.

FINDINGS

Research Trends-Descriptive Analysis

The findings on the number of publications by year, source of publication, and publications per country are presented in Table 1 as a summary of descriptive analysis. The trajectory of the total number of publications has been limited to the 10-year period between 2012-2021. The first paper linking culture to BIMM research was found in 2012. According to Moretti and Giana (2018), the research on the BIMM research has been rising since 2009. This disparity is because the first established BIMM models are more process-focused than human or culture focused (Wu, *et al.,* 2017). A relatively flat-lined series is present from 2012 until 2015. Although in last years the overall number of publications has not been extensive, the number of publications per year is notably surged from 2015 to 2021, from two publications in 2015 to 26 publications in 2021. This is going in line with the scientometric analysis conducted by Jin, *et al.,* (2019) on BIM-based research, which found a significant increase in research in the field after 2015.

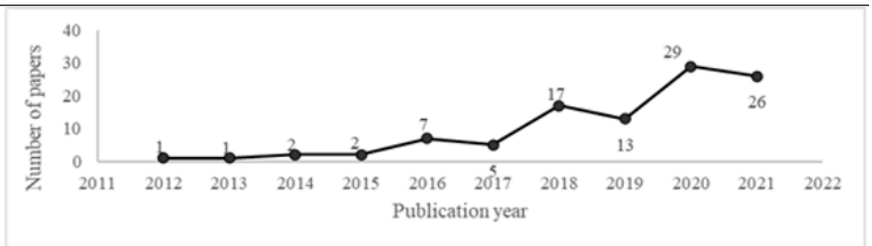
Amidst the gradual increase in the total publications, there was a rise and fall in the number of publications between 2015 and 2021, with 2020 experiencing the highest number of 29 published articles. Overall, there is an increase in academic interest, reflecting the flourishing of culture research in the BIMM context. A total of 103 papers on culture in BIMM model research were extracted, 79 (76.7%) of which came from journals, while the remaining 24 (23.3%) were conference articles. Guo and Feng (2019) mention that leading outlets for publishing studies provides a more comprehensive perspective of the current state of a research area. Thus, publication sources were evaluated, and only the top five sources with at least four published articles on culture- BIMM research. Engineering Construction and Architectural Management journal (8 out of 103) and Journal of Construction Engineering and Management (8 out of 103) published most of the articles in the field. Many bibliometric analysis and systematic reviews conducted in the BIM arena recognise Automation in Construction as the dominant source (Jin, *et al.,* 2019). However, this study contradicts the above statement as Automation in Construction has only two publications in the culture- BIMM field. This might be due to the highly technology-oriented nature of the papers in this journal compared to other journals, focusing on management and professional issues (Guo and Feng, 2019).

The countries at least four publications are included in the analysis, and the United Kingdom tops the list with 27 articles (29%). This could imply that the United

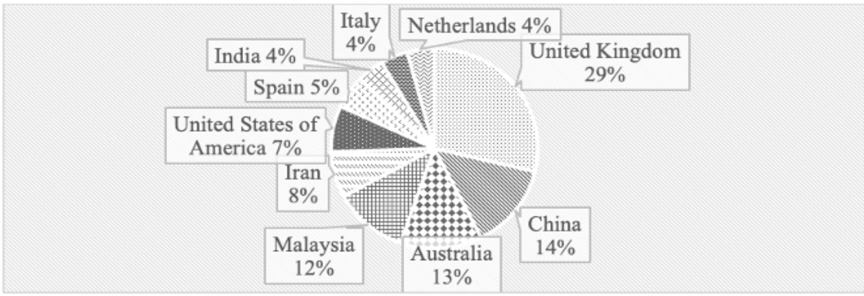
Kingdom is a market leader in BIM implementation, owing to the government's policy-driven mandate for all public projects (Alankarage *et al.,* 2021) . This was followed by China and Australia publishing 13 and 12 articles, respectively. It is surprising that being a developing country; China has a competitive interest compared to developed countries like the United Kingdom and Australia. The emerging interest of China in BIM and organisational culture related research was also emphasised by the recent systematic review done by Alankarage *et al.,* (2021). Rapid developing countries in the field like India, Malaysia and Iran show increased research attention in the culture-BIMM context. However, a surge of publications in other developed countries like Italy, the Netherlands and Spain could be justified by the active business operations, cultural background, and high concentration of academic institutions (Aghimien, *et al.,* 2020).

Criteria	Distribution

Year of publication



Location



Source of publication		
	Engineering Construction and Architectural Management	8
	Journal of Construction Engineering and Management	8
	Architectural Engineering and Design Management	5
	Construction Innovation	5
	International Journal of Construction Management	4

Figure 1: Summary of descriptive analysis

Research Trends-Co-Occurrence Analysis

The keywords used in a research study summarise the main findings of the study, and it is possible that they will have better relationships with one another (Guo and Feng, 2019). Therefore, a keyword co-occurrence analysis was conducted to demonstrate highlights of studies covered in the filtered set of publications. Developing a co-occurrence map using the bibliographic data gathered is starts with setting the minimum number of co-occurrences for the keywords to be extracted. This is critical for effective keyword clustering into themes that can be used to explain the areas of concentration in previous studies (Aghimien, *et al.,* 2020). Even though the predefined minimum number in Vos viewer for co-occurring keywords is 5, many studies have used different numbers as the minimum threshold. For example, Saka and Chan (2019)- 2 co-occurrences, (Aghimien, *et al. (*2020) - 4 co-occurrences arguing that adopting the default minimum of 5 gives a very light output, whereas using 2 or 4 results in a significant number of repeated keywords. Growing from this argument, this study adopted a minimum co-occurrence number of 2. This means that for a keyword to be extracted, it must appear at least two times in the author and source indexed keywords. The analysis of 103 extracted publications revealed 376 keywords in total. 46 keywords met the threshold of two co-occurrences out of the total keywords. To ensure the consistency of the analysis, a manual normalisation was used to avoid spelling errors and word repetition. Terms with general meaning such as Malaysia, and survey were excluded. Terms with different spelling, such as Building information modelling and Building information modelling were merged. Accordingly, the final number of keywords in the co-occurrence network is as in Figure 2.

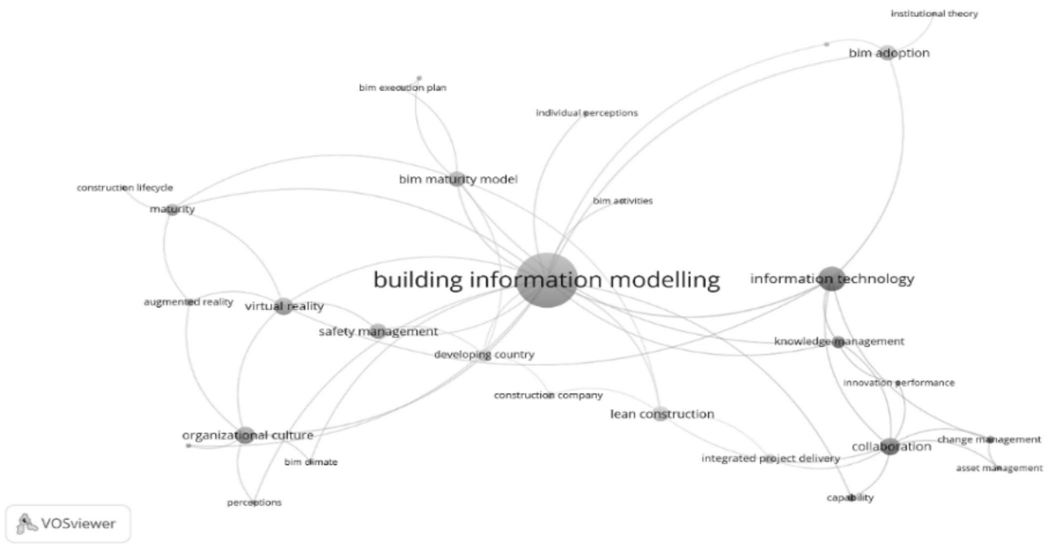


Figure 2: Keywords Co-occurrence network

The circle size reflects the frequency of the occurrence of keywords in the selected papers. The line lengths represent the closeness of the keywords, and it is vital to note that the higher the co-occurrence of keywords, the closer they are to each other (van Eck and Waltman, 2010). In this visual word co-occurrence network, the node sizes represent the frequency of occurrence of the respective keywords. The arcs represent keyword co-occurrence relationships. The line thickness represents the strength of each relationship (Wang, Pan, and Luo, 2019). The keywords listed in the same group appear to have close similarities in terms of research topics. From the keyword analysis, 5 clusters were found where different colours of circles in Figure 2 indicate different clusters. The keywords are grouped in 5 clusters: BIM adoption research, basic management research, safety culture research, waste management research, and pure culture research. Only the cluster 5 articles are directly tried to understand the BIMM in cultural perspective. Based on the keyword co-occurrence, the leading articles with these keywords; the first three articles with the highest citations in each cluster, are presented in Table 1.

Table 1: Leading articles in each cluster

Cluster	Cluster 1- BIM adoption research	Cluster 2- Basic management research	Cluster 3- Safety culture research	Cluster 4- Waste management research	Cluster 5- Pure culture research
Reference	(Ahmed and Kassem, 2018) (Ahuja, *et al.*, 2018), (Enegbuma, *et al.*, 2016)	(Abbasnejad, *et al.*, 2020) (Matthews, *et al.*, 2018)	(Bhagwat, *et al.*, 2021) (Olugboyega and Windapo, 2019)	(Ahuja, *et al.*, 2018) (Fakhimi, *et al.*, 2016)	(Khan, *et al.*, 2018) (Lee, 2020) (Xu *et al.*, 2018)

A content analysis of the leading articles in each cluster was conducted considering the cluster 5 as the core cultural studies in the domain. The analysis revealed that the role of 'organisational culture' in BIMM research has been developed on a dual way. Some consider organisational culture to be a variable- it is only a one element that the organisation has (Siebelink, *et al.,* 2021), while others consider it to be a root metaphor (Enegbuma *et al.,* 2016). They believe that organisation itself is the culture; in other words, organisation equals culture. Accordingly, Figure 3 presents a schematic representation of the relationship between organisation and organisational culture as depicted in this literature. The circle represents the organisation, and within it, the organisational elements are shown.

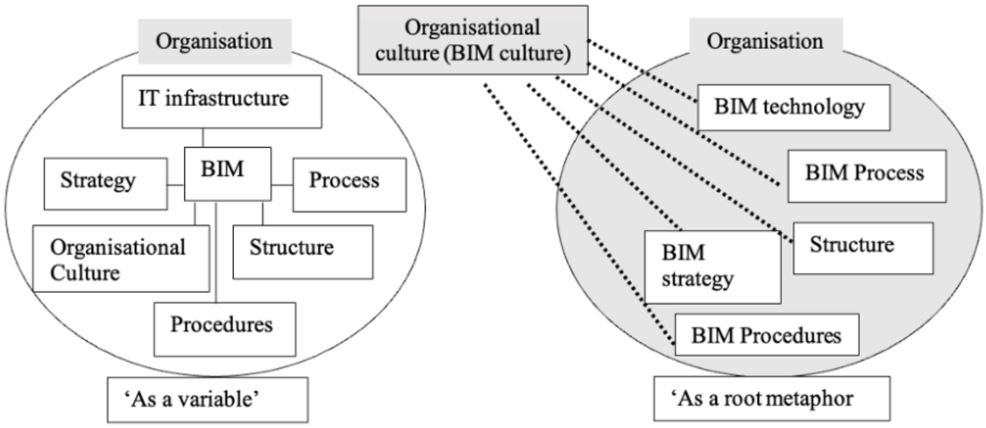


Figure 3: Schematic representation of the relationship between organisation and culture

Culture as a variable

The term culture is frequently mentioned in the literature as an impediment or an aid in coping with the changes that come with BIM use. Siebelink, *et al. (*2021) identify organisational culture as one of the critical barriers to BIMM in construction organisations. Culture is presented in these studies as a variable that the organisation can manage, control, or manipulate to achieve the desired level of BIMM. Culture is viewed as a variable "X" that influences variable "Y," which is BIMM. By viewing organisational culture as a variable allows for investigating how it varies and how these variations are related to organisational BIMM. The study by de Almeida *et al.,* (2017) analyses organisational culture in Brazilian construction companies and conclude that clan culture is the ideal setup for successful BIM deployment. Recently developed BIMM models identify organisational culture as a component affecting BIMM. Sebastian and Van Berlo (2010) include culture in their BIMM model, alongside organisation and management, information structure and information flow and tools and applications.

To Siebelink *et al.,* (2018), culture was one criterion of their BIMM model, among other criteria such as strategy, organisational structure, processes and procedures, IT infrastructure and data. These studies assume that culture is one element of a BIM using organisation and make predictions about BIMM. They attempt to characterise organisation culture with a goal to develop and understand causal relationships with other variables such as technology, structure, and strategy before trying to control or manipulate these variables to attain a desired BIMM level. This functionalist approach proved attractive to many researchers. Many of the authors who consider culture a variable that is frequently mentioned culture in their studies, but no explanation is provided to define it.

Culture as a root metaphor

This approach is not much popular in BIMM research. The root metaphoric representation of culture sheds light on the end results (BIM performance) and other processes (change). Xu, *et al.,* (2018) explain the culture in BIMM through concepts of BIM climate and BIM culture, and BIM climate and the BIM culture are defined by the individuals' perceptions on BIM implementation. To them, culture is more of a process than a variable. Siebelink *et al.,* (2018) define BIM culture as the organisational culture rooted in fundamentally shared issues, which groups must deal with when trying to achieve higher BIMM levels. They abandon the notion that culture is something an organisation has in favour of the notion that a culture is something an organisation is.

Hua and Liu (2017) emphasise that the way to achieve higher BIMM is the cultural fit between BIM and the organisational culture. Their inquiry focus was also on the members' beliefs or assumptions of the culture and how BIM users think and what patterns of reasoning that are shared among them. According to Enegbuma *et al.,* (2016), BIM systems and business processes should be integrated to reshape the organisational culture. Chen *et al.,* (2014) describe the differences between USA and non-USA members of the same organisations from different national cultures. To mature in BIM, USA experts focus on training, whereas non-USA experts focus on regulating the team structure, suggesting that to USA experts, BIM is a technology and to non-USA experts BIM is more like a process. Culture was centred on other concepts like BIM enabled Safety and BIM integrated lean construction. The term culture was used often conjunction with other words (Ex: Lean culture, Safety culture) and BIM was considered as a tool enabling the safety culture BIMM and lean culture maturity (Ahuja, *et al.,* 2018; Olugboyega and Windapo, 2019). However, like Safety and lean culture maturity models, no BIM specific culture maturity models are developed. Therefore, as these studies emphasise an organisation needs to embrace the BIM culture within the organisation to attain the needed levels of maturity.

CONCLUSIONS

This paper investigates the role of organisational culture in BIMM model research and research trends in the domain. According to the collected bibliometric data, topic culture is an emerging research focus in the BIMM research, whereas the domain studies showed an increase from 2015. The highest number of publications were recorded from the UK, followed by China and Australia. Publications in a broad spectrum of journals show a higher interest in the research community in the culture-BIMM research. Despite the importance of understanding the culture to achieve higher BIMM, studies on pure culture-related research were limited. The research is spread through the areas of BIM adoption, Basic management, safety culture, and waste management. The deep conceptual structure of the field shows that the focus of culture research in BIMM takes more of a functionalist view and considers culture as a variable influencing and influenced by BIMM. However, with emerging research on BIM organisational culture, it is necessary to look at the culture from the interpretive perspective to understand the BIM culture maturity. Therefore, future research can consider a more in-depth analysis of an organisational culture in the BIM environment.

This paper presents an analysis to understand the evolution and the role of culture in BIMM research. However, the study possesses some limitations. The data collection is limited to the Scopus database, which might not include all the articles in the field.

Further, only articles published in English were considered. Therefore, future research can consider more databases, including the web of science and articles from multiple languages. This might give additional insights into the research area. This study will serve as a basis for future research in the culture- BIMM domain, being the first literature paper to explore BIMM research through a cultural lens.

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CITY-WIDE DIGITAL TWIN: ARCHITECTURE, ENGINEERING, CONSTRUCTION, AND OPERATIONS AS A 4.0 INDUSTRY

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Cities are expanding not merely in size and intensity but also in complexity and interconnectivity among their components, emphasising the importance of rendering cities smart, which can be achieved through a Digital Twin (DT). Lack of comprehension of what a DT could entail is the focus of this paper. This research paper presents an account of technologies that, when amalgamated, can aid in the development of a City-wide Digital Twin (CDT). A systematic review is included in the study to identify knowledge gaps and create an overall picture of a CDT. Further research and recommendations are also provided to aid in the planning of DTs of existing and prospective cities. Knowledge gaps are recognised and defined after a rigorous literature study. Based on this, a conceptual model is delineated in the form of a schematic of the overall picture, depicting how numerous technologies must be combined to build a CDT where sensing, connectivity, and intelligence are key factors. This study can ignite an innovative debate between diverse stakeholders and professionals from within the Architecture, Engineering, Construction, and Operations (AECO) industry and outside.

Keywords: BIM; digital twin; big data analytics; city information management

INTRODUCTION

The Urban Millennium references the announcement made by the U.N. in 2001 which addressed the problems associated with leaving rural settlements and shifting to cities (United Nations, 2001). The shift to cities and the swelling in population are expected to place extra demands on cities, emphasising the need for more sustainable urban areas which address the challenges associated with the whole life cycle performance at a city-wide scale. The rapid advancement of digital technologies has resulted in significant changes across all industries, leading to a paradigm shift in the way we work, communicate, establish business models, and customise procedures (Hidayatno, *et al.,* 2018). The Fourth Industrial Revolution, also known as "Industry 4.0", is the name given to this technological evolution.

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The industrial revolution refers to the quick and extreme change that has occurred throughout history because of new technology and ways of viewing the world, causing a change in various domains across all industries. Industry 4.0 builds on the technologies of the Third Industrial Revolution, often known as "the digital revolution," and is defined by the fusion, interoperability, integration, and interaction of technologies across physical and digital domains (Schwab, 2016).

The Internet of Things (IoT), Cloud Computing, Artificial Intelligence (AI), Machine Learning, robotics, nanotechnology, and quantum computing are just a few examples of such technologies. Those technologies have transformed all industries, but the effects have been unevenly dispersed (Philbeck and Davis, 2018). Because the rise of the Architecture, Engineering, Construction, and Operations (AECO) industry is a subset of the universal set of gross domestic product value, Industry 4.0 has an impact on the construction industry and built environment as well (Maskuriy *et al.,* 2019).

To be able to deliver a more sustainable product and function under more efficient work processes, the AECO industry must build maps, simplified abstractions of an underlying reality of the present that makes it easier to forecast the future. However, the AECO industry has a reputation for being hesitant to accept new (digital) technologies including BIM and DT (Bello et. al, 2020).

Benefits and problems related to developing a City Digital Twin (CDT) and leveraging the huge amounts of data and information generated by cities are recognised through comprehensive research and literature review. The literature review will begin with an examination of the terms and definitions linked with the implementation and use of technology to manage cities. Second, the study will examine the existing state of maturity in CDT as well as potential future advancements. The literature review concentrated on looking at recent works on the topic of DT in construction that date back no later than 2019 to capture the present state of DT maturity in the industry.

In comparison to BIM, DT is a recent technology notion that is a few steps forward in the digital/virtual world. DT can be as little as a single component of an airplane or a building, or it can be as large as an entire product, a structure, or even a city or an entire country. DT is a trending topic on this scale and is more creatable and manageable than it is on a global scale. However, conceiving, designing, and developing a CDT for a specific city is a lengthy, complex process. At a city-wide scale, DT would cut through a wide range of disciplines, assets, components, and layers of a city that range from physical to non-physical dimensions. While buildings and infrastructure are physical; systems and subsystems of a society's social and economic worldview are nonphysical. A CDT needs to capture and integrate both.

There is a substantial knowledge gap in this regard, not necessarily in the applications of technologies themselves but in stacking and integrating them to deliver a city-wide DT. This knowledge gap, being the hurdle of delivering a DT, has yet to be thoroughly evaluated, analysed, and documented. The aim of this research to produce an account of current technologies which can contribute to a CDT and assess the readiness of the AECO industry to adopt, adapt and amalgamate such technologies. Furthermore, the study identifies knowledge gaps and defines them for more effective communication between the various stakeholders of the industry, including academic researchers and practitioners. This research investigates the interplay of some of Industry 4.0 technologies and how they might help improve existing and future cities.

Technologies and Definitions

Digital Twin

Digital twinning, as well as the technologies that enable and power the DT, has increasingly become an important topic in the (AECO) industry (Mathupriya, et al., 2020). Although the notion of DT is relatively new to the AECO industry, it has long been a part of other industries, such as the automotive industry. The term and concept of DT were first coined by Michael Grieves in 2003 in his lecture on Product Life Cycle Management at the University of Michigan. A DT links the physical system with a virtual equivalent and fully describes actual or potential physical systems at all levels, from the micro atomic level to the macro geometrical level (Grieves and Vickers, 2017). A DT is made up of three parts: a physical system, a virtual system, and the connection that links them together.

The first application of DT was in 2012 by The National Aeronautics and Space Administration (NASA) in which the DT was defined as a multiphysics, multiscale, probabilistic simulation of a high-fidelity as-built physical system that mirrors the state of its corresponding physical twin, in a timely manner, based on historical data and real-time captured sensor data (Glaessge & Stargel, 2012). To realise the anticipated benefits from the DT, which is an ultra-realistic depiction of its physical twin, the DT must consider the physical asset's major interdependent systems and their probable integration scenarios (Glaessge & Stargel, 2012). It can be concluded that DTs are virtual representations of subsystems within a system of systems.

It is critical to distinguish the DT from other notions like digital replica and digital shadows. A digital replica is just a digitised model of a real/physical system with no data exchange between the real/physical and digital systems (Errandonea, et al., 2020). Digital shadows are digitised representations of real/physical systems with a single flow of information exchange between the digital and real/physical systems, where changes in the real/physical system influence change in the digital system (Errandonea, et al., 2020). The DT, on the other hand, has interaction and data and/or information flow in both directions between real/physical and digital systems (Errandonea, et al., 2020). With that being said, the DT still stands at its preliminary stages of application, especially in the AECO industry, as it relies on advancements of various Industry 4.0 technologies, such as IoT, Big Data Analytics, and Machine Learning, to achieve an automated flow of data and information exchange between the physical and digital systems (Deng, et al., 2021).

In the AECO industry, DTs are essential to achieving digital transformation. Multiple DTs will make up a City-wide Digital Twin (CDT), which will represent the city's actual physical components, buildings, infrastructure, and ultimately its non-physical components (Tao, et al., 2019). DTs of physical and non-physical components of a city form the building blocks of a CDT. A comprehensive review of the application of DT in the construction industry was conducted by Opoku *et al.,* (2021) after carefully selecting and searching the literature, in which a total of 22 papers were determined to be related to the research.

The modest number of publications in AECO on the topic of DT may suggest a limited number of studies on DT application in the industry. According to the conclusions of Opoku *et al.,* (2021) research, the industry's focus on DT has increased since 2020; nevertheless, it has mostly focused on a single lifecycle phase of the asset, design, and engineering, while completely ignoring the asset's demolition and recovery phases. Among the 22 reviewed papers, only 8 tackled the use of DT during the operational phase of the asset.

Furthermore, Opoku *et al.,* (2021) research points out that the studies that focused on DT throughout the design and engineering phase were all centred around BIM. This could indicate that the AECO industry is still grappling with the definition of DT, especially as the definition differs by industry and application (Tao, et al., 2019).

Building Information Modelling Management

Building Information Modelling (BIM) is defined as "the use of a shared digital representation of a built asset to facilitate design, construction, and operation processes to form a reliable basis for decisions" (ISO, 2018).

BIM, as the definition implies, is a digital replica of assets authored mostly during the asset's design and engineering phase and can afterward be utilised as a foundation for using other technologies to operate and manage assets and infrastructures. A building information model is made up of geometrical and alphanumerical data with granularity levels that correspond to the asset's function and lifecycle phase (BSI , 2020). An information model of a built asset can be described as a static information model, a digital replica. Examples of city digital replicas are the models of the city of Wellington, Shanghai, Damascus, and Singapore.

Powered by other technologies, an information model of a built asset can be transformed from a simple digital replica to a digital shadow. The implementation of BIM in conjunction with other technologies, including Virtual Reality (VR), Augmented Reality (AR), sensors, IoT, AI, point clouds, and others, has resulted in substantial changes in the AECO industry. Such technologies facilitate Virtual Design and Construction (VDC) in which technology solutions and intelligent algorithms are used to capture and inform design decisions, simulate construction sites, and achieve data-driven project management (Lu *et al.,* 2020). Similar technologies are paired with building information models and used in operations and maintenance, such as remote-sensing devices, cameras, Radio-Frequency Identification Readers (RIFD) and wireless sensor networks.

VDC and technology-driven facility and asset management approaches enable professionals to forecast the performance of a built asset and collect data throughout its lifecycle to support better decision-making. The flow of data and information from the physical asset to the digital asset is created by aligning BIM-based technologies, which is eventually stored in the asset's Common Data Environment (CDE), where it is used to guide decisions that are manually implemented on the physical asset.

Building Information Management, aided by technology, transforms the static information model into a digital shadow, showing a flow of data from the physical asset to the digital asset. Yingtan in China is an example of a digital shadow where IoT is used to capture data within 43 categories (Huawei, 2020).

Given that this does not fully exhibit DT characteristics, which revolve around co-evolving the physical and digital twins in an autonomous process (Zheng *et al.,* 2018), a CDT cannot be realised by simply creating a Common Data Environment that hosts information models of all the city's components and their captured data.

Big Data Analytics

Big Data and Big Data Analytics (BDA) have become the frontier for innovation across all industries in research and development (Chen and Zhang, 2014). BDA is an emerging science that is based on Big Data and AI and has been identified as a critical technology that supports data acquisition, storage, and analytics in related data management systems (Bi & Cochran, 2014). Big Data is an umbrella term for a collection of data sets from a variety of sources that are often too vast and/or complex for typical data processing technologies to manage (Maheshwari, 2017).

Big Data's primary premise is that everything leaves a digital trail that can be captured and used to guide better processes and decisions (Marr, 2015). Big Data has already changed people's lives by making everything smarter: smarter sports, smarter healthcare, smarter homes, smarter businesses, and even "smarter love"! When considering the different layers that make up a city, as well as the areas in which BDA already plays a significant role, it seems Big Data and BDA will become an integral part of the digital infrastructure of future cities. BIM-enabled technologies can capture huge amounts of data from built assets to inform decisions, such as maintenance plans and asset repurposing. Digital Shadows of built assets can use BDA to inform decision-making. However, BDA as a stand-alone technology is insufficient to power a DT

Machine Learning
Machine learning (ML) is an area of AI and Computer Science that focuses on using data and algorithms to mimic the way humans learn and improve accuracy over time. Without being explicitly programmed, ML allows systems to learn and improve from experience. (IBM Cloud Education, 2020).

ML learns from training data and acts like a human for creating predictions by educating itself using Algorithms, whereas BDA pulls raw data and looks for patterns to aid in stronger decision-making. A perfectly built ML Algorithm does not require human intervention. The Scope of ML is to improve the quality of predictive analysis, faster decision making, and support more robust, cognitive analysis.

ML Algorithms can estimate unknown future results, recognising attributes, and enforcing decisions without human intervention. This is known as Deep Learning, and it is a subfield of Machine Learning alongside Artificial Neural Networks (ANNs). ML is more dependent on human intervention, while Deep Learning is not. This is required to satisfy DT characteristics and enable two-way communication between the digital and physical twins. Given the large volumes of structured and unstructured data captured from the city's physical and non-physical layers, which eventually shall sit within a CDT's CDE, all subfields of AI; ML, Deep Learning, and ANNs must be used to fully power the DT's ability to make decisions based on the data captured from its physical counterpart.

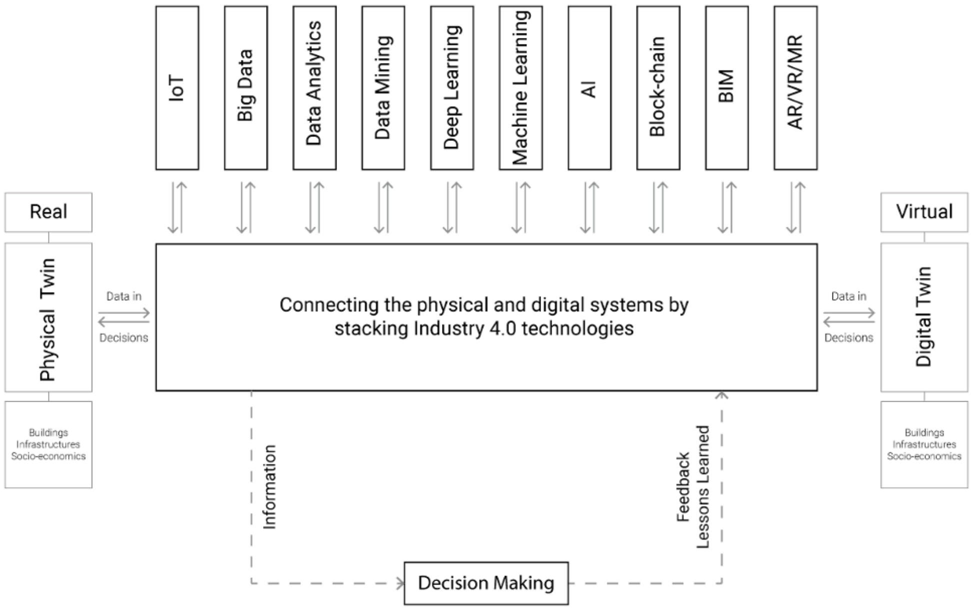
CONCLUSION

A CDT, which consists of an ecosystem of connected DTs, necessitates the usage and integration of a variety of technologies beyond those discussed in this paper, such as security-focused technologies. DTs are virtual representations of subsystems within a system of systems; nevertheless, definitions should not be applied to DTs because their composition is determined by their purpose and use case. To develop and realise the anticipated benefits of a CDT, data and information need to be compatible across all its DTs, implying the necessity of having a uniformed framework. A CDT could provide benefits to society, the economy, business, and the environment. (CDBB, n.d.).

While collaboration is the heart of BIM, technology amalgamation is the heart of the Digital Twin. According to the findings of this research, the AECO industry is aware of current technology that contributes to the construction of a DT, but it is behind in terms of recognising the value of stacking, integrating, and repurposing such technologies. Furthermore, the industry is continuing to focus on the technological connections that can be made while overlooking the social connections, which are more difficult to achieve but are just as crucial in realising a purposeful CDT.

To develop a CDT, a system of connected DTs must be established under a common framework to enable shared data connections between the city's physical and non-physical components. While the AECO industry may not be able to precisely define the DT, a broad grasp of what DTs are and the technologies they include must develop to create DTs that are appropriate for their purpose. Despite efforts to establish city and national DTs, such as the efforts of CDBB and Huawei, semantic interoperability across the ecosystem of connected twins remains unclear and unidentified for the AECO industry.

Figure 1: provides a schematic model of the CDT and the technologies enabling it



By providing a standard industry understanding of DTs, CDT can assist strategic decisions that address the entire built environment, driving positive change for humans, nature, and the planet.

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'TOTAL BIM' AS A DIGITAL DISRUPTION

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Digital technologies and information systems are challenging the construction industry. Existing literature focuses on different digital technologies in construction projects and the intricacies around technology improvement itself. However, there are limited discussions about how construction management (CM) organisations respond to disruptive change and pursue business model innovation. Drawing from emerging literature on digital disruption, we argue how the 'Total BIM' approach can disrupt the way value is created in a construction project. 'Total BIM' could be described as an approach where the design process and BIM are focused on production orientated design and BIM is used as the legally binding construction document. A construction management company in Sweden implemented the 'Total BIM' concept that embraced it to the fullest in the Celsius project This paper is based on data from in-depth interviews with construction management company practitioners from the Celsius project. It frames such improvement as a digital disruption which transforms the current traditional business models heavily based on the parallel processes of producing and maintaining 2D drawings for the construction site. Findings illustrate how the 'Total BIM' approach disturbs the existing roles, relations, and processes, creating cross organisational and systematic shifts.

Keywords: digital disruption; Total BIM; innovation; digitalisation; transformation

INTRODUCTION

Building information modelling (BIM) has long been an area of interest for construction management researchers. Much of the literature evolved around the expectations that BIM will create a transformative change and lead the construction sector to a better future (i.e., Singh 2018). To address performance and productivity issues, construction companies have long been oversold the benefits that disruptive technologies may offer, explaining why some organisations may be reluctant to fully embrace BIM (Love *et al.,* 2020). This study contributes by illustrating how an approach known as 'Total BIM' was implemented by a Swedish construction management (CM) company in a way that seems to create real organisational impact. The selected case illustrates when BIM is used as a contractual document and accepted as the single source of information during production, it can challenge the status quo by altering the roles, responsibilities, and relations among project participants, hence reconfigures the current business model. This resonates with the notion of 'digital disruption', which refers to a process that digital attributes and

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innovation shifts the established paradigms in a domain (Baiyere and Hukal 2020). Drawing on disruptive, innovative, and digital concepts, which are seen as the three properties of digital disruption, we aim to discuss how the 'Total BIM' approach can disrupt the traditional business models in the construction sector.

The paper is structured as follows. The theoretical background of digital disruption is reviewed with reference to both construction literature and the broader management disciplines. Consideration is then given to the Total BIM approach. This is followed by presenting the details of the empirical work. Given that the research is the initial part of a larger research project exploring the organisational level impacts of digital disruption, the paper is specifically positioned to encourage feedback and critical reflection.

Disruptive Innovation

In recent years, digital disruption has emerged as an important concept to discuss the profound changes resulting from the increasing embeddedness of digital technologies. Disruptive innovation theory can be accepted as the initial point of such discussions (Christensen 1997). The disruptive innovation theory offers an explanation why established companies failed to recognise the disruptive characteristics of new technologies while new entrants capture the market with either low-cost and low-performance offerings or creating a new market. Markides (2006) extended this by identifying product innovations and business model innovations as two specific types of disruptive innovations. Business model innovation is argued as the formation of a significantly different business model or reshaping the way that the service provided in an existing market or business by the impact of technology. For Markides (2006) 'business model innovators do not discover new products or services; they simply redefine what an existing product or service is and how it is provided to the customer'. To date, little attention has been given to understanding the disruptive impacts of digital technology adoptions on the current business models within the context of the construction sector. Ernstsen at al. (2018) notably adopted disruptive innovation theory to discuss whether the construction industry is ripe for disruption by presenting a comparison between the health sector and the construction sector. They emphasized that being the first mover in technological investment, identifying overserved customers and non-customers and focusing on value creation for the customer are identified as the path towards creating disruption. Chan (2020) also discussed how digital platforms, leading disruptive innovations in other sectors, are studied in construction specific research. He offered that CM research on platform business should shift from increasing the functionality of platforms to discuss the ways how platform business can impact the value creation in the broader eco-system of the construction sector.

The Properties of Digital Disruption - Digital, Disruptive and Innovative

More recently, 'digital disruption' is emerging as an alternative concept to explain the transformative effects of digital technologies. The common argument is that the decisive boundaries of 'disruptive innovation theory', emphasized by Christensen in several different publications, does not fit to explain the impact of digital innovations on existing business models (Skog *et al.,* 2018; Baiyere and Hukal 2020). This critique applies to difficulties to discuss the potential impacts of digital transformation in the construction sector, because disruptive impacts of digital technologies transcend the offerings of new entrants. Hence, we draw on the concept of 'digital disruption' which refers to:

> The rapidly unfolding processes through which digital innovation comes to fundamentally alter historically sustainable logics for value creation and capture by unbundling and recombining linkages among resources or generating new ones (Skog *et al.,* 2018: 432).

For Baiyere and Hukal (2020), digital disruption refers to three key properties as digital, disruptive, and innovative and when they are combined, they alter the traditional logics in a domain (Table 1). These properties are seen useful concepts to discuss how digital technologies have potential disruptive effects on the status quo in the construction sector. The intention of this paper is to discuss how the use of digital technologies impacts organisational aspects by disturbing the existing roles, relations, and processes, creating cross organisational and systematic shifts. More specifically, we aim to explain whether the Total BIM concept, as explained in the following section, can be seen as a digital disruption in the construction sector.

Table 1: Three properties of digital disruption (Baiyere and Hukal 2020)

Properties	Meaning
Disruptive property	'Profound alteration in a prior paradigm, an alteration in an existing logic'
Digital property	'Innovation should be created by unique attributes of digital technology'
Innovative property	'Introduction of something new into the domain through which digital disruption occurs'

TOTAL BIM

Despite the enormous opportunities BIM is said to offer the construction industry adoption has been slower than expected (Walasek and Barszcz 2017). These opportunities are often discussed in relation to BIM in the design stage but are limited when site work is still dominated by 2D paper drawings (Davies and Harty 2013). The process of creating and maintaining traditional construction drawings from BIM is costly, leads to errors and delays (Davies and Harty 2013). Two parallel processes exist where both BIM and 2D drawings are used. Recently in Scandinavia a new trend called 'Total BIM' is emerging where BIM is embraced in its totality, in reference to Stockholm's Slussen project (Cousins 2017). BIM is used in all project stages, including production. There is a single source of construction information, completely replacing 2D paper drawings. BIM is the legally binding construction document and developed to create a fully accurate representation of the project. Design focus shifts from creating drawings to technical design issues and trust is gained in the model (Cousins 2017). BIM is implemented in the production phase where site workers extract information directly from the model themselves on mobile devices. Typically, Swedish construction projects are delivered with three main information carriers, drawings, technical specifications, and quantity lists. In a Total BIM project, all information is connected to BIM as a central communication platform. There have been some previous attempts at pushing towards Total BIM type projects but are mostly infrastructure projects or faced other limitations, for example the Röfors bridge case, which faced technical limitations back in 2013 (Johansson and Roupé 2019). In this study we focus on the novel Total BIM approach by the CM company used in the complex Celsius project.

This study is focused on a small Swedish CM company that constructs an identity emphasizing a fully digital way of working. The company has been established for over 20 years but undergone an important transformation through adapting their business model to a fully digital way of working. The transformation resulted in a change in the employee profiles, the leaving of senior members and employment of key actors with digital capabilities. The intention of the company was to move towards focusing on larger, more complex projects.

The driving force for digitalisation was emphasized as the frustration with traditional work methods and mistakes that occurred. For example, a glass façade was ordered from out-of-date drawings. This led the company to taking action to create value for their ecosystem and to innovate the industry. They want to remain a small company and continue to work in small project teams, rather than to grow. With the client, the CM company decided to implement an innovative, digital construction process in the Celsius project, focusing on production and building directly from BIM. According to the case company they have a self-developed CM production system that enables them to continuously improve. They are hired by the client to act as advisors for the whole construction process. This includes leading the design of the building, managing the bidding process for subcontractors and leading on-site construction, for which they are paid hourly according to a pre-determined budget.

METHOD

The empirical analysis described below draws from the tradition of case study research (Flyvbjerg 2004) to explore the impacts of the Total BIM approach, especially from the lens of 'digital disruption'. The empirical analysis presented in this paper is based on two semi-structured interviews with senior managers from a construction management company that apply the Total BIM approach in Celsius Project. The interviews were conducted following a systematic analysis of the company documents and earlier discussions with representatives from the company. The managers were asked to interpret the development of their organisation, digital shift in their business model and the transition process towards adopting a fully digital way of working (drivers, problems, reactions of the stakeholders, etc). The interviews were based on semi-structured questions which allowed interviewees to articulate their perspectives while at the same time enabled researchers to keep control of the discussion on the organisational impacts of the Total BIM approach. The data analysis followed an iterative process between the documents and the relevant literature. The discussion is designed in line with the concepts in the digital disruption literature.

BIM as a Digital Disruption

Drawing on the conceptual properties of digital disruption, this section presents a discussion on disruptive, innovative and digital aspects of the Total BIM approach.

Disruptive aspects

The empirical study highlights three disruptive aspects regarding the use of the Total BIM. First, the interviewees described how the decision to adopt a fully digital way of working initiated an 'organisational transformation' process in the company. The phrase repeated by both interviewees was that the people who 'did not really feel that they fit in with the new organisation, left'. This was followed by emphasizing the employment of people that had digital capabilities and led the transition towards the Total BIM approach. The driving force of embracing a fully digital way of working was linked to a 'dedicated leader' who was fed up with the inefficiencies of traditional work methods. Such emphasis on leadership resonates with the literature around 'digital champions' (Criado-Perez *et al.,* 2021).

One of the key issues emphasized in the interviews was the size of the company and the emphasis on keeping it small, with core teams working on each project. Interviewees said that each project has team members that come from both design and the construction site with active VDC participation. One of the interviewees emphasized that the transition towards a fully digital way of working is difficult in large companies because they change project teams in each project, and they do not have consistent teams that are keen to apply digitalisation. The emphasis on company size resonates with the discussion on why incumbent firms fail to adopt disruptive innovations (Christensen 1997).

The second disruptive aspect are the shifts regarding cost structures and the bidding process. The interviewees emphasized that the use of Total BIM resulted in higher design cost, but less production cost. In the words of an interviewee:

> [The client] was a little bit concerned about the increased design cost and the risk, … we had to convince [The client] saying that we will spend less in the construction itself because there will be less errors ... [the client] is big and they feel like that they need to help the industry to innovate, they need to take some initiative in doing something new!

The above quote illustrates how the CM company convinced the client to spend more on design to have less production cost. It also refers to the 'digital champions' narrative once more. The interviewees also described shifts in the procurement processes. For example, subcontractors bidding on the project were provided with quantity data, technical documents and the IFC model taken from BIM. Hence, they no longer had to extract quantities themselves. As emphasized by the interviewees, following such a process resulted in more bids with less variance between them. In addition, competition was more based on how smart they could carry out the work, rather than who measured incorrectly

FINDINGS

The third disruptive aspect is related to the roles and relationships among the stakeholders. The empirical material shows that working with a Total BIM approach calls for a shift in key actor's roles and relationships in a project, especially the roles of the design team and CM company. The below quote illustrates the communication between two sides:

> Designers were naturally against it, thinking it was madness, how would it work, the architect asked many times “do you mean that we should draw everything and draw it right?” Yes! He thought that perhaps in 2D you can cheat a little, normally where the detail isn’t solved beforehand, but you still get what you need later on. I tried to remind him that this time is behind us. It went relatively well.

Such reaction from the design team can be seen as resistance to the shift of their role and the business model that they are used to work with. They are called to have less control on design development by the active involvement of site people in the CM company. They were also faced with an expectation to produce an accurate BIM. The interviewees argued that production of an accurate BIM contradicts with developing a design project based on 2D drawings which requires several revisions during the construction phase. Another change is that subcontractors were expected to bid based on the measurements given by the CM company. This seems to disrupt subcontractors' business model and profit calculation. The shifts in roles and responsibilities of different stakeholders might seem small changes but they disrupt the current patterns and traditional logic of how construction projects are delivered.

Digital aspects

The digital aspect commonly refers to disruption / innovation being enabled or induced by some new or unique attributes of technology. In the most recent project of the case company, we see three main (digital) enablers; cloud-based model repository, user-friendly and powerful mobile BIM-viewer, as well as an efficient mobile communication platform. Although we have examples of previous (successfully realized) model-based projects, such as Slussen and the Röfors bridge, certain technologies have always been missing for a Total BIM project to reach its full potential.

Table 2: Digital disruption interview data from the case company

CM company	Disruptive	Digital	Innovative
The CM company used a fully digital construction process where BIM was the legally binding construction document and no 2D drawings were used on-site. Site workers extracted views, measurements, dimensions on demand. A novel construction process for creating value by using BIM as a single source of information and as a communication platform.	<u>Organizational change</u> Several employees left the company and downsizing happened in 2014. Some left due to retiring and others felt they did not fit in the new organization. Disruption occurred due to a shift towards digitalization and larger projects. New employees were hired to work with digital processes. <u>Redistribution of costs</u> Design costs increased by 18% due to the new approach, but production costs decreased compared with a similar project. The project was delivered under budget and within time. Costs structures in projects were altered that may affect typical stakeholders. The high-quality design reduces errors found in the production phase, also shifting earning potential away from late changes. <u>Bidding process</u> Subcontractors bidding on the project were provided with quantity data, technical document and the model. They no longer had to extract quantities themselves. Resulting in more bids that with less variance between them. Competition was more based on how smart they could carry out the work, rather than who measured incorrectly. <u>Business model and roles</u> Stakeholders are affected by new roles and business models. Architects are challenged with new demands and requirements. The subcontractor's bidding process is simplified, and they use new work methods on-site. Clients are faced with new cost structures.	<u>Cloud-based BIM</u> A single source of up-to-date construction information where designers and site workers could access the model. Information was accessed digitally on-site. <u>Wi-Fi</u> A dedicated Wi-Fi network was established at the construction site to ensure broad and reliable connectivity. <u>Mobile BIM viewer software</u> BIM was accessible on mobile devices on-site on software featuring digitalized communication tools e.g., case management and checklists. Construction information was linked to objects and filtered based on the subcontractor's discipline. <u>Communication platform</u> Traditional documentation and communication methods were replaced with StreamBIM's inbuilt digital platform. Surveyed workers graded the project highly for communication compared with other projects in Sweden.	<u>Construction document</u> BIM was the legally binding digital construction document. Designers worked to create a high-quality, accurate model, which site-workers were required to use. BIM completely replaced traditional 2D drawings. <u>Accurate BIM</u> All parts of the building had to be included and accurately designed in BIM. Requiring architects and designers to adopt new work methods and quality controls, to maintain an unbroken information chain and information sustainability. <u>BIM in production</u> No 2D drawings were used on-site. Contractors and sub-contractors had to adapt to working with a new medium and were excluded from the project if they refused. Support and training were provided for site workers to create and extract construction information they needed to carry out work themselves.

Supervisors and construction workers found it difficult to extract information and dimensions directly from the model, and the design team therefore had to put extra resources on producing additional, static, 3D-views with annotations. In contrast, the use of the StreamBIM mobile application on-site in the Celsius project essentially enabled the construction workers to extract all the information they needed directly from the BIM. With a novel and user-friendly interface - that had not been available before - even rather complex tasks, such as measuring, and dimensioning could easily be performed by the construction workers themselves. In a similar way, cloud-based model repositories and work-sharing environments have significantly matured in recent years, especially if all design disciplines work within the same software suite (e.g., Revit). What used to be a simple file-based storage and version control system can now support simultaneous model editing (i.e., work-sharing) and automated model processing tasks. With almost all design work performed in Revit, the Celsius project could take advantage of these features and enable a "live" design environment with instant work-sharing in BIM 360 Design. An exception was Tekla Structures for the prefabricated concrete elements where design collaboration was performed through IFC-files synced with a desktop connector.

Not only did the BIM 360 design environment allow the design team to have a 'single source of truth', but they could also take advantage of automated nightly IFC-export jobs that were then pushed to the StreamBIM mobile platform for use on the construction site. As already explained, the StreamBIM mobile BIM-viewer was primarily chosen for the construction workers to be able to easily retrieve and consume the information and build directly from the model. However, during the project, the team started using more and more of the functionality in StreamBIM, such as issue reports, check lists, inspection documentation, and as-built documentation, that it eventually became the natural path of communication within and between the design and construction teams. That is, although not initially planned for, the attributes and functionality of the technology almost induced the use of it as a communication platform, or as expressed by an interviewee:

> We thought at the beginning of the project that we wouldn't be able to get as much information into StreamBIM as we eventually did. We had all cases, relationships, decisions, controls, requests in StreamBIM. Everything got a lot better, just with having all the information there in one place and being directly available to the right people. We tried to connect all information to the model, and it became a communication platform. which offered us so much more than just building without traditional drawings.

Furthermore, with so much of the communication handled electronically and all the construction documents (i.e., models) managed and stored in the cloud, a fast and secure network becomes much more important than for a 'normal' construction project. In fact, as used in the Celsius project, 5G and Wi-Fi can almost be seen as important technological enablers for a Total BIM project.

Innovative aspects

The innovative aspect is considered as the answer of what is new to whom in a digital disruption process (Baiyere and Hukal 2020) One innovative aspect of the case is the decision to use 'BIM as the legally binding document'. This disrupts the way actors communicate and take roles in the project process. Designers are expected to create a high-quality, accurate model, and workers are required to use BIM to do their daily tasks. This requires developing digital capabilities for the actors, especially the ones on-site. As described by one of the interviewees:

> It was more of a change for people working in production, our site managers and supervisor working on the field really like to take notes and do a lot of analogue note taking and communicate with the drawings. They have now also been incorporated with this way of working and there’s no going back for them. We’ve managed to implement these digital tools that help them do their daily work in a better way.

The interviewees also emphasized the requirement for an unbroken information chain and data flow to use BIM as the legally binding document. This shows how three aspects of digital disruption are interwoven.

Another innovation is the mandate to work on an accurate BIM throughout the project. That requires designing all parts of the building accurately, which forces architects and designers to adapt new work methods and quality controls. For the interviewees, this also requires active involvement of site personnel during design development. One of interviewees says:

> We wanted to emphasize that we were doing something different. We were not going to rely on drawings. Such as “oh screw this 3D BIM, we go back to drawings.” We didn’t want to have that mentality. No! It’s the model that’s the legal construction document and you should do as much as possible in that, so skip all the 2D and only focus on that. To really focus the design teams to understand that this was serious. Then we could go forward. We had all the tough discussions early with the designers that this is what we want to do, that we deliver the 3D model as the binding construction contract document. Then they can’t cheat on creating the models because the models really need to be good.

The above quote illustrates how targeting an accurate BIM disrupts the logic of working through design changes and earning from claim management. Having an accurate BIM is also seen as a key step towards achieving digital twins.

Lastly, the interviewees emphasise that the 'no 2D drawings' decision was the key to achieve production based on a model. They say that if 2D drawings are produced, they become the main communication channel and BIM becomes a secondary document, used mostly to represent 3D views and clash detection. With the 'no 2D drawing' principle, contractors and subcontractors had to adapt to working with a new medium because they were excluded from the project if they refused. This shows how the Total BIM approach brings innovation to the traditional way of working based on 2D drawings. It is important to note that the CM company provided support and training to site workers to create and extract construction information they needed to carry out work themselves.

CONCLUSIONS

This paper positions Total BIM as a digital disruption to the traditional way of working in construction projects. The empirical study has demonstrated how the use of BIM as the contractual document, not allowing 2D drawings and developing an on-site communication platform for use within and between design and construction teams, challenges the traditional business model. Drawing on the three properties of the digital disruption concept, the case study illustrated details regarding disruptive, digital and innovative aspects of the Total BIM concept.

Our case analysis highlighted the disruptive aspects regarding the use of the Total BIM approach. The empirical data describes a substantial organisational change when the company decided to pursue a fully digital way of working. More importantly, adopting this approach emerged as a key strategy pushed through by the company leader and supported by the hiring of employees with digital capabilities. Another radical shift was regarding the bidding process and the redistribution of costs. Costs for the design process increase but are lower the during construction phase and the bidding process is simplified for subcontractors. It is also seen that the traditional business model and the roles assigned to different stakeholders were challenged, for example expectations increased on design teams to produce an accurate model and collaborate with site professionals with production knowledge.

Digital technology is a key enabler for a successful Total BIM approach. Previous advanced BIM projects have been limited by, user-friendliness of software, accessibility, multiple sources of information, as well as software and hardware capabilities. In this context the CM company recognized BIM as a potential platform for a single source of information on the construction site. During the project they also recognized StreamBIM as an enabler of communication between designers and construction workers, which became the communication platform for the project. This was made possible by using cloud-based BIM and installing Wi-Fi across the construction site, granting users easy access to the most up to date construction information. By combining digital technology uses in a successful way it enabled the CM company to embrace BIM to its totality - Total BIM.

The empirical data also indicated some key innovations which was leading disruptions in the described case. One important innovation is the use of BIM model as the contractual document. This appears to create a disruptive impact on the current procurement methods and the roles ascribed to traditional stakeholders such as architects, contractors, etc. This opens a space for further discussion on the potential impact of BIM regarding traditional procurement methods, especially towards new business models. Another innovation was targeting an accurate BIM model, which enabled expanding the active use of BIM throughout the entire project, including design and production. Also having BIM as the common data source for all parties might be seen as a means to further improve collaboration among different stakeholders throughout the whole project. Lastly, excluding 2D drawings seems to be a key innovation, especially considering the role of 2D drawings as the common language throughout the history of construction projects.

While the findings here are based on the case of a Swedish construction management company and their project, Celsius, the study aims to contribute to construction management literature in two ways. First, it extends BIM research by conceptualizing it as a digital disruption. Second, it extends the methodological debate by mobilizing the three properties of digital disruption to guide an empirical analysis.

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MOVING BEYOND 'BUSINESS AS USUAL'? EXPLORING DIGITAL TRANSFORMATION IN THE SWEDISH CONSTRUCTION SECTOR

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Digital transformation (DT) refers to a process of integrating digital technologies that will lead to new forms of relationship among actors; organisational processes; and business models. It is frequently portrayed as something that can improve; but also, potentially disrupt; the construction sector (CS) as we know it today. As DT requires distributed actions; collaboration; and coordination across inter-organisational boundaries in the sector; we apply an ecosystem perspective to explore the current state of DT in 14 Swedish construction incumbent firms. Findings show the need to address the heterogeneity of the actors; their respective roles; positions in the value chain. The sense of urgency to transform is highest for actors with business models based on selling hours. DT is mainly linked to incremental improvements regarding internal efficiency and cost reductions rather than exploitation of new business models. Finally, the role of leadership in the transformation process is rather absent and the actors take a more reactive role waiting for others to demand change.

Keywords: digital transformation; disruptive innovation; ecosystem; digital business

INTRODUCTION

Digital transformation (DT) has emerged as a key narrative with an emphasis on the convergence of physical and digital worlds and restructuring of the economies, industries, and society (Vial 2019, McKinsey 2020). It is argued that the increasing diffusion of digital technologies in work processes is disrupting the existing nature of industries and leading to the redefinition of traditional business models (Rachinger *et al.,* 2018). The discussions on DT roots back to two different lines of research; information systems (Yoo *et al.,* 2010) and disruptive innovation theory (Christensen *et al.,* 2018). While the former pays attention to digital and technological aspects, the latter focuses on the organisational and management aspects of DT. Following the latter, this research started exploring the literature on 'disruptive innovation' theory which offers an explanation why established companies fail to recognise the disruptive characteristics of new technologies while new entrants capture the market with either low-cost and low-performance offerings or creating a new market (Christensen *et al.,* 2018). Rather than focusing on what might be accepted as a

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'disruptive innovation' within the context of the construction sector (CS), our interest moved towards understanding the concept of digital transformation and its impacts on value reconfiguration on the ecosystem level.

There is also a growing attention to understand how the construction sector will address the impacts of DT (i.e., Lavikka *et al.,* 2018, Bosch-Sijtsema *et al.,* 2021, Cidik and Boyd 2022). Yet, to date, the scholarly literature on DT has largely focused on exploring digital technologies to improve daily activities of construction while transformational impacts on current business models remain understudied. It is important to note that DT of the construction sector is a multifaceted phenomenon referring to different actions and processes including a variety of stakeholders who have different business models and priorities. Therefore, this research reports the initial results of a research project aiming to map, through an ecosystem perspective, how value is created today and then identify future potential trajectories and states of digitalisation driven business models in the construction sector. The aim of the current paper is to discuss the results of current state analysis of digital transformation based on interviews with 'traditional' actors in the Swedish construction sector.

Digital Transformation

Increased digitalisation has put pressure on companies to reform their current business models, update their product and service offerings and relationships with stakeholders (Kraus *et al.,* 2022). Digitisation, digitalisation, and DT are described as the key phases to explain the impact of digital technologies in business and management in all sectors (Verhoef *et al.,* 2019). Digitisation refers to an initial phase when analogue information was replaced by digital information (i.e., text, scan). Digitalisation is seen as the following phase within which digital technologies are embedded in the business processes to achieve better performance (i.e., CAD, BIM). DT is accepted as the current phase referring to the use of new digital technologies to enable business improvements or change the business models completely (Rachinger *et al.,* 2018, Vial 2019).

Uber, Airbnb, and Spotify emerge as the key points of reference to explain how digital innovations created significant impacts in certain industries and replaced the traditional actors and business models with new ones (Skog 2018). The common argument is that digitalisation creates disruptions on many levels from achievement of simple tasks to the way how value is created in different sectors. As defined by Vial (2019:118), digital transformation refers to "a process that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies". Hence, the DT research in construction requires widening up the research scope from focusing on the use of a specific technology to improve day to day activities to addressing how increasing digitalisation are impacting the entire business ecosystem.

Digital Transformation in the Construction Sector

This research started with a review of construction related literature in the topic of digital transformation. The review showed that DT is mostly used as a keyword within the studies focusing on the use of digital tools to improve current operations (ie. Aibinu and Papadonikolaki 2020, Ezzeddine and Garcia 2021) with few exceptions that emphasizing the transformational impacts of digitalisation on broader scale (Woodhead 2018, Succar and Poirier 2020) or adapting a critical approach to discuss DT in construction (Cidik and Boyd 2022). Hence, much of current research lacks articulating the broader impacts of digital technologies, especially from the perspectives of new digital business models and value reconfigurations on the ecosystem level. However, the review enabled us to identify four themes that are emphasized as the key issues impacting DT in the construction sector.

Leadership

One common theme is that DT requires dedicated leaders or called elsewhere 'digital champions' (i.e., Morgan 2019, Ernstsen *et al.,* 2021). Morgan (2019) presents an empirical study in a UK based design firm and emphasizes leadership support as one of the key issues enabling successful diffusion of BIM. Similarly, Zulu and Khosrowshahi (2021) cast leaders as the key actors who could embrace DT and identify different leadership approaches exhibited by construction sector leaders. Alternatively, Criado-Perez *et al.,* (2022) introduce four different leadership thinking schemas required to assist DT strategies based on an empirical study in the Australian AEC sector. They argue that leaders need 'future scenario thinking' (1) to create future scenarios which are assumed to be initiated using 'strategic thinking' (2). Then, 'capabilities thinking' (3) is offered as the next step to align the company towards its intended future. Lastly, 'experimental thinking' (4) is seen as the step towards targeted visions. The emphasis on 'future scenario thinking' and 'capabilities thinking' directly resonate with other key themes emphasized in most of the DT studies. Such emphasis on leadership led us to look at how leaders in the Swedish construction sector make sense of DT, especially regarding its impact on the current business models.

Capabilities

The second theme emerges as the capabilities required for DT (i.e. Aghimien *et al.,* 2021, Bhattacharya and Momaya 2021). This line of research draws on dynamic capabilities view which suggests that firms have both ordinary and dynamic capabilities (DC) (Teece *et al.,* 2007). The former relates to operational and technical capabilities required to accomplish tasks; the latter focuses on the ability of firms to adapt to changes in their business ecosystem. The advice is that organisations should improve their DC to embrace DT. For example, Aghimien *et al. (*2021) conducts a bibliometric study to understand the DC needed for successful DT of construction sector organisations. They argue that organisations should develop their capabilities relating to industrial management and strategic planning, organisational learning, enterprise resource management and innovative information technology. There is a call for construction sector organisations to sense disruptions, seize technologies and reconfigure their business models; however, less has been discussed how such capabilities are utilized regarding DT. One key question to address is how the focus of construction sector organisations can be stretched from day-to-day business to developing capabilities to achieve successful digital transformation.

Enablers and barriers

The third theme is the enablers and barriers impacting the DT in the construction sector (Bosch-Sijtsema *et al.,* 2021, Olanipekun and Sutrisna 2021). For example, Olanipekun and Sutrisna (2021) conduct a systematic review of 151 publications in CM related literature. As result, they identify nine enablers (digital champions, attraction of digital technologies, training opportunities, innovativeness, third-party support, new forms of organisation, culture inclusion, external legitimation, and research potential) and ten barriers (complex data processing, data access and ownership, lack of system integration, ROI uncertainty, low standardisation, lack of owner buy-in, displacement of old workers, old business models, digital divide and security risks) in common. However, it is hard to make sense how and why any of these parameters are seen as barriers and enablers to whom. Considering the heterogeneity in the CS, we selected our interviews representing different actors with an expectation to grasp differences among what they see as enablers and barriers.

Future scenarios

The fourth and most popular category consists of future scenarios regarding DT in the construction sector (i.e., Erdogan *et al.,* 2009, Lavikka *et al.,* 2018, McKinsey 2000). In one of the earlier studies, Erdogan *et al.,* (2009) create scenarios for the construction sector in 2030. The ideas are Lego style design and construction, smart buildings, and offsite construction which are the core arguments populating the currently growing literature on Industry 4.0 (Bolpagni *et al.,* 2022). Another key concern emerging in the future of DT is the importance of data and issues regarding data ownership (i.e., Lavikka *et al.,* 2018). Future scenarios are also in the agenda of global consulting firms. For example, McKinsey (2020) listed four emerging disruptions in the construction sector as industrialisation, new materials and improved logistics, digitalisation of products and processes and lastly new entrants disrupting the current business models. The threat of new entrants (especially start-ups) has long been a key focus of the studies drawing on disruptive innovation theory; however, it is yet to be fully elaborated within the context of construction. Recently, Hall *et al.,* (2022) argue how new entrants accelerate DT and shift to new business models requiring vertical and horizontal integration in the fragmented nature of the construction ecosystem.

The four common themes discussed above supports our argument that understanding DT in the construction sector needs multi levels analysis from individual (i.e., leadership) to organisational (i.e. capabilities) and to broader ecosystem level (i.e., enablers and barriers and future scenarios).

METHOD

Empirical data is drawn from an ongoing research project exploring DT in the Swedish construction sector, focusing specifically on an ecosystem perspective. This approach is grounded in previous research indicating that DT requires distributed actions, collaboration, and coordination across the inter-organisational boundaries (Kraus *et al.,* 2022). To capture an ecosystem perspective, the research project is set up in collaboration with a large group of sector partners, representing the full range of 'traditional' CS companies, including architects, technical consultants, contractors, public clients, material suppliers, and real estate firms. This paper draws on preliminary findings from the first phase of this study in which we interviewed one actor, particularly initiated in business perspectives of digital technologies, representing each one of these sector partners. This interview study consists of 14 open-ended interviews spanning between 60-90 minutes each. While the previous review of the literature on DT (especially the four themes discussed above) was used to structure the preliminary analysis of current states and future trajectories, the interview study was designed in a more open-ended fashion. This was grounded in a methodological consideration that recognizes that open-ended storytelling (Alvesson and Sköldberg 2017) is an important data source for new insights in construction management research (Sergeeva and Green 2019). Because it is aptly geared to capture the context-specific aspects of the phenomena under scrutiny (Hopf 2004), here being the dynamics of DT unfolding amidst the specifics of the construction ecosystem. We therefore asked the respondents to tell their stories about DT across a few loosely structured thematic areas, including: "How they work to develop and implement DT in their operations and business offerings today", "what they consider the major challenges and opportunities related to digital technologies", and to "share their visions and examples regarding the potential future(s) of DT", "related both to their own processes and business models, as well as to the construction ecosystem as a whole". Within this open format we intervened frequently with follow-up prompts, such as "why", "what do you mean", "can you give an example" and "who are the 'we' you are referring to ", to challenge them to provide us with thick descriptions. We also persistently challenged them to explicate future scenarios by providing as many details as possible. All the interviews were transcribed verbatim and analysed and discussed by all authors to strengthen the relevance and accuracy of the results (Taylor *et al.,* 2010).

FINDINGS

Incremental Improvements Within 'The Silos'; Internal Efficiency, Cost Reductions, and Business-as-Usual

The results show that digital technologies are increasingly being implemented by the incumbents in the construction ecosystem. Primarily, the implementation of digital technologies is aligned to improve current internal operations of each organisation's core of business. Only for a few of the actors, DT implies deliberate organisational and/or business model transformation. For example, materials supplier #1 has a comprehensive digital and sustainability strategy, that governs all operations in the company, as well as new technologies (i.e., 3D printing). This actor is, however, one rare outlier in our study that have used digitalisation in a clear strategic way, as to transform the whole business model and propel more extensive organisational change. Common for all the actors is a broad uptake of more generic off the shelf IT solutions, used to pave the wave for more efficient administrative processes.

In those instances where digital tools are used for design and construction-related operations, there is a general emphasis on choosing tools that fits current operations, rather than altering them in any significant way. Current transformation in relation to digitalisation is therefore best characterized by incremental improvements of current operations as to improve efficiency and reduce costs, and not as a mean to transform the business models regarding, for instance, generating new revenues or profit. A converging finding across all the actors in the study, is that one major reason for why digital tools is yet to alter the construction value chain in any significant way, is because the incremental improvements remain within each different actors' 'silo' of operations. For digital technologies to transform the operations in the sector, there is an absolute need for coordination, compatibility, and integration across the organisational boundaries. The actors themselves are well-aware of these aspects and repeatedly emphasized this as the main hinder for a more substantial, or even radical, DT. The lack of co-creation and collaboration underlying the vast unrealized potential of digital technologies were described in various ways, but the well-recognized project-based temporality was indeed emphasised as a core hinder, cementing the traditional state of the operations in the value chain: including lack-of long-term alliances between design and production, clients and contractors, contractors, and sub-contractors, etc. It is also considered hard to find either incentives or mandates to influence digital technology development and/or implementation beyond the own organisational boundaries, and as a result the digitalized processes remain undistributed and unsubstantial in their nature.

Envisioning the Future: The Unrealised Potential of Digital Technologies

Table 1 below offers a summary of the actors' own visions regarding the potential future(s) of DT in the construction sector. Seeing that these visions are collected from the perspectives of many different actors, they also reflect the perceptions of how the actors' respective positions/roles in the ecosystem would change, in the case the digital tools would transform the sector in any significant ways in the future. The actors could indeed articulate how digital technologies - in theory - could be used to significantly transform processes and business model in the construction sector. Thus, visions about the future exist regarding digital technologies and data-driven business models. There is a strong consensus that DT will imply possibilities for future business opportunities, but also threats to existing operations and revenues. Most of the technologies listed in the table above exist already today in matured forms; that is, standing in-between these visions are mainly new ways of applying these technologies, rather than technology development as such.

Table 1: Future visions

Type of Company	Role description actor	Key words regarding future visions
Architect firm # 1	CIO	automated design, data-driven business model
Architect firm #2.	Partner	automated design
Architect firm #3	CIO	automated design, data-driven business model
Constr. Client Association	CEO	Data-driven processes, enforced data/IT-standards
Construction Company #1	CTO	Data-driven processes
Construction Company #2	CIO	Total BIM, robots in production
Construction Company #3	CSO	Integrated IT systems, Total BIM, data-driven processes,
Material Supplier #1	CEO	Integrated IT-systems, data-driven processes
Material Supplier #2	CEO	additive manufacturing, big data BIM-objects
Public Client #1	Real Estate Manager	Data-driven maintenance
Public Client #2	CAO	Data-driven maintenance
Public Client #3	Unit Manager	Visualization and integration geo-data
Tech. Consultancy Firm #1	CIO	automated design, big data, data-driven business model
Tech. Consultancy Firm #2	Business Developer	automated design, data-driven business model

In Search for a Roadmap for Digital Transformation

The results contain a significant lack of details regarding any clear and actionable roadmaps to realize these 'digitalized construction futures'; lacking explanations of, for instance, the key-events, leading actors, potential collaborations, and fruitful processes needed to catalyse and facilitate the transformation as such. Put differently, fruitful strategies for the transformation as such is largely missing in the actors' stories. There are also no clear visions for how any transformation would impersonalise in terms of 'change agents', such as radical changes undertaken by existing actors and/or entrance of new types of actors.

It is also important to point out that the sense of urgency for DT clearly differs between the actor categories. The highest sense of urgency for applications of new digital tools is found among the architects and the technical consultancy firms, with business models that currently are based on a 'selling by the hour' logic. Interestingly, this sense of urgency is grounded in a certain dual nature of both the threats and the opportunities that digital tools bring for these actors´ business offerings. For instance, the various design automation technologies that already now can speed up parts of the design process in a substantial way, are already now reducing the number of hours that these actors can charge their customer. Following this, finding alternative business models is a prioritized concern.

Accordingly, reflecting the higher sense of urgency, decisiveness, and stream of initiatives among these specific categories of actors is how they already now devote financial resources and personal, at a seemingly much higher rate compared to the other actors in the study (and according to our results, in particular discussing business models based on more value-based offerings and 'productification'). They also gave the impression of a much more structured strategy work geared towards business model transformations, facilitated by digital technologies. With that said, these actors too seem to have a long way to go before being able to realize the potential end-states that they were able to envision, albeit on a general level. One aggravating circumstance is a clear internal demand for the immediate application of new ideas. That is, rather than engaging in radical exploration, they are still restricted to stay within such a creative scope that encapsulates directly billable ideas; as a member of an architecture firm put it, when talking about their current innovation strategies related to new business models and digital tools: "we need to already now be able to walk on the bridges [here referring to new business ideas] that we build".

The contractors', material suppliers' and the public client organisations' stories do not mirror the same sense of urgency. On the contrary, they emphasise the value of digital technologies used to realize more low-risk improvements. Altogether, there is less strategic reorganisation taking place due to DT on the organisational level. Instead, resources are directed and adopted to the individual projects, serving as test beds for new digital technologies and processes, as well as for competence development of their employees (which was perceived as another key dimension). The large contractors seem to devote rather little investments on strategic/organisational level, generally employing one full-time professional being responsible for DT. The public client organisations, generally have no personal focusing on DT, but are buying digital competence on a project-to-project basis. In sum, we can see that the driver for DT comes in the form of a sense of urgency to implement, adapt and react to digital technologies that are already in place, while agreeing that the future is likely to entail more data-driven processes and business models. Thus, 'how to' transform existing business models in line with DT is characterised by an awareness that action is required. However, the road ahead is outlined by looking into the rear-view mirror and slowly adopting risk-free solutions, while also carefully navigating potential threats.

Another aspect, that is mitigating the general sense of urgency, is how the actors experience a lack of demand for digital solutions. This is a very clear finding in the study, in particular pertaining to the interaction between clients and contractors. The contractors express that more demanding customers would speed up the DT, noting, for example, that "other sectors have more demanding customers, we could need that as well” (Citation Contractor). The clients, on the other hand, seem to disagree with this point and pass the initiative back: "they (contractors) do not deliver well enough on the low demands we have today… they keep blaming us for not demanding more from them, yet they cannot even deliver in regard to the present demands " (citation Client Association). Having that said, what the actors in the study express in unified voice is the emphasis on collaboration and co-creation as a central aspect for DT to occur. First, as to develop the required technologies, hardware and software, the construction sector actors must interact with tech-actors as the CS actors do not have this as internal competences today. Second, collaboration is required to enable the necessary integration and compatibility for distributed digitalized processes (which also is seen as a recursive transition as aligning digital tools also can help increase the general levels of collaborations). Finally, some actors express the value of digital technologies as they might enable interaction with actors that previously only have had indirect connections, but via digital platforms and cloud solutions may enable new ties, and thus, opportunities for increased learning and future business opportunities.

Discussions of the digital transformation in the construction is commonly addressing the sector level; thus, unit of analysis is the sector as a single, homogenous “actor” (i.e., Criado-Perez 2022, Bhattacharya and Momaya 2021). Findings from the study in this paper points to the need to address the heterogeneity of the actors in the sector, and their respective different actor roles, positions in the value chain, business models etc. This inflicts on, for instance, the urgency of transforming: some actors experience a contemporary threat to their current business models, hence, the urgency to transform, whereas others mainly address the potential of digitalisation for improvement of current operations, but not in terms of urgent need to transform the business models.

DT is thus not the same for all actors in the construction value chain, and research and practice would benefit from more studies with a focus on the heterogeneity of actor roles and what DT would entail for the respective role, including the interaction to other direct and indirect parties, in the construction ecosystem. Most likely, actors will transform differently, and some actors might become obsolete and new actors will be part in the ecosystem. Such scrutinisation of DT must consider the different actors’ roles and how these actors relate to each other.

DT is a process, a series of progressive and interdependent steps, in a reimagining of business in the digital age. So far, one could argue that the CS is only taking baby steps in comparison with other sectors (i.e., Lavikka *et al.,* 2018). In fact, DT is not one process, but several parallel processes, when actors act, react and interact over time. DT is hence not only in the hands of the individual actor, but dependent on the interaction among actors, and several processes will feed each other, causing changes in the ecosystem that will, possibly and likely, also transform the value propositions and distribution among the actors. Thus, DT is a myriad of steps, where no single actor has full control over the process in the ecosystem. Managing in the ecosystem regarding the exploitation of digital technologies to transform will thus involve new types of collaborations, and even vertical and horizontal changes in terms of scope of business among incumbent actors and likely, new actors entering the ecosystem.

Leadership research has established a convincing correlation between leadership and successful change on organisational and sector levels. Many construction researchers have also indeed stressed that DT requires successful leadership (i.e., Zulu and Khosrowshahi 2021, Criado-Perez 2022). Our results show, however, that the actors in our study almost never talk about leadership. Instead, they emphasized “demanding customers and collaborators” (on individual and organisation level) as one missing driver. Rather than looking for a leader-like figure who inspires, empowers, takes proactive lead into the future (Criado-Perez *et al.,* 2022), the actors seem instead to wait for any actors that merely could raise the bar for the minimum requirements. Rather than showing any interest in taking on a leadership role which could instil a more proactive and visionary transformational discourse, the results show the actors rather kept passing around in circles the responsibility for actions to others.

While previous researchers have highlighted the need for renewed organisational capabilities to support DT (i.e., Aghimien *et al.,* 2021, Bhattacharya and Momaya 2021), our result highlight how the majority of the hinders lies in the inter-organisational boundaries. Seeing that the main hindrances are related to process integration and digital tool combability, it is unlikely that any intra-organisational transformation would be enough. Instead, our results suggest that DT would be achieved only by new processes that are distributed across many different actors. Any new organisational capabilities would therefore most likely require high degrees of co-creating and collaboration, to achieve the necessary levels of integration and combabilities across the organisational boundaries.

CONCLUSION

While previous research has portrayed the construction sector as a homogeneous unit and/or level where DT might unfold, our results highlight large differences among the sectors´ actors regarding many different dimensions of DT, such as, the resources they spent on it, the sense of urgency, their current progress, as well as their visions for the future. Drawing on these results, it can be concluded that there is a need to understand DT from a multi-level perspective, involving a large group of heterogeneous actors. Furthermore, while many of the key mechanics underlying DT will reside in various inter-organisational spaces, there is a strong consensus the central role that leadership (both on the individual- and organisational level) can play both to catalyse and support such transformation. This paper highlights how leadership perspectives and roles currently are being downplayed, among all the different categories of actors in the sector, which then potentially points at a key barrier for change - one that deserves increased attention from both researchers and practitioners.

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COST-ESTIMATION IN CONSTRUCTION: BIM VERSUS 'TOTAL BIM'

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Implementing Building Information Modelling (BIM) has been promoted to address cost overrun issues in the construction industry by improving the efficiency and quality of cost-estimation processes. Recently, the 'Total BIM' concept has emerged in Scandinavia, where the BIM is the legally binding construction document, 2D-drawings are excluded, and stricter BIM requirements are implemented. This paper highlights, explores issues, challenges, and opportunities within the cost-estimation process. Ten interviews were conducted with participants from traditional projects, involving the parallel use of BIM and traditional construction documents. An in-depth investigation of a 'Total BIM' project was also performed. Findings show that even in projects where BIM is present, traditional 2D-based methods were still used for cost-estimation due to a BIM's unclear legal status and lack of trust in BIM. 'Total BIM' may reduce cost estimation time by up to 90%, but issues regarding training, data and information management and education must be addressed.

Keywords: BIM; cost estimation; digital construction; Total BIM

INTRODUCTION

It is well known that cost overruns are an issue in the construction industry, and in an industry with such small profit margins there is always a desire to cut costs (Flyvbjerg 2002). To improve efficiency and quality in cost-estimation processes, implementing Building Information Modelling (BIM) has been promoted. In recent years, BIM adoption in the design phase has rapidly increased due to several reported benefits (Barlish and Sullivan 2012; Smith 2016; Tingvall 2020). However, it is still common that BIM and 2D paper drawings are used together in projects where two parallel design processes occur, and designers focus on delivering 2D drawings as the legally binding construction document (Disney *et al.,* 2021; Sundqvist *et al.,* 2020; Johansson *et al.,* 2019). When this happens, BIM usually ceases to be updated and becomes merely a reference model for visualisation purposes on the construction site. In Scandinavia some firms have begun exploring a broader use of BIM and the concept of 'Total BIM' has emerged (Cousins 2017). In a Total BIM project, BIM is the legally and contractually binding construction document for both designers and site workers. On the construction site, sub-contractors extract all information directly from BIM on mobile devices (Disney *et al.,* 2021).

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This includes creating production-oriented views on-site where filtering, dimensioning, sections are all performed by the construction workers themselves to carry out their work. BIM is the single source of information and a central platform for communication, utilizing modern hardware and BIM viewer software. Where question-handling, checklists, change orders and other construction processes are integrated in the software and connected to BIM. This approach completely excludes traditional 2D paper drawings and puts more requirements on the actual BIM, which may promote more use during cost-estimation and construction (Disney *et al.,* 2021). The Total BIM concept has gained attention after the recent success of the Celsius project, that was delivered under time and under budget and scored highly in worker surveys in Uppsala, Sweden.

The cost estimation process in construction is complex and has many factors to consider. There is no standard approach or data for estimating costs, which adds to the difficulty of the cost-estimation process (PMBOK 2017). Cost-estimation is significant in a project's lifetime, and inadequate cost-estimation can have disastrous consequences (Ottosson 2009). Human factors and lack of information are among the most common reasons behind under estimation (Klakegg and Lichtenberg 2015).

Recent projects carried out in Sweden with an aim of implementing the Total BIM concept show the benefits and how it can improve the cost estimation process during bidding and construction (Disney *et al.,* 2021). However, many actors are still hesitant to use this approach and are unsure of the benefits. This paper aims to add to the understanding of current issues in the cost estimation process and using BIM in this context. These two areas, cost estimation and BIM use in cost estimation, are first analysed individually to understand how Total BIM can be used in the cost estimation process for a construction project.

Related Work

In a report made by Brohn (2018) it is shown that the amount of time needed for a cost estimation differs greatly depending on the technology used. He writes that it takes approximately 160 hours of work with traditional manual calculations, 100 hours of work when using Bluebeam (digital drawings), and 15 hours when using a BIM model. Furthermore, the author also states that the model should be the primary source of information. Investigating the use of BIM for cost estimation is important, to unlock the reported potential benefits.

Cost estimation

Klakegg and Lichtenberg (2015) state that cost overruns are a significant problem for the construction sector, cost estimation is complex and considers many factors. According to Ottosson (2009), cost estimation is a key part in a project's lifetime. Despite its importance, initial cost estimation due to its complexity can often range from 25% under budget to 50% over budget on large projects, from the initial estimate to final actual cost. The process of cost estimating can vary due to the amount of approaches available (PMBOK 2017; Sayed *et al.,* 2020). However, they all have their own benefits and drawbacks, meaning that cost estimation is not only complex due to the number of factors, but also due to the number of methods available (PMBOK 2017). In research it has been argued that using BIM enables many benefits, such as time, cost savings and increased collaboration between disciplines (Tingvall 2020). On large projects savings of 8-12% of the total cost can be realized with the use on BIM (Tingvall 2020). Furthermore, BIM is starting to gain traction in the construction industry today and companies are starting to grasp the potential of BIM (Smith 2016).

Data management and standards
According to Smith (2016) the key to successfully working with BIM is data management. Many clients do not see the value in paying for a high-quality BIM and lack the knowledge to know if the BIM is detailed enough, leading to poor and inadequate data. A study made in the USA by Barlish and Sullivan (2012), tried to measure the benefits of BIM to argue for greater investment in projects. They found that long-term savings with a flexible design outweigh the initial extra costs and risk of rework, further adding that implementing BIM in the construction process leads to cost savings.

In a report by BIM Alliance (2016) they found that there needs to be standards for processes and definitions of terms to avoid misconceptions and increase clarity in contracts. In the report the authors also found that the requirements and gains from BIM must be made clearer so that BIM can be optimized for the various project phases and actors. However, the process of implementing BIM standards remains challenging because today most contracts and regulators do not require detailed BIM use (Vukovic *et al.,* 2015). Therefore, whilst BIM use has become more common in projects its full potential has not been realised.

METHOD

To investigate the cost estimation process and Total BIM, a literature review followed by interviews with different stakeholders in the Swedish construction industry was performed. The initial part of the study investigated the current state, found issues and the research gap connected to cost estimation and Total BIM processes. The two research areas are firstly separated to gain a deeper understanding of each. Then they are combined and developed to see how Total BIM can improve the cost estimation process.

Interview Study

Ten interviews were conducted, eight of these were one-on-one, the other two occurred with interviewees in pairs. In total twelve professionals were interviewed, and all interviews were performed online on Microsoft Teams. The interviewees held different positions, including two clients, two contractors, five consultants, one software developer, and two estimators. The interviews were semi-structured, and the questions were divided into two parts, cost estimation and BIM. One of the interviewees was responsible for digital implementation in the successful Total BIM project, Celsius. Another interviewee was responsible for the digital implementation and strategy for the project Total BIM project Kaj 16, which is used for the case study in this paper.

Case Analysis

The interview study findings were later tested and validated in an ongoing Total BIM case project in Gothenburg, Sweden. The case was an ongoing project called Kaj 16, which aims at being a Total BIM project (Figure 1). The project is currently in the design phase and is still being revised prior to the building permit process. BIM is to be used to calculate and estimate quantities and costs in the project. This study is limited to the concrete elements of the basement instead of the entire project due to time constraints. However, the findings should not be affected by the scope of the research and the highlighted issues should remain relevant throughout project. The study tested using two different methods for performing a cost estimation. The first method used BIM viewer and collaboration software, StreamBIM's own export and data structure to calculate quantities.

Figure 1: a: StreamBIM screenshot of Case project, Kaj 16. b: Filtering of the BIM use classification system.

The second method exported the model as an IFC-file, which was then imported into Solibri (Figure 2).

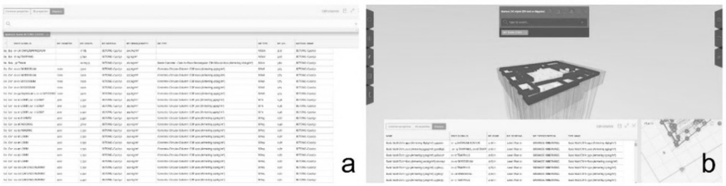

Figure 2: a: Quantity take-off in StreamBIM. *b:* Case where rebar is not stated in a column leading to more manual work.

Data Analysis

To analyse the findings from the study, a thematic analysis was adopted. This approach allowed for a data analysis where data can be searched and sorted according to themes and patterns (Alhojailan, 2012). This method of analysis enabled a flexible examination of the findings and generates insight through categorising the empirical data into themes.

As stated above, the empirical data found in the interview study was validated in a case analysis to improve the trustworthiness of the study and gain a deeper understanding of the findings. The data analysis was therefore twofold, an initial analysis after the interview study and later when the findings had been validated in the case study, i.e., Kaj 16.

FINDINGS

Interview study

All interviewees said that cost overruns are a problem in construction projects but there are many complex reasons for them. Most also said that it is a serious issue that affects everyone in the industry. Furthermore, there did not seem to be any standard cost estimation process, even within the same company and it could differ greatly between projects. Interviewees stated that cost estimation only acts as a tool in the decision-making process and managers may alter the numbers depending on their goals. The most common reason given for making the alterations was to increase the competitiveness of the company, which is why projects often exceeded estimated costs. As stated by one interviewee,

> "we have many employees, and they must have work. […] So, for a project that we really want, we can submit a low bid and even accept it at a loss. And for some project that we don't really want, we can bid anyway but really high. It is difficult to identify cost overruns because it depends on how we approach the project."

However, the interviewees still emphasised the importance of accurate cost estimation. The consequences of inaccurate cost estimation would be twofold if managers were to alter an incorrect cost estimation. The interview results also showed that lack of information in early stages of a project is a common reason for cost overruns, along with a too short design phase.

When discussing BIM, the interviewees all agreed that it is standard in their new building projects. However, the level of usage and quality differs greatly, sometimes rendering BIM useless. It was also apparent that to succeed with implementing BIM in an organisation or project there needs to be key leaders who are driven and invested in the approach. According to some of the interviewees a reason for BIM being limited in projects is that it is difficult to use the model as a legal document in contracts. However, other interviewees contradict this statement by showing examples of successful projects that have used the model as the legally binding document. These interviewees do not see any legal issues with BIM and state that the legal issues are only myths made by 'naysayers'. One interviewee working for a large client explained that they hired a legal team to investigate potential legal issues with BIM and that they could not find any. They said,

> "we've discussed with a number of legal practitioners about working digitally and they stated there are no issues. They also said our current standard agreements work fine with BIM. One legal practitioner even said that it is better because it increases the traceability of the documentation."

This connects to a wider issue regarding BIM adoption which is scepticism without reason. Most interviewees noticed this in their work. Many actors were sceptical about the technology, but when it becomes apparent that they lack knowledge, their view usually changes. It is clear from the interview study that the issue with data management in BIM is not the lack of data, but the overflow of unnecessary unstructured data. Data that is unsorted becomes unclear what it should be used for. The interviewees state that poor unstructured data is almost as bad as no data. Adding that transferring data between parties often leads to loss of data and misunderstandings. When asked about the issues with BIM, many interviewees mentioned communication, technological maturity, and knowledge, where knowledge was the most limiting. Many clients believe that BIM is only a 3D-viewer and that makes it difficult to work with, which also leads to trust issues. Several interviewees stated that there is a lack of trust in the model and that they had to check BIM data many times, as there is often inconsistent information. One estimator stated that,

> "…currently the issue is that you still have to double-check BIM data with the drawings, which leads to more work. […] As an example, I calculated a garage with a slab roof which was part of a building further on. In the drawings, they added information about the slab not being included, but not in BIM, leading to many millions [Swedish crowns] too much."

There is no hesitation amongst the interviewees that BIM is the future of the construction industry. Most thought that BIM should be used earlier in the building process and that the construction process should have a more collaborative approach than we have today.

Case study

As mentioned, some statements and findings were validated in an ongoing Total BIM case project Kaj 16. During the experiment in the case study, two different methods for cost estimation were tested. The first used StreamBIM to export data and the second imported an IFC file into Solibri. Both methods led to an Excel sheet with quantities which meant that they had to be manually updated. BIM was extensive with detailed object information. However, StreamBIM's functionality is lacking in some respects. It is still quicker to export the IFC file to Solibri for a better quantity take-off due to the abilities to structure data.

The experiment in the case study showed the importance of data management. It was important to have the desired data in the model with a good structure and sorting out undesired data. In this case study experiment, a quantity take-off for concrete was performed but the BIM lacked detail as no reinforcement was included, so it had to be manually calculated. Information also had to be sorted into different property-sets to ease the data management for the user (Figure 2). Maintaining a good data structure throughout the project is essential. Otherwise, information chains and information sustainability may be jeopardized when transferring data between users, leading to a loss of quality. Therefore, well-structured data is essential to achieve an accurate cost estimation process.

One of the most challenging aspects and a learning experience from the case study was the process of discovering and learning the different software functionalities to perform an accurate cost estimation. Software like Solibri is tailored towards expert users and not sufficiently user-friendly, which highlights drawbacks and limitations towards end users lack knowledge of using software. It is likely that an expert in the software may be able to perform a more accurate estimation than a novice user, but on construction sites the target group is a "novice user". Currently projects may benefit from having additional support or expert users present on-site, to help with training and problem solving. Furthermore, the case study showed the differences between software and how the software can affect the quality of the cost estimation. However, the case study showed a clear benefit of using the BIM approach to cost estimation compared with a traditional 2D-drawing approach. Having data structured in BIM massively decreases quantity take-off time and increases take-off accuracy.

Finally, the case study test showed that exporting data may lead to version control issues. Working in a cloud-based model ensures that information is accurate and up to date. This, in turn, leads to all actors working with that same information, and one source of truth.

In an industry with small profit margins, it might be expected that there is an emphasis on accurate cost estimation and budgets, but this is often not the case. Although the findings show that cost overruns are a significant problem in projects, the willingness to improve them seems to be lacking. Some interviewees thought that the issue is not with methods and processes of cost estimation but with tendering and procurement. Furthermore, cost estimation in many cases is just a guide for managers and decision makers to use for the bidding process. The client that was interviewed thought that a thorough cost estimation was not worth the effort because it is usually not detailed enough anyway. This could be an issue in the cost estimation process because the clients that are funding projects do not work with the same profit margins as contractors.

It is apparent that there needs to be more standardised BIM processes, especially regarding implementation in the cost estimation process. If the construction industry tried to implement a BIM based approach to cost estimation today, there would be issues adapting it to all the different methods that currently exist. Whilst flexible methods may benefit some actors, they represent significant challenges moving towards a more standardised, automated BIM approach. As the findings from the case study experiment showed, software like Solibri is tailored towards expert users and not user-friendly enough for non-daily users such as those on construction sites. In the Celsius project they recognized this as a problem during the bidding process and therefore provided sub-contractors bidding on the project an Excel-sheet with all the relevant quantity data. This quantity take-off Excel-sheet was updated weekly throughout construction as change orders were updated by the design team (Disney *et al.,* 2021).

Identifying issues with BIM today are necessary to understand how to improve and implement BIM in the future of cost estimation. There are opportunities to save both time and money as occurred in the Total BIM project, Celsius. While BIM implementation has developed significantly over the last decade, its benefits are not fully realised (Disney *et al.,* 2021). BIM is still mostly used in the design stage of projects, where parallel processes occur to produce 2D drawings from BIM. The model ceases to be updated and trust is lost in the model. To be able to use BIM for accurate cost estimation it is important that BIM represents what is going to be built, with accurate quantities. Then users can begin to trust the model and perform accurate work.

Today there is a significant lack of knowledge regarding BIM in the construction process. From the interviews we heard that BIM is still thought of as merely a tool for representing a model in 3D and the case study highlighted the need for expert software users. An interviewee stated that information from the model may as well be in 1D (a list in Excel), because the current focus is on data and not the 3D viewer. The interviewee meant that the real benefit of BIM is not the viewer but data management. This creates issues later in the project because some actors do not have the knowledge to know what the information is used for. Furthermore, knowledge regarding the available BIM tools needs to improve and users must fully understand how to use them.

To implement the Total BIM concept, companies need to invest in educating workers. User-friendliness of software, ease of access and information structures may also help adoption. It is also apparent from the interviews that for change to occur and a wider use of BIM, company leaders must be fully committed. Differences between the tools could also lead to potential issues. However, the issues are linked to the user's experience and compared to estimating costs without BIM the issues are minor. By using BIM significant time savings can be realised. A key difference between using BIM and 2D paper drawings is that users have access to all the information instantly. To achieve this, it is required that BIM is developed to an appropriate level of detail and quality. Low-quality BIM is useless for cost estimation and can in the worst-case lead to more work. It can also very easily lead to trust issues, which were discussed during the interview study as an important issue limiting further implementation of BIM. Trust issues can also relate to the user-friendliness of software. If there is a risk of missing information due to user software skills, trust in BIM decreases.

Traditionally 2D drawings are the legally binding construction documents, which means that to develop production-oriented BIM, extra work is required. Otherwise, BIM is used merely as a reference model and not used to its full potential. When there are few or no requirements set on BIM it is difficult to trust and information must be double-checked. This makes it difficult to work with and there is no incentive to do so. In a Total BIM project, BIM has a higher legal status than 2D drawings and completely replaces them.

At this point BIM becomes the single source of information and an accurate representation of the object to be built, as it is legally required to do so. The case study findings also support this, since attempting to use BIM for cost estimation when BIM cannot be trusted is pointless. However, as Brohn (2018) described, there is a huge potential to save time by using BIM in cost estimation compared with traditional methods. If BIM is used in this context higher demands and requirements must be placed on developing an accurate representation. Incorrect or missing data could have serious consequences, so trust needs to be established. The importance of BIM as the primary source of information and the legally binding document is therefore essential. This still may be a novel concept but has been proven by the Celsius case and the interviewee findings where no legal barriers could be found.

Despite scepticism, legal issues connected to Total BIM have been shown to be minimal (in Sweden) and not hinder the process of implementing Total BIM or using BIM in cost estimation. However, it should be noted that this may not be possible in other countries due to local regulations, but the Total BIM approach in Celsius does highlight the need for it to be considered. In Sweden regulations have been established around traditional 2D documents and they are lacking regarding BIM. While there are not currently any issues there still needs to be a certain level of BIM maturity before using it as legally binding.

Users need training to adapt to new work methods. It can be discussed whether BIM, 2D drawings or technical documents should be ranked highest in projects, but another benefit shown in the Celsius project was using StreamBIM as a central communication platform. In StreamBIM all case, issue management, question-handling and more occurred through the platform. To support this, all object information, technical documents, and construction information were linked to BIM, and easily accessible. Establishing the model as the single source of all construction information and a single construction process. This single process if executed well may streamline the unnecessary work that goes into producing and maintaining 2D drawings. As found in other parts of this study, an accurate BIM has potential to be used for accurate cost estimation, providing users have the necessary support.

As stated above, data management is essential in BIM and to structure data there needs to be a classification system, which users can easily understand. When analysing the results, it shows that although some users may not see the need for a standard classification system, it may help to implement more structured processes and methods when working with BIM. It could also help actors to quicker understand and comprehend project data if it is structured consistently between projects. Data management is a key part of working with Total BIM successfully and implementing BIM in cost-estimation. The importance of data management found in the interview study is also found in the case analysis. The case study showed that for cost estimation to work with BIM, data must be well structured. Findings suggest that it is highly important to be able to structure and filter data in BIM to easily find the desired information. While data may be accessible even without a good structure, it should be structured in a way where users can easily filter to information that is relevant to them. In a Total BIM project this is essential since BIM is the single source of information and construction workers must be able to easily access the information they need.

This paper shows that connecting cost-estimation and BIM in today's process is not as efficient as it could be, it remains challenging due to the level of complexity in construction projects. It also shows that both the cost estimation process and BIM lack standards which may be necessary to achieve accuracy and consistency. However, if BIM was used to a greater extent in the cost estimation process, there needs to be a more structured approach than found in most projects today. By going 'all-in' on BIM and using a structured Total BIM approach, where BIM is legally binding, other benefits may also be achieved. Designers work more collaboratively as they work on the model at the same time, focusing on high-quality design where all object information is present, and consider how construction occurs on-site. Producing 2D drawings is no longer necessary and site workers can construct directly from BIM by using mobile devices to extract the construction information they need themselves.

CONCLUSION

As highlighted in this paper, BIM is very time efficient when it comes to quantity take-off and cost estimation. However, as BIM in most cases is not used as a legally binding construction document, design teams focus more on delivering accurate 2D drawings instead of BIM. This causes quality and trust issues when it comes to using BIM on construction site and for cost estimation. The interviewees mentioned the lack of trust in BIM and that they had to double check data with drawings and descriptions if it was used. Using BIM in the cost estimation process requires that all disciplines trust it. If trust issues arise towards BIM, it will quickly become redundant. This could have greater consequences further down the project's lifetime. However, in Scandinavia the Total BIM approach has started to gain interest as it focuses on implementing BIM in its 'totality', as a single source of information, a communication platform, and the legally binding construction document.

In conclusion, Total BIM has future potential in achieving a more cost-efficient way of working. However, to successfully implement Total BIM in the cost estimation process, there are some areas that need attending. If BIM is going to be used to a greater extent in the cost estimation process, it needs to be more structured. The information, data and management structures are key to being successful. Another finding is the lack of knowledge surrounding BIM is a big reason for the lack of implementation. For instance, findings also show a lack of understanding and maturity in the industry regarding Total BIM, as the belief and statements of legal obstacles and scepticism without real-knowledge or reason occurs.

In this case the industry must be educated and acquire more understanding and knowledge. Total BIM can be a diving-force for using BIM on the construction site and increase the efficiency and quality in the cost estimation process. Furthermore, comparing Total BIM to the traditional cost estimation approach it is apparent that the process is not only more efficient but more accurate as well. However, to reach its full potential, the industry has some issues to tackle, there must be a willingness to invest more knowledge, resources, and time into the design process to obtain a higher-quality BIM. The findings in this study, contribute, add knowledge and understanding to current issues and how these can be approached by implementing Total BIM in the cost estimation process.

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BUILDING INFORMATION MODELLING CORE COMPETENCIES EXPECTED OF CONSTRUCTION MANAGEMENT GRADUATES: A NIGERIAN CONSTRUCTION INDUSTRY CASE STUDY

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Building Information Modelling (BIM) has been in existence since the 3rd industrial revolution phase. Most literature indicates its low usage in developing countries despite its great benefits. Moreover, the construction industry is still faced with getting knowledgeable professionals and graduates who understand the BIM model's integration and application. Thus, a need to employ construction management graduates (CMG) who possess substantial competencies in this regard. Therefore, this study investigates the expected BIM core competencies (EBCC) of CMG. 13 variables were obtained through review. Primary data was sourced through google form using a snowballing technique. 350 valid responses were obtained. Results found that all 13 variables were enormously significant: with RII values ranging from 0.88 to 0.93. ANOVA/KW reveal no notable difference between the perspectives of the three respondent groups. However; 7 EBCCs were ranked as the most important. This study will contribute to the body of BIM knowledge and innovative competencies expected of CMG.

Keywords: BIM; client; core competencies; Nigeria

INTRODUCTION

The technological advancement through the industrial revolution stages does not leave the construction industry behind. The rapid advancement of several technologies in the construction industry globally, including BIM, Augmented Reality, Robotics, Artificial Intelligence, Prefabricated or Modular Construction, 3D Scanning and Photogrammetry, Wireless Monitoring, 3D Printing, Cloud and Mobile Technology, Wearable Technology, and Machine Learning. These required more sophisticated competencies than the traditional methods of construction. Decades ago, construction professionals found it difficult to quickly upgrade themselves to technological advancements (Torres-Machí *et al.,* 2013). Similarly, quantity surveyors (QS) also did not find it easy to adapt to the revolving QS competencies in the construction industry (Yap *et al.,* 2021). Although the advancement is not limited to technology alone, it spans through "sustainability in construction", "social value in construction",

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"climate change agendas", and "global impacts on material management" (Farag *et al.,* 2016; Thuesen and Opoku 2018).

Nevertheless, the construction managers (CM) are under tremendous pressure as most of them struggle to align themselves with the evolving technology (Demirdoven and Arditi 2014). They need to quickly master the implementation and coordination of those software, applications, and models to remain relevant in the industry as innovation unfolds. The Architecture, Engineering and Construction (AEC) industries now experience a constant change in the mode of their activities, majorly due to the incorporation of new technologies; one of such is BIM (Toyin and Mewomo 2023). BIM is more than just a software program; it incorporates human activity, which substantially improves the building industry's processes (Demirdoven and Arditi, 2014).

BIM adoption in construction has notably improved building design, production, management, and operation and maintenance (O&M). BIM implementation gains more acceptance in the construction sector (Toyin and Mewomo, 2023). As a result, BIM knowledge is an essential skill expected of construction management graduates (Kolarić *et al.,* 2018). Construction management graduates (CMG) are employed in numerous organisations in the industry. These include construction and project management consultancy, building and civil engineering contracting, client (public and private) organisations, and developer organisations (Vaz-Serra and Mitcheltree, 2021).

However, CMG must be equipped with vital skills and competencies, including knowledge of recent software used in construction. These will enable them to operate effectively and proficiently with other professionals in the industry, subsequently giving them a range of career options (Dada and Jagboro, 2012). Moreover, the construction industry's distinctive structure, the innovative global transformation in construction and evolving regulatory requirements. Have forced the AEC employers to seek for CMGs who are academically sound and possess substantial competencies in construction-related software applications tools such as "BIM". In addition, "Intelligence, flexibility, adaptability, and the capacity to deal with uncertainty and rapid change" are all-important personal qualities that potential employers look for (Love *et al.,* 2001).

LITERATURE REVIEW

It is important to check if colleges/institutions reflect the evolving construction technology in their curricula. Mihara *et al.,* (2014) compared the curricula of UK and Japan Universities. The authors submit that most institutions have incorporated information technology studies such as BIM in their curricula. It implies that CMG from such institutions is expected to be familiar with the BIM process by default.

Competencies

GWA (2022) defines competency as the behavioural characteristics, abilities, skills, and knowledge necessary to deliver satisfactory results while on the job. Buvik and Rolfsen (2015) see competence as "the abilities, skills, and capabilities that a person has in a particular domain". Based on the above understanding, competency could be generally seen as the capability to utilise specific attributes of knowledge, skills, talent, or personal quality needed to achieve/deliver crucial tasks or jobs efficiently. According to Turner (2017), "the key competencies expected of project managers encompass technical knowledge and behaviours, leadership capabilities and expertise in strategic and business management".

Torres-Machí *et al.,* (2013) researched in Spain focused on CMG students. The authors seek their point of view to know why the unemployment rate was high among young graduates of CM professionals. Lack of adequate communication (language barrier, due to the diverse nature of professionals in their industry), inadequate preliminary university program (lack of BIM knowledge), no eagerness to work, failure to explore other countries, inadequate master's degree to fulfil market demands, economic crisis, a surplus of universities awarding the similar graduate degree were seen as the primary reason. Nevertheless, researchers have documented extensive findings on the expected competencies of built professional graduates in the construction industry, but the available primary study focused on the Quantity Surveyor (QS). Dada and Jagboro (2012) researched Nigeria; their study result indicates the essential general skills are "computer literacy, building engineering, information technology, economics, measurement/quantification and knowledge of civil/heavy engineering works".

Wherein noted, the vital competencies for QS were: "cost planning and control, estimating, construction procurement system, contract documentation, contract administration and project management". Yap *et al.,* (2021) conducted a similar study in Malaysia. The authors also focused on QS's current and future expected competencies; their findings identified the most critical contemporary competencies as "cost planning, valuation of works, measurement/quantification, and contract documentation.". Moreover, the authors recalled that the expected future competencies required by expertise are: "communication and negotiation, ethics and professional conduct, and value management". Yogeshwaran *et al.,* (2018) conducted research focused on developing countries.

The authors submit that graduate QS competency in areas such as "cost planning," "strategic planning," "life cycle cost analysis," "sustainability," "building surveying," and "business management" is at accepted levels that exceed what the industry requires. Mitcheltree *et al.,* (2019) and Vaz-Serra and Mitcheltree (2021) researched in Australia, focusing on CMG competencies. It was concluded that more critical concern was placed on "interpersonal skills" and "competencies defined as traditionally fitting within core technical knowledge" within the Australian construction industry - however, the limited publication in this study context real low concentration to this study area. At the same time, non or few have investigated CMG's expected BIM core competencies in the construction industry. However, this study aims to add to the body of knowledge in this area and serve as the first empirical study in the Nigerian AEC industry. Therefore, this study intends to investigate the EBCC required of CMG by the employers (contractor/consultant and client) in the Nigerian construction industry. Table 1 shows the expected BIM core competencies required of CMG as identified from the published articles.

METHOD

This study adopts two distinct methods to source data. First method; secondary data were obtained through a thorough review of past published literature in the framework of this study. These yield 13 crucial Expected BIM Core Competencies (EBCC). Thus, identifying the 13 possible EBCCs is based mainly on competencies that have received ample consideration in studies conducted in different countries. Similar methods were adopted by (Chan *et al.,* 2018). The authors agreed it is "more appropriate to use well-known factors for a research study, as that would allow respondents to respond easily".

Table 1: Expected BIM core competencies for CMG

Code	Competencies	References
EBCC1	Good communication	(Hodorog *et al.,* 2019; Kolarić *et al.,* 2018)
EBCC 2	Analytical and problem-solving skills	(Ku and Taiebat, 2011)
EBCC 3	Basic Modelling specification, validation, access management and control.	(Hodorog *et al.,* 2019; Kolarić *et al.,* 2018; Ku and Taiebat, 2011)
EBCC 4	ICT competence	(Hodorog *et al.,* 2019)
EBCC 5	Teamwork	(Raiola, 2016; Wang *et al.,* 2020)
EBCC 6	Basic understanding of the BIM process	(Raiola, 2016; Uhm *et al.,* 2017)
EBCC 7	Knowledge of the construction process	(Raiola, 2016; Bozoglu, 2016)
EBCC 8	Design coordination	(Mitcheltree *et al.,* 2019; Bozoglu, 2016)
EBCC 9	BIM coordination	(Wang *et al.,* 2020)
EBCC 10	Enthusiasm for learning new software	(Kolarić *et al.,* 2018)
EBCC 11	Experience using virtual design and construction (VDC)/Big room method	(Yakami *et al.,* 2017; Mitcheltree *et al.,* 2019)
EBCC 12	Quality and document management	(Ku and Taiebat, 2011)
EBCC 13	Technical Decision making	(Yakami *et al.,* 2017)

Second method; A web-based questionnaire survey was constructed to collect quantitative data. The questionnaire survey encompasses two main steps to assess the relevance and reliability of the questionnaire. Firstly, the questionnaire was reviewed by two real estate human resource managers (RE-HRM) and a contractor with over 10 years of practising experience in Lagos, confirming that unclear expressions were not contained in the survey and that suitable technical terms were used.

These professionals were assigned because; RE-HRMs are conversant with the essential required competencies and are responsible for interviewing /screening and employing potential employees; The contractors know the nature of the job and the possible competencies needed to carry out the job. The questionnaire covered the main expected BIM-related competencies required of CGM. Snowballing sampling technic was adopted to locate the relevant respondent, a similar approach adopted by Gledson *et al.,* (2016). Secondly, a pilot study with 20 respondents was first conducted to test the comprehensibility and design of the questionnaire before its wide distribution. The expected BIM core competencies were measured on a five-point Likert scale from 1 ("not significant") to 5 ("strongly significant"). One of the reliable methods used to validate quantitative questionnaire reliability is using Cronbach's alpha technics (Toyin and Mewomo, 2021b).

These technics determine the average relationship or internal regularity amongst factors/variables in a questionnaire. Using the IBM SPSS 27.0, the calculated α value for the 13 EBCC was 0.889. These indicated the measurement is reliable at a 5% significant level based on the five-point Likert scale. The collected data sample can be suitable for further descriptive and inferential analysis. As no further modification was made to the pilot study questionnaire, the responses of all 20 respondents involved were included in the primary survey. In this study, "section A requests demographic information of the respondents and section B requests expected BIM core competency (EBCC1-EBCC13), measured on a five-point Likert scale. The target population is CMG, contractor/consultant, and client (developer). The sample frame involves representatives from the target population in the country's southwest region.

The students' viewpoints were obtained as they had reasonable experience with the employer's demands from their industrial training program experience. At the same time, the viewpoint of contractor/consultant and client was obtained since they deal directly with construction managers and know what is expected of them. Descriptive analysis: the mean Item Score (MIS) was used to rank the EBCS variables, while the relative importance index (RII) was used to rank the level of its significance. The variables were evaluated using the 5-point Likert scale to help determine the importance of each variable.

Inferential analysis: "Homogeneity of variances, one way ANOVA and Kruskal-Wallis (KW) tests are used to evaluate the perceived importance of the expected BIM core competencies between the different respondent groups of contractors/consultants, clients, and students". 'Secondary data obtained through a thorough literature review of related publications are then used as a guide for discussion and plotting of the findings (Yap *et al.,* 2021).

FINDINGS

Background Information

This section entails the respondent's background information categorised using gender, current role, and years of experience in construction. Table 2 shows detailed results in this regard. It reveals that 76% of the respondents had substantial working experience in construction. It could be concluded that the information gotten from them is reliable.

Table 2: Respondent background information

Demographic data	Respondents	Percentage %	Cumulative
Gender	245	70%	70%
Male	105	30%	100%
Female			
Current role			
Contractor/consultant	112	32%	32%
Client (Developer)	85	24.3%	56.3%
Student	153	43.7%	100%
Years of experience in the construction industry			
Less than 5 years	91	26%	26%
5-10 years	82	23.4%	49.4%
11-15 years	73	20.9%	70.3%
16-20 years	54	15.4%	85.7%
More than 20 years	50	14.3%	100%

Analysis of Results

Using the IBM SPSS 27.0 Statistical software, the Cronbach's alpha value of 0.893 for the 13 variables is superb, indicating that the five-point Likert scale measurement was reliable at the 5% significance level. The RII results reveal that all the (EBCS1-EBCS13) are statistically significant. Table 3 presents the mean scores and standard deviations of the significance ratings for each EBCS overall and as viewed by the respondent types. Overall, the mean scores range from 4.42 to 4.67; Contractor/ consultant from 4.22 to 4.71; Client from 4.36 to 4.72 and student from 4.31 to 4.61. overall, the seven most essential competencies are: EBCS1, EBCC 5, EBCC6, EBCC4, EBCC7, EBCC8 and EBCC9 being good communication, Analytical and problem-solving skills, Teamwork, Basic understanding of BIM process, Knowledge of construction process, design coordination and BIM coordination with mean scores of 4.67, 4.62, 4.62, 4.61, 4.54, 4.54, and 4.54 respectively.

However, EBCC11: Experience using virtual design and construction (VDC)/Big room method; EBCC3: Basic Modelling specification, validation, access management, and control, with a mean score of 4.32 and 4.35, respectively, are ranked lowest. However, looking at the top-ranked variables, it could be deduced that the industry expects much from intending and current CMG. Good communication is essential in any labour-intensive organisation. Ranking it first shows that it's very crucial. Table 3 shows all the three respondent groups unanimously agreed on the criticality of the competencies. In the case of EBCC11 and EBCC3, ranking them as least important from the variable list doesn't mean they are not significantly important. The MIS is relatively strong.

Table 3: EBCC descriptive analysis for each group

Code	Contractor/ consultant N=112		Client (Developer) N=85		Graduate Student N=153		Overall N = 350	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
EBCS1	4.71	0.46	4.72	0.45	4.61	0.54	4.67	.559
EBCS2	4.46	0.67	4.52	0.55	4.53	0.60	4.51	.609
EBCS3	4.41	0.72	4.34	0.63	4.31	0.75	4.35	.710
EBCS4	4.55	0.72	4.68	0.54	4.61	0.57	4.61	.618
EBCS5	4.60	0.68	4.68	0.49	4.60	0.61	4.62	.607
EBCS6	4.60	0.59	4.69	0.56	4.59	0.73	4.62	.648
EBCS7	4.53	0.63	4.55	0.52	4.54	0.63	4.54	.603
EBCS8	4.47	0.71	4.65	0.57	4.52	0.63	4.54	.645
EBCS9	4.62	0.62	4.48	0.67	4.52	0.70	4.54	.666
EBCS10	4.48	0.70	4.51	0.63	4.49	0.67	4.49	.667
EBCS11	4.22	0.77	4.36	0.75	4.37	0.80	4.32	.780
EBCS12	4.39	0.79	4.42	0.66	4.46	0.69	4.43	.714
EBCS13	4.35	0.73	4.39	0.67	4.48	0.69	4.42	.700

From Table 4, the RII result ranges from 0.88 to 0.93. It could be concluded that the 13 variables, according to the viewpoint of the 350 respondents, are statistically strongly significant.

In this study, homogeneity of variance (HV) based on the mean (BM) was first conducted for the inferential statistics. Using SPSS 27.0, the significance level of 0.05 and confidence interval of 95.0 % were set. It was assumed that out of the 13 variables, EBCS4 and EBCS8 violated the rule of HV. Thereafter, one way ANOVA/KW statistical tests were conducted. The result shows that all the 13 variables accept the null hypothesis statement: 'The distribution of the EBCS1 to EBCS13 is the same across categories of 3 respondents' group. The decision was to retain the null hypothesis. These could be deduced from the result of Table 4. The significance level of all the variables is greater than 0.05. Fig. 1 and Fig. 2 justified the result of EBCC 4 and 8. Thus, no significant difference from the perspective of the respondents.

Table 4: Descriptive and inferential statistical test

Descriptive					HV		Hypothesis Test	
N = 350					Levene's Statistic:		ANOVA/KW	
Code	Mean	SD	RI I	Rank	BM	Sig.	F	Sig.
EBCC1	4.67	.559	.93	1	2.235	.109	1.418	.244
EBCC2	4.51	.609	.90	8	.994	.371	.390	.678
EBCC3	4.35	.710	.87	12	3.091	.047	.614	.542
EBCC4	4.61	.618	.92	4	4.396	0.13*	1.054	.350
EBCC5	4.62	.607	.92	2	2.529	0.81	.592	.554
EBCC6	4.62	.648	.92	3	2.495	0.84	.735	.480
EBCC7	4.54	.603	.91	5	1.614	.201	.0.47	.954
EBCC8	4.54	.645	.91	6	4.755	.009**	2.159	.117
EBCC9	4.54	.666	.91	7	2.466	0.86	1.145	.319
EBCC10	4.49	.667	.90	9	.260	.771	.031	.970
EBCC11	4.32	.780	.86	13	1.065	.346	1.348	.261
EBCC12	4.43	.714	.89	10	1.375	.254	.327	.721
EBCC13	4.42	.700	.88	11	.002	.998	1.308	.272

RII values	Significance level
0.81≤RII≤1	Strongly significant
0.61≤RII≤0.8	Significant
0.41≤RII≤0.6	Neutral
0.21≤RII≤0.4	Less significant
0≤RII≤0.2	Not significant

a. The test statistic is adjusted for ties

b. Multiple comparisons are not performed because the overall test does not show significant difference across samples. (TS)= Test Statistic. Sig= Significance (P value).

Fig. 1 and Fig. 2 indicate the opinion of the respondents are likely the same across the three categories. Showing the Likert scale selection option falls from 3 to 5. Therefore, building back wiser from the traditional means of construction and design process, the CMG must possess the highlighted 13 minimum required competencies in the Nigerian AEC industry.

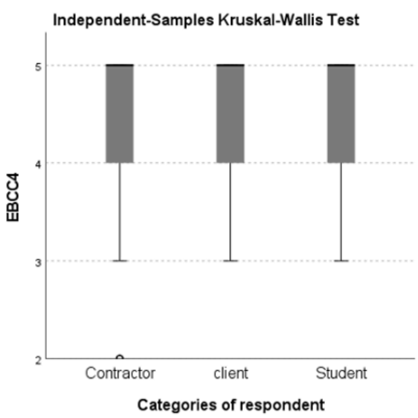

Figure 1: ANOVA/KW result (EBCC4)

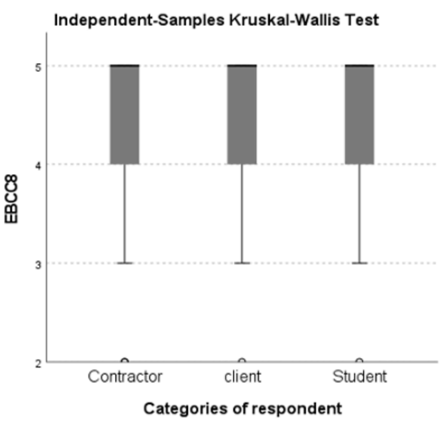

Figure 2: ANOVA/KW result (EBCC8)

CONCLUSIONS

This study investigated CMG's expected BIM core competencies in executing and managing their professional duties within the construction industry. The industry demands for BIM knowledgeable graduates are increasing rapidly and becoming more complex. For CMG to remain employable and relevant in the industry, they need to recognise and key into the required core competencies of the construction industry. This study obtained secondary data from the meta-analysis of the literature, which identified 13 core BIM competencies. These were further subjected to targeted respondents to elicit primary data.

A structured questionnaire was used to solicit viewpoints from the three groups of respondent contractor/consultant, the client (developer) and CMG in the Southwest region of Nigeria. The data collected were analysed using both descriptive and inferential statistics. Overall, this research provides the answer to its study aims. It identified 13 core competencies and out of which seven were regarded as the most important: EBCS1, EBCC 5, EBCC6, EBCC4, EBCC7, EBCC8 and EBCC9, being good communication, Analytical and problem-solving skill, Teamwork, Basic understanding of BIM process, Knowledge of construction process, design coordination and BIM coordination.

The relative importance index reveals that all the 13 expected BIM core competencies are significantly important. At the same time, the inferential statistical analysis noted no notable difference between the respondents' perspectives. Based on these findings, it could be concluded that the Nigerian AEC industry expects CMG to acquire substantial construction innovative knowledge and personal competencies. These will enable them to quickly catch up with the advanced construction process during their undergraduate programme or internship. They must acclimate themselves to the evolving BIM-related software, programs, tools, and models and have good communication skills. These will enhance on-site productivity, information management, quality of work, and overall construction management. This study is only limited to the southwest region of Nigeria; therefore, it may not be generalised to the remaining five regions.

The only data gathering method, the use of questionnaires, may cause monomethod favouritism. Nevertheless, the adopted method for this survey is best suitable for efficiently collecting data from a large respondent sample size to enable easy statistical analysis computation. Nonetheless, the conclusions of this study are supported by data triangulation, which involves comparing them to earlier related research. Moreover, a questionnaire survey based on a Likert scale is a universal means of gathering data from a broad group of individuals. Different respondents may interpret each question differently. Regardless it is noted as one of the best widely utilised psychometric instruments for assessing self-reported views. More study is required using mixed method approaches to build a framework for measuring total construction management competency for future relevance.

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CONSTRUCTION DESIGN AND TECHNOLOGY

KNOWLEDGE INTEGRATION THROUGH RESOURCE COMBINING: THE CASE OF A NATIONAL STANDARD FRAMEWORK FOR HOSPITAL DESIGN

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The hospital design process contains technical and organisational challenges. The paper investigates how the Swedish national healthcare project framework and database, Program for Technical Standard (PTS), is used to facilitate knowledge integration within and across hospital projects and the outcomes thereof. The study covers data from 7 Swedish regions based on 12 semi-structured interviews with 14 facility mangers, 2 property managers as well as the national system administrator for PTS. PTS is considered to support the design process; however, some actors also perceive that PTS as a standard is not compatible with the call for adaptation. By mapping how the specific resource, PTS, is combined differently in various resource constellations, the results show that the value is contingent on the integration (or lack of) of numerous technical and organisational resources interfaces within and across organisations, projects, and regions. In particular, the perceived value of using the standard framework relates to its integration with the client's internal resources and project processes, and the matureness of digital competence. The divergence of knowledge integration is shown to be present on a project level as well as on a national level among the regions.

Keywords: client; design process; network; health care

INTRODUCTION

During the last 10 years, many construction projects have been carried out (and are still being carried out) in Sweden to renew existing hospitals, which were primarily built 40-50 years ago (Ring, 2017). The total sum for investments in emergency hospitals alone amounts to just over SEK 100 billion (SOU 2021: 71). Renewal is necessary to update medical technology and support new healthcare provision to face existing and future challenges of an aging population, multi-sick patients, antibiotic resistance and spread of infections. The projects' early stages are commonly facing high uncertainties and in the framing process it is difficult to establish the content of the project and consequently, time and cost overruns are not uncommon. The design process of a hospital contains several technical and organisational difficulties, including the need to integrate knowledge from several actors, for example, the architect, facility management, health care experts and users as to create the right functionality of the building (Adams, 2008). Various digital technologies, foremost

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BIM, has been advocated to substantially transform design and enable integration by facilitating communication and teamwork among the parties involved in the design (Merschbrook and Munkvold, 2015; Peansupap and Walker, 2005). One of the most profound challenges is the limitation to learn, apply, and facilitate knowledge integration across projects. The organising of interaction processes for knowledge integration within and across projects is thus of outmost importance, including routines for integrating gained knowledge and experiences back to the organisations to meet project budget and time frames.

The Swedish national healthcare project framework and database, PTS (Program for Technical Standard) aims to support decisions in early project stages concerning the right design, function, and quality of the building. PTS is available for the 21 Swedish regions that are individually responsible for their hospital projects. PTS is an ICT-system with system functions to support early stages in health care projects, including room layouts, and a network to share knowledge among users, projects, and regions. The role of establishing ICT systems to support and store knowledge has been brought forward in research of project settings due to their temporary nature, but these systems have not met the expectations, one explanation being that knowledge is also constructed through joint experiences, thus embedded in a social context (Jacobsson and Linderoth, 2010; Newell *et al.,* 2006). This makes PTS an interesting case to study, when functioning as a resource with both technical and organisational features, enabled via ICT and social networking, with the purpose of knowledge integration within single projects and on national level to improve the design process.

The paper explores the role and function of PTS in the design process of hospitals in Sweden, including how (if) it supports the design process. Accordingly, the aim of the paper is to investigate the embedding of the inherent knowledge of the PTS standard framework as one resource and how this affects integration and implementation in the design process, and the outcomes thereof. Three research questions are explored to fulfil the aim: i) How is PTS exploited as a resource to facilitate knowledge integration in the hospital design process in the various regions? ii) What are the outcomes from using PTS as a resource in the design process? iii) How is knowledge integration facilitated across the regions via the use of the PTS standard framework?

PTS

PTS as an ICT system was developed in the early 90's by the Jönköping region. The region is the main responsible for the system. The development was mainly driven by the incentive of creating a framework within the region that provided guidelines for incorporating spatial requirements connected to the early phases of the design process. Later, in the early 2000's, when shifting from providing illustrations and guidelines in binders to a web-based interface of the system, multiple adjacent regions to Jönköping joined PTS. As a result, PTS became an ICT-system and the 'PTS Forum' that serves as a network for knowledge and experience exchange among regions. The ICT-system mainly revolves around the availability of 3D models of 272 standard rooms of varying complexity (i.e., ranging from common areas to operating and radiology rooms) and guidelines with related spatial requirements connected to these rooms. PTS Forum revolves around a few meetings per year for discussion and updates on the requirements connected to the standard rooms, e.g., guidelines, spatial requirements. The meetings gather representatives with different roles and not only facility managers, such as subcontractors, BIM experts and procurement managers from the different regions. The suggestions for improvements that are decided on the joint region meetings are handed over to PTS's national system administrator and PTS's national requirement analyst at the Jönköping region, and ultimately translated to updated requirements in the ICT-system by the ICT supplier responsible for development and management of the it-system. PTS Forum also hosts a web-based forum where users can ask for advice regarding design from other user of PTS, who can share their knowledge.

Consequently, the objective of PTS in the form of the ICT system and the professional network of PTS Forum, is to facilitate cross-regional knowledge and to integrate that knowledge to continuously improve PTS as a tool to support the design process in early stages. However, the use of PTS faces multiple challenges and PTS has not met the expectations of improving the design process in individual projects and in the different region's work processes. Specifically, the challenges in facilitating of knowledge integration across projects are addressed. The concept of knowledge integration (KI) has been studied in different theoretical and empirical contexts, ranging from organisation theory, product development, information systems, project management and human resource management (Berggren *et al.,* 2011), including construction (e.g., Hastie *et al.,* 2017; Ruan *et al.,* 2015). What the concept knowledge integration entails differ with at least 30 different definitions, and regarding what the process of KI consists of, there are also some differences: "KI as sharing or transferring knowledge, KI as use of similar/related knowledge and, KI as the combination of specialised, differentiated but complementary knowledge" (Berggren *et al.,* 2011, p. 24). In this paper, the industrial network approach (or IMP approach) is used as the theoretical lens to explore knowledge integration as intertwined with the development and use of various resources in interaction processes. Resources are crucial enablers of various activities and provide reasons for interaction among various actors (e.g., Håkansson and Snehota 1995; Håkansson *et al.,* 2009). From this follows some important notions regarding resources. First, no organisation possesses all the necessary resources, such as technologies and knowledge, in-house and inter-organisational interaction is thus a means to access, develop, adjust, and combine resources across organisational boundaries.

As such, inter-organisational interaction through business relationships is a central activity for firms to get access and relate to resources and activities of other firms, and relationships are thus important resources in themselves (Gadde *et al.,* 2003, Håkansson *et al.,* 2009). Second, resources are heterogenous, which means that the value of a resource depends on the way in which it is combined with others (Penrose, 1959). The same resource can thus have various roles and functions in different settings, and a resource does not have a given value - it is the service that the resource provides, through its relation to other resources, that provide a specific value in a specific setting (Håkansson and Waluszewski, 2004; 2002). Outcomes in relation to resource combining and the value of a resource can be distinguished in the form of: i) direct effects for the organisations that are involved in the development and production of a resource, ii) indirect effects in the development and production of a resource, iii) direct effects for the organisations using the resource, and iv) indirect effects from using the resource (Håkansson and Waluszewski, 2004). Third, resources relate to each other in resource constellations in space and time, crossing the boundaries of individual organisations and the content of these resource constellations develops over time when actors make resource adaptations, introduce new resources, and/or eliminate existing resources (Håkansson and Snehota 1995; Håkansson *et al.,* 2009).

Fourth, resources are classified as either physical, reflecting material or technical resources, such as physical products and facilities (factories, machinery, information systems etc.), or organisational, reflecting social and organisational resources, such as organisational relationships or organisational units (departments, business units, teams, individuals etc.) (Jahre, 2006; Gressetvold, 2004, Håkansson and Waluszewski, 2002). One notion is particularly important, knowledge as a resource is not considered a resource type in itself, instead, knowledge is regarded as an integrated part of these technical and organisational resources (Håkansson and Waluszewski 2007). From this follows that knowledge integration is accomplished through interaction processes in the combining of resources, technical and organisational, that in turn, will generate new knowledge manifested in existing resources and/or the development of new resources.

METHOD

To advance the understanding of how knowledge integration is enabled through the joint use of PTS as an ICT system and the relationships between the various actors involved with PTS Forum, a single qualitative case study was conducted. Qualitative case studies provide depth, detail and richness of data and have proven to be a fruitful approach for studying phenomena of interaction processes (Dubois and Araujo, 2007; Easton, 2010), This allowed for capturing a phenomenon where it was critical to understand the dynamics of the social context (Halinen and Törnroos, 2005). Data collection consists of semi-structured interviews connected to the different regions. The interviewees consisted of 14 facility managers and 2 property managers in 7 regions and 1 facility manager from the region not part of PTS, as well as the PTS's national system administrator responsible for maintenance and coordination with PTS in the Jönköping region.

The main strategy for identifying and selecting the interviewees was based on individuals that interact with PTS, either using the ICT system and/or engagement in the inter-regional PTS Forum, thus approaching PTS members in the data collection. The interviews captured current work processes, how healthcare staff are involved in the design process (e.g., study visits, using different information medias) and information flow through projects (e.g., learning from previous projects, documentation).

A particularly important aspect was to capture how the knowledge integration on a regional level between healthcare staff and facility managers in different projects translate to national guidelines and recommendations via PTS. Altogether, the empirical data illustrates how PTS is used in the design process in different regions, how the utilisation of PTS relates to the work processes of individual regions, who is involved in the interaction via PTS, and individuals' perceptions of using and interacting with PTS. The data was analysed by making use of the theoretical framework in line with the research questions as to guide the analytical process aiming at fulfilling the aim of investigating how PTS as a resource could potentially act as a linkage in terms of knowledge integration between the various regions, including the Jönköping region where PTS originates from and who has the integration responsibility on a national level.

FINDINGS

The perspectives of facility managers in the use of PTS within different regions

One important aspect in the design process in early stages is the involvement of users (i.e., healthcare staff) (or not) in the work procedures to transform the knowledge of medical operations into accurate building requirements. Most facility managers expressed that in the established workflow processes there is an overall challenge of involving users whilst also considering the requirements of the facility managers that must be met.

As a result of this, many facility managers explained how they often face the issue of unintentionally creating false expectations related to the level of influence users believe they have during the design process. Considering this, spatial requirements provided by PTS has proven to be useful as means of facilitating decisions when current workflow processes are insufficient. A facility manager described how the level of PTS integration is dependent on the level of organisational processes:

> "There is a need to coordinate and have solid processes within the region to include the users (healthcare staff). Otherwise, one runs the risk of implementing PTS incorrectly and an effect of that would be causing the projects to be perceived as more unstructured than they already are. It is important then to consider to not oppose the organisational culture, especially if it is already working."

Related to making changes within the regional organisation to use PTS more in the design process, and, in affecting the development of PTS many facility managers expressed the difficulties in influencing the design requirements, with representatives from the smaller regions experiencing not feeling included. The larger regions, with some being among the first members of the PTS Forum network, there are different processes for different type of projects, with project scale being the key distinctive factor: larger project often involves architects and generating user-influenced spatial requirements whereas smaller projects tend to be design reviewed by the facility managers themselves, as they often have a background as architects. A facility manager from one of the larger regions explained how using PTS more for design review purposes could help facilitate user-involvement in a project more clearly rather than the current more complementarily role PTS had for them:

> "The gap of spatial understanding emerging between actors who typically have a design background and non-design actors (users) can often be translated to change order. Using PTS 3D models could potentially help us mitigate changes done after commission."

In this context, the facility manager from the region that is not part of the PTS network, expressed how their region's decision to not join the PTS network is primarily based on relying on the current intra-regional work processes they already use. The local adaptions in such work-processes conducted by each region differs:

> "It (PTS) is a good template to begin with and it advantageous when it is nationally established. However, there is a difference in organisational culture among the regions and the level of local changes conducted, creating a gap in terms of local changes between each region using PTS. Consequently, this affects how the spatial requirements are generated among the different regions."

Connected to the process of generating spatial requirements was, according to many facility managers, the challenge of using multiple disciplines in the PTS It-system. Specifically, facility managers experience, particularly in larger projects, that the PTS ICT-system crashes due to the component responsible for generating documents from the database is not capable of handling large dataset, resulting in system crash. Lastly, some facility managers described how their access to the PTS database is not shared with other project members due to sign-in access being limited to facility managers when there are no projects. As a result, actors such as architects tend to stick with their own standards that are not PTS and gaining access to the it-system and room functional programming documents once these have been generated by the facility managers themselves.

The perspectives of the PTS national system administrator and property managers
As described by the property manager in the region responsible for PTS, PTS initially started out as a regional cross- region knowledge integration in the early 90's. with the most recent members having joined in recent years. These regions who have only recently joined had according to the property manager internal workflow processes that worked well, something the property manager evidently observed:

> "Those who were last to join PTS already have a solid work process and have "yet" to see the benefits it (PTS) provides. Some expressed prior to joining that they wanted to partake in the requirement set by PTS and saw it as incentive to join to gain access to these requirements."

This discrepancy in how much PTS is used by the different regions is something the property managers believe is rooted in the work process culture. More specifically embedded in current work processes and the ability to set the right conditions for integrating new work processes and the size of each region being an influencing factor, with smaller regions having less demand for building more, thus causing less sense of urgency for change within the established work culture:

> "It is a cultural question. It does not matter if one uses PTS or something else. The larger organisations tend to differ in terms of work processes for different projects, causing a drift in creating a "common working culture". Smaller regions on the other hand tend to build to a less degree making them more reliant on PTS for setting requirement, although we have encountered challenges within these regions in terms of using spatial requirements provided by PTS more rather than their own."

PTS's national system administrator also described how they experience that the regions can at times limit themselves with the degree PTS is used, with the organisational culture being a limiting factor:

> "It is important to ask oneself whether it is the organisational culture dictating the level PTS is integrated (or lack thereof) or how PTS can influence the organisational culture and thereby create conditions for knowledge integration."

Also, they have experienced a growing enthusiasm in the workshops conducted a few times per year where representatives from every PTS involved region participates to create the basis for PTS spatial requirements.

DISCUSSION

Knowledge integration within and across regions
Looking at how PTS is exploited as a resource by the various regions and how knowledge integration is facilitated (or not) using PTS, analysis identifies the following aspects as crucial: challenges from organisational culture, processes for follow-up work and involvement of healthcare staff in the design process.

Specifically, organisational culture, according to both those developing PTS and facility managers, needs to be considered when integrating a technical standard framework as to combine the framework knowledge with existing resources. As such, the usefulness of a technical resource is contingent on how it is "activated" in the combination with other resources, where organisations play a crucial role in terms of inherent knowledge (Håkansson and Waluszewski, 2002), creating a technical-organisational interface (Jahre *et al.,* 2006). The established resource constellations and work processes are outcomes of how the design process for previous projects have been conducted, leading to organisations building up knowledge from previous experiences.

The experience feedback-loop and workflow processes from previous projects is then leveraged in new projects, which can potentially lead to project members relying rather on cross-project knowledge within the region than knowledge gained from cross-region knowledge integration as intended with the PTS Forum. Consequently, this influences the regions' perception on the value PTS provides, as resources are allocated in relation to existing work practices and routines, that are "already working". This view on PTS is further affected by what facility managers expressed as inability to influence PTS requirements that are revised and discussed during the yearly workshops and conferences.

Despite the intention of using the input from the regions for development of PTS to improve its usefulness as a resource, regions' representatives, especially smaller regions, or regions that have recently joined PTS, felt that neither did their input matter, nor did PTS organisation encourage the interaction. Due to these conferences and sessions being one of the primary ways for regions to provide feedback back to the PTS organisation, it can be argued that it is important to further explore how the feedback and knowledge emerging in these forums is later integrated into the PTS requirements as part of the development and further improvement of PTS to increase its usefulness, which is crucial for value creation. As such, the value of the resource both from a technical and organisational aspect is hampered by the lack of interaction (Håkansson *et al.,* 2009).

This sense of not feeling involved in the PTS process was also expressed by users (e.g., healthcare staff), as mentioned by some facility managers. When conducting design review sessions with users who typically have a lack of spatial understanding (e.g., healthcare staff) via 2D drawings, the ability (or lack of) to accurately review and provide feedback on the design becomes a key factor. Moreover, when most projects in a region are conducted via 2D drawings, the 3D based standard rooms with connected spatial requirements provided by PTS cannot be used to the extent that would have otherwise been the case, if reviewing via 3D models had been the norm.

However, even the regions that conducted design reviewing primarily via 3D models expressed concerns over the provided PTS 3D models in terms of lack of standard room intended for advanced healthcare operations (e.g., radiology room, surgical room) and outdated models that require revision, resulting in longer project lead times. Independent of information medium used for design review, there appears to be a lack of a structure for a feedback loop between users and facility managers in place, which hinders the development and use of PTS. There is a lack of established processes for following up and validate the feedback provided by users in early phases in the later phases. The absence of resource interfaces and lack of interaction is thus a barrier for knowledge integration between users and facility mangers, and thus also between the regions and the PTS organisation. Relational interfaces then play a crucial role for development of resources as to enable an increased value creation for different users (Andersen and Gadde, 2019).

A side-effect of these barriers is the need for alternative processes for leveraging user knowledge, such as study visits. Several regions, differing in both organisational size and length of time connected to PTS, have made many study visits to adjacent regions with the ambitions to generate enthusiasm among the healthcare staff to feel included and help facility managers better understand how others have approached projects similar to what they planned to build. However, facility managers also acknowledged the difficulties: lack of structure for documentation of learnings and difficulties with knowing what parameters to look for during the visits to make accurate comparisons. PTS could potentially mitigate the number of visits if the framework had a higher technical standard and could meet the requirements of usefulness as to exploit the knowledge in PTS.

Another factor affecting how much PTS is utilised is the lack of complex standard rooms available in the PTS database, e.g., radiology rooms, surgical rooms. Many of the facility mangers expressed how this absence caused a challenge in how to use PTS in the projects due to many regions already having their own database for less complex rooms (e.g., waiting room, reception desk), often with the same functionality in smaller hospitals, thus relying on their own database rather than the standard rooms available in the PTS database. Moreover, the sign-in access to PTS is bound to facility managers and not to other project members (i.e., architects) during times when there is no project. This hinders incentives for architects to become involved in the process of generating the early spatial requirements together with the facility managers and thereby contribute with producing accurate requirements, reflecting the wants and needs of the healthcare staff.

The PTS forum's role for national knowledge integration

One important result is the significant importance of organisational culture. It could be argued that this is mainly because both property managers and the national system administrator are not necessarily involved in the building projects and PTS Forum being their closest relationship with the regions, thus explaining the absence of technical aspects in knowledge integration between them as an organisation and the regions. The knowledge integration is intended to be manifested in the PTS Forum and workshops conducted. Discrepancy emerges in how these sessions are experienced and valued, with regions expressing that an increase in the number of workshops and conferences would be desirable, and smaller regions even experience exclusion. The national system administrator identifies a need to scaling up PTS Forum as to encourage increased interaction with the ability to influence future development of PTS, independent of regions' size.

CONCLUSIONS

The study investigates how the inherent knowledge of the PTS standard framework is integrated and implemented in the design process, and the outcomes thereof, including how (if) PTS facilitates knowledge integration among resources within and across Swedish regions. In conclusion, the findings of the study shows that the potential of PTS as a resource for knowledge integration is not exploited to its fullest, due to the lack of embeddedness into existing technical and organisational resource constellations. PTS is used to various extent in the different regions. Jönköping region is in the forefront of using PTS, which can be explained by the fit of the technical and organisational resources within the region, that in turn is an outcome of that Jönköping also has the development of PTS, thus, development and use of PTS go hand in hand with other technical and organisational resources in the region, which improve the resource utilisation and enables exploitation of embedded knowledge. As a comparison, regions with little digital competence, thus, 2D drawings still rule the game in the design process, cannot exploit PTS, as the technical features cannot be exploited due to the lack of digital technical knowledge in the organisational units of the regions.

But the membership for these regions in PTS can cause indirect effects in the development of digital competence: a driving force to take the leap from 2D to 3D. This would, however, require investments in new resources, such as BIM coordinators to facilitate the technological change within the region. Furthermore, utilisation of PTS is also deterred as some of the organisations, such as architects contracted by the region, in the design process do not have a direct interface to PTS, which hinders knowledge integration from these organisations. Hence, a first conclusion is that within each region, resource combining of technical and organisational resources must be improved to reap the benefits of using PTS. Embedding PTS in a regional setting requires a certain technical and organisational maturity.

A second conclusions is that in terms of outcomes, PTS today functions mainly as part of the set of requirements and/or as a validator in the design process to verify the value of other resources in the form of 2D-drawings and 3D-models. A conclusion is that to develop PTS further and increase the utilisation of PTS, more interaction would be needed among the regions. This would improve the development of PTS and align with the users' needs and processes, thereby increasing the value of PTS. Today, the lack of interaction results in individual regions developing their own processes and room prototypes, instead of exploiting the potential of standardisation across regions.

Thus, PTS as a knowledge carrier must be supported by more, and in depth, technical and organisational interfaces to leverage and combine the regions' resources and knowledge for hospital design. This would enable a more sustainable use of hospital construction project resources on a national level as PTS could guide the design process and create imprints in hospital buildings across Sweden. By gaining an increased understanding of the criteria required for fully utilizing PTS, a more accurate comparison with a non-Swedish hospital standard could be realised. Knowledge and experience connected to healthcare facility projects could then potentially be utilised beyond a Swedish context. This would help understand how a best-practise approach to healthcare facility planning could best be achieved.

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ARGUMENT MAPPING OF THE PROPOSED BENEFITS OF AGILITY AND AGILE PRACTICE ADOPTION IN CONSTRUCTION PROJECTS

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Some agile methods and practices have been argued to have potential benefits for construction, but those arguments have not been analysed critically. Argument mapping analysis, based on the Toulmin (1958) model of argument, is used to examine how research has constructed arguments about the benefits of agility in construction and whether the adopted agile practices have met the proposed benefits. Results showed that pro-agile arguments were constructed around flexibly responding to changes in construction management. However, some of these lack empirical evidence. Organisational and project-level barriers to agile adoption were claimed in con-agile arguments. Studies also showed negative attitudes towards agile practice adoption and resistance to the pro-agile arguments. Findings are relevant to construction managers considering agile solutions for better performance. In addition, identifying how claims surrounding agile are constructed can also lead to an evaluation of the influence of these accounts on researchers and practitioners.

Keywords: agile supply chain; agile methods; agility; management

INTRODUCTION

Construction projects are characterised by complexity and rigid, irreversible schedules (Ribeiro and Fernandes 2010). COVID-19 pandemic implied that it is time for construction industry to think about resilience capabilities and to question about what may be considered 'matter of fact' ideas in construction management to remain competitive in the post-covid environment. Construction firms should not be satisfied with 'what we know' as unanticipated changes continue to challenge construction projects, but to establish ideas on 'where we should go' in the future in a resilient and sustainable way (Abu Hammour and Abuhammour 2020).

Agility describes the ability to cope with unanticipated changes in a timely manner (Conboy 2009). In the construction environment, agility has been argued as the ability to have flexible and on time responses to customer requirements and project environment changes, which if ignored will lead to cost burdens, project delays and even rework (Saini, Arif and Kulonda 2018). To build up agility in construction firms and projects, some ‘agile’ methods and practices have been applied in construction management (Mostafa, Chileshe and Abdelhamid 2016, Suresh, Roobaswathiny and

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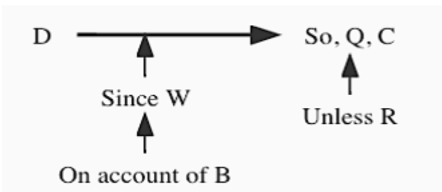
Lakshmi Priyadarsini 2021, Zender and de Soto 2021). Agile supply chain, agile software development, and agile project management were all mentioned to have potential in construction.

However, by reviewing literature upon this topic, it is found that some arguments related to benefits of ‘agile’ practices in construction are based on rhetorical persuasion rather than enough supporting evidence. Based on Toulmin (1958) theory of informal logic and argument model, argument mapping is a useful analytical tool for researchers to summarize arguments and to examine the structure of arguments and the degree to accept the argument as a reader. Argument mapping analysis is used in the paper to examine how the research constructed arguments about benefits of agile practices whether the proposed benefits have been met. The analysis generated a clear map of existing arguments on topics around agility and agile practices in construction, which critically points out information that may be overlooked in a more general literature review, including the status of adoption, unsupported arguments, and potential benefits and exception conditions of using agile practices in construction projects.

Theoretical Framework

Based on Toulmin (1958) theory of informal logic, arguments are rhetorical acts in a proper form of components, like an organism, and are persuading in nature. The basic form of an argument can be seen as ‘given the data D, so C’. As arguments are tended to persuade or convince people, the basic form of argument needs to be enriched with more information to achieve that purpose (see Figure 1). To explain the relationship between the data(D) and the claim(C), warrant(W) has been inserted to implicitly link the logic as a bridge. Backing(B) is the relations or conditions that explains the warrant(B). The claim (C) may not be certain in every circumstance so the degree of force which the data confer on the claim need to add to the model, as qualifier(Q). The condition of exception is called Rebuttal(R).

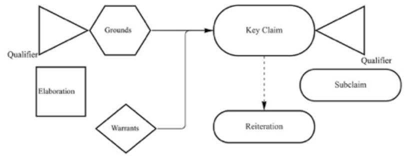
Figure 1: Toulmin (1958) model of argument



Fletcher and Huff (1990b) adapted the model by excluding backing because they believed in practical, it is hard to differ between warrants and backings. Also, they identified three subordinate elements to the model of argument, which are Elaborations (clarifying statements for all components), Subclaims (subordinate claims dependent on the acceptance of the claim), and Reiterations (restatements of the claim). Fletcher and Huff (1990a) classified claims and warrants into categories based on purpose of a claim or a warrant and generated a flow chart diagram to illustrate their adapted model of argument (see Figure 2).

The paper adapted the model to a simplifier diagram (see Figure 3). Reiterations and elaborations are excluded in the analysis because the research topic is relatively new and limited to a small number of materials. Also, the relationship between key claims and reiterations is out of analysis scope and hard to detect.

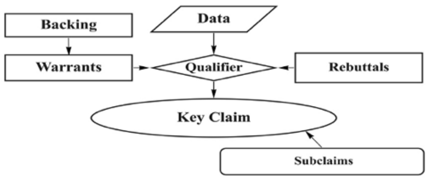
Figure 2: Fletcher and Huff (1990a) flow chart model



The explanations of components followed Fletcher and Huff (1990a) and Hirschheim, Murungi and Peña (2012), including:

- Key claims: a claim is a statement put forward for the audience to believe
- Data: evidence produced in support of a claim
- Warrants: logical connection between claim and data
- Qualifiers: the degree to accept the key claims are true
- Rebuttals: potential objections or exceptions to accept the key claims are true
- Backing: relations or conditions that help explaining the warrant
- Subclaims: subordinate claims dependent on the acceptance of the claim

Figure 3: adapted model of argument



METHOD

The argument mapping analysis used Scopus as search engine and database in data collection. The process of data collection followed steps in Fletcher and Huff (1990a). Microsoft Excel, Endnote 20, and Miro provided technological help on organizing the electronical files and coding the text extracted from the selected literature.

Literature identification and marking: A rigorous search on related literature was conducted by using Scopus database, which has the most comprehensive coverage on peer-reviewed articles and guarantees the quality of the searched papers (Paul, *et al.,* 2021). The search string was set as: TITLE-ABS-KEY ("agile" AND "construction”). 113 articles returned from the search (saved in the Excel sheet) and went through a quality check on the research area and availability of full paper. Finally, 17 articles were selected for the next step coding. Full papers were archived to Endnote 20 and a full-text content analysis was conducted focusing on extracting the components of arguments made in the article. Highlights were made on the articles marking out the components of arguments.

Entry of the text of the components on the coding sheets: For each selected article, the adapted model of argument (see Figure 3) was constructed in a separate online whiteboard provided by Miro. The highlighted text of the components of arguments were coded at the adapted model on online whiteboards.

Data analysis: On the online whiteboard, components of arguments extracted were linked to other components and rechecked the relationship with original discourse in the literature. Arguments that inside the selected articles but are secondary to the research topic were excluded. In total, 15 models of arguments were set up in 15 online whiteboards. Components of arguments in each whiteboard were then mapped to an overall diagram and grouped around 'pro-agile claims' and 'against-agile claims' for cross analysis and discussion.

FINDINGS

Existing problems of construction industry served as Backing in the argument model which can be considered as background of the arguments around agile and construction. Fragmentation and complexity were seen as two major factors in the poor construction performance (Ribeiro and Fernandes 2010). These factors offered both opportunities and barriers to adoption of agile practices in construction management. Ribeiro and Fernandes (2010) noted that fragmentation was caused by industry structure, which 99% construction companies are SMEs and SMEs are characterised with fragile business, less completable and lack of management capabilities compared with big companies. On the other hand, construction projects need to mitigate risks through clear divisions of responsibility and procedures, which caused complexity in planning and executing (Schwarts and Amaba 2017).

Another backing of the argument is the understandings of agility in management area. In 1950s, agility was used to describe an aircraft's ability to manoeuvre state or as the time derivative of manoeuvrability in the field of air combat (Breu, *et al.,* 2002). With the development of manufacturing industry in 1980s, agility was popularized in manufacturing and supply chain management. After entering the era of Internet, agility was spread quickly in information technology areas as a new methodology of managing software development and engineering projects. The success of some agile software development methods in project management, for example Scrum and Extreme Programming, attracted many agile users in 2000s (Chow and Cao 2008, Pikkarainen, *et al.,* 2012). The scope of 'Agile' application had been expanded to industries and projects other than software development in 2010s onwards (Conforto, *et al.,* 2014, Zender and de Soto 2021).

1. Responsiveness and adaptive

'Agile' contains the meaning to be responsive in business activities (Brennan, *et al.,* 2015, Holweg 2005). The focus on response to change had been continuously discussed and emphasized. Shafer, *et al.,* (2001) believed that agile was nimble and change-hearty. This idea had also been discussed by the famous Agility Forum in 1994. The Agility Forum regulated the time frame for acting agile, which means that response need to be performed in a useful and timely manner (Goldman, Nagel and Preiss 1994).

2. Flexible and speed

Flexibility and speed are always linked when talking about 'agile' in organisations (Jin 2004). This view closely followed the Prater, Biehl and Smith (2001) viewpoint. Speed means that agility is based on quick response ideas (Fayezi, Zutshi and O'Loughlin 2015) and agile organisation system is to make sense quickly, make decisions nimbly and redeploy resources rapidly (Brueller, Carmeli and Drori 2014).

3. Collaboration

Agility related closely with collaboration. Collaborative forecasting partnerships bring better information, improved decision support technologies and process improvement to the trading partners, thus result in the increased agility (Aviv 2007). Gunasekaran, Lai and Cheng (2008) stated that agile manufacturing relies on the strategic alliance and partnerships in achieving speed and flexibility. Relationship integration has strong impacts on the supply chain agility and flexibility development (Fayezi and Zomorrodi 2015).

4. Iterative and incremental

In publications after 2000s, the understanding of 'agile' as an iterative and incremental method largely increased. The reason lies in the popularity of Agile Manifesto at 2000s in software development and information system industries (Beck, *et al.,* 2001). Agile methods were constructed based on an idea of iteration, which means the software was developed by iterations and each iteration includes phases from planning to delivery (Abbas, Gravell and Wills 2008).

Some research argued that agile software development methods or agile supply chain positively led to agility and have potential benefits for construction management. For example, Gibson (2018) argued that firms who want to compete in dynamic markets need to build more agile operations and Hardie (2016) argued that construction SMEs have more agility factors to trigger innovation. The related claims, warrants and data were extracted and analysed to show the logic of arguing in this section (See Figure 4).

Some claims were argued with evidence from the field. Frutos and Borenstein (2003) designed an object-oriented model for mass customisation in building projects and argued as to provide agile interactions between customer and building companies. They built up the claim based on the logic of by increasing flexible interactions between customer and building company, the total customisation time and cost would decrease, user satisfaction would increase, and companies would gain more knowledge about customer preferences that would help new projects. Data came from a field test of a Brazil residential project got good result on using the model for six months (Frutos and Borenstein 2003). Carlos and Amaral (2018) claimed on continuous roadmap updating that incorporates agile principles supports construction planning and evidence from action research validated agile principles positively impacted on managing roadmap in construction projects.

However, some claims were weakly argued and lack supporting evidence to convince readers. For example, Martek and Chen (2015) researched on procurement strategy of foreign constructors in China and case study showed that one international construction firm using agile procurement strategy in managing their supplier relationships in China, which in this paper, 'agile' means the firm does not hold permanent linkages with up-stream supplier. The finding cannot lead to a claim on benefits of agile thinking adoption in construction since the performance information of the mentioned company was not provided in the paper. The finding only implies there is a view in research that a flexible procurement strategy can be seen as 'agile'.

Hardie (2016) claimed that construction SMEs have more agility in innovation and warrants came from characteristics of SMEs that containing less bureaucratic, more skilful individuals and potential to partnership with other SMEs. The author used 10 case studies on Australian construction SMEs that showed more proactive responses to changing circumstances to support the claim. However, the rebuttals also came from characteristics of SMEs. SMEs have less financial space to plan and innovation for change. Since there are many SMEs, companies encountered high level of competition, but they are less able to monitor their competitors. In terms of business goals, SMEs may want to survive rather than to grow.

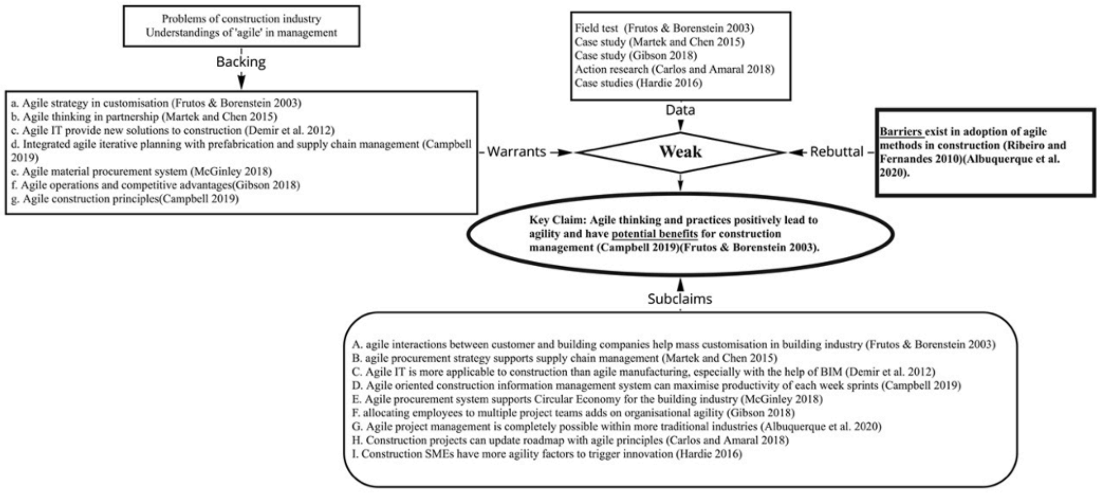


Figure 4: Model of pro-agile arguments

McGinley (2018) termed agile circular economy and argued that agile procurement of used materials in construction projects supports circular economy. An agile material system was structured in the paper using software development method to search for BIM required materials on eBay. The most obvious limitation of the argument is it has not been tested in field, so no data or evidence was provided to support the argument.

Gibson (2018) argued that multiple team membership increased organisational agility, but the data on a case study showed an inverted U shape relationship between multiple project teams and project delivery, which means when there are too many teams that have multiple team membership, the performance will decrease. Thus, the argument is not convincing to readers since conditions and relationship is not clear in the claim.

Campbell (2019) developed a construction information system model with iterative planning method and prefabrication in supply chain management. Agile software development methods were argued as more applicable to construction environments than agile supply chain thinking as agile software development methods provided practical solutions to construction such as iterative planning with the help of IT system (Demir, *et al.,* 2012). The agile information management system proposed by Campbell (2019) was claimed to improve the resilience and productivity of residential construction projects, but no empirical validation was provided in the paper to support the claim.

In sum, some claims on benefits of agile in construction management were only argued with theoretical explanations and were not mapped with empirical evidence. Lack of evidence can be viewed as research gap in this area that if good results are achieved in future empirical research, the convincing level of the pro-agility claims will increase correspondingly. For example, a case study on performance appraisal of a construction project, which adopted McGinley (2018) model of agile material system, would examine the benefits of agile procurement on circular economy and give readers more data to accept or reject the claim. Methodologically, longitudinal study on an agile adoption in construction project with triangular data would improve the convincing level of the pro-agile claims more than a quantitative survey on construction managers' attitude of agile practice adoption. The reason is that since people's understanding of agile is different and the complexity in construction projects makes it hard to ensure that people in different construction jobs understand agile-related concepts in a correct perspective in each survey question.

Claims on barriers existed in adoption of agile methods in construction were Rebuttals to pro-agility arguments and evidenced with empirical analysis results (see Figure 5). No direct adoption of agile practices shown in the case studies in Ribeiro and Fernandes (2010) and interviewees were aware of value of agility but their attitudes towards agile practices were negative (Albuquerque, Torres and Berssaneti 2020).

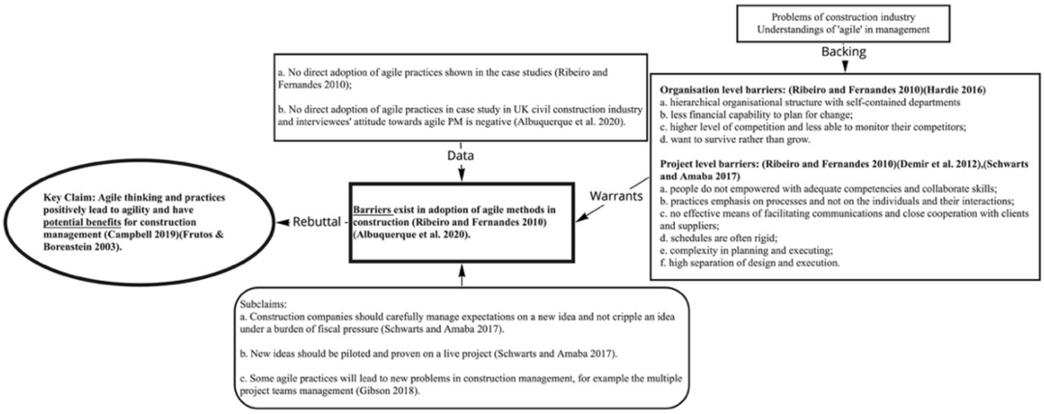


Figure 5: Model of con-agile arguments

SMEs occupied a large percent of construction industry, who have less financial capability to plan for change and suffered with higher level of competition, that turned the SME to strategically focus more on survive other than grow (Hardie 2016). Big construction firms do not have those concerns, but their hierarchical organisational structure and self-contained departments can easily have more resistance to change (Ribeiro and Fernandes 2010). In project level, less empowered people, and no effective means on solving the classic construction problems (rigid schedule and poor communication) were demonstrated as logic relationship that explains the phenomenon observed from the case studies (Demir, *et al.,* 2012, Ribeiro and Fernandes 2010).

Subclaims under this research stream advocated that construction firms need to carefully manage the expectations on a new idea to avoid further cost burden on the adoption of new idea. Pilot project is useful approach for construction firms to test the new method or practice (Albuquerque, Torres and Berssaneti 2020). Also, some agile practices may cause new problem in construction management, for example, Gibson (2018) argued that multiple team membership could increase organisational agility, but this research also noted that teams with temporary stuff who have multiple memberships will be more fragile in management.

In all, the argument mapping of both pro-agile claims and con-agile claims were constructed (see Figure 6). The proposed benefits of agile thinking, including practices originating from agile manufacturing and agile software development, were the most relied upon for pro-agile arguments by researchers.

However, the Qualifier (the degree of accepting the pro-agile arguments as true) is affected by lack of supporting evidence and the Rebuttals (barriers of adoption noted in the literature). Given the fact that some of those arguments were only constructed at a conceptual level with rhetorical explanations rather than supporting evidence, it is likely to infer those researchers were trying to influence the reader opinion of agile, which is fundamental to creating a management fashion for agile concepts in construction management.

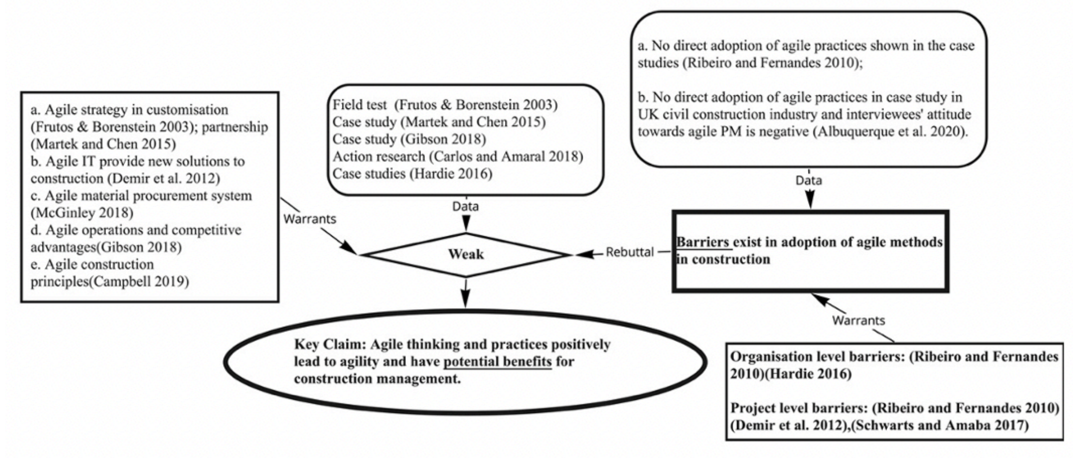


Figure 6: Integrated model of arguments

Moreover, some studies had conceptual discussions on benefits of agile practices, but their empirical analysis showed no adoption in practice. Barriers of adoption were also claimed in existing research. Organisational and project-level barriers were noted as explanations of the claim and evidence of no existing adoption in case studies supported the claim that construction firms should properly manage their expectations of innovative ideas such as agile adoption.

CONCLUSIONS

Construction firms are faced with more challenges in the post-COVID-19 period with changing customer requirements and external environment, which leads to the need for increasing resilience capabilities and thinking about where construction projects should go in the future. Agility as a capability to flexibly respond to changes was noted in construction research and agile related practices, transferred from agile supply chain and agile software development, which have been argued as have potential benefits. However, an argument mapping analysis shows that some of the benefits claimed in the research lack supporting evidence, which in turn lowered the degree of convincingness of the proposed benefits to readers. Barriers to adoption of agile practices in construction have been noted in research with some negative attitude from industry. Critically, this argument mapping results implies that both pro-agile and con-agile arguments call for future research in theoretical relationship analyses of agile practices and construction problems, empirical research on validating the proposed agile framework and models in construction projects. Construction researchers need to put more effort on questioning and demanding validations on 'matter of fact' things or ideas rather than following and arguing management fashion. Managers in construction, who wish benefits from agile practices, should be aware of the barriers and consider a pilot project before large-scale adoption of new agile practices.

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A FRAMEWORK SUPPORTING MIXED PRODUCTION STRATEGIES IN PLATFORM DEVELOPMENT: A CASE STUDY IN POST AND BEAM BUILDING SYSTEM

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Industrialised house building (IHB) design incurs complexities as extensive engineering are required due to high customisation. Companies use different production strategies (PS) to develop building components ranging from standardised to customised depending on the requirements. Platform-based product development has received increased attention from IHB companies striving to be competitive in the industry. However, strategies for platform development supporting the design process are not well-defined for companies using a combination of PS in their development. This study proposes a framework using different PS in the development of a product platform to support the design phase of the post and beam IHB system. Empirical data were gathered from a Swedish multistorey house building company. The main contribution of this study is to provide insights into production strategies while designing components. Moreover, the case is used to exemplify how different subcomponents of the building system can be classified into production strategies and facilitate postponement of strategies to achieve platform-based development. The potential application of different support tools and methods in incremental platform development has been presented.

Keywords: design management; industrialised house building; production strategies

INTRODUCTION

The design phase of IHB is challenged to develop products with lower costs and reduced lead time (Jansson *et al.,* 2014). The degree of detailing and information level increases due to unique requirements from the customers, legal challenges, market demands, production constraints etc. (Thajudeen *et al.,* 2022). Here, extensive engineering work is required for certain components as customisation yields a high level of complexity (André and Elgh, 2018). Consequently, the construction industry has been traditionally characterised as being engineer-to-order (ETO) in the engineering dimension (Gosling and Naim, 2009). However, companies use a combination of PS to develop building components ranging from select variants to ETO depending on the customer needs (Thajudeen *et al.,* 2018). Researchers, therefore, highlighted the importance of Customer Order Decoupling Points (CODP) by introducing different PS from pure standardisation (no customer input) to pure

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Thajudeen, S, Elgh, F and Lennartsson, M (2022) A Framework Supporting Mixed Production Strategies in Platform Development: A Case Study in Post and Beam Building System *In:* Tutesigensi, A and Neilson, C J (Eds) *Proceedings of the 38th Annual ARCOM Conference,* 5-7 September 2022, Glasgow, UK, Association of Researchers in Construction Management, 93-102.

customisation (customer engaged in design) (Schoenwitz *et al.,* 2017). According to Johnsson (2013), pre-engineering is a potential option for ETO companies, although firms allow the client to affect the product design. In fact, ETO based companies can apply many product standardisation strategies by defining part of the product structure and preparing reuse of existing designs to increase efficiency (Cannas *et al.,* 2019).

LITERATURE REVIEW

For the design of customisable products, product platform and product family are the two key elements (Meyer *et al.,* 2018; Simpson *et al.,* 2014). Platform-based product development has received increasing interest from IHB companies that strive to be competitive in the industry by offering customised solutions and lowering internal costs (Lennartsson *et al.,* 2021). Research on product platforms (Jansson *et al.,* 2014) and product customisation (Hvam *et al.,* 2008; Jensen *et al.,* 2015) indicates that modularisation requires customers to move from ETO strategies to configure-to-order (CTO) strategies, in which the CODP point changes. Here, the level of predefinition must be increased for components and the CODP must postpone to a later stage of the value chain to achieve the benefits of the use of platforms (Bonev *et al.,* 2015). There are plenty of strategies and methodologies for companies to rationalize their product portfolio. Despite various studies on product platforms and PS in the IHB industry (Bonev *et al.,* 2015; Jansson *et al.,* 2014; Johnsson, 2013), some research gaps remain, particularly when it comes to supporting the design process of building components having a mix of production strategies. Moreover, Cannas *et al. (*2019) identified the need of investigating different choices in terms of the combination of decoupling points and strategies. A better understanding of the impact of PS and product architectures on design and production processes is therefore needed to facilitate platform implementation. Therefore, this study proposes a framework using different production strategies in the development of a product platform to support the design phase of the post and beam IHB system.

Product platform strategies have been widely accepted as enablers for customisation to serve a wide variety of products while maintaining business efficiency (Bonev *et al.,* 2015; Jansson *et al.,* 2014; Jensen *et al.,* 2015; Meyer *et al.,* 2018). Robertson and Ulrich (1998) defined product platforms as a collection of four sets of assets, namely components, processes, knowledge, and people/relationships. Platform thinking enhances component decomposition in terms of commonality parts and modularity parts guide a way to adopt the pre-engineering strategy (Jiao *et al.,* 2007). Jansson *et al. (*2014) suggested integrating design support methods for daily work when using platforms in an ETO context. Hvam *et al. (*2008) proposed an approach for the development of configuration systems for predefined platform components. A study performed by Thajudeen *et al. (*2022) demonstrated how to reuse the design assets of building components having ETO characteristics with the support of parametric modelling. The design platform approach (DPA) is used to gain the benefits of platform thinking in a company utilising both the residing engineering assets and as a formalized model that can be supported by IT applications (André and Elgh, 2018). Several studies have been conducted adopting DPA in both manufacturing and IHB industry (Lennartsson *et al.,* 2021; Thajudeen *et al.,* 2022). The different constructs of DP include Process, Solution, Synthesis Resource, Assessment Resource, Geometry Resource, and Project and have been considered as the building stones of a product variant. These resources are linked to a generic product structure (André *et al.,* 2017) and can be used for modelling any components ranging from standard to unique in terms of their degree of predefinition.

CODP refers to the point at which the customer enters the supply chain and to explore the potential for platforms and companies can use different PS based on CODP (Johnsson *et al.,* 2013). The four strategies used by companies according to Hansen (2003) are ETO, modify-to-order (MTO), CTO and select variant (SV). A view of two-dimensional CODP has been introduced by Wikner and Rudberg (2005) in which engineering and production are considered as different flows of activities that can be dissociated independently (Cannas *et al.,* 2019). Moreover, they refined the engineering dimension and dissected the ETO production strategy to extend into three strategies which are design-to-order (DTO), adapt-to-order (ATO) and engineer-to-stock (ATS). These diversifications of the ETO strategy were further tested by Johnsson *et al. (*2013) with a multiple case study in house building. The findings show that the DTO based strategies of the platform are undefined while ETS platforms are fully predefined. A movement away from the ETO strategies followed in traditional construction to a more product-oriented based on a MTO, CTO, or SV strategy represents a shift from a project focus to a greater focus on processes and products (Lundkvist, 2015). Here, the combination of PS presented by Hansen (2003) and Wikner and Rudberg (2005) has been used as a framework for empirical analysis.

Table 1: Analytical framework of production strategies with definitions (adapted from Hansen (2003) and Wikner and Rudberg (2005)

Production strategies	Definitions
ETO	The highest level of customization is categorised by the fact that engineering work needs to be steered for each customer order. The subset of ETO is DTO, ATO, ETS as below
DTO	Entirely new products are designed from scratch.
ATO	When parts of the solution are pre-engineered to some extent and the final product is realized through combining these parts.
ETS	The condition where solutions are pre-engineered.
CTO	Provide automatically configured product variants based on fully defined product parts, modules, and a set of configuration rules.
MTO	Supported by generic product structures and predefined modules and sets of rules that govern the design of product variants.
SV	Product development by use of standard components and processes.

The literature review shows several examples of platform-based development studies from different applications areas. However, they are mostly focusing on specific PS. Moreover, there seems to be no research that deals with the mix of PS strategies supporting the platform development from a complete building system perspective.

METHOD

The research was performed in two stages: Data collection and data analysis with framework development and validation. This study uses the combination of case study research and literature review by following a qualitative approach. A Swedish multi-storey house building supplier using a post and beam system was selected as the case. A case study allows focusing on a particular issue within a real-life context (Yin, 2018). The unit of analysis was subcomponents of a building system with a varying level of predefinition, each following a distinct production strategy. Figure 1 shows the overview of the research process.

A literature review presented in the previous chapter was the starting point of this study. An analytical framework was created by selected PS with their definitions to familiarise the participants from the company. This is used during the interview to compare the PS of different components, supported by parallel analysis of data. The empirical data were gathered from interviews, workshops, reviews of the archival sources and other sources such as informal conversations.

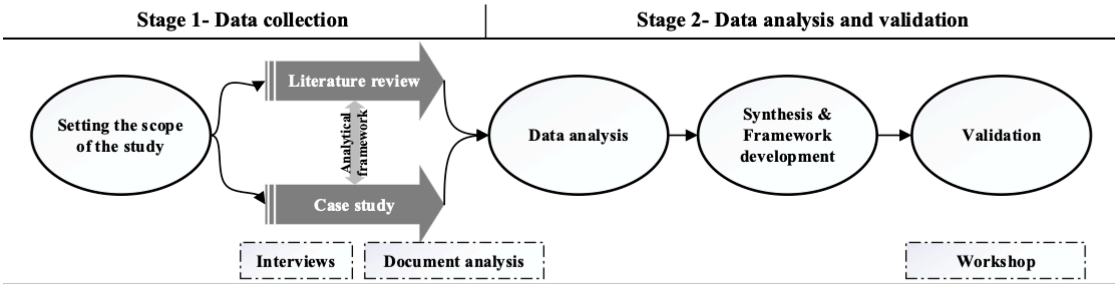

Figure 1: Overview of the research process

Here, method triangulation has been employed to increase the accuracy of data and to test validity through the convergence of evidence from different sources (Yin, 2018). In total, 5 interviews were performed ranging from 1-to 2 hours including the design manager, two structural engineers and two design engineers. The participants were selected based on their experience and knowledge in building systems from various positions in the companies, which enabled a more consistent understanding of the product portfolio. The intention was to gather additional empirical insight into the applicability of different PS and the impact of platform-based product design.

The interview results were analysed by categorising data for individual building components to examine the suitable strategies to adopt while designing. Besides, archival data sources helped to find different strategies adopted by designers in previous projects by analysing the 3D models of buildings, design templates, excel spreadsheets, custom component libraries etc. A framework has been proposed with the support of gathered data. Finally, a workshop was conducted by including key personnel from the case company as part of the evaluation and to investigate the impact of the support method and its ability to realize the desired situation.

Case Study

A Swedish subcontractor of Glulam (Glued laminated wood) based multi-storey housebuilder has been selected as the case company. They offer a multi-storey house building system named Trä 8, a flexible, wood-based and lightweight construction system for both residential and public buildings. The main reason for the selection of the case is due to the degree of predefinition offered by the building components and the uniqueness in all projects offered by the building system. Moreover, they are currently working on the adaptation of a platform-based development to be more competitive in the housing market. The main components of the building system are shown in table 2, including pillar/ post, beams, trusses for stabilisation which are made of glued wood, floor elements and roof elements made of Kerto material and steel connectors. The product view and subcomponent view of the Trä 8 building system is shown in Figure 2.

Framework for Platform Development

A framework is proposed for the case company to support platform development by adopting the benefits of PS in component design. An overview of the framework is shown in Figure 3. This is developed based on a detailed study of individual sub-component of the Trä 8 building system with the support of experienced designers during the empirical data collection and motivation gained from the literature study.

The practical goal of this study is to increase the understanding of suitable production strategies while designing a component with the support of a product platform.

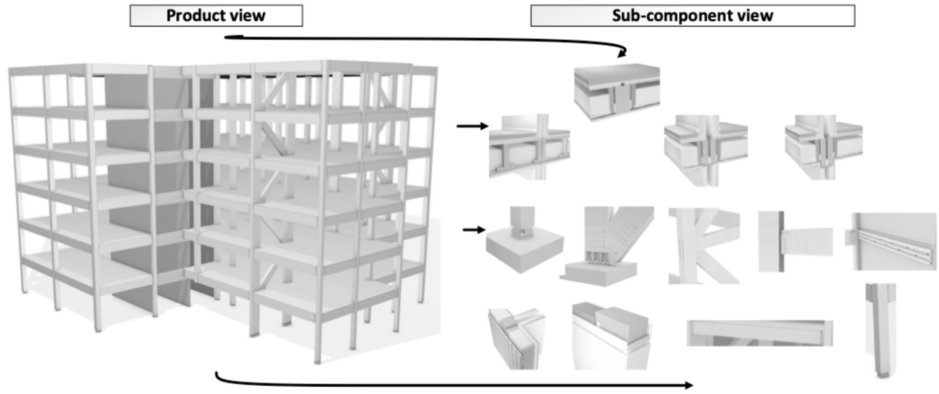

Figure 2: The product view and subcomponent view of the Trä 8 building system

Table 2: Components of building system

Components	Description
Post	They are made by gluing small lamellas and are used to handle the vertical load both compressive and bending forces imposed on the building which is anchored to the concrete foundation.
Beam	The beam primarily functions as the vertical load-carrying member from the floor element of the building. It is connected horizontally to the posts with the help of steel connectors.
Trusses	Trusses are the diagonal structure that is used as stabilizing members to balance the fluctuating load. The truss elements are connected to the column with steel fin plates and dowels to provide stiff connections between the members.
Floor element	They are built with a top slab of laminated veneer lumber (LVL) sheet and beam frame of glulam where cavities are insulated with mineral wool for sound insulation. The elements are light, and stiff, which contributes to good characteristics of failure, vibration, and soundproofing, especially at low frequencies.
Roof element	The roof structure is most conveniently designed with the element of LVL discs having surface insulation with a layer of insulation on top of the element.
Steel connectors	Steel connectors are designed to transfer imposed loads from one structural member to another and then to the foundation. All building components are connected with steel brackets that are designed for a rational assembly.
Stabilizing element	The main stabilization element is the staircase and elevator shaft which is generally made of the concrete structure and the purpose is to stabilize the entire post and beam structure, especially with high span.

As shown in the figure, the development includes the conceptual phase, the system-level phase, and the detailed design phase. The proposed framework can be used as decision support for designers in the design phase. The core part of the framework is the classification of building components based on the PS adopted for the product realisation. The PS developed by Hansen (2003) and the subset of ETO presented by Wikner and Rudberg (2005) has been utilized. Every component follows a PS based on its level of pre-engineering (Johnsson, 2013). The colours represent the level of complexities in designing the building components. For instance, steel connectors have been considered as a critical component of BS having an ETO nature that requires extended engineering work whereas the framing components such as post, beam and trusses can be realised easily based on the load and span width of the building. The subset of ETO has been used due to the characteristics of the components offered by BS. Table 3 shows the detailed classification of components into different PS and existing support used to design together with the support of engineers.

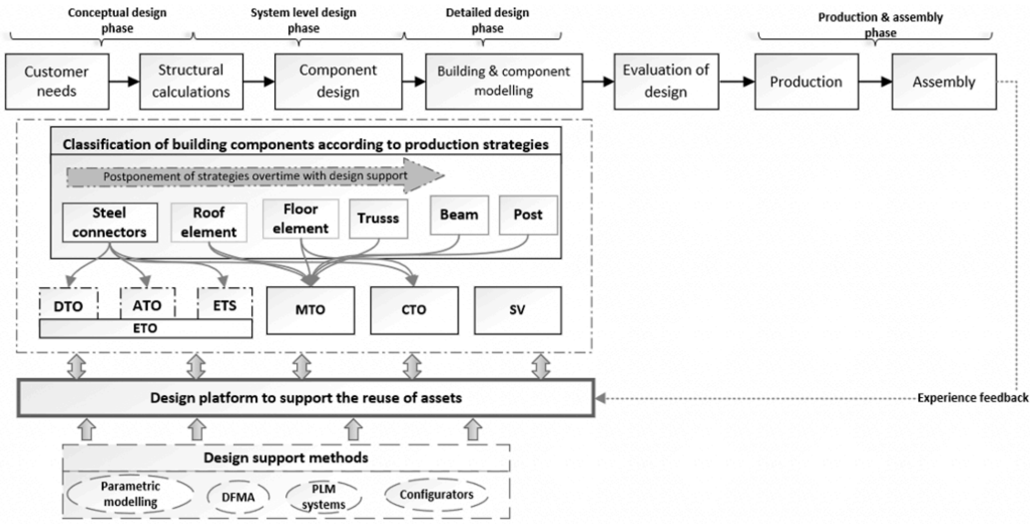

Figure 3: Framework for platform development using mixed production strategies

The key criteria for the classification of components are the knowledge of different assets and experience in designing. For instance, the design of a new component starts generally with DTO and could incrementally move from the subsets of ETO to MTO, or CTO based strategies as shown in the figure. From a design platform perspective, this is occurred due to the reusing of design assets where the solutions created for the first time in DTO can be adapted for the next project, and turn into an ATO strategy (André *et al.,* 2017). To achieve this postponement in design, the designer must first distinguish components that need to change and determine how such changes propagate through different attributes.

In principle, the structural calculation for post, beam and trusses starts from scratch for all projects as requirements are unique. Here, the dimensions of these components depend on the span width and internal and external loads. Structural engineers often reuse the previous solutions such as Mathcad sheets, excel sheets made from the previous project to some extent and adopt them for new projects. Currently, several Mathcad files for brackets, column footing, and floor elements are reusing. For the modelling, custom component libraries, BIM managers and parametric modelling are currently used as support for developing solutions. Here, the assets are predefined, and this way of working can be related to the DPA (André *et al.,* 2017). It can be methods or tools that enable reuse in the early stage of engineering as a support for designers. However, engineers do not have a structured and shared approach to follow.

DPA was chosen as it can be used for the realisation of ranging from standard to unique variants supporting the generic modelling of a product platform using the product structure and design assets of a company (André and Elgh, 2018). It supports sufficient review and assessment of design variants available and guides designers in the process (Lennartsson *et al.,* 2021). Hence, a good alignment can be achieved with components that provide an idea about what kind of asset can be built and used in different projects. Moreover, the approach is intended to expedite the decision-making process that supports the designers with a set of proven design solutions and assets to find an optimal solution.

Table 3: Classification of building components and mapping of production strategies

Building components	Subcomponents	Production Strategies	Structural design support	Modelling support
Post	215X225 mm - 215X 800 mm	MTO	Excel guide, Statcon	BIM manager
Beam	90X360 mm - 215-900 mm	MTO	Excel guide, Statcon	BIM manager
Trusses	215X225 mm - 215X 800 mm	MTO	Excel, Trusscon/ RFEM	BIM manager
Floor element	Variant 1- LVL	CTO and MTO	Mathcad	CCM, Semi-PM
	Variant 2- CLT	CTO and MTO	Statcon/Rfem	CCM, Semi-PM
Roof element	Variant 1	CTO and MTO	Mathcad	CCM, Semi-PM
	Variant 2	MTO	Statcon/Rfem	CCM, Semi-PM
Steel connectors	Column footing	DTO, ATO ETS, CTO	Mathcad	CCM, PM
	Column footing with truss	DTO, ATO	Mathcad, Statcon	Manual modelling
	Bracket	DTO, ATO ETS, MTO	Mathcad	CCM, PM
	Truss connections	DTO	Statcon	Manual modelling
	Stabilizing part	ATO, ETS	Mathcad	PM, BIM manager
	Balcony	DTO	Mathcad, Statcon	Manual modelling

CCL- Custom component library, PM- parametric modelling, CLT-cross laminated timber

If the designers have an overview of components in a platform, the same can be reused across different kinds of projects by adopting a platform approach. According to the structural engineer, “Platform development based on PS could benefit the design process and change the culture of way of working". This helps the company to improve the level of pre-engineering. However, the potential of DPA has not been fully explored. This was the motivation for a structured framework for supporting a platform-based product development by utilising the PS of sub-components.

The framework suggested various support methods and tools that are potential to use to improve the design process. As pointed out by Jansson *et al. (*2014), the support methods are employed to reduce the gap between the standardized components defined in a platform and the project-specific parameters. For example, the results from Thajudeen *et al. (*2022) show that by integrating the parametric modelling approach, it is possible to change the engineering strategy gradually from ETO to CTO strategy to be more efficient in the design process and meet the challenges due to customisation. Reuse of engineering assets of ETO based components can push the boundary towards adoption of the configuration of variants from those components. This initiates the incremental development of platform-based design in a firm (André *et al.,* 2017). A high degree of interdependence between the variants leads to the generation of a high number of variants. The knowledge about the component assets is crucial when moving towards CTO or MTO approach. Finally, the experience feedback from production and assembly creates a complete loop where information is feeding the designer for any variations (Lundkvist, 2015). As part of the evaluation, the proposed framework has been verified in a workshop by including key people from the case company.

DISCUSSION

IHB companies typically place themselves randomly in a PS without having a thorough knowledge of own assets and not conducting a detailed analysis of the subcomponents. Developing project-specific and unique solutions create a perception that the BS follows an ETO based strategy (Schoenwitz *et al.,* 2017). However, in reality, building components can be even classified into various PS and companies can develop strategic decisions based on the component portfolio (Johnsson, 2013). Several components can be classified to be configured or modified depending on the functionality where the power of reuse can be adopted (Cannas *et al.,* 2019). Thus, familiarizing the product portfolio from a production perspective something simple to understand and tangible is important for success.

This is an explorative study performed to analyse the possibilities of classifying subcomponents of BS according to the mix of PS to find what is the rationale for this classification and what picture can be drawn from a product platform perspective. The analysis of BS shows that post and beam type IHB companies typically build houses with components that have a combination of standard, modified, configurable and fully customised building components (Thajudeen *et al.,* 2018). For instance, the framing components can be developed with the MTO approach based on different loads acting on the building. Here, design preparations are not required to a great extent but ensure the components are structurally strong and withstand the loads. However, connectors require a more ETO approach. Thus, the concept of simply reusing the process and product from a previous project cannot be directly applied in the engineering development of ETO based components. The growing degree of complexity inherent in the ETO approach due to fluctuating changes eventually leads to higher design time and cost. For example, the brackets have variants ranging from MTO to ETO where a few could be standardised and the rest require more effort in design (Thajudeen *et al.,* 2022). Here company can allocate more resources and support methods to those components that need more attention.

By applying different engineering support methods ETO-based components can be shifted towards MTO or CTO (Jansson *et al.,* 2014). This is achieved by the pre-definition of different assets gathered from a component and the reuse of those assets in future projects brings a platform-based development (Bonev *et al.,* 2015). Some special components are always started from DTO and then adapt to other types of strategies. This can be considered as part of incremental platform development achieved by reusing knowledge (André and Elgh, 2018). In this context, a DPA would be the suitable platform approach that can take care of component design ranging from standard to ETO nature (André *et al.,* 2017). Moreover, the postponement of production strategies is the key outcome of using this approach. The novelty of this study is an approach to platform development based on a detailed classification of a BS from a holistic perspective.

The results show that one way to adopt platform-based development is by the postponement of existing PS with support methods and tools. Also creates opportunities to streamline the design process, balance resources and focus on tasks that certainly require engineering knowledge and skills. Designers can build a strategy based on this framework and highlights the importance of decomposing a product before making decisions. These benefits support the ideas of BUILD BACK WISER from a construction management perspective, by improve the design phase. The main implication of this study is that understanding the different dimensions of component variants, their interconnections, and possibilities to achieve various designs would help designers select the production strategies that are appropriate for their specific context (Hansen, 2003; Wikner and Rudberg, 2005). The understanding of the platform not only includes components, but also other assets is important for any company to adopt a platform culture. There is a potential, if the assets can be added to a platform and managed regularly, not individually, but also shared with other designers, more to be seen as a design platform asset. This framework would provide a path forward for the case company to improve the design process. Therefore, the industrial contribution includes adding knowledge about the platform development based on PS and best practices to improve the design process of building components. Here, the classification of components is made with the support of designers from the company which improves the reliability of the work. Moreover, the archival data and workshop support the evaluation of results.

CONCLUSIONS

This research has attempted to identify the dimensions of PS in a post and beam IHB system and establish a way forward to achieve a platform-based product development. A framework is proposed that highlights the importance of the DPA for the reuse of assets (André *et al.,* 2017), the choice of PS in the engineering dimension (Hansen, 2003; Wikner and Rudberg, 2005) and how components can be classified with the support of a design platform. The developed framework can be used as a road map for the case company to develop a strategic decision-making tool and adopt this support for designers in developing solutions. The findings reported in this paper are specific knowledge gained from a single case based on their BS (Yin, 2018). However, this case is an explorative study to obtain a preliminary result from the application of the proposed framework. This could be an inspiration for other types of BS and can be assessed to test the practical applicability in a different context. The disposition of PS may change in different contexts based on the component's nature, customisation offered, level of pre-engineering etc. More detailed studies are required to show how this approach can be realized and this can be considered a future study.

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CONTRACT MANAGEMENT

IS THE COMPETENCE OF INTERNAL STAKEHOLDERS IN CONSTRUCTION PROJECTS AN ANTIDOTE TO CONSTRUCTION CONTRACT DISPUTES?

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Previous research on construction disputes has focused on identifying general sources of disputes. However, the occurrence of disputes follows causal sequences which have not been sufficiently studied. With increasing investment in megaprojects, the construction industry is bound to suffer consequences of disputes whose occurrence mechanisms have not been thoroughly investigated. Against this background, research was undertaken to improve the understanding of causal sequences of sources of disputes to facilitate better project performance. The research adopted a single case study strategy of an infrastructure megaproject. Secondary data including project reports, contract documents, minutes of meetings, and project communications were collected and analysed using thematic analysis. The findings show that while the sources of the dispute studied are numerous, their primary cause is the limited competence of internal project stakeholders. The results demonstrate the need for improving the competence of construction professionals in the areas of construction contracts, procurement management, contract administration, and project governance.

Keywords: competence, developing countries, disputes, infrastructure, megaprojects

INTRODUCTION

Investment in megaprojects is increasing across the globe because of their associated benefits which include the creation of sustainable employment, improvement of the environment, and improvement of productivity (Flyvbjerg, 2014). Megaprojects have a significant impact on society, the economy, and the environment (Risk Group, 2017). However, the performance of megaprojects is affected by construction disputes that occur frequently during construction (Arcadis, 2021). Construction disputes are some of the main factors responsible for the unsuccessful completion of projects (Rauzana, 2016). After their occurrence, construction disputes often take a long time to be settled (Arcadis, 2021) which often results in stagnation of project activities and subsequent project delays. Furthermore, settlement of construction disputes involves transaction costs and often leads to financial claims. As such, construction disputes are undesirable, yet recurrent in the construction of megaprojects.

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Available literature suggests that emphasis has been put on general factors that lead to construction disputes with less concentration on their causal sequence. Most of the literature has not indicated competence aspects of project stakeholders to be an important factor in causing disputes yet the human resources are involved in all project activities. The fact that occurrence of disputes has not declined (Arcadis, 2021) implies generalisation of dispute sources is not appropriate (Love et al., 2008). This calls for case-by-case investigation of the events leading to occurrence of disputes. The need to investigate the escalation process of disputes in megaprojects inspires the work in this paper. The paper concentrates on the identification of a mechanism of occurrence of a construction dispute in a single case study. Understanding the causal sequence of construction disputes identifies a primary dispute source (Kumaraswamy, 1997; Love et al., 2011) where the limited organisation resources can be focused to eliminate the corresponding secondary sources and the dispute(s). Therefore, the research aimed to determine the mechanism of occurrence of disputes to contribute to the realisation of better performance of construction megaprojects.

Sources of Construction Disputes

A dispute is a circumstance in which two parties disagree over the assertion of a contractual right, leading to a contract decision, which then becomes a legal dispute (Arcadis, 2021). Kumaraswamy (1997) emphasises that the management of disputes should follow the identification of the sources of disputes. The importance of identifying sources of construction disputes lies in the fact that it helps to ensure proper management of disputes. Understanding the sources of construction disputes is a prerequisite for appropriate dispute management (Love et al., 2008). The causes of construction disputes are varied, and often multiple (Love et al., 2008). Extant literature identifies several sources of construction disputes. The common sources include: the failure of stakeholders to comply with contractual obligations (Arcadis, 2021), payment delays (Kumaraswamy, 1997), poor project management (CRUX, 2020), scope change (CRUX, 2020; Arcadis, 2021), inadequate contract management (CRUX, 2020), errors and omissions in contract documents (Cheung and Pang, 2013).

The above literature suggests that efforts have been made to identify general sources of disputes in the construction industry and megaprojects in particular. However, the identified dispute sources are non-exhaustive considering the unique nature, complexity, and vast stakeholder involvement in projects (Soni et al., 2017). Since most of the researchers have used questionnaires to research the causes of disputes, the factors provided by the literature lack contextual meaning and have not hindered the reoccurrence of construction disputes (Love et al., 2011). Trends in Arcadis (2021) and CRUX (2020) imply that sources of construction disputes are dynamic and differ for different contextual situations. As such, characterisation and generalisation of sources of disputes is inadequate (Love et al., 2008) and therefore the need for source sequencing of disputes ((Hietanen-Kunwald and Haapio, 2021).

Love et al. (2011) argues that many researchers have falsely attributed the actual causation of construction disputes to single events and ignored the chain of events that lead to disputes. Hietanen-Kunwald and Haapio (2021) also asserts that disputes are often the end of the escalation processes and the real underlying causes need to be investigated broadly. Cheung and Yiu (2006) shows that the immediate causes of disputes are only triggering events that follow various underlying events and processes. Love et al. (2008) and Love et al. (2011), among others, emphasise the need for further research to study construction disputes and identify their underlying causes to supplement the existing body of knowledge. Studying escalation processes of disputes is vital in understanding the primary causes of construction disputes (Hietanen-Kunwald and Haapio, 2021). Further investigations, including case studies, are necessary to obtain an ameliorated understanding of the underlying conditions that contribute to construction disputes (Love et al., 2011).

METHOD

To identify a mechanism of causal factors for construction disputes, a desk study was conducted on a single case study to undertake an in-depth investigation (Saunders et al., 2019) of the sources of disputes during the construction phase. The case study had large amounts of data and the available resources were only sufficient for one case study. Although case study research is not theoretically generalisable, the purpose of this study was to provide exemplary knowledge from the case (Thomas, 2010). A desk study was appropriate since there was sufficient and reliable secondary data from the case study project. A desk study involved reviewing the secondary data of the case study to identify disputes and map mechanisms of the factors that led to the disputes. The desk study involved a critical review of over 10,000 pages of project documents. The documents included 11 contract documents the employer had with three key project stakeholders, 108 project progress reports, 36 project management consultant's reports, 70 files of minutes of meetings, 6 reports by a panel of experts, 3 project audit reports, and over 200 project letters. Minutes of meetings were official representation of agreement by all involved parties and therefore portrayed collective responsibility. Reports and letters were project documents based on evidence portraying the true project facts and were considered to represent collective responsibility. Informed consent was sought from the client organisation and anonymisation of the project and project stakeholders was a priority. Therefore, for this paper, the project and its stakeholders will be unidentifiable.

The project documents were analysed using thematic analysis with the aid of NVivo 12 software (Grbich, 2013). The desk study aimed at identifying disputes and mapping the escalation of the causes that led to the occurrence of disputes. Analysis of documents involved familiarisation of data, coding, and theme formation and refinement (Braun and Clarke, 2006) that were done concurrently. The thematic analysis was done inductively (Saunders et al., 2019) to identify all potential links to the disputes under consideration. The researchers also used interpretivism to incorporate their subjective interpretation of the causal factors as a supplement to document analysis (Saunders et al., 2019). The themes that highlighted the factors that led to the dispute were mapped into a causal mechanism and visualised on a relationship diagram. Timeframes of occurrence of the causal factors were identified to demonstrate that time logic was fulfilled between causes and effects.

The case study is a public infrastructure project under construction in a developing country (country Y) and is referred to as "Project Z" in this paper. Country Y is a developing country working towards middle-income country status and Project Z was initiated to support the country's economic development. The government of Country Y is represented by a government agency which is the client organisation of Project Z and a ministerial body. Among other duties, the government ministerial body was responsible for procurement of the contractor and owner's engineer for Project Z. Project Z is a flagship megaproject with a lump sum cost exceeding $1.5 billion. The project involves multinational stakeholders including the contractor, owner's engineer, panels of experts, and the lender. The contractor is responsible for Engineering, Procurement, and Construction and was procured under a turnkey procurement strategy. The project had the involvement of two asynchronous owner's engineers during the construction phase. Construction of Project Z commenced in the early 2010s and was still ongoing as of April 2022 with more than three years overrun.

Preliminary analysis of "Project Z" documents suggested the existence of many disputes between the contractor and the owner's engineer. Disagreement on the withdrawal of payments made to the contractor is one of such disputes and is the focus of this paper due to the relatively high attention it was given by various project stakeholders in project documents.

FINDINGS

Triggering Event: Withdrawal of Payments Initially Made to the Contractor
Findings show that the dispute between the owner's engineer and contractor resulted from the withdrawal of interim payments initially made to the contractor. The contractor disputed the decision of the owner's engineer to recall a percentage of payments initially made to the contractor. This was because the deduction resulted in a negative net payment that was bound to affect the successive interim payments. The contractor then decided to suspend the application of interim payments for over a year. As a result, project activities stalled and resulted in a contractor's claim worth 1.5% of the EPC contract price and additional time equivalent to 11% of the planned project duration. Withdrawal of the contractor's payment was only a triggering event for the dispute between the contractor and the owner's engineer. As suggested by Cheung and Yiu (2006), the research uncovered a mechanism of causal factors (highlighted in Figure 1) that led to the withdrawal of initially certified payment. Figure 1 shows the mechanism of occurrence of the dispute that was triggered by the withdrawal of the payment previously made to the contractor. The oval and rectangular shapes represent the causal factors whose cause-effect relationship is represented by arrows. The periods of occurrence of the causal factors are indicated to show that the chronological sequence of cause and effect was satisfied. The mechanism shows that the causal factors belong to two major categories i.e., the pre-contract phase (denoted as T0-N) until contract formation (denoted as T0) and the contract administration phase denoted as T0+N (where N is time before or after T0).

Causal Factors During the Pre-Contract and Contract Formation Phase

Limited competencies of internal project stakeholders
Competence is the combination of training, skills, experience, and knowledge that a person has and their ability to apply them to perform a task safely (Health and Safety Executive, 2021). Competence also entails positive values and attitudes (Chan and Yeung, 2020). As such, the attributes of competence considered in this paper include skills, experience, knowledge, attitudes, and positive values of the human resources. The findings show that limited competence manifested in the human resources for all the major stakeholders i.e., the employer, contractor, and owner's engineer. Analysis of data and authors' subjective judgement shows that limited competences were one of the primary factors that escalated into the dispute. Limited competence manifested in various attributes. The employer had inadequate knowledge of procurement strategies for megaprojects. The contractor had limited workmanship skills and inadequate knowledge of some international design codes and project quality management. The owner's engineers had inadequate experience in undertaking engineer's roles on mega projects, and inadequate knowledge in project quality control contract administration and procurement strategies. The owner's engineer also showed negative values such as

a lack of commitment to the project. Therefore, aspects of limited competence manifested in both pre-contract formation and post-contract formation phases.

Figure 1: Mechanism of occurrence of the dispute

Inadequate knowledge of employer of procurement for mega projects

Analysed secondary data suggested that the employer procured an inexperienced consultant and owner's engineer for Project Z. The owner's engineer who was also appointed as the consultant for the pre-construction activities had insufficient experience to undertake such roles for megaprojects. This was the responsibility of the employer to ensure procurement procedures were followed and in turn appoint the most appropriate organisation. Using the researcher's subjective interpretation, the appointment of the inappropriate consultant suggested limited competence of the human resources. The employer seems to have considered least cost as a major selection criterion. As is common with traditional contracting, the procurement selection criteria focused on the least cost and the less experienced organisation met the cost criteria. Procurement based on the least cost is not recommended for megaprojects. Turner (2022) guides that procurement for megaprojects should rely on economic advantage rather than the least cost. The human resources of the employer seem not to have had sufficient knowledge about the best practices.

Inexperienced consultant

The consultant who assisted the employer in the preparation of the EPC contract was not experienced in megaprojects. The consultant was expected to be technically competent and was responsible for drafting the EPC contract with input from the employer. Therefore, the inadequate experience and knowledge of the consultant resulted in an inadequate EPC contract. The EPC turnkey contract for the >$1.5 billion Project Z was based on World Bank's standard bidding document for small works not exceeding $10 million. The consultant (owner's engineer) lacked the necessary skills to draft a suitable contract for the technically complex Project Z mega project. Despite the ongoing project, the same owner’s engineer was relieved of duty by the employer after the expiry of their contract due to their unsatisfactory performance inspired by limited competencies of human resources. Inadequate skills, knowledge, and experience of the owner's engineer directly contributed to their failure to fulfil contractual obligations. Among other tasks, the owner's engineer was responsible for ensuring quality control and assurance for Project Z. Their human resources lacked the necessary competencies and often approved inadequate drawings and failed to supervise activities as per drawings.

Inadequate EPC contract

The EPC contract for Project Z was an arm's length contract since the contractor and employer had no previous work relationship. The EPC contract was a modification of contracts for small projects not exceeding $10 million under the World Bank framework. As such, most of the contract terms were unsuitable for megaprojects. The EPC turnkey contract on Project Z emphasised control through the principle-agent relationship between the contractor and the owner's engineer. For instance, the contractor had to seek the design approval of the owners before undertaking any activity. This high level of control is unexpected for a>$1.5 billion project that Project Z was and is suitable for small projects (Turner, 2022). As Turner (2022) emphasises, trust is key in mega projects, and this is promoted by a principle-steward relationship. Based on trust, turnkey contracts should specify desired project outputs to be met by the contractor (Turner, 2022). The EPC contract instead required the contractor to seek approval of work methodologies from the owner's engineer. This should not be the case for turnkey projects. It was therefore expected for the principle-steward relationship based on trust to be reflected in the EPC contract for Project Z.

The inadequate contract between the employer and owner's engineer

The contract between the owner's engineer and employer emphasised the control of the contractor's activities and promoted distrust of the contractor. This contradicts the requirement of trust required in megaprojects (Turner, 2022). The contract should have considered the contractor as a steward and the role of the owner's engineers would be to oversee rather than micro-manage the megaproject. The inadequate contract was partially responsible for the incompetent human resources of the owner's engineer. The contract between the employer and the owner's engineer only stated the level of education and experience requirements from the human resources. There was no mention of required competencies and continued development of human resources. Complex projects have dynamic demands and call for innovation rather than following traditional project management practices (Turner, 2022). Innovation requires the application of a variety of competencies and skills that should have been indicted in the contract. This implies that the planning of the human resources (PMI, 2017) was inadequately done. Since the development of human resources was not required in the contract between the owner's engineer and employer, the dynamics of Project Z seem to have been too complex for the owner's engineer. However, training would have imparted the necessary skills to administer the contract better. Development of human resources requires resources that will unlikely be paid by a project-based organisation whose aim is to maximise profits. Development of human resources would have been enforced if it was a contractual requirement.

Ambiguous contract

The EPC contract was ambiguous and promoted biased interpretation by the contractor and owner's engineer. For instance, some design codes were not specified which led to different preferences by the owner's engineers. The contractor, with the acceptance of the owner's engineer, considered certain standards on which designs, and installations were based. The successor owner's engineer preferred different international standards. All this was a result of a contract that allows for subjective interpretation. Good contracts are usually detailed enough with a specification of international standards and design codes to guide the project. This was not the case with Project Z. For the unspecified standards, it was up to the contractor and owner's engineer to agree on a standard for consideration. The disadvantage of this is that opportunistic behaviour and prior experience can lead to the adoption of less appropriate standards as was the case for Project Z. Sufficient contract details would have eliminated ambiguity and the subjective judgment by the stakeholders.

Causal Factors During Contract Administration

Inadequate knowledge and skills of the contractor
The contractor's inadequate knowledge and skills were responsible for the inadequate designs, poor workmanship, and poor-quality work. These characterise the failure of the contractor to fulfil contractual obligations. Adequately skilled human resources would ensure designs are done following the appropriate international standards and installations are made as per the approved drawings. As such, issues of inadequate designs and poor workmanship would not manifest. The EPC contract highlighted the education and experience requirements of key contractor's human resources. However, relevant competencies were not mentioned. Megaprojects like Project Z are complex and require dynamic approaches (Turner, 2022). Training and continued development would have been important in the skills development of the project's human resources.

Limited skills, knowledge, and negative values of owner's engineer
The limited competence of the owner's engineer was shown in different aspects. The owner's engineer had insufficient experience to supervise complex megaprojects, inadequate knowledge, and skills which resulted in approving inadequate designs and certifying defective work. Further details have been referred to in the section discussing the "failure of owner's engineer to fulfil contractual obligations". Another aspect of competence was the lack of commitment of the owner's engineer to the project. The owner's engineer exploited the two months before the expiry of their contract for their benefit. They had less commitment to the project and approved substandard work knowing that another owner's engineer would replace them for the remaining project duration

Although the owner's engineers had no motivation to commit to their contractual obligations in that period, it was their responsibility. Since they still had a running contract with the employer, the owner's engineer had to respect the contract and fulfil their obligations. Their action of negligence explains their incompetence in terms of lack of commitment. Lack of commitment to the project goal led to work not conforming to the employer's requirements. Commitment would have encouraged the preservation of a relationship by cooperating and prioritisation of the long-term benefits of maintaining the relationship over attractive short-term alternatives (Chohan, 2020). There was no more relationship to preserve since the employer had fallen out with the owner's engineer and no relationship existed before the project. Therefore, the arm's length contract partially contributed to the limited commitment of the owner's engineer and their selfish action.

Failure of the owner's engineer to fulfil contractual obligations
Some activities were undertaken without drawings while others were characterised by poor workmanship, low quality, and deviations from approved designs. It was the owner's engineer's responsibility of managing project quality management and contract administration. One of their obligations was to approve all designs before

construction and installation. As such, the owner's engineer neglected their contractual duty and failed on major obligations of ensuring the contractor's adherence to the contract and ensuring project quality management. One of the ways to ensure compliance of the contractor to the contract is withholding payments if the contract requirements are not realised. The owner's engineer instead certified payments for such works considering them as complete milestones. This meant there was hardly any penalty for the contractor's contractual faults and therefore a loophole that would encourage the contractor to deviate from contractual obligations. As such, this partially inspired the contractor in deviating from their contractual obligations.

Failure of the contractor to fulfil contractual obligations
The contractor was responsible for Engineering, Procurement, and Construction. As such, designs were a major deliverable and prerequisite for any construction activity. However, some project activities were undertaken without design drawings. For such activities, the execution was done without prior approvals by the owner's engineer as required in the contract. Some designs were inadequate, and installations were of inadequate quality and poor workmanship. As such, the contractor deviated from the contract and employer's requirements and failed to fulfil contractual obligations. For turnkey procurement strategies, the contractor is responsible for all project phases from detailed designs to commissioning. Detailed designs are a major deliverable under such procurement strategies. Engineering principles and best practices emphasise the need for considering designs as prerequisites for construction. A contractor being guided by engineering principles was not expected to make installations without designs. Furthermore, the EPC contract for Project Z specified that construction and installations should follow designs approved by the owner's engineer. This, therefore, implies that the contractor ignored industry best practices and deviated from the contract in cases where installations were done without designs.

Opportunistic behaviour
Opportunistic behaviour was another reason for the failure of the contractor to fulfil contractual obligations. The contractor took advantage of desperate project situations to fulfil their interests. For instance, when the owner's engineer failed in project quality management, the contractor continued to provide inadequate quality work. Opportunistic behaviour is common human behaviour in projects based on a principle-agent relationship in which agents are self-interest-seeking (Chohan, 2020). The contractor on Project Z took advantage of the owner's engineer's limited competence and commitment to fulfil self-interests. The contractor persuaded the owner's engineer to certify and pay for the inadequate quality work. Limited competencies and commitment of the owner's engineer provided a fertile ground for the contractor to complete as many milestones as possible before the change of the owner's engineer. The opportunistic behaviour of the contractor in Project Z exposed the agency problems related to principle-agent relationships. This is because any loophole in control was an opportunity utilised for opportunism by the contractor at the cost of the project.

Principle-agent project governance
The opportunistic behaviour of the contractor resulted from a principle-agent relationship on Project Z. The contractor was treated as an agent while the owner's engineer acted as the principle despite the contractor being responsible for engineering, procurement, and construction. The relationship between the contractor and owner's engineer relied on distrust and contractor had to work under close supervision of the owner’s engineer. As such, the relationship between the contractor

and the owner's engineer was entirely dependent on control. This principle-agent relationship encourages parties to concentrate on what is good for themselves rather than the project resulting in agency problems such as opportunistic behaviour. The principle-agent relationship was inappropriate for Project Z since it was a megaproject with aspects of technical complexity. Recent body of knowledge in which many empirical studies are synthesised and captured in Turner (2022) shows that principle-agent governance is inappropriate for megaprojects. The use of a principle-steward governance system would have mitigated the opportunistic behaviour of the contractor since it encourages all parties to prioritise what is best for the project.

Non-conformance to employer's requirements

The findings show that the discovery of non-conformities to the employer's requirements inspired the owner's engineer to deduct the interim payments previously done to the contractor. Non-conformities with the contract and employer's requirements were identified for electro-mechanical works after payment for the same milestone was reached. The non-conformities majorly included defects, poor workmanship, poor quality work, and work done without drawings. The owner's engineer raised the non-conformities with the contractor, but the latter was reluctant to rectify the non-conformities. As such, the owner's engineer decided to deduct the previous payments as a compliance mechanism for the contractor to rectify the non-conforming works. The failure of stakeholders to fulfil contractual obligations and an ambiguous EPC contract resulted in work not conforming to employer's requirements.

CONCLUSIONS

Construction disputes are frequent in megaprojects and their occurrences follow a chain of events that originate from a primary source(s). The research findings showed that several factors contributed to the causation of the dispute in Project Z although it was pronounced by a triggering event. All the causal factors were linked to competence issues in which limited competencies of the project stakeholders during tendering, design, and construction phases of the project. Although the dispute and its causal factors was identified on a megaproject case study in a developing country, the findings may be generalisable empirically not theoretically on other projects in various projects. The findings therefore portray the importance of ensuring project stakeholders especially the project management team have sufficient competence attributes. Training and continuous professional development of human resources through the lifecycle of the construction projects can improve their competencies. Therefore, there is a need to emphasise proper human resource planning to ensure adequate estimation, acquisition, and development of human resources during the lifecycle of megaprojects. From the research undertaken and reported in this paper, the authors contend that the competence of internal stakeholders of infrastructure projects is an antidote to contract disputes in infrastructure projects. The authors suggest undertaking of further case study research on the causation mechanisms of independent disputes to identify causal factors for specific disputes.

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EVALUATING THE PROCUREMENT DOCUMENTS OF DUTCH WATER BOARDS PORTFOLIO: A STEP TOWARDS MORE RELIABLE PUBLIC CLIENTS

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Although a considerable amount of literature has addressed the public procurement in the construction industry, still little is known about procurement in small and repetitive activities. In practice, however, public clients are often involved in repetitive tasks such as maintenance activities. Dutch water boards, regional governmental bodies responsible for providing water management services, are the focus of this study. For this research, three main procurement documents of the water boards were performed using content analysis. The aim is to evaluate these documents and to identify the typology of the repetitive activities and the procurement volume of these tasks from a portfolio perspective of the public client. Most of the contractors/suppliers involved in these activities are local Small and Medium-Sized Enterprises (SMEs). The findings of the study indicate that insights into the typologies of these repetitive works and their expected volume over time delivers crucial value for the public procurer. Given the amount of repetitive works procured by public clients, creating such an insight to both clients as well as contractors can ultimately increase efficiency and improve investment opportunities.

Keywords: public client; public procurement; repetitive works; water; portfolio

INTRODUCTION

Public clients in the construction industry usually have large portfolios with significant volume of public procurement which provides opportunities for improving their procurement processes. These opportunities might be missed since the focus is mainly on one-off projects and less priority is given to procurement of repetitive works. The current study evaluates the procurement document of Dutch water boards, using publicly available information and a portfolio document review of four water boards on outsourced projects and tasks. Dutch water boards (also known as regional water authorities) are decentralized and independent government organisations and currently, there are 21 water boards in the Netherlands. Within the scope of work of regional water boards three main programs can be recognized: water quantity (preventing droughts or water surpluses such as performing dredging); water quality (treating wastewater from households and businesses); and water safety (managing and maintaining primary and secondary flood defences such as dikes and locks). Since they are a governmental body, they finance their activities by collecting taxes

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from industries and households (de Graaf *et al.,* 2017). Together, the water boards have an annual budget of €2.9 billion and an investment budget of €1.6 billion in various water related projects (Unie van Waterschappen 2013). As a result, they are one of the main clients in the Dutch construction market (de Graaf *et al.,* 2017).

These repetitive activities in fact form most of the volume of construction work, this is especially the case for water boards in which around 80-90% of tasks are repetitive. These repetitive tasks are usually small and medium in size and are mostly executed by small and medium enterprises (SMEs). Surprisingly little research is available about the composition of these repetitive tasks in the portfolio of a public client organisation. Research on small scale projects and activities is scarce as well (Nase and Wong 2017).

The goal of the research is to evaluate the procurement data and to identify the repetitive activities from the portfolio of the water boards as a public client. This ultimately can contribute to more efficient procurement and execution of such activities by market parties. This research aims to address this question: to what extent do the available procurement documents of Dutch water boards help in identifying the repetitive tasks within their portfolio and the expected procurement volume of such tasks?

Public Procurement in the Netherlands

In general, Dutch procurement law is largely influenced by the European Union. Every government organisation must follow an appropriate tendering procedure for three categories of tasks (European Commission 2014): works; supplies; and services. To ensure the uniform application of a classification system, improve the transparency and efficiency in public procurement, the Common Procurement Vocabulary codes (CPV-codes) were developed by the European Commission. PIANOo is the Dutch primary public body responsible for professionalisation of procurement and tendering procedures in all government authorities (European Commission 2019). A list of the general categorisation of the CPV-codes is published by PIANOo. To facilitate eProcurement, Tenderned was developed which is the online marketplace for public procurement in the Netherlands. All the public contract notices above the EU limits are obliged to be published on Tenderned (European Commission 2019). Table 1 presents an overview of the number of contracts and procurement volume, for tasks above the threshold and below the threshold during the period between 2017 and 2019, according to the recent report of Team Significant Synergy (2021).

Table 1: Total estimated procurement of Dutch government, 2017-2019 (Team Significant Synergy 2021)

	2017		2018		2019	
	Number of contracts awarded	Procurement volume (in € billion)	Number of contracts awarded	Procurement volume (in € billion)	Number of contracts awarded	Procurement volume (in € billion)
Above the threshold sum	5,031	27.3	5,790	29,7	6,397	29.8
Below the threshold sum (estimated)	130,900	52	150,400	56,6	163,500	57,7
Total	135,900 *	79.3	156,200 *	86,3	169,900 *	86.5

* Rounded off to the nearest hundred

According to Table 1, the total procurement volume of the Dutch public authorities has increased gradually by 9.2%, from €79.3 billion in 2017 to €86.6 billion in 2019. The table also shows that the annual procurement volume of the contracts below the limit is nearly twice that of the contracts above the limit, suggesting the importance of small and medium tasks. Most of these relatively small contracts are awarded to small and medium-sized enterprises (Team Significant Synergy 2021). SMEs play a crucial role in the European economy because they represent around 99% of all businesses (Bakker *et al.,* 2011, CBS 2015).

Public Procurement in the Dutch Water Boards

With an estimated annual procurement volume of €2 billion, water boards play a crucial role in stimulating successful collaboration in the water construction sector (Team Significant Synergy 2021). The association of Dutch water boards is responsible for professionalisation of procurement and tender procedures of the water boards. Such professionalisation cannot be achieved by the European rules and regulation only, therefore additional policies are required, which are fitted to the specific context of the water boards (Unie van Waterschappen 2013). By doing this, the association of Dutch water boards contributes to the professional public commissioning role of water boards and ascertains uniform application of tender and procurement activities between water boards and other public authorities (Unie van Waterschappen 2013). In 2016, the market vision is established with the aim of facilitating and improving the collaboration between the water boards and market parties. Project calendar is developed by Economisch Instituut voor de Bouw (2021) with the aim of providing a multiannual overview of the projects within the water boards and ensuring a match between supply and demand. PIANOo (2016) also published a list of the categorisation of the CPV-codes which is specifically developed for the contracts within the water authorities. In this study, only CPV-codes for works and services are considered for further analysis.

Repetitive Works in the Portfolio of the Public Client Organisation

The focal point of this research is repetitive works in the portfolio of project-oriented organisations. Therefore, these three concepts are explained in this section: portfolio, repetitive works, and project-oriented organisations. In the project organizing literature, a project is defined as a temporary organisation with a beginning and an end, management process and sequence of tasks established to create a unique or customized product, service, or result (PMI 2021: 2). A program is a set of interrelated projects for achieving a specific goal, when this goal cannot be achieved by each project individually (PMI 2021: 2). A portfolio is a set of projects and programs which share scarce resources, managed to achieve the long term's strategic objective of an organisation (Winch 2009). Following these definitions, a project mostly involves performing tasks in a one-time situation that will not be repeated in future, however, in practice every project involves some degree of repetition (Engwall 2003). Repetitive projects seem to be an opposite of unique projects and some scholars address this distinction in their studies.

Every organisation might primarily be involved in performing repetitive or unique works (Lundin and Söderholm 1995). Davies and Brady (2016) reviewed literature that provide definitions for these two concepts, and they realized that various terms used for addressing these two categories of projects, for instance simple vs novel (Loch *et al.,* 2011) and repetitive vs first-of-its kind (Davies and Brady 2000). Shenhar and Dvir (2007) recognize that projects might be primarily "strategic" to enhance or maintain the firm's competitive position by creating new products, services and markets or they can be "operational" to maintain its current market by improving or extending its existing products and services. "Simple projects" involve predictable and repetitive works, whereas "novel projects" usually deal with uncertain and unforeseen situations (Loch *et al.,* 2011). In any organisation, a combination of repetitive and unique projects is managed in a project portfolio by adopting an explicit project management culture (Gareis and Huemann 2000). Delisle (2019) argued that portfolio, has a repetitive character since it is a continuous process and follows the existing procedures of the organisation.

Project-oriented organisations can be defined as an organisation that "perceives projects and programmes as temporary organisations for the performance of complex processes" (Gareis and Huemann 2000: 32). Arvidsson (2009) made a distinction between project-oriented and project-based organisation, in which the former has a permanent and stable structure and processes for generating revenues and time-based projects are the main source of costs. The focus of the project-based organisation is primarily on temporary endeavours and project dimension. In practice, however, he argued that organisations might combine these two repetitive and temporary structure in order to employ the benefits of both. A purchasing public owner organisation is considered primarily as a project-oriented organisation because projects are not its core business (Kay 1995). For such an organisation, projects are intended to extend their resource base and that is the reason they outsource projects to project-based firms for whom projects are their core business (Winch and Leiringer 2016).

Public client organisations are one of the crucial buyers (service or product) in the construction industry (Kadefors *et al.,* 2021). They are involved in a wide range of repetitive activities such as maintenance, renovation, activities related to sustainability or upgrading the assets. Usually, these repetitive projects are relatively small in terms of budget. This is also acknowledged by the study of Dunston and Reed (2000), in which four characteristics for small projects are considered: repetitive work; simple or uncomplicated construction process; renovations, remodelling or upgrades; total project costs less than US$1 million; and maintenance projects. Managing these small projects in the portfolio of the public client organisation is a crucial task of such organisations. As an example, nearly half of the projects of the water boards are small or medium in size with a total cost between 1 and 5 million Euro (Economisch Instituut voor de Bouw 2021).

In the current research, repetitive works are defined as the activities performed by the suppliers for the public client with a high-frequency in a certain period of time, such as performing certain type of task in different locations. The focus of the study is tasks in the portfolio and not per se projects. The reason is that every project consists of several inter-related tasks. These tasks might have different characteristics and therefore require various resources, but they contribute to achieving the project goal. Indeed, these tasks also have a temporary nature and can be considered as sub-projects. But in this research, the terms tasks or activities are used. In addition, in practice no separate projects are usually defined by the public client for performing these repetitive tasks, for instance reactive maintenance of installations at water pumping stations.

METHOD

In this research, a document review of the available water boards funded projects and their procurement data was conducted to answer the research question. The unit of analysis is the portfolio of the public client organisations. The aim is to get an insight into the whole portfolio of each water board, including small and medium scale tasks, projects, and contracts. Since there is no obligation to publish those small and medium size contracts below the EU limit on Tenderned (Nase and Wong 2017), this platform cannot be used for identifying such contracts. In order to achieve the goal of this study, three main documents were studied: (1) the multi-year budgeting program of each individual water boards; (2) the project calendar published by Economisch Instituut voor de Bouw (2021), (3) and the set of purchase orders of each of the water boards. As suggested by Winch and Cha (2020), a case survey study (Larsson 1993) is suitable for analysis of patterns across a large volume of textual data. Four steps were followed for data analysis in the current study. In the first step, based on the goal and context of research, the type of data needed was established. In step two, a preliminary data analysis was performed to gain an overall insight into the procurement data in each specific document. In step three, a set of exclusion and inclusion criteria was determined. In the last step, the codes, and categories of the relevant tasks in the documents were generated. These four steps, however, only were applied for the analysis of the purchase orders. For multi-year budgeting program of the water boards and project calendar, we stopped after step 2. The reason was that we could not find the required data in these documents. This is further explained in the results section.

Content analysis (Weber 1990) is used for identifying the typologies of the procured tasks and projects and their procurement volume. The approach for analysis is both inductive (Schreier 2012) and deductive (Armat *et al.,* 2018): the CPV-codes of PIANOo (2016) were used as the starting point for determining the typologies (deductive) and the codes and key typologies emerged from data (deductive). Based on the content analysis of the purchase orders of the four water boards, an overall quantitative analysis of typologies of repetitive tasks and their associated procurement volume were provided. In addition, an in-depth qualitative analysis of the description of the tasks per type of the repetitive tasks was also performed.

FINDINGS

The starting point for the document review was the multi-year budgeting program of six water boards. These documents usually are developed for the coming 3-5 years and are publicly available on the website of each water board. They give an insight into the type of projects per program and investment and operating budget of their projects. In these programs, however, the underlying expected tasks per project were not explicitly provided. This is specifically crucial, because usually projects are divided into sub-projects, and they are procured in more than one contract.

In the next step, the project calendar consisting of 608 projects was studied. This publicly accessible document gives an overview of the current and future projects in 2021 and 2022. Although various elements such as different types of projects, type of tender, and contract type per project are considered in this document, again there is no detailed information about the (expected) tasks per project.

In the last step, the portfolio document of four water boards were analysed. More water boards were approached to get the purchase orders of the organisation, however, extracting such information was not easily possible for some water boards. These documents are not publicly available, and they are only available via the internal financial system of the organisations. In this study, the purchase orders of four water boards in the past 3-4.5 years were received. The expenditure of all the outsourced tasks and projects are collected in this document. Unlike the previous two documents, the detailed information of the tasks per project or program is to a large extent given in the purchase orders. An overview of the attributes of the three procurement documents of the water boards is presented in Table 2.

Table 2: Overview of the three studied procurement resources for water boards

Criteria (attribute)	Multi-year budgeting program	Project Calendar	Purchase order of the water boards
Availability	Publicly available	Publicly available	Not publicly available
Forward-looking or backward-looking data	Forward-looking	Forward-and backward- looking	Backward-looking
Duration	Different per water board, usually for the next 3-5 years	Current or upcoming projects in 2021 and 2022	Available for any period of time (in this study the past 3-4.5 years)
Portfolio overview	Budget per project and per program	Expected contract price of 608 projects, type of tender and contract per project type	Expenditure of the outsourced projects and tasks with/without description of the contract
Distinguish between investment and operating budget	Provided	Not provided	This is explicitly mentioned in the purchase orders of only one water board
Overview of the underlying activities per project/program	Not provided	Not provided	To a large extent provided

Table 3 gives an overview of the attributes of the purchase orders of each studies water board in this study. From 405,249 purchase orders considered, 42,235 purchase orders with the total procurement volume of €399.1 million were relevant (based on the inclusion/exclusion criteria) for this research.

Table 3: General overview of the purchasing orders of four studied water boards

Attribute	Water board A	Water board B	Water board C	Water board D
Duration	3.5 years	3 years	4.5 year	4.5 years
Total number of purchase orders	18,032	81,291	225,046	80,880
Total number of unique tasks	243	180	170	247
Number of purchase orders relevant for this research	3,510	8,563	21,672	8,490
Procurement volume of the relevant purchase orders (in € million)	43.6	105.6	195.8	54.1
Number of unique tasks relevant for this research	29	21	18	40

The analysis of the purchase orders showed that different terms and concepts are used in these documents across various water boards. To make sure that similar data are analysed, the elements considered in purchase orders are compared across the water boards, summarized in Table 4. From this comparison, it can be concluded that some elements are to a large extent applied in a unified format, for instance coupling the purchase orders with CPV-codes. Some other elements, however, are not explicitly acknowledged by most of the water boards, for instance categorisation of the tasks below or above the EU thresholds is only considered in the purchase orders of one water board.

Table 4: Comparison of the elements in the purchase order of four water boards

Elements of the purchase order	Water board A	Water board B	Water board C	Water board D
Coupling with CPV-codes	+	+	+	×
Coupling with project	○	+	+	○
Coupling with program	○	○	+	○
Coupling with (ref. number of) contract	+	+ With many decoupled tasks	+ With many decoupled tasks	○
Distinguish between investment and operating budget	○	○	+	×
Distinguish between tasks above or below the threshold	○	○	+	○

○: Not provided; +: Provided; ×: not explicitly provided.

Using content analysis and based on the three main programs of the water boards and physical characteristics of the purchase orders, five main types of repetitive activities were identified: (1) activities (including maintenance) on waterways such as dredging; (2) mechanical and electrical works such as maintenance of water pumps and moving and rotating parts of water pumping stations; (3) innovation, building, and maintenance of water construction activities such as water pumping systems and locks for the navigation of water; (4) maintenance and placing installations in sewage treatment plants; and (5) civil construction works and maintenance of primary and secondary flood defences. Based on the analysis of purchase orders, the procurement volume per type of activities could be extracted which can be considered as the indication of the frequency of the performed tasks in these water boards.

Implications For Practice

The evaluation of the existing portfolio documents of the water boards shows that there is no explicit categorisation of the repetitive tasks and overview of their expected volume. Lack of such an insight would result in inefficiency of the budget allocation by the client and suboptimal allocation of the resources and capacities by the market parties. In other words, it leads to imbalance between the supply and demand. To provide such an insight at the portfolio level, three main implications for the public client organisations are discussed in the following.

Availability and Quality of the Procurement Data

During data collection, we have encountered some difficulties for getting the suitable procurement data of the water boards. It is important to make sure that such procurement data is available for public client, and it can be easily extracted. In addition, in the purchase orders, different elements with various interpretations are considered across the water boards. This makes it difficult to create a comparable and high-quality database across the organisations. Some potential subdivisions that can be considered in the procurement databases and can be valuable for practice and market parties are procurement volume below or above the EU limits, investment and maintenance activities, projects, and sub-projects (including tasks) per programs of the water boards, and procurement volume per type of repetitive tasks. Optimal clustering of the activities is one of the capabilities of public client (Winch and Leiringer 2016) and it could provide better and faster insights into the required capacity from the market. Furthermore, it contributes to more reliable and transparent requirements from a public organisation.

Unified approach over the procurement data at the portfolio level
The second implication is to provide a unified approach across the water boards. The analysis showed that the way in which procurement data is stored and handled is different across the water boards. As a result, there is no well-founded insight at the management level into the type of repetitive activities and their expected procurement volume. One possible reason is that procurement data are not consistent across the organisations. Comparable databases can also be used as a basis for knowledge sharing regarding the tender and procurement procedures across the water boards and even other public organisations. Given the large volume of the purchase orders and their fragmentation, it is difficult to create a clear and structured overview of the procurement volume, contract type, and the contractors that preform these tasks on a regular basis for the public client organisation.

Such clear overview is required to direct and stimulate the innovation by market parties which is vital for a public client (Kattel and Mazzucato 2018). This is also in line with the recent attention of the government for facilitating opportunities for SMEs to implement innovation and promoting innovation-oriented procurement (Ministry of Economic Affairs and Climate Policy 2021).

A forward- and backward-looking insight into the repetitive activities and their expected procurement volume
Finally, the study showed that the two important procurement documents of the water boards are created at different levels: the multi-year budgeting of each water board gives a high-level overview of the estimated budget per project and per program, whereas purchase orders provide a detailed insight into the procured and executed tasks. In addition, these two insights on the estimated and executed tasks are not linked with each other. To provide a sound basis for estimating the volume of the repetitive tasks both forward- and backward-looking insights by the public organisations for market parties are required. In addition, most of the tasks and sub-projects are performed by SMEs, which highlights the importance of detailed view for the market. The data on the executed tasks are updated regularly, it is therefore suggested that the procurement data are evaluated systematically to provide a holistic and detailed insight into the procured tasks.

CONCLUSIONS

Most of the tasks within the portfolio of the public clients in the construction industry have a repetitive character rather than unique nature. These repetitive tasks, however, are often overlooked in research. The first step for the clients is to identify the typology of the repetitive tasks and their expected volume over time. In this study, three available procurement documents of the Dutch water boards were reviewed. The findings showed that there is a lack of clear understanding on the nature of those repetitive tasks and their expected procurement volume at the portfolio level of the water boards. Based on the findings, five main types of repetitive activities were distinguished. In addition, based on the historical procurement data, the procurement volume of these repetitive tasks can be identified. The research contributes to the project organizing research by providing insights into the repetitive works in the portfolio of a public client organisation. From the practical point of view, the research suggested three main implications for public clients: availability and quality of the procurement data, unified approach over the procurement data at the portfolio level, and a combined forward-and backward-looking insight into the repetitive activities and their expected procurement volume. This study indicates the importance of the insights into repetitive tasks (and mostly small tasks) and their procurement for public clients and contractors to increase efficiency. Since research on project governance also tends to focus mainly on large, mega, and one-off projects, there is a need to take a wider view reflecting what is happening in practice. Further research is required to explore how collaboration between the public and private parties is facilitated in these repetitive tasks and how different clustering of the tasks and contract types can affect collaboration in such tasks.

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ESTABLISHING THE COST AND TIME PERFORMANCES OF PROJECTS EXECUTED BY SOUTH AFRICAN CONSTRUCTION COMPANIES USING DIFFERENT PAYMENT SYSTEMS

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The poor performance of construction projects and organisations is a global phenomenon. Inappropriate payment systems often impact the successful delivery of projects to client requirements and dispute avoidance. This study investigates the different payment systems employed and the performance of construction projects in South Africa. The study used a quantitative research approach employing questionnaires randomly distributed to construction companies. The researchers analysed eighty-eight projects comprising heavy construction, building maintenance, and commercial, industrial, institutional, and residential buildings. The study found that thirty-seven projects have cost underrun, with the highway maintenance project having the highest percentage of cost underrun using the interim project payment system. Based on these findings, the study concludes that heavy construction and commercial building projects executed using an interim payment system and payment on completion will experience underrun. Therefore, it is recommended that clients consider the project type in their choice of the payment systems.

Keywords: cost performance, payment systems, time performance, South Africa

INTRODUCTION

Clients expect that the construction project is finished at a specific estimated cost that is within budget and on time (Windapo *et al.,* 2017). However, this has not been the case. The poor performance of construction projects has been recognised internationally (Kazimu, 2012). Project success is a critical obstacle to the construction industry's performance (Danuri *et al.,* 2006). Oke *et al.,* (2016) established that construction projects are faced with numerous simple to complex difficulties ranging from late payments to litigation. One of the significant factors answerable for this is inappropriate payment system. Moreover, an inappropriate payment system has been cited as contributing to global failed projects (Kenley, 2003).

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While Sherif and Kaka (2003) indicated that achieving an excellent financial performance of any construction project depends on the appropriateness of the chosen payment system to the project qualities and client requirements, Suhaini (2005) viewed inadequate payment systems as a severe problem that needs to be identified and solved. Njie *et al.,* (2005) submit that when there is insufficient money to continue with construction project activities as planned, it results in mistrust amid supply chain teams and leads to a reduction in project performance in all ramifications. Furthermore, according to Danuri *et al.,* (2006), payment has always been the main subject of disputes, which leads to financial adversity if these disputes result in arbitration or litigation (Bob, 2005). Davis and Seah (2000) note that construction payment problems have a domino effect on the payment chain of a construction project. When delays occur in the payment of a contractor from the client, such delay affects the payment due to the subcontractor or supplier bound in a contract with the construction company.

The difficulties with the flow of cash down the chain of beneficiaries have been acknowledged as early as the 1960s in the UK when the Banwell report (1964) noted the significance of prompt payments and the call for a practice to have the proper flow of money, after that, followed by the Latham (1994) and Egan (1998) reports. Previous studies have revealed that many countries, including Malaysia, Australia, New Zealand, Singapore, and the United Kingdom, have included payment systems in the construction industry as part of their construction-specific constitutional policy of payment procedures/legislation arrangement to purge inadequate payment systems and to support continuous construction project activities (Danuri *et al.,* 2006). In South Africa, the cidb recommends modification to the policy that inculcates prerequisite for "prompt payment" (CIBD, 2012).

This underscores the importance of payment system on project cost and time performances. However, none of the previous studies has holistically examined the reliant effect of project payment system on cost and time performance. Construction companies must comprehend their choice of project payment systems that suit and are appropriate to business and project environments. Thus, this study aims to establish the cost and time performances of projects executed by South African construction companies using different payment systems.

The interim or progress payment system is the most used payment method in the contract condition (Ansah, 2011). Interim payment system serves as payment terms that aim to speed up the completion of a detailed contract section on the condition that the contractor has incentives for goal achievement on or before a specified date (Omopariola and Windapo, 2018b). Interim payments are suitable for functional elements of larger projects such as ramps, intersections, or bridges, structural and reinforcement steel, retaining walls, and materials to a site such as excavation and backfill, concrete and asphalt (Maritz and Robertson, 2012). The features that made the interim payment system suitable for the construction project environment include consideration of limiting factors in decision making and project activities about the functional elements of larger projects in terms of project environment (Omopariola and Windapo, 2018a). Previous researchers (see Gary *et al.,* 2010) have shown that an interim payment system allows the overall project schedule to be maintained in cases where there are sequential contracts, supports proactive and creative approaches by contractors and strives to complete the project on time, enhances safety and assist in the reduction of the amount of administrative requirement by the parties involved. Though it has its related drawback and risks, as identified by Gary *et al.,* (2010), an increase in costs due to accelerated construction requires innovative methods and materials and more work hours.

Advance payment system, stage payment system, milestone payment system, and payment on completion are the other payment systems that have been mentioned in the literature. Kaka and Lewis (2003) refer to advance payment as the amount of money remunerated to the contractor by the employer at the early start of work on site. This is done to aid the contractor in commencing the work when due and fund the contract without having to look externally for funds. Ansah (2011) posited that this payment system is mostly used in public works projects. Aje *et al.,* (2017) depict advance payment as a strategy to lower projects' outturn costs. According to Omopariola and Windapo (2018b) stage payment system reduces administration time and cost of design and preparing interim payments, allowing the reliable project stakeholder to embark on productive project performance.

Milestone has been described as payment made to the contractor upon attaining different construction activities or after all work items have been effectively completed (Cheng *et al.,* 2009). Cheng *et al.,* (2009) note that the flexibility of milestone payment is open for abuse if it is not administered correctly. From the contractors' point of view in the work of Olatunji *et al.,* (2017), payment on completion is the preferred choice for settlement of payment for work carried out, but this is done in exceptional cases where the contract is based on drawing and specification, i.e., where the project is relatively small and to be executed within the range of client’s financial budget to pay without stress at once. Payment on completion as a type of payment could lead to poor financial, practical, productivity, managerial efficiency, profitability, and not meeting client and employee satisfaction because the contractor is solely responsible for funding the project and unless the phase is attained and certified by the contract administrator before the contractor can be remunerated.

METHOD

A questionnaire survey was conducted to collect quantitative data for this study. The questionnaire survey was internet-based due to the geographical location of the construction companies comprised in the study (Saunders *et al.,* 2009). Before the questionnaire survey, the complete list of the construction contractors with their full contact details was requested and obtained from the construction industry development board (cidb) head office. In this list, only grade 7, 8, and 9 (high level of viability) contractors were selected for the study. This was done because of the need for credible and verifiable financial information.

The criteria for verifying the financial credibility of the contractors include the availability of financial statements, stamped business bank statements, proof of financial sponsorship, audited financial statements, financial track records, financial history, the financial capability of R40million and above, annual turnover of R20million and above, work capability of R9million and above, and available capital of R4million and above. Next, an invitation letter was sent to the targeted contractors' contact details in the selected regions to inform them of the questionnaire link and to participate as they received the email invitation, expecting a higher response percentage. The chosen proportional size was based on non-response bias using a calculating smallest sample size method (Ankrah, 2007).

Though, there were problems with low response rates when collecting data through online surveys, as posited by (Archer, 2008). However, the enormous benefits of web-based surveys cannot be underestimated. For instance, it strengthens the investigative knowledge of either the researcher or the respondents, simplifies the administration of questionnaires together with reminders, wider accessibility of survey strategy and design, and application tool, not expensive and established features that make data cleaning easier (Boyer *et al.,* 2010). Therefore, this study used an online survey (Survey Monkey: www.surveymonkey.com) to collect data for the research. At the end of the survey, a total of 155 respondents out of 216 respondents completed the questionnaire survey, which is a response rate of 71.76%. The data collected were analysed using the Chi-Square test.

FINDINGS

Frequency distribution and percentage of the respondents were determined to determine the distribution of the respondents' profiles. The distribution includes the educational background of the respondents, designation of respondents, the profession of the respondents, and years of experience. Concerning the educational background of the respondents, 55.15% (75) of the respondents have a bachelor's degree, 24.26% (33) have a higher diploma, 16.18% (22) have a diploma with Grade 12, and 5.88% (8) have N4-6/NTC 4-6 Certificate. Table 1 revealed that respondents in the Director Cadre accounted for 67.63% (94) of the response rate. Respondents closely follow this in the Management Cadre, which accounted for 26.62% (37) of the response rate. Only 2.88% (4) of the respondents are Technical Officers. About the profession of the respondents, construction managers accounted for 40.58% (56), Engineers accounted for 23.91% (33), Quantity Surveyors accounted for 12.32% (17), and Architects accounted for 1.45% (2) of the total respondents. Regarding the year of experience of respondents, 42.03% (58) of the respondents have gathered 1-29years of working experience, 36.23% (50) have gathered 30-49 years of working experience, and 25.36% (35) have gathered 50-69 years of working experience. This result suggests that the respondents possess the knowledge, qualifications, and experience to understand the questions raised in the questionnaire and provide useful information.

Analysis of the characteristics of projects executed by construction companies using different payment systems in the last five years was carried out and presented in Table 1. These include the client for the project procurement method used for the project, conditions of contract for the project, and payment systems for the project. Questions such as 'kindly specify the project type (e.g., Residential, Building, Institutional, Commercial, Industrial, Specialised industrial, Highway, and Heavy Construction Project) and indicate the estimated cost, final cost, construction start date, estimated duration, and final duration for the specified projects' were used to elicit this information. As concerns the clients for the projects executed by the construction organisations, the results show that the local government-owned 51.85% (70) of those projects, 32.59% (44) by private clients, and 24.44% (33) by the national government. More than half of these projects, 68.38% (93), were executed under the traditional procurement method, while 17.65% (24) and 16.91% (23) were executed under the management procurement method and integrated (design and build) procurement method.

The general condition of the contract was found to be the most common (50.75%:68) conditions of contract used for the projects executed by the construction organisations. This is closely followed by the Joint Building Contract Committee (41.04%:55), New

Engineering Contract (19.40%:26), and International Federation of Consulting Engineers (11.19%:15). The most significant number (77.04%:104) of these projects were executed using an interim payment system. This is closely followed by payment on completion (14.81%:20), milestone payment system (11.85%:16), stage payment system (9.63%:13), and advance payment system (8.15%:11). This result suggests that the projects will provide relevant and practical information for this research. Eighty-eight (88) projects were analysed for cost and time performance. Seventeen of these projects are heavy construction projects, 20 are commercial buildings, four are industrial buildings, 12 are residential buildings, 13 are highway projects, two are specialised industrial projects, six are building maintenance projects, and 14 are institutional buildings.

Altogether, 37 projects were found to have costs underrun. The highway maintenance project had the highest percentage of cost underrun (20% cost underrun). The commercial building project had the highest cost overrun percentage (140% cost overrun). The project with the lowest percentage of cost overrun is a residential building project (1.25%), while 21 projects were found to have zero per cent cost overrun. The project with the highest percentage of time underrun was heavy construction project (33.33%) and commercial building project (33.33%). Heavy construction projects had the highest percentage of time overrun (300%). In total, 45 projects were found to have had time overrun. Concerning the project with the least percentage of time overrun highway construction was found to have 0.08% time overrun. Table 2 analyses these projects' cost and time performance regarding the payment systems utilised. The cost and time performance of these projects were assessed using time overrun and underrun as well as cost overrun and underrun. Information such as project type, estimated cost, final cost, construction start date, estimated duration, final duration, and payment system used were elicited from the respondents.

As explained in Table 2, 37 projects with a cost overrun and 13 projects with cost underrun were executed using an interim project payment system. Thirty-eight projects with time overrun and two projects with time underrun were executed using an interim payment system. This made the interim payment system have the highest number of projects with cost and time overruns. Interestingly, the interim payment system also has the highest number of projects with cost and time underrun. This indicates that the interim payment system could be the most popular in South Africa or effective with characteristics that are useful in specific projects. Table 2 revealed that the advance payment system has the least number of projects with a cost overrun (two) and underrun (zero). Payment on completion closely followed the interim payment system, with six projects having cost overruns. In contrast, milestone payment has the highest number of projects (six) after the interim payment system with time overrun.

These results imply that it is difficult to determine the impacts of payment systems on project cost and time performance because clients favour only the use of interim payment systems. The results suggest that payment systems affect project cost and time performance because using an interim payment system was evident in projects with cost and time overruns and underrun. The results also suggest that the choice of interim payment system must be determined based on the expectations of clients on cost and time performance as well as the type of projects. Heavy construction projects show compatibility with the use of an interim payment system. This further confirms that project type must determine the choice of the payment system.

A chi-square test of independence was performed to examine if there are significant differences in project cost and time performance due to different payment systems used. The results in Table 2 show that the differences in project cost and time performance due to the usage of different payment systems were insignificant [x2 (DF=2, N=88) =5.893, p>0.05]. The Chi-square statistic is 5.893. The p-value is 0.921. The result is not significant at p<0.05.

Table 1: characteristics of projects executed by construction companies using different payment systems

Answer Choices	Response Percent	Responses
Clients for the project		
Local Government	51.85%	70
Private	32.59%	44
National Government	24.44%	33
Procurement method used for the project		
Traditional	68.38%	93
Management	17.65%	24
Design and Build/Integrated	16.91%	23
Conditions of contract for the project		
GCC - (General Conditions of Contract)	50.75%	68
JBCC - (Joint Building Contract Committee)	41.04%	55
NEC - (New Engineering Contract)	19.4%	26
FIDIC - (International Federation of Consulting Engineers)	11.19%	15
Payment systems for the project		
Interim/Progress Payment	77.04%	104
Payment on Completion	14.81%	20
Milestone Payment	11.85%	16
Stage Payment	9.63%	13
Advance Payment	8.15%	11

Table 2: Significant differences in the cost and time performance of projects as a result of different payment systems used

Payment system used	Number of projects with a cost overrun	Number of projects with cost underrun	Number of projects with time overrun	Number of projects with time underrun
Interim/Progress Payment	37	13	38	2
Payment on Completion	6	2	4	1
Milestone Payment	5	2	6	0
Stage Payment	3	0	2	0
Advance Payment	2	0	2	1
Chi-square value: 5.893				
p-value: 0.921				

To investigate the cost and time performance of projects executed by construction organisations using different payment systems, the respondents were requested to identify familiar construction projects undertaken by their organisations in the last five years. The respondents used the details of these familiar construction projects to indicate the project client, procurement method used for the projects, the project type, standard condition of contract used for the projects, form of project payment used for the projects, estimated and final cost for the projects, as well as estimated and final duration for the projects. This information was used to determine these projects' percentage cost overrun, percentage cost underrun, percentage time overrun, and percentage time underrun. This was in line with the argument by Nguyen *et al.,* (2004) that a construction project succeeds when executed within budgetary cost and time schedule.

The results in the Tables reveal that clients prefer interim payment systems, making it difficult to determine the impact of different payment systems on project cost and time performance. Ansah (2011) concurred that the interim payment system is the most popular payment system employed by clients. This finding only provides insight into the impact of the only interim payment system on project cost and time performance. The information on other project payment systems was insufficient to provide the basis for comparing the impact of interim payment systems and other types of project payment systems on project performance. Projects with overruns and underrun of time and cost were found to be executed using an interim payment system. This corresponds with the conclusion by Adjei, *et al.,* (2018) and Gary *et al.,* (2010), which revealed that cost and time overrun are highly associated with the use of an interim payment system.

It must be noted that time and cost overruns are unavoidable for a specific type of construction project due to their complexities and variations. Therefore, the occurrence of time and cost overruns on projects where the interim payment system was used cannot be entirely attributed to the impact of the interim payment system on these projects. Likewise, time and cost underrun of projects could result from other project success factors. Therefore, it will be erroneous to conclude that the interim payment system was solely responsible for the time and cost underrun of these projects. Project performance or success is broader than the determination of time and cost underrun for projects. Hence, the time and cost underrun of projects executed using an interim payment system is not a reasonable basis for concluding the success of these projects.

CONCLUSIONS

A valid observation from the findings implies that project type and expectations must determine the choice of the payment system. This indicates that project expectations must measure project performance and must be based on project type. Following this strategy, it will be easier to base the choice of the interim payment system on the project type and evaluate its impact on project performance. It is important to note that the use of an interim payment system by clients puts pressure on construction organisations to complete projects within the estimated time and cost because if the construction organisations renege on the contract conditions, the clients will not complete the payment.

The finding of this study is important because it provides information on the importance of project payment systems to project performance. It also provides insights into assessing the impacts of project payment systems on project performance. This seems to be the only logical explanation for an interim payment system's impact on the improved time and cost performance of construction projects.

The limitation of this study is that the accuracy of the scheduling and costing processes used by the respondents were not ascertained, and these may contribute to the over / under run for both time and cost on a project. Also, this study did not consider the impacts of poor scheduling, inaccuracy in cost determination on cost, Key Performance Indicators, and project management systems on time and cost over/underrun of projects. Future studies on the impact of project payment systems on project performance should be tailored towards the characteristics of different project payment systems. This should be linked to the project expectations and characteristics. This will provide insights into matching project payment systems with different projects.

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CAN PROFESSIONALISM MAKE CONTRACT DISPUTES IN INFRASTRUCTURE PROJECTS DISAPPEAR?

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Despite general resignation that occurrence of disputes in construction projects is inevitable, it is possible to avoid or prevent them. That, however, requires anticipation and prediction of the series of events that might lead up to disputes and yet there is a general paucity of such information. The research reported in this paper sought to contribute to a better understanding of dispute-emergence mechanisms by exploring the series of factors that foster emergence of disputes in large infrastructure projects. To achieve that, a single case study methodology was adopted, focusing on a major dispute encountered in a large infrastructure project. Secondary qualitative data were collected and analysed using thematic analysis. This research highlights that a deficiency in professionalism facilitates dispute-emergence and highlights the need for upskilling construction industry professionals in the development and administration of construction contracts.

Keywords: contracts; disputes; professionalism; infrastructure

INTRODUCTION

It is a widely accepted view that the occurrence of disputes in construction projects is inevitable, more so in complex projects (Cheung and Yiu 2006; Hardjomuljadi 2020). These disputes are generally detrimental to a project as they usually affect the realisation of the project's main objectives (Fenn 2007). Seeds of dispute are sown the moment any one of the parties involved in a project feels dissatisfied (Rowlinson 2019), and the common causes of construction disputes include poor contract administration, ambiguous contracts, failure to meet contractual obligations, unrealistic allocation of risk, employer-imposed changes, unrealistic expectations, among others (Semple *et al.,* 1994; Allen 2011; Viswanathan *et al.,* 2020).

Despite their perceived inevitability and known detrimental effects, construction disputes, fortunately, can be managed by, preferably, entirely avoiding them or at least minimising their negative effects. To accomplish that, it is important to understand the events and conditions that cause the disputes and be able to anticipate and predict their occurrence (Fenn 2007; Tanriverdi *et al.,* 2021). Early prediction would make dispute avoidance more achievable although it would require a good understanding of the various factors along the trail of events and conditions leading up to a dispute-not

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just its immediate causes, as is usually the focus. That being the case, the aim of this paper/study is to provide a better understanding of dispute-emergence mechanisms by exploring the series of factors that foster the emergence of disputes in a large infrastructure project.

Disputes and Conflicts

Disputes on projects are generally undesirable as they drain critical resources away from the main objective i.e., completion of the project on time, on budget, and to the required standard (Fenn 2007). They are also often expensive and time-consuming to resolve - severely hindering the realisation of value-for-money - with the added effect of damaging stakeholder relationships, that are not always easy to build or mend (Fenn 2007).

As observed by Fenn *et al.,* (1997), disputes and conflicts are taken to be the same by some authors whereas others acknowledge the conceptual differences between them (conflicts and disputes). Conflict is defined by Gardiner and Simmons (1992) as "any divergence of interests, objectives or priorities between individuals, groups, or organisations; or nonconformance to requirements of a task, activity or process" and Fenn *et al.,* (1997) also asserts that conflict is universal and exists wherever interests are incompatible.

Reid and Ellis (2007) argue that there is no single definition for a dispute as it is a subjective issue that requires a common-sense approach based on facts, law, and consideration of policy. FIDIC (2017), however, indicates that a dispute arises when a claim is wholly or partially rejected by the other party, or if there is disagreement on the determination made regarding any claim. Much as the specific definitions of a dispute vary in literature, it seems that they all revolve around the idea of a disagreement between parties which requires extra effort and resources to resolve. Comparably, in this paper, a dispute is considered to arise when a determination made on a claim/assertion raised by one party, with respect to the performance of the contract, is invariably and formally rejected by the other party. A claim, in this case, is considered to be a request by any party for an entitlement they deem to be due to them under the contract.

Manifestation of disputes

Disputes in construction projects can arise from several sources as revealed by the different studies conducted on the subject. Common among the sources and causes of disputes covered in the literature are poor contracts, poor contract administration, changes in project scope, technical ineptitude of key stakeholders, opportunistic behaviour, among others (Semple *et al.,* 1994; Kumaraswamy 1997; Fenn *et al.,* 1997; Cheung and Yiu 2006; Allen 2011; Arcadis 2015; Viswanathan *et al.,* 2020; Arcadis 2021). Most of these studies on the manifestation of disputes, unfortunately, ignore the relationships that exist between the different factors that lead to disputes and mostly present them as independent variables. Love *et al.,* (2010), however, uses causal modelling to try to determine the underlying dynamics that influence disputes and asserts that a dispute cannot be attributed to a single variable.

The preceding paragraph alludes to the reality that the corpus on the manifestation of disputes in construction projects is vast, mostly pointing out and focusing on the various immediate sources and proximate triggers of disputes. So, what about the triggers of those triggers? - the root causes of disputes? How far back along the chain of events preceding a dispute's immediate source or trigger does the dispute have its roots? There is a paucity of research answering these questions and, therefore, this study seeks to fill that gap by looking into the series of factors that foster the emergence of disputes in large infrastructure projects. It would also seem that the averment in Fenn *et al.,* (1997), echoed in Love *et al.,* (2010), that there is not much empirical evidence to back up the various theories presented regarding the causation of disputes, still holds true to this day. Tracing and mapping the roots of a dispute will enable the identification of various intervention points to halt the progress of the dispute's mechanism, effectively preventing the dispute. Much like removing a domino would stop a "domino effect", removing a factor(s) from a series of factors known to cause a dispute should stop, or at least delay, the dispute's emergence.

METHOD

The research was a cross-sectional qualitative study that adopted a single case study strategy and an interpretivist philosophy. This philosophy is subjectivist and generates descriptive theory to provide new and deeper understanding/interpretation of particular or categorical phenomena and contexts (Hallebone and Priest 2009; Saunders *et al.,* 2016). A single case study was selected due to the need to focus on and understand a specific dispute in a particular large infrastructure project to map its mechanism of emergence. A case study allows for a detailed investigation of a topic or phenomenon in its natural setting (Yin 2014).

The case study selected was a debt-financed public sector infrastructure project in a developing country that cost over 500 million US Dollars. It involved multinational stakeholders and was implemented under an EPC (Engineering, Procurement and Construction) contract and a Principal-Agent governance approach involving the Employer-composed of the responsible Government Ministry and a State-owned Implementing Agency; the Project Manager-appointed as the Employer's representative; the EPC Contractor-procured to design and construct the project. The case study was representative of the large infrastructure projects undertaken in the country, from its international stakeholders, procurement system and financing, to the governance approach used.

The study principally relied on secondary data obtained from a collection of 118 project letters, 13 progress reports, 7 expert review reports, 8 contract documents, and 5 sets of minutes of meetings, adding up to over 5,500 pages. The selection of the relevant documents was purposive, focusing on a high-value high-impact dispute identified by the Employer (client organisation). All data on the chosen dispute were acquired through reference-tracking to retrieve all available and accessible documents.

The data collected were analysed through reflexive thematic analysis, it being a flexible method suitable for analysing large qualitative datasets (Nowell *et al.,* 2017; Saunders *et al.,* 2016). This was justified by the fact that the study was characterised by large qualitative datasets. The thematic analysis involved familiarisation with data collected by reading, annotating and creating memos. The data were then coded to group data with similar meanings, followed by identifying emerging themes (dispute causes/factors) and relationships among the codes and then refining the themes identified. All this was organised in and facilitated by NVivo (Release 1.6.2), a computer-aided qualitative data analysis software (CAQDAS). Due to ethical considerations, all data are presented anonymously in this study.

FINDINGS

The Dispute

22 months after the case study project's takeover by the Employer, a dispute arose over the Project Manager's determination to extend the project's defects liability period (DLP) by 12 months, following the Employer's claim for a 24-month extension. As per the project's contract, a dispute was deemed to arise when the Employer or Contractor raised a notice of dissatisfaction with the Project Manager's determination on a claim raised by either party. In this case, the Employer and Contractor both expressed dissatisfaction with the determination. The dispute was eventually resolved (over 2 months later) through high-level negotiations, with the parties agreeing to a 12-month extension of the DLP. The impact of the dispute included the time lost while resolving it, the corresponding transactional costs and the strained relationship between the parties.

The analysis revealed 3 immediate causes of the dispute: differences in contract interpretation; delays in completing works (presented as the main reason for the Employer's claim); and unfitness-for-purpose of the facility. Figure 1 below illustrates the mechanism of the dispute, showing the different series of factors that led to the emergence of the dispute.

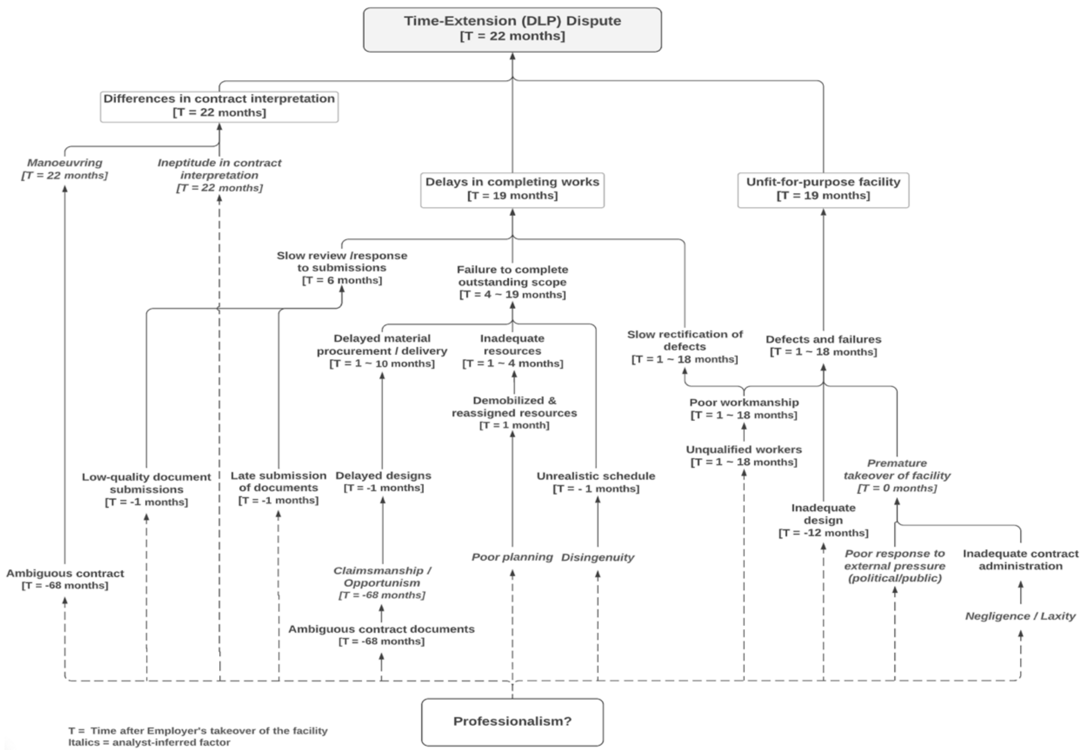

Figure 1: Mechanism of dispute-emergence

Differences in contract interpretation

The DLP extension was deemed to be a dispute as soon as the Employer and Contractor formally notified the Project Manager of their dissatisfaction with the determination on the Employer's claim. Their dissatisfaction was based on varying interpretations of the contract to defend the different views they held. For instance, the Contractor argued that, by issuing the claim notice after the 6-month deadline set for completing the outstanding works at the time of project takeover, the Employer did not do so "as soon as practicable", and the claim was, therefore, not valid. In fact, much as the contract specified that notices for claims by the Contractor should be issued "as soon as practicable, and not later than 28 days after the Contractor became aware, or should have become aware, of the event or circumstance giving rise to the claim", no such cut-off for "as soon as practicable" was explicitly placed on claims raised by the Employer-except that a claim notice for extension of the DLP should be before expiry of the DLP, which was so in this case. The contract, in that respect, was not explicit enough to preclude misinterpretation. The Contractor's selective interpretation, nonetheless, can be put down to manoeuvring or ineptitude in contract interpretation. Clegg (1992) does maintain that contractual documents are usually problematic and ambiguous because they always need to be interpreted, and yet their interpretation is never free from bias or the influence of interests and the limitation of knowledge of the party interpreting them.

Delays in completing works

As a condition for issuing of the taking-over certificate, the parties agreed that the documented outstanding works-that were deemed to be minor at that time-would be completed within the following 6 months, as per the schedule proposed by the Contractor. Consequently, those works would have at least 18 months of the 24-month DLP that commenced after takeover. Unfortunately, the Contractor did not meet that deadline. The Employer's claim for the extension of the DLP was on account of the Contractor's failure to complete the outstanding scope works within the 6-month schedule, as well as the anticipated failure of the Contractor to complete all pending works (including rectifying defects) by the expiry of the DLP. The outstanding works included items such as submission of complete/approved contractor's documents (O&M manuals, as-built drawings etc.), (re)commissioning of critical systems etc. The extension was sought to enable the completion of all outstanding works and provide adequate time for observing those works and rectifying all defects that would arise in that period.

The failure to meet the deadline, for some components, was attributed to delayed procurement/delivery of materials (most of which had long lead times); inadequate resources due to a reduction in the Contractor's workforce as key technical personnel (and equipment) were demobilised/reassigned in the months immediately after the project's takeover-all of which affected the Contractor's capacity to execute the works. The Contractor, however, later expressed that the 6-month deadline to complete the outstanding scope of works was unrealistic and "not practically reasonable in view of the facts on ground".

The procurement/delivery of materials was delayed predominantly due to the delayed design of some components. The designing of some critical facilities was started as late as 3 months into the DLP. This delay in design was a result of inadequate/ambiguous contract documents which were not explicit about the need for some components during the preparation phase of the project. The ambiguity enabled the Contractor's misinterpretation of the contract as not including those components, thus their omission from the Contractor's plans. The ensuing delays in procurement/delivery of materials, as well as re-mobilisation of personnel (sub-contractors/manufacturers) for the outstanding works, were also attributed to an 8-month travel restriction imposed due to a force majeure event.

Regarding the Contractor's documents, delays were partly due to the low-quality work (failing to meet the Employer's approval requirements), which necessitated several cycles of review and resubmission. The absence of these documents consequently delayed the (re)commissioning of their corresponding systems-for which they were a prerequisite. The delays in completing the documents were also due to the Project Manager's very slow review and response to the Contractor's submissions-exceeding the 21-day timeline prescribed by the contract-with some responses/comments being provided up to 6 months late. This was partly ascribed to and compounded by the Contractor's last-minute bulk submission of documents for the Project Manager's review.

There were also delays in rectifying defects which were ascribed to poor workmanship, often meaning that repairs were ineffective, leading to persistence or recurrence of defects. The poor workmanship was due to the Contractor using unqualified semi-skilled workers to execute specialised tasks e.g., concrete treatment. Delays in defects rectification were also due to the numerous defects overwhelming the limited number of personnel available to address them. The closeout of some defects was also partly delayed by the absence of the Project Manager's experts who were meant to witness the recommissioning of some systems and satisfy themselves that the remedies applied were adequate. This was a result of poor coordination between the Project Manager and the Contractor, as well as the travel restrictions caused by the earlier-mentioned force majeure event.

Unfit-for-purpose facility
On top of the incomplete works, defects/failures emerged in some of the facility's major systems/components which rendered them-and, according to the Employer, the entire facility by extension-unfit to serve their intended purpose, thus necessitating their modification or replacement. This was pinned mainly on inadequate designs that did not consider some important factors/conditions. The modified or replacement systems/components would, therefore, need recommissioning and additional time for observation i.e., a DLP extension. The allegations of unfitness-for-purpose were vehemently contested by the Contractor.

In their defence, the Contractor pointed out that the facility was being used by the Employer and was, therefore, fit for its intended purpose. They added that the emergence of defects was expected and covered under the contract through the DLP provision as well as other safeguards like retention money and performance guarantees. Indeed, the emergence of defects alone may not get a project branded unfit-for-purpose provided the functionality requirements prescribed in the contract are met consistently. In this case, however, the Employer's intention, as per the contract, was "to develop, construct, commission, and operate the project, including all auxiliary structures and necessary equipment, in such a manner as to ensure their safe and efficient operation with at least 97% availability throughout their operating life". Since, due to the breakdown of systems and emergence of defects the facility did not consistently meet the 97% availability criterion, it was, technically, unfit-for-purpose by that standard. Yet, if the emergence of defects is expected, and their rectification-as is the Contractor's obligation during the DLP-may require the affected systems to be temporarily unavailable, would it not be paradoxical to always hold the contractor to such a high standard/criterion of availability during the DLP? Perhaps not, since the Employer's expectation was that defects after takeover would be "minor".

Considering the frequent reports of incomplete works and numerous defects (new and recurrent) throughout the DLP-which was meant for notification and rectification of defects identified after takeover-it is safe to infer that the project was taken over by the Employer prematurely. The contract prescribed completion of the facility ("except for any minor outstanding work and defects which will not substantially affect the use of the facility for their intended purpose") as a precondition for taking over. The Employer and Project Manager's consistent subsequent complaints during the DLP that works critical to the operation of the facility were not completed, indicate that the precondition was not met. This deviation from contract guidelines in issuing the taking-over certificate is a demonstration of inadequate contract administration. Cognisant (or not) of the incompleteness of critical works and the project's lack of substantial completion, the Project Manager's recommendation for the Employer to take over the facility can be construed as a breach of the duty of skill and care-negligence.

This, in turn, may be an indication of incompetence-in this case, the Project Manager's possible lack of appreciation of their decisions' wider implications on the performance of the project. To a lesser extent, the upheld deviations from contract guidelines also indicate laxity among the Employer's project management team, who, being expected to be familiar with the contract, should otherwise have identified and addressed the Project Manager's shortcomings. On the other hand, the project, being publicly funded and one of the country's flagship infrastructure undertakings-featuring prominently in its strategic plans-attracted significant political and general public interest. The resulting political and public pressure to swiftly commence operation of the facility (to start revenue generation and loan repayment) may have influenced the project management team's decision to make compromises in recommending takeover by classifying the outstanding works as minor and inconsequential to the basic functionality of the facility-hence the premature takeover. Reflexively considering all the afore-presented dispute-fostering factors, the fundamental causes of the dispute appear to be related to and/or rooted in professionalism-or a lack thereof. This supports the assertion in Love *et al.,* (2010) that a lack of professionalism may ultimately materialise as a dispute.

Professionalism

APM (2019) presents professionalism as "the application of expert and specialised knowledge within a specific field and the acceptance of standards relating to that profession", and, similarly, the Oxford Dictionary of English defines it as "the competence or skill expected of a professional". The fundamental principles of professionalism adopted in codes of professional conduct include (1) integrity - being honest, objective, impartial, and true to moral values; (2) competence - bearing relevant knowledge and expertise for any work undertaken; (3) responsibility - acting with skill, care and diligence. The contravention of these principles of professionalism seems to have initiated or catalysed the initiation of the series of factors that culminated in the dispute.

For instance, in proposing and agreeing to an unrealistic schedule for completing the outstanding works-the confidence and basis upon which the project was taken over-the Contractor was disingenuous, contravening the principle of integrity. Further, the Contractor's swift reduction of their available resources soon after takeover by the Employer may be construed as a disregard for and a lack of commitment to their agreed obligations and the established expectations to close out the outstanding work as soon as possible. This would contravene the principle of responsibility. But then again, it is reasonable and common for a contractor to partially demobilise their resources (equipment and personnel) from the site after takeover, given the significantly reduced scale of works. In that case, the absence of the required suitably qualified personnel may be chalked up to poor planning by the Contractor and a general underestimation of the amount of work to be done. This lapse of planning and foresight, however, would not be expected from a contractor who was, by all accounts, procured based on their experience on similar complex projects. This contravenes the principle of responsibility.

Additionally, the Contractor's omission of scope behind the excuse of ambiguous contract documents bears the hallmarks of contractor "claimsmanship". Zack (1993) highlighted that a common claim game during bidding involves bidding of alternative items (materials or equipment) or alternative methods/techniques, and in some cases, bidding what is not specified to gain a competitive advantage or provide grounds for fair adjustment later in the project. The Contractor had the opportunity to seek timely clarification from the Employer regarding the ambiguous specifications but chose to be opportunistic by adopting an interpretation that enhanced profitability instead. This contravenes the principle of integrity. Table 1 summarises the link between professionalism and the upstream dispute-fostering factors in the dispute's mechanism.

Table 1: Relationship between professionalism and dispute-fostering factors

Cause of dispute		Breached principle of professionalism
Differences in contract interpretation	Ineptitude in contract interpretation	Competence
	Ambiguous contract (manoeuvring)	Responsibility, Integrity
Delays in completing work	Poor planning (underestimation of work)	Responsibility, Competence
	Disingenuity (preparing unrealistic schedules)	Integrity
	Low-quality document submissions	Competence, Responsibility
	Late document submissions	Responsibility
	Ambiguous contract documents	Integrity
Unfit-for-purpose facility	Inadequate design	Competence, Responsibility
	Negligence /Laxity	Responsibility
	Poor response to external pressure	Responsibility
	Unqualified workers (poor workmanship)	Competence, Responsibility

Professionalism is a, seemingly, clear-cut subject whose benefits and merits are known and whose values institutions of learning and professional bodies have striven to instil and encourage. However, this paper, in the foregoing disquisition, demonstrates that the principles and values of professionalism are still not always upheld in construction projects. The subject, therefore, cannot be taken for granted and measures should be purposefully taken to design and institutionalise (i.e., nurture, encourage and enforce) professionalism in construction projects. The measures could involve recognising and rewarding professionalism, requiring the affiliation of key project players to recognised professional bodies (that maintain oversight of members' knowledge, skills and conduct) and ensuring appropriate and consistent punitive consequences for unprofessional conduct.

CONCLUSIONS

To avoid/prevent disputes in infrastructure projects-or any construction project for that matter-it is essential to understand the series of events, factors and conditions that lead up to them to be able to anticipate and predict their occurrence. To that end, this study identified the immediate causes/triggers of a major dispute (extension of the defects liability period) in the case study project and proceeded to explore the series of events, factors and conditions that set off those causes/triggers. The study revealed 3 immediate causes/triggers of the dispute: differences in contract interpretation, delays in completing works and unfitness-for-purpose of the facility. Meanwhile, the dispute-fostering factors in the dispute's mechanism were observed to arise from deficiencies in 3 main areas: quality of contract, quality of contractor and quality of contract administration. Furthermore, the study identified that the series of dispute-fostering factors in the project were, ultimately, connected to violation of the fundamental principles of professionalism: integrity, competence and responsibility. So, can professionalism make contract disputes in infrastructure projects disappear? The answer, in the context of the dispute considered in this paper, is "yes!" It is safe to surmise that had the principles of professionalism been upheld consistently, the upstream factors in the dispute's mechanism might never have materialised and the "chain reaction" leading to the dispute would not have been initiated. That being said, it would not come as a surprise if the mechanisms of other disputes (on similar projects) have their roots connected to contraventions of the principles of professionalism.

Eventually, as our industry moves to "build back wiser", this research drives and reinforces the following:

- Enough time should be provided, earlier in the project development phase, to identify possible areas of ambiguity in contracts and effectively clarify them. The Employer's requirements, for example, should be as explicit as possible, with a clearly defined scope and performance criteria for fitness-for-purpose. This would help to prevent disputes rooted in ambiguous contracts.
- An Employer, particularly in the public sector, should have a working understanding of contract development and contract administration regardless of whether they appoint and delegate the role to an external party/ representative. This will ensure that they can identify and address any weaknesses of their representative and, therefore, cannot easily be misled. In that regard, the Employer's in-house project management team should be supported and required to attain and continuously improve their competence in contract development and administration, as a minimum.
- Procuring a contractor is, arguably, the single most important task an Employer undertakes during a project's life cycle and should, therefore, be done based on appropriate and well-considered procurement assessment criteria, driven by clear and well-communicated objectives.
- Professionalism is a, seemingly, clear-cut subject but its principles and values are still not always upheld in construction projects. As such, measures should be deliberately put in place to institutionalise (nurture, encourage and enforce) professionalism in construction projects, such as recognising and rewarding professionalism while consistently penalising unprofessional conduct, and requiring the affiliation of key project players to recognised professional bodies. This is, especially, important in projects with international players whose competences and backgrounds are not always easily verifiable.

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DISASTER MANAGEMENT AND RESILIENCE

ENHANCING PROPERTY RESILIENCE TO FLOOD: LESSONS LEARNED FROM THE RECOVERY OF FLOODED HOSPITALITY PREMISES

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Flood is one of the main climate-related challenges of this age and to mitigate and adapt to some of its impacts; the importance of learning from the past cannot be overemphasised. Some studies have been conducted on business recovery; but further understanding is needed on how to ensure the resilience of the business premises. This study is a cross-case analysis of the recovery process of three hospitality business organisations. The study involved 9 interviews with key management officials and key actors in the preparatory and recovery process. The interviews focused on the capabilities deployed pre-, during- and post-flood events. The themes that emerged were classified under appropriate headings and discussed concerning disaster phases and the built environment. One of the key findings of the study is the importance of a dynamic approach to stakeholder identification and management for a speedy recovery in a flood risk area. It is important to note that the appropriate accumulation and utilisation of existing knowledge is germane. Indeed, the submissions based on the first-hand experience of the respondents in this study will be very useful for business and property owners.

Keywords: business; flood; property; disaster recovery; resilience; stakeholders

INTRODUCTION

Business properties have a significant role in ensuring social needs and generating revenues to stabilise the economy. In recent years, the intensity and frequency of torrential rain floods have increased resulting in extensive losses to both residential and business properties (Li et., 2018). Flood considerably affect business properties causing disruptions to communities and interrupting the economy's normal functionality and stability (Environment Agency Report, 2018). Providing a significant portion to the economy, business properties generate turnover in billions with an average growth rate of 2.2% since 2008. Therefore, the value of business properties spread over a broader spectrum ensuring both local and national economic prosperity (Xiao *et al.,* 2020). The UK hospitality industry was rated as the 3rd

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biggest employer in 2017 with a 3.2million and 2.8million direct and indirect employment. Further, the sector accounted for £72bn and £86bn direct and indirect gross value contribution to the UK economy (Ignite Economics, 2018). After the 2007 flood, the hospitality industry through the British Hospitality Association had to make a special appeal to the government for the suspension of national insurance, business rates and Value Added Tax. This was to enhance the recovery of affected trades as the physical damage caused among others was anticipated to require many months to remedy (Helen, 2017).

Aside from other implications, delayed recovery of hospitality businesses slows down community disaster recovery as social activities will be on hold and tourist arrivals cannot resume (Hamzah *et al.,* 2012) even when water level has gone down. More than 8000 businesses have been affected by floods since 2007 with records of more than 35, 000 insurance claims per year (Brisibe, 2020). There was a £513 million loss for business property damages during the 2015-2016 winter floods, ranging between £410 million and £616 million paid out by the insurance industry as business claims (Bang and Burton, 2021). The United Kingdom (UK) is continuously affected by floods which impact properties and put the annual costs of flood damage at £ 1.1billion for the whole country (Bang and Burton, 2021). These statistics are a compelling urge to increase the resilience of properties in the UK (Xiao *et al.,* 2020).

Sincerely, numerous studies have been undertaken to investigate solutions and strategies to minimize flood impacts on businesses. However, an in-depth study through first-hand experience of recovery processes in a specific sector such as hospitality will complement existing literature. The hospitality industry's contributions to the UK Gross Domestic Product (GDP) and other indirect contributions to the economy are significant (Oxford Economics, 2015). This will enhance the proactive and preventive efforts of organisations and will influence preparedness planning, control, response, training, and recovery activities for future floods (Xiao *et al.,* 2020). Since each sector has peculiar property and content attributes, it is ideal to explore the resilience planning and recovery experiences of businesses, with a clearer focus on specific sectors. This study aimed to advance knowledge on the flood recovery process of businesses by highlighting tactical capabilities relevant to the process from the perspective of previously flooded hospitality businesses.

LITERATURE REVIEW

Flood resilience of properties is established by implementing various measures which facilitate speedy recovery after flood impacts; it helps minimise disruption and allows business restorations and operations as soon as possible (Ismail and Halog, 2017). Discussions on the use of Flood Performance Certificates (FPC), a certificate showing the flood risk profile of each property, emerged in the United Kingdom to encourage businesses and property owners to embrace flood resilience measures (Akeson and Salzenstein, 2021). This is expected to have several other implications which include tenants having a clearer briefing on the flood resilience ability of assets, and insurance companies making decisions based on the FPC ratings of properties. It is also an opportunity for businesses to consider resilience steps that could be achieved incrementally rather than all at once. All of these would support the spread of the financial burden of flooding over time more easily (Akeson and Salzenstein, 2021) and probably better across stakeholders. Trialling and further considerations are required in terms of overall policy, regulatory and implementation infrastructure for

FPCs (FPC, 2020). Its applicability to businesses also must be further considered. Achieving speedy post-flood recovery involves the deployment of some capabilities across the different phases of a disaster (Figure 1). Technically, capabilities are basic skills, attributes and competencies deployed to achieve a purpose. In the context of flood resilience, capabilities related to physical facilities, institutional relationships, societal coping mechanisms, human knowledge, skills, social relationships, as well as leadership and management. Kunreuther and Useem, 2010) described the overall timeline of disaster risk and what generally needs to be done at each stage (Figure 1).

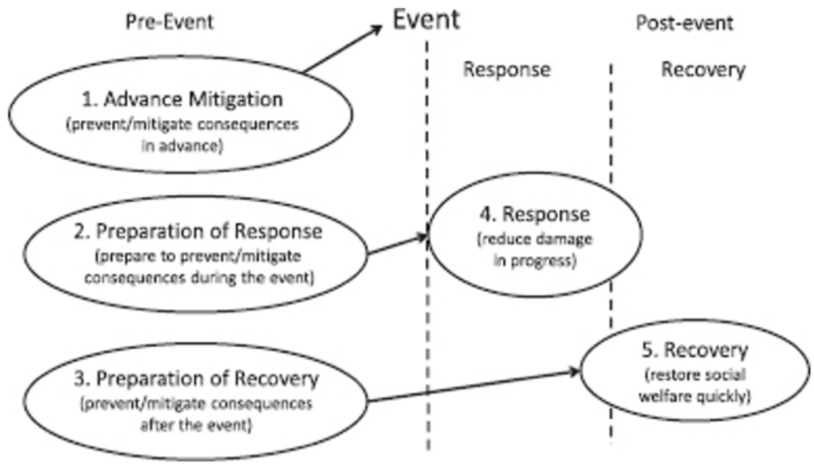

Figure 1: Timeline of disaster risk (Kunreuther and Useem, 2010)

This study explores the flood recovery account of case organisations with a focus on the capabilities deployed or would have been deployed at the different timelines of disaster risk.

METHOD

The qualitative approach was selected for this study because it concentrates largely on words that can be interpreted to understand what happened, the outcome of the occurrence and clear narration of surrounding issues beyond what is contained in the literature. Fellows and Liu (2015) highlighted the capacity of understanding people's opinions and experiences concerning a question of interest through qualitative research. Although Naoum (2019) described qualitative research as being subjective, its subjective tendency does not erode its suitability for thoroughly investigating a phenomenon. To eliminate bias and the influence of subjectivity, interviews were conducted with at least three respondents within the organisations selected for this study and consistency was observed in the submissions. Technically, qualitative research choice is considered to generate rich and deep outcomes, it is a good choice for discovering specific facts and processes (Bryman, 1988). Qualitative research is interpretive and naturalistic; qualitative researchers interpret a phenomenon of interest based on the account of the persons experiencing it (Denzin and Lincoln, 1998). The case study research approach was adopted, and a semi-structured interview was the method of data collection deployed. The interviews focused on the capabilities deployed by the respective organisation's pre-, during- and post-flood events. Thematic analysis was used, it helps in extracting rich findings with limited data loss. Yin (2014) discussed the suitability of the case study research strategy for exploratory, descriptive, and explanatory purposes to answer the question 'what', 'how' and 'why'.

The case study strategy allows a relatively detailed focused evaluation, analysis, and reporting (Yin, 2014). As a result, the approach was adjudged suitable for this study and was adopted accordingly. Multiple case studies guarantee inferences that are more reliable and as well reduce misinterpretation (Yin, 2014). The rationale for selecting the cases includes being in the hospitality business, membership of relevant England's property uses class order E, Suis Generis, C1 (Planning Portal, 2022), possession of previous flood recovery experience, and readiness to participate in the study. The selected hospitability businesses were a guest house, restaurant, and hotel for cases 1, 2 and 3, respectively. The selection of cases in the hospitality business was based on the UK Standard Industrial Classification (SIC) code. According to this code, the three cases are attached to section I i.e., "Accommodation and Food Service Activities".

This section includes the provision of short-stay accommodation and meals and drinks fit for immediate consumption. The amount and type of supplementary services provided within this section still vary but the existing similarity kept them within the same UK Standard Industrial Classification (SIC). Data was collected about each organisation through the interview of individuals as supported by Yin (2014). The individuals involved in the recovery processes were selected in each case for the interviews. The protocol was a set of questions covering pre-event, event/response, and post-event/recovery phases to know 'what' transpired, 'how' and 'why' in terms of capabilities deployed to enhance the resilience and recovery of the business premises. While recovery processes take place at the authority level, flood recovery entails psychologically driven and organisationally demanding work for business owners as they tend to manage their repair and restoration works themselves. Considering this, this study focused on the recovery processes from the perspective of business owners.

Brief on Case Study

Case study 1 (CS1) is a bed and breakfast, overnight lodging establishment often patronised by individuals and groups that do not want to stay in conventional hotels. It is located at Lake District national park in England; it is adjacent to Derwent water and close to River Greta. The property is a semi-detached three-storey edifice built in Lakeland. All bedrooms have en-suite shower rooms, and the kitchen and utility rooms have steel sink units. The business currently has an average turnover of 72,000 pounds per annum (£ 72,000/annum). The property was significantly flooded in 2009, 2012 and December 2015.

Case study 2 (CS2) is a restaurant situated on a waterfront, River Ouse, York, United Kingdom. The restaurant boasts of serving a selection of chicken dinner, burgers and chargrilled steak and others. The Landlord owns the hotel being operated on the upper floors of the property, but the restaurant owners were given the liberty to use and manage the ground floor of the building. The property is an early 19th-century asset. Currently, the restaurant records an annual turnover of about two hundred and fifty thousand pounds (£250,000 per annum). The business was flooded about five times in 2015 due to its closeness to a river that overflows its banks because of torrential rain. The premise consists of an eating area with furniture, a bar, a kitchen, and a store, it was submerged in floodwater up to six feet in December 2015.

Case study 3 (CS3) is a hotel situated in Lake District in the United Kingdom. It is a hotel with over 70 stylish rooms, an en-suite bathroom, a restaurant, a beautiful terrace, and a steam room among other facilities. The hotel has twelve varieties of room types described based on the view through the window and the size of the room. Before its current operation, the property underwent a major redevelopment and reopened in 2012. A director manages the solely owned hotel as well as the property and the business records around 6 million pounds annual turnover. In December 2015, the business was flooded; this resulted in damage to premises and caused around 7-month closure. The three case studies utilised in this study are at different geographical locations, but they share the attribute of being located close to rivers that do overflow and have contributed to flooding within the past ten years.

FINDINGS

Table 1: Background information of respondents

Case reference	Business type	Interviewees
Case study 1 (C1R1)	Guest House	Property owner/Business owner
Case study 1 (C1R2)	Guest House	Property owner/Business partner
Case study 1 (C1R3)	Guest House	Staff
Case study 2 (C2R1)	Restaurant	Property owner/Business owner
Case study 2 (C2R2)	Restaurant	Business partner
Case study 2 (C2R3)	Restaurant	Staff
Case study 3 (C3R1)	Hotel	Manager
Case study 3 (C3R2)	Hotel	Staff
Case study 3 (C3R3)	Hotel	Staff

The interviews were first analysed within cases and then a comparison was made across the three cases to aggregate the findings and identify good practices.

Case Study 1 (CS1) - Guest House

CS1 is a guesthouse that has experienced significant flooding in the past seven years. After the property got flooded in 2009, C1R1 and C1R2 (the property owners) who are also the business owners attempted to achieve a complete seal around the house. C1R1 said, "The staircase was taken out, all electrical wiring was made to drop down and everywhere was sealed up with waterproof adhesives as much as possible, existing suspended floors were replaced with impermeable concrete slab" - C1R1. CIR2 described the challenges faced while attempting to build a water-proof wall and still comply with building regulation standard that requires the insertion of insulation in walls. The ability of the insulation to absorb water thereby dampening the wall made it unappealing. A damp-proof membrane was inserted into floors, but wall insulation started from a height to prevent the insulation from wicking up water.

C1R1 and C1R3 stated that wooden skirting boards in the property were replaced with tiles and waterproof grouting, and swimming pool adhesives were used for tiles and concrete waterproof floors. Some furniture in the guest house kitchen was raised and some parts were made detachable for easy conveyance to the upper floor during a flood. All the activities were undertaken with due consultation with the loss assessor, the insurance company, and a construction firm. Also, C1R1 and C1R2 reported some challenges with proper installation of doors, cracks on the floor, and installation of insulating material; all these affected the duration of recovery. This emphasises the need to understand community needs (Perera *et al.,* 2017) and for practitioners to effectively deliver their duties within the resilience agenda (Perera *et al.,* 2018). The strategies highlighted above were identified under the "pre-event stage" and subsection of "advance mitigation" as the property has been fortified with advance mitigation measures to enhance recovery. C1R1 stated that the property got flooded in 2009 and this caused the business to remain shut for 51 weeks, and 17 months in 2012, these are part of the losses recorded (Li et., 2018). The property owner (C1R1 and C1R2) then made a significant investment of about £30,000 in waterproofing the property. Beyond the earlier described resilience and resistance techniques adopted after the 2012 flood, non-return valves were used for water pipes, and sewage pipes and a sump pump fitted with a generator were also installed. These strategies are aligned with the “post-event stage" and subsection of “preparation of recovery” of the disaster risk timeline and help achieve the recovery process in future. It ought to be part of advance mitigation.

The other lessons from the recovery process of the premises include an arrangement with neighbours to support the installation and activation of flood gates and pumps, use of personal funding, a community foundation-funded post-flood survey, and identification of relevant stakeholders as developments emerge - dynamic identification and good network strength. There is always a stakeholder to attend to a need -flood groups, insurance firms, loss adjusters, flood forums, environment agencies, local councils, professionals, etc. This is a strategy to be arranged at "pre-event", the subsection of “preparation of response”, deployed at “event" - and "post-event - recovery efforts". Also seen as relevant capabilities are the acquisition of suitable flood resistance facilities, the ability to set up the acquired facility and having it maintained as appropriate.

Undertaking the retrofitting activities and discussing the flood survey implies that the business understands flood risk, has reviewed a flood resilience scheme, and sourced funds for crisis response, a significant need (Davidson *et al.,* 2016). C1R1 submitted that the presence of a flood-proof store is equivalent to having an upper floor in the property and these would help limit the extent of content damage and mess within the property thereby aiding the speed of recovery of the premises. CIR1 and C1R2 emphasised the need for maintenance and post-flood relationships, the need for regular meetings and communication with agencies, professionals and manufacturers for update and post-flood assistance. C1R1 stated that there is a need to keep in touch with flood-related developments in one’s community because community decisions affect one’s property flood resilience (Ismail and Halog, 2017). C1R1 and C1R3 highlighted the importance of disaster scenario simulation to training and perfection of skills required for setting up flood protection facilities and ensuring that facilities are functioning. Further, insurance was identified as a relevant capability, but its non-availability to businesses through the FloodRe insurance scheme in the UK remains a concern.

C1R1 referenced her organisation’s arrangement with neighbours and staff to help protect the premises of the business whenever the need arise. They are permitted to make informed decisions in emergencies without a request for permission from superiors. All members of staff and even neighbours know where necessary keys are, how flood barriers are fixed, how pumps are operated, and the agency to communicate. This is for the “event stage” and subsection of “preparation of response”. C1R1, C1R2 and C1R3 identified the need to review happenings after flooding i.e., post-event review, analysis, and management, they also submitted that a crisis response budget is indeed important but might be difficult for a small hospitality business to set funds aside for that purpose, unlike larger ones. Despite deploying a series of resources C1R1 and C1R2 (the business owners) lamented the non-effect of their investment on the market value of the property. The property was dried out and ready for reoccupation within four weeks in 2015, with outstanding limited repair works as against the 51-week closure period experienced after the 2009 flood and 17-month closure after the 2012 flood. This is clear evidence of the effective deployment of relevant capabilities at the “post-event stage” made possible by "advance mitigation", "preparation of response", and "preparation of recovery".

Case Study 2 (CS2) - Restaurant

Stakeholders in CS2, C2R1, C2R2, and C2R3 were interviewed. The property got flooded about five times in 2015, but it was able to re-open within two days at a time. This was made possible using resistant facilities and resilient construction materials - such as flood gates and waterproof membranes under a stone-cement floor, part of the floor is finished with light brown tiles, the walls are made of stones (stonewalls), and the furniture is low water absorbing wood, plastic and metal chairs are with a cushion while the tables have low water absorbing legs - "advance mitigation", clean-up was easier and drying equipment was mobilised quickly, this is an outcome of well-executed 'preparation of recovery' at the "pre-event stage" - post-event consequences were mitigated.

This is a good practice according to Xiao *et al.,* (2020). Post-event flood-survey was conducted a few times to further prepare the premises for the future. Flood updates are continually monitored and stakeholders such as community groups and agencies are often contacted, referrals are provided by them depending on necessity. The staff members can set up flood defence facilities, and initiate premises protection steps like lifting items off the ground. As part of daily operations, once the river level reaches a level based on updates, premises protection activities are initiated ‘the more we do it, the faster we became’- C2R1. According to C2R3 and C2R1, all employees are updated and have been trained on what to do when warnings that require actions are received. This strategy is well aligned with the “event stage” under the subsection of “preparation of response”. Business savings were utilised to restore the premises, though the facility had content insurance, arranged by the occupant, and property insurance arranged by the property owner, payment does get significantly delayed.

On utility during flood events, emergency lighting comes on to initiate restoration. Cleaning and premises restoration activities were executed by the owner and the staff of the organisation. C2R1 and C2R2 emphasised the advantage of knowing where to source facilities and necessary assistance, their inability to connect with appropriate persons caused more damage to the property during the previous flooding, this delayed business recovery. Recovery is a comprehensive process (Davidson *et al.,* 2016) but the experience will speed up the process. Emphasis was made on the tendency of speeding up the recovery process with the availability of funds for cleaning, repair, and reopening publicity. The respondents stated that reaching out to customers during closure does strengthen a relationship, facilitates a successful return to business and guarantees continuous cash flow for offsetting debt and pre-future flood preparations. Currently, decision-making is still significantly centralised because of the size of the organisation; employees often report almost all activities to the manager, C2R1, C2R1 will then assign duties. This approach could be effective if there is enough time to make flood arrangements, otherwise, it will be counterproductive. Another capability area identified is 'flood safe' or a raised store space to keep some essential items. This aligns with the event stage as well as the post-event stage, it aids speedy recovery.

Case Study 3 (CS3) - Hotel

Respondent C3R1 commended the efforts of fire servicemen, it was recorded that the continual pumping of water away from the property prevented damage to some facilities including the generator. Because of the magnitude of the flood and the non-resilient construction materials used for the ground floor, significant damage was experienced. The respondents described the magnitude of renovation after the flood as significant. The activity called for the engagement of a loss adjuster, construction company, the insurer of the property, property surveyor, and government agencies among others, aligning with the "post-event stage" but a result of pre-event 'preparation for recovery'. To minimise the impact of future events, during recovery, floodwalls protecting the area as well as the property and drainage system were re-examined. Automatic self-closing airbricks were installed, damp proof membrane and concrete floor were introduced, and the ground floor was finished with ceramic tiles, an approach supported by Xiao *et al.,* (2020).

Reopening publicity was undertaken by sending gifts to selected customers when the premises were still being restored, media rebranding and re-opening events. This was done to encourage pre-booking and it is in line with the need to ensure pleasant future cash flow and general customer management. This is the only way to accrue sufficient resources to finance or offset the cost of installing structural resilience measures to achieve future premises resilience. These strategies align with the "event stage" and "post-event" stage under the subsections of preparation of response and recovery. A careful mapping of the findings from the cross-case analysis resulted in the alignment of capabilities with disaster stages as shown in Table 2. All the themes shown are expected to be ensured at the pre-event stage but deployed at the disaster risk timelines indicated in Table 2.

Table 2: Summary of themes - capability areas utilised at the different disaster risk timelines

SN	Themes	Pre-event	Event/Response	Post-event/Recovery
1	Property flood risk awareness	✓		
2	Analysis and selection of flood resilience scheme	✓		
3	Pre-flood property flood survey	✓		
4	Acquisition and installation of property level flood resilience products	✓		
5	Product maintenance and management arrangements	✓		✓
6	Knowledge of property level flood facility operations	✓	✓	
7	Planning and execution of flood simulation scenario	✓		
8	Customer management and cashflow preservation		✓	✓
9	Insurance administration knowledge			✓
10	Alternative utility and communication systems		✓	✓
11	Flood proof/upper floor storage		✓	
12	Strategic business record management	✓	✓	
13	Governance of disruption at the organisation level	✓	✓	
14	Crisis response budget		✓	✓
15	Decision making without recourse to superior in emergency situations		✓	
16	Clear definition of roles and responsibilities and how it changes in disaster situations	✓	✓	
17	Post event review strategy			✓
18	Dynamic stakeholder identification	✓	✓	✓
19	Comprehensive structural premises resilience measure		✓	

Eleven themes were aligned with the pre-event stage of the disaster risk timeline and fit into Bosher and Chmutina's (2021) non-cyclical disaster timeline perspective. The response stage also includes eleven themes largely covered but not clearly outlined in Whittle *et al.,* (2010) discussion on community recovery lessons. The post-event stage included 7 themes which are largely non-structural recovery capabilities for restoring social and economic welfare, an objective described by Kunreuther and Useem (2010). Dynamic stakeholder identification as a theme is common to all the phases, flood recovery entails a collaborative effort, and this was deployed by the hospitality business.

CONCLUSION

The case studies revealed that both structural measures and a series of other non-structural capabilities are required to achieve business premises recovery. Some of the capabilities would trigger and support decisions, operations, and efficiency of the structural measures. Such includes property flood risk awareness, review for a flood resilience scheme, crisis response budget, dynamic stakeholder identification, among others. As a result, flood performance evaluation of properties will ideally have to exceed physical property attributes alone. Hospitality organisations can learn from the accounts presented.

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MODELLING EARTHQUAKE DAMAGE REPAIR COSTS: IMPROVING ACCURACY FOR PREPAREDNESS DECISION MAKING

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Natural disasters damage physical assets causing causalities and interruption to businesses. Disaster impacts can be addressed proactively (preparedness) or reactively (recovery). Building adaptation measures; as a form of disaster preparedness; can reduce the level of damage should the disaster occur. Nevertheless, building owners need to be convinced that it is cost-effective to invest in pro-active adaptation measures. An accurate prediction of the repair costs associated with recovery is paramount to determining the economic viability of ex-ante disaster risk reduction investments. Currently, antecedent loss modelling is based on numerous assumptions about risk; vulnerability; and the required damage repair cost. Determining the critical factors influencing overall damage repair costs can reduce such inaccuracies. Damage recovery costs and selected details for 7999 properties recorded from 66 towns in the Italian province of Emilia Romagna damaged by the 2012 Earthquake were assembled. Statistical analysis was undertaken to correlate the repair costs and the damage status; location of the property; floor area of the property and the repair duration. The paper questions the reliability of antecedent loss modelling related to property damage using simplistic and generic economic models. Factors that predict the repair cost are also highlighted.

Keywords: antecedent loss modelling; risk reduction; disaster recovery; repair

INTRODUCTION

Natural disasters damage physical assets causing causalities and disruption to businesses. In addition, they can cause significant disruption to education, impact mental health and increase the crime rate. In this paper, we use the term losses to mean the monetary value of the resultant damage. Among all natural disasters, earthquakes are the greatest threat to life and cause significant economic losses to individuals, communities, and nations (MunicRe, nd). Losses caused by earthquakes are on the rise, and in the last two decades, earthquakes losses have exceeded USD 775 billion (SwissRe, 2021). Accurate prediction of the scale of such losses prior to an earthquake could provide vital information for effective disaster preparedness. According to Daniel and Wenzel (2014), modelling is considered an effective way to appraise the effectiveness of various proactive and reactive mitigation options to

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physical assets (e.g., structural improvements to buildings), operational procedures (e.g., implementation of an early warning system), or financial recovery procedures (e.g., purchasing disaster insurance). Loss modelling can also reduce the time taken for impact assessment and support rapid allocation of resources to business organisations and local authorities without waiting for lengthy field observation.

This paper discusses loss modelling practices related to direct economic loss associated with physical damage to buildings; construed as the total repair costs required to reinstate damaged buildings to pre-disaster status (Ramirez *et al.,* 2012; Leil and Deierlein, 2013). Several researchers have contributed to advances in earthquake loss modelling (Hill and Rossetto, 2008, Vitiello *et al.,* 2017). Loss assessment models first estimate physical damage to properties as a function of potential earthquake characteristics and the buildings' structural vulnerability. These damage levels are then converted to monetary values by applying damage cost functions. The former phase of damage modelling entails advanced seismic and structural modelling, whilst the latter is concerned with economic modelling. Loss assessment research has primarily focused on advancing damage modelling, with limited attention being paid to cost modelling approaches and in particular, converting damage states into economic losses.

LITERATURE REVIEW

Recent research comparing loss modelling estimates with actual losses with from recent earthquakes in Italy, Turkey, and Greece (see works of Del- Vecchio *et al.,* 2018, Spence *et al.,* 2003; Eleftheriadou *et al.,* 2016) highlighted significant inaccuracies of antecedent loss modelling approaches. Whilst authors have highlighted the inaccuracies related to the weaknesses in damage modelling methods, no detailed investigation has been made to identify the weakness of converting damage state into losses or the impact of this conversion on the accuracy of loss estimates. The advancement of modelling approaches to both phases (damage estimation and loss) is crucial to improving antecedent loss modelling accuracy and subsequent mitigation decisions based on the models.

To this end researchers have highlighted the need for further research to accurately predict the relationships between damage state and losses to improve loss assessment accuracy and avoid making inappropriate assumptions (Hill and Rossetto, 2008; Meroni *et al.,* 2017). Using actual damage repair cost data for (the direct economic loss) of residential properties across 60 towns damaged by the 2012 Emilia Romagna Earthquake in Italy, this paper presents the relationship between physical damage levels and monetary losses. It evaluates the accuracy of standard damage cost functions used in the antecedent earthquake loss modelling. Such results will provide valuable insights to loss modellers regarding the adjustments they could make to standard damage cost functions and the provision of any contingencies to the total loss assessment.

Earthquake Disaster Loss Modelling

Disaster loss modelling has received considerable attention from scholars and modellers. Authors such as Ramirez and Miranda (2009), Meroni *et al. (*2017), Erdik *et al. (*2011), Alani and Khosrowshahi (2007), and Kahandawa *et al. (*2020) have reviewed existing loss assessment methodologies in detail. Other studies (see Daniell and Wenzel, 2014, Erdik *et al.,* 2014) have reviewed software platforms to simplify complex modelling calculations. For example, the FEMA P-58 methodology developed by Applied Technology Council in 2012 is considered one of the most widely accepted approaches to loss assessment. Performance Assessment Calculation Tool (PACT) within the FEMA P-58 could simulate a probabilistic estimate of downtime, repair cost, casualties, and unsafe placarding based on quantitative inputs related to ground shaking intensities and structural vulnerability and other economic data.

Scholars have assessed the reliability of the FEMA P-58 methodology by comparing predicted data and observed actual earthquake data (e.g., Cremen *et al.,* 2016; Del Vecchio *et al.,* 2020, Cremen and Baker, 2019, Baker *et al.,* 2016). Researchers have developed a range of algorithms to model the physical damage or damage status (e.g., Cremen *et al.,* 2020; Hashemi and Alesheikh, 2011; Indirli *et al.,* 2013; Munich Re, nd; Giovannetti and Pagliacci, 2017; Canesi and Marella 2017; Kim *et al.,* 2005). These algorithms used variables related to the characteristics of the earthquake (e.g., magnitude, distance, probability; location), the nature of the ground (e.g., subsoil conditions, resonant frequency), and typology of buildings (e.g., foundation type, primary construction material, age); as well as socio-economic characteristics of the location.

Physical damage can either be modelled at the building or element/component levels. Building level damage modelling methodologies are widely used and considered to offer several benefits for rapid loss assessments in peace times and the immediate aftermath of an earthquake (Vona *et al.,* 2018). Similarly, for component level damage, assessment methodologies could be used when more accurate estimates are needed for decision making. Recent investigations (Cremen and Baker, 2019, Baker *et al.,* 2016) showed that loss estimates based on component level analysis are more accurate and consistent. However, component level analyses involve complex procedures and requires substantial expertise based on a multidisciplinary view of structural assessment (Del Vecchio *et al.,* 2020, Vona *et al.,* 2018).

Economic models (damage-cost functions or damage-cost ratios) convert the damage status into economic loss values. Damage cost functions represent the relationship between damage levels (such as slight damage, complete damage etc.) and a property's (building or component) replacement cost. As a typical example, the Hazus MR4 loss assessment methodology assumes 2%, 10%, 44.7%, 100% (of the property value) as the basis for the damage-cost function to calculate the repair cost associated with 'Slight', 'Moderate', 'Extensive', and 'Complete' damage states (respectively) for single-family dwellings. For a multi-family dwelling, 2%, 6.5%, 41.3%, 100%, respectively are used. Meroni *et al. (*2016) produced similar damage-cost functions for use with the EMS 98 damage scales applied to European buildings; 5%, 20%, 45%, 103% damage cost functions to calculate the repair cost associated with 'Slight damage', 'Moderate damage', 'Substantial-heavy damage', and 'damage beyond repair.

Other scholars such as Chaves (1998, cited in Roca *et al.,* 2006), Milutinovic and Trendafiloski (2003), Kappos and Dimitrakopoulos (2007), Polese *et al. (*2010), Vecchio *et al. (*2017) have also developed damage-cost functions. Kappos and Dimitrakopoulos (2007) and Milutinovic and Trendafiloski (2003) have identified value ranges for damage-cost functions, as opposed to single percentage values. Key approaches to determining damage-cost functions are either based on expert judgement (e.g., Stojadinovic et al.,2017; Roca *et al.,* 2006) or empirical investigation using computer simulations (e.g., Scholl *et al.,* 1982, Vecchio *et al. (*2017). The reliability of these functions has not been independently verified. Further details on how earthquake loss assessment has advanced over time can be found in Vitiello *et al.* (2017).

METHOD

The work presented in this paper is based on a single case study into damage repair costs for residential buildings damaged by the 2012 Earthquake in the Italian region of Emilia Romagna. This region had no similar recent disaster events and accompanying repair cost databases to conduct a multiple case study. It is one large case study with multiple units of analysis. After the earthquake and damage to the buildings, separate restoration programmes were set up for residential buildings, historical buildings, cultural heritage and infrastructures, and business premises.

The region developed an IT platform - MUDE (Unique Digital Building Model) to manage applications for funding for the reconstruction of residential buildings damaged by the earthquake. All applications were to be made through the platform by December 2017. The present study accessed a copy of the data on request in 2016 while the applications were still in progress. Additional data was accessed later when it was made publicly available via the Open portal (https://openricostruzione.regione.emilia-romagna.it/ricostruzione-privata). This data set contained records from 66 towns (multiple embedded units of analysis) within the Emilia Romagna region.

Previous authors (Del Vecchio *et al.,* 2018; Eleftheriadou *et al.,* 2016) have used multiple embedded case study approach to evaluate selected buildings for their repair costs. Results from those studies aimed at improving the accuracy of the repair cost prediction at building level. The research presented here attempts to investigate a large data set to improve economic modelling at a regional level and provide additional insights to building level repair cost estimation.

Data Extraction

A total of 7999 cases (individual applications) were accessed from 66 administrative authorities such as towns, municipalities, and cities (collectively known as “Comune” in Italian) in the Emilio-Romagna Region. For brevity and disambiguation, the term "Comune" (with capital C) will be used throughout to mean a town, municipality, or city in the region. The region is divided into nine administrative provinces. Four provinces within the region had reported cases of damage from the earthquake. The number of reported cases from Comunes ranged from the lowest of 1 case (in Bagnolo in Piano municipality to the highest of 847 cases (in Mirandola city in the Province of Modena). The top 15 (24%) most affected Comunes contributed over 5263 cases (80%) - which is closer to the Pareto distribution (20% of Comunes contributing to 80% of the damage).

Each case related to an application made by the owner of damaged buildings for financial resources to repair or restore their buildings. Applications contained details related to a brief description of the intervention(s), intervention type (repair and reconstruction, or repair and reconstruction and seismic improvement), details of the building such as address and location and name of the applicant, construction duration, details of the designer and constructor, number of dwellers residing within the damaged buildings, total floor area and their functional use(s), damage level and operational level (the usability status of the buildings building prior to repairs) of the building(s) assessed by professionals, and the cost (€) assigned for undertaking repair and restoration intervention(s).

Whilst factors such as building age, foundation and structural type, number of stories and other building characteristics has an impact on the building damage and recovery, the large dataset studied here is limited and did not contain this information.

Data Analysis

The data set was analysed to investigate two research questions listed below.

1. What variables impact the earthquake damage repair costs? For this purpose, all 7999 cases were first analysed to identify the correlations between the repair/reconstruction rates and nine other selected variables.
2. What are the possible variations to the damage-cost functions used within antecedent loss assessments? For this purpose, a subset of the data set, 3176 cases related to minor repairs (those buildings assigned 'B/C damage and operational level' status within the database) were analysed: A) to calculate the average repair cost rates for each Comune; b) to calculate repair cost/house value proportion (damage-cost functions) for each Comune.

Since the buildings related to each case are different, the total costs of interventions were normalised for comparison. For each case, the cost assigned for undertaking interventions was divided by the total floor area to calculate repair and reconstruction rates in the form of cost/m2. Recoding the dataset helped recategorise continuous cost and time data into a five-point Likert scale for visibility. The new dataset was, therefore, more suited to nonparametric statistical analysis. The first analysis cross-tabulated the data for greater visibility of the new categories (see Table 1).

Table 1: Crosstab of damage level against intervention

	Intervention Type			
Category and level damage the building sustained	Repair and restore	Repair and restore with seismic improvement	Partial/complete reconstruction with Seismic improvement	Total cases
B/C Low damage habitable before repair	3177	1	0	3176
E0 - Low Damage partial habitable before repairs	0	675	16	691
Repair and restore with seismic improvement	0	599	62	661
E1 -E2 Heavy building damage	0	483	141	624
E3 - Demolish and reconstruct	1	214	1183	1398

There were two primary interventions: (1) Repair and restore, and (2) Repair and restore with seismic improvement. During the recording process, a third category was added to separate seismic improvement for reconstruction from improvements made to a simple repair and restore. Spearman Correlation analysis was then undertaken to establish the critical factors that strongly influence the overall cost to repair and restore damaged buildings following the earthquake. The analysis correlated the unit cost with nine other variables recorded in the MUDE. Results confirmed a strong correlation among the variables. There is a very strong positive correlation between two key variables (Rho = 0.962; $p<0.01$): the damage level and the intervention type. In other words, the two variables were almost synonymous with the similarity of 92% (measured by the coefficient of determination). Simple descriptive statistics functions available within MS Excel were used to compute the mean repair rate and damage cost functions for each Comune to answer the second research question.

FINDINGS

In total, € 3,160,621,021.97 was assigned to 9,916 housing repair and reconstruction interventions throughout the programme (ER openricostruzione, 2022). Figure 1 below shows the extent of the earthquake's impact on the region (Right) and the funding spent on each town (Left). Dark coloured towns in the Left picture represent places that received high amounts of monetary resources.

Factors Affecting Repair and Reconstruction Rates

With regards to the predicators of the recovery cost, the correlation analysis established three statistically significant links (and we identify these as tier 1 factors):

1. Type of intervention (Rho = 0.853; p<0.01)
2. Level of damage (Rho = 0.830; p<0.01).
3. The duration to complete the repair (Rho = 578, p<0.01).

The analysis did not find a direct statistical correlation between the recovery cost and use of the respective properties, such as the number of units or occupants in residential properties, number of commercial units, number of office units and storage units. These factors, however, were statistically correlated to one another. These internal correlations imply an indirect correlation with the recovery cost as they are linked to habitable floor areas used to compute the unit recovery cost rates.

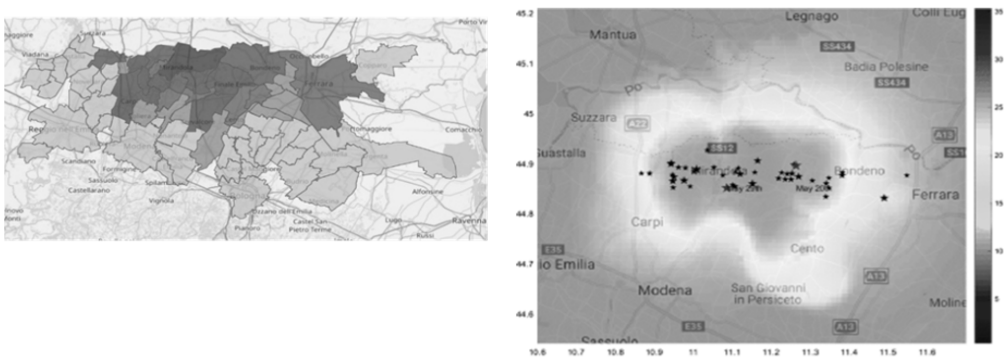


Figure 1: Maps showing reconstruction resource allocation and the impact of the earthquake in Regia Romagna Province (ER openricostruzione, 2022 and Rossi et al., 2019)

Regional Variations for Repair Rates for Minor Repairs

Figure 2 compares the observed damage repair rates for the Comunes. The analysis did not find substantial variations between the minimum and mean repair cost rates for different Comunes. The variability may have influenced these results in the number of cases for each region. Whilst ‘Bagnolo In Piano’, ‘Castelnovo Di Sotto’ and ‘Quattro Castella’ the N=1, other Comunes recorded a higher number of cases - e.g., Mirandola (n=375), Ferrara (n=299), Finale Emilia (n=241). However, this graph shows a striking difference between the maximum repair cost rates from the mean value, affecting some regions more than others. Correlation analysis did not find a statistical difference between the mean and maximum repair costs across Comunes, and they are not correlated either (Correl = 0.1866). These results suggest that location did not influence cost variations for minor damage repairs. A more detailed analysis would be needed to establish specific reasons for the high costs of repairing individual cases. For example, a closer look into the intervention descriptions of extremely high-cost interventions found extremely high costs were reported for contextual reasons such as repairing monumental buildings with decorative elements, small-sized units within a larger building and where the repair was required to comply with new regulations introduced following the earthquake event.

The correlation between the mean repair cost and the average house value for minor damage repairs is weak and statistically insignificant (-0.1876). This finding contradicts previous findings (e.g., Canesi and Marella 2017, Meroni *et al.,* 2017), who claimed (in general for all repair types) a correlation existed between construction (repair) price levels and house values of regions due to economic and social reasons.

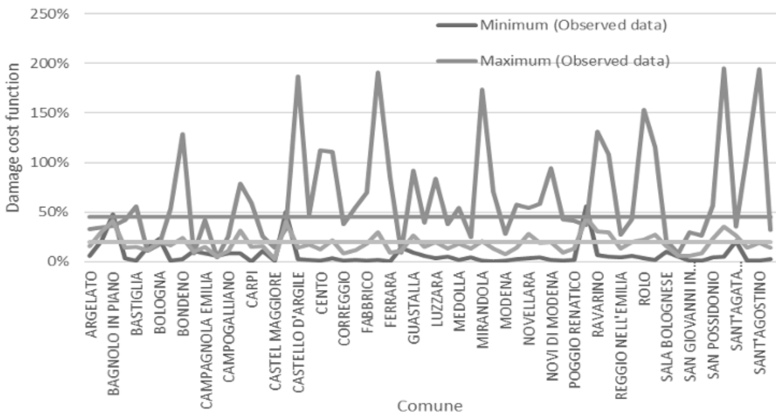
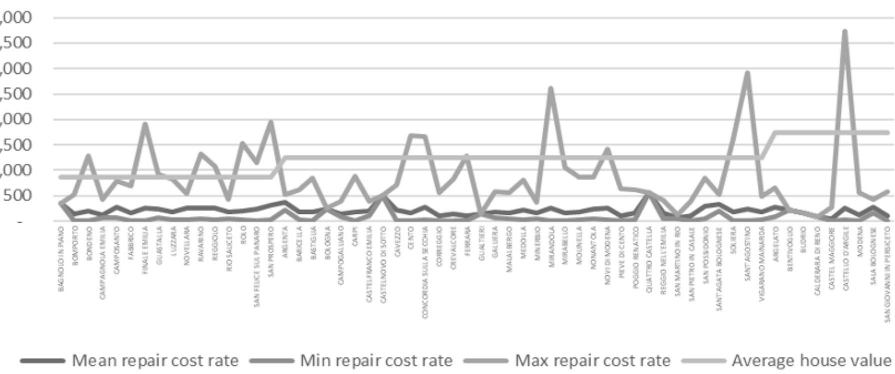


Figure 2: Repair rates for the communes (€ per m2 of floor area)

Reliability of Typical Damage Cost Functions

Further analysis was undertaken to compare damage cost relationships with standard damage cost functions used within antecedent loss assessments for European buildings (EMS-98) (Figure 3). Nine outliers were omitted to improve the consistency and readability of the results.

Figure 3: Damage cost functions for minor/low damaged buildings



Results show that the observed mean damage-cost relationship closely aligned with the standard damage cost ratio of 20%, which is used to predict losses associated with moderate damage (Chaves 1998, cited in Roca *et al.,* 2006). In addition, the data set considered here contained residential units belonging to various building typologies. However, the analysis showed that the maximum damage repair values were almost always above the standard damage-cost ratio of 50% for the “substantially" to "heavily” damaged buildings.

These two findings signify the degree of uncertainty in modelling repair costs between "low-moderate" damage and "Substantial and Heavy" Damage. The findings highlight the importance of making decisions based on probabilistic risks and considering factors that increase damage repair costs associated with individual buildings. The findings suggest that simplified loss assessment methodologies using typical damage cost functions may provide reasonably accurate estimates for repairing minor damage for large building stocks, i.e., regional-level estimates. Hence widely used simplified approaches for loss assessment may offer benefits and provide an accurate basic for decision making for local authorities or organisations owning a stock of buildings for low impact earthquakes.

This paper investigated only the economic modelling of the tangible losses related to damage to buildings, which is a part of overall disaster losses. A broader loss estimation needs to consider environmental, social, and historic losses and their impact to overall economic loss. Social losses tend to persist over a person's lifetime hence cause long-term socio-economic impacts to the society and businesses (The Australian Business Roundtable, 2016). Approaches to the valuation of intangible outcomes (such as revealed preference approaches, stated preference approaches and subjective wellbeing approaches) and macro-economic approaches are useful in broad loss assessment attempts. More research is required to identify the impact of indirect losses on the restoration of buildings and other tangible assets.

CONCLUSIONS

This research investigated repair and reconstruction costs for residential units damaged during the Emilia Romagna Earthquake in Italy in 2012. Standard damage-cost functions used in loss assessment for European buildings closely tally with mean observed damage-cost functions for minor damaged buildings. Therefore, estimates based on standard damage-cost functions would not have significant inaccuracies at the regional level for low impact earthquakes or building stocks undergoing minor damages. However, high repair cost rates did deviate from modelling estimates, irrespective of the location. Therefore, estimates at the individual building level may need careful consideration to identify possible increases from typical cost models. Further investigation into high-cost interventions is needed to identify the causes of the cost increases and provide valuable insights to determine contingency allowances for individual building level estimates.

ACKNOWLEDGEMENTS

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EQUALITY AND DIVERSITY

DO WHAT I SAY NOT WHAT I DO: INCREASING THE REPRESENTATION OF MINORITIES IN THE CONSTRUCTION SECTOR

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The minorities are still underrepresented in the Swedish construction sector despite initiatives launched to answer a growing demand for workforce. Whereas many studies have focused on the minorities, we propose here to look at how the majorities maintain their dominance in the case of a civil engineering education. To do so, we build on the concept of privilege accounting for the dynamics which marginalize some while benefitting others. Drawing on a mixed method approach, the empirical material of this qualitative research includes the reviewing of 120 individual assignments of MSc students in construction management, 16 interviews of these students, and the authors' teaching experience. The preliminary results show a blindness towards one's own privilege, and an overfocus on the differences attributed to the minorities. The paper contributes to a wider understanding of the social dynamic of discrimination within sector.

Keywords: diversity management; minorities; civil engineering education; privilege

INTRODUCTION

On the advent of a predicted shortage of qualified workers, building industries are opening to diverse minorities which so far have been underrepresented within them (Haakestad and Friberg 2020, Jurisic *et al.,* 2021). Taking the gender work division in Sweden as an example, the proportion of women among is around 5.2% among site managers (SCB 2018). Masculine ideologies seem to pervade the totality of norms, beliefs and assumptions that serve to enact specific images of, e.g., leadership work roles (Styhre 2011), or a "macho" culture (Åstrand 2021), rather than building on an assessment of skills and competences (Arditi *et al.,* 2013). The situation has improved for women with university degrees, as they have a significantly higher level (39.4%) of education compared to the men in the industry (including both architects and civil engineers) (Olofsdotter and Rasmusson 2016, Åstrand 2021). However, they tend to be employed in headquarters and planning offices, having the highest share in administrative tasks (Olofsdotter and Rasmusson 2016, Åstrand 2021).

On another note, while the representation of foreign companies contracted in Sweden is increasing, the number of foreigners employed in the industry is more difficult to estimate. There is an important share of posted workers - averaging 12,900 workers a

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month, - but as they are employed by subcontractors, they are not listed in the national employment survey (Ahlstrand 2022). Similarly, whereas foreigners are well-represented among blue-collar workers (Thörnqvist and Bernhardsson 2015), their participation as managers has been identified to be limited (Byrne *et al.,* 2005). Moreover, studies show that there are stigmatisation and segregation against foreigners, mostly non-Europeans, in both the national labour market and the housing market (see, e.g., Ahmed and Hammarstedt 2008, Arai and Skogman Thoursie 2009, and Ahlstrand 2022).

So, in the Swedish supposedly equalitarian society, there is still evidence of discrimination, and despite numerous relevant initiatives (e.g., for increasing the representation of women in managerial positions), minorities' participation has not grown significantly over time (Arditi *et al.,* 2013, Johansson *et al.,* 2021). Moreover, when these minorities are reaching managerial positions, they still may face stigmatisation and discrimination (Conway *et al.,* 2018, Ahlstrand 2022). So, once again, we propose to reopen the black box of minorities' integration in the construction sector and hopefully contribute to reducing the discrimination against them. To do so, we build on the concept of privilege, which enables us to look at not only the way minorities are stigmatised, but also at how the experience of privilege shapes the life of "majorities" - therefore accounting for the dynamics which, by creating inequality, marginalize some while benefitting others. The concept of privilege aims at making the advantages (i.e., small or large benefits) granted to dominant groups more visible in order to be able to contribute to defining a policy of integration (Kimmel 2017). In the present paper, we aim at understanding how majority groups contribute to maintaining certain privileges. Focusing on a master's education program in construction management, the overreaching purpose of our study is to create awareness among future practitioners, as many perceptions and embodiments of privilege in engineering education are perpetuated in the sector itself.

Moreover, according to Billmoria and Lang, (20012) there is a leaking pipe leading to engineering professions where minorities victims of discrimination are slowing dropping out at the different levels of their education and career, and which accounts for the strong homogeneity of the sector. So, we also expect to be able to further provide solutions towards the diverse and equitable development of our education and avoid the pipe from leaking. Drawing on a mixed method approach, the empirical material of this qualitative research consists of the review of 120 individual assignments of MSc students in Construction Management (where they assessed their own performance and collaboration ability in group work), interviews with 16 of these students, and the authors' own teaching experience.

It should be noted that due to the delimited scope of this paper, we simplify the categorisation of minorities, e.g., we conventionally use a binary understanding of gender. However, we are fully aware that such traditional notions like gender binarism are increasingly being challenged in scholarship and social representation (Kosciesza 2022). Nonetheless, it might be helpful to characterise these socially constructed relationships in the manner described above, to identify some of their features and be able to dismantle them (Goodman 2021). Besides, we are aware that many of the accounts we have collected tend to be individualised and personalised processes which, in fact, should be understood to reveal social and structural inequalities (Kimmel 2017). Finally, second-generation immigrants are also segregated in Sweden. It even appears very clearly in the classroom that these students are keeping (or have been kept) to themselves. However, it is impossible to document the importance of the phenomenon, as all differentiation of gender, ethnicity, sexuality, or religion would be considered as an act of discrimination punished by the Discrimination Act (2008, amended in 2014). As such, we are facing a situation of segregation which we cannot properly describe, measure, or assess.

This introduction is followed by the research method, a literature review on the concept of privilege, the empirical focus on the aforementioned master's education program, a discussion offering critical insights, and the conclusions.

Theoretical Framework

When discussing discrimination, we tend to focus on the problematised groups, but rarely mention the contrasting groups, i.e., the ones advantaged and legitimated as they are assumed to be "normal" (Pratto and Stewart 2012). In this paper we are discussing discrimination though the lens of privilege. Instead of thinking about inequality from the perspective of the ones who are hurt by it, we turn our attention to the ones who are benefitting from it (Kimmel, 2018, p. 7). The concept of privilege is multidimensional and has been used to refer to preferences for, and access to, certain people, places, or things in society (Goodmann 2011). Privilege can be defined as unearned benefits awarded to those having an internal, perceived, and/or expressed identity that matches cultural expectations (Case *et al.,* 2012).

Privilege as an unearned asset or status is based on social identities, which translate into advantages, opportunities, benefits, or access to societal resources for those to whom it is assigned (Ferber 2003, McIntosh 1998, Kimmel 2018). Social identities are based on membership in various social groups consisting of people sharing a range of physical, cultural, and social characteristics, such as race, ethnicity, sex, sexual orientation, gender, age, disability, and class (Cudd 2005, Goodman 2011). When individuals or groups benefit from institutional practices such as rules, laws, expectations, behaviours, or norms that harm others, they are said to have privilege (Cudd 2005, Taiwo 2018). Moreover, privilege can be influenced by the degree to which an individual's appearance and behaviours conform to socially endorsed ways of being (Blumenfeld and Jaekel 2012, Ferber 2012).

These privileged identities are the "mythical" norm against which all others in society are judged (Lorde 1984). Goffman (1963) described the non-privileged group as spoiled identities or stigma, felt and or enacted, where the stigma resides in the relation between the attribute and its audience (representing the "normal" or dominant group). Being stigmatised, meaning non fitting with the expected "normal", not only frames the present interaction, but can also condition future relationships and contribute to creating a career where one is continuously stigmatised (Goffman 1963). At the same time, different contexts create different "normalities", and the attribution of privilege is therefore a dynamic process (Kimmel 2013).

The term "dominant group" not only reflects that the group in mention gets unearned privileges and has greater social power, but also sets the social norms by producing and spreading values, images, and experiences of the dominant culture (Goodman 2011). Research on gender privilege has underlined that this often remains invisible to the privileged themselves, as they see it as legitimate entitlement and consequently neglect that others are denied the very same opportunities (Flood and Pease 2005, Galea 2018). Perpetuating this distribution of privilege can also actively happen within education, by legitimising the assumptions, values, and norms of the dominant group - and in doing so, education contributes to rendering privilege invisible (Carnevale *et al.,* 2013). Thus, making it visible can be seen as a major strategy for critique and change (Kimmel 2018) - also in the context of Swedish engineering education and, by extension, to the industry sector itself.

METHOD

This paper builds on an interpretive qualitative study combining elements of autoethnography, action research, and content analysis. Autoethnography is utilized to gain insights and qualitative results through self-observation and self-reflection - also implemented in the construction academia and industry (Grosse 2019). It is hereby deployed to draw on the authors' own experiences (teaching in the master's program for, respectively, more than nine and three years). Moreover, the authors utilize action research in the context of higher education (Gibbs *et al.,* 2017) to reflect the intent of enacting research to benefit the students' learning, not harming them, and ultimately leading to knowledge co-production with them (Gibbs *et al.,* 2017). Finally, content analysis (Donald 2022) was deployed for reviewing 120 individual assignments of first-year master's students that self-assessed their performance and collaboration in group work, as well as for analysing the interviews held with 16 of those students. The students' sample for the interviews consists of 11 international students, seven females and four males, and five local students, two females and three males. The students' citations mobilised for this paper are excerpts from their assessment and the interviews.

All participants were informed about the goal of the study, the recording of the interviews and the anonymity of their contribution. The interviews were transcribed and analysed according to the themes developed in iteration with the theoretical framework on privilege. To carry out our analysis, we have followed the five-steps model of qualitative analysis suggested by Taylor-Powell and Renner (2003): Knowing the data by getting over it several times; identifying key questions or topics to organise the analysis; categorising information by themes and features; identifying patterns and connections within and between categories; and interpreting by attaching meaning and significance to the analysis. The results and interpretations of the different methods of gathering data have been triangulated and discussed between the two authors and with some our colleagues of the diversity management group.

In the context of our methodology for the empirical part, we recognise our study's limitations due to the apparent diversity in the students' individual characters and dispositions, the relatively small sample size, and the differences between the periods in which our material was collected. However, we argue that these limitations can also be understood as strengths in our study, as they reflect a strong contextualisation which avoids claims for unbased generalisation.

Empirical Part

The education under scrutiny is a master's programme in design and construction project management, which aims at preparing technically qualified engineering students to face the challenges met by the sector - such as production, quality, sustainability, digitalisation. Building on the complementarity of different disciplines, the programme has the ambition to provide future practitioners with a combination of prescriptive and analytical tools to solve those challenges. The prescriptive tools aim at planning, organising, managing, and controlling the construction processes, as well as addressing the individual, social and organisational aspects of the sector; the analytical tools, methods, and theories, aim to enable the future practitioners to develop a holistic view, be more reflexive about the context they are evolved in, and accordingly make informed decisions.

The programme is popular and continuously in the top three of the most sought graduate education tracks in the institution it belongs to. The class offers 50 seats to internal university students from different programs, and 25 for external students from both Swedish and international universities. The waiting list is typically long for both internal and external applicants. Universities' education is free of charges for EU and EEA citizens in Sweden but requires an annual tuition fee of 140 000 SEK (around 11 300 GBP) for students coming from other countries.

The participants' selection is carried out by the administration without contact with the programme and is based on the previous academic results of the students (high grades being the first criterion). The university owning the programme is also regarded as one of the most selective in Sweden, a status which has had some unfortunate consequences on the ego of the local students. The programme runs over two years. In the first semester, the courses are mandatory - meaning that all the students follow the same progression and are gathered in the same class. Attention to diversity and segregation is translated into classroom initiatives aiming at guided integration through work in mixed groups, introduction to cultural relativity, diversity in the education team, and lectures and exercises in conflict negotiation and resolution.

In-class gender distribution is almost fair in binary terms, with an average of 43% of female students over the last 5 years. In contrast to gender, it is more difficult to trace the percentage of national and international students, as we cannot collect information about the students' background. We therefore used language as a selection criterion, where the students who do not speak Swedish fluently are labelled as international. The percentage of non-Swedish speakers is around 15-17%, a figure - like the in-class representation of students coming from other Swedish universities. The teaching team is around 70% Swedish and 75% male dominated.

FINDINGS

Students and Privilege
First, the good news: our students, both national and international, did not perceive a gendered difference of behaviours or treatments. This does not imply that there is no dfferences, but the students we have talked to cannot find examples of gender-related privilege.

Nonetheless, this does not mean that there is no hierarchy in project work. When dealing with their assignments, the students recognise differences in being legitimised to take on a leading role, according to criteria such as having on-site experience or having worked in the industry. Being active in the sector seems to confer students the possibility to be dominant and allow them to make decisions without being challenged. However, this practical experience is recognised only for the national students of both genders, but not for the international ones, whose professional past regardless of the number of years spent in the industry tends to be simply disregarded.

But if gender is not a problem for our students, discrimination linked to ethnicity is. The distribution of students in mixed groups is often communicated as being “forced”, by the local students preferring to revert to a Swedish - non-Swedish repartition. However, as the number of international students is limited, the latter end up working with always the same partners if the groups are not organised by the teachers. There is an apparent lack of trust towards “foreigners” (a “we-them” mentality), and emerging conflicts are taken at the level of nationality instead of differences between individuals - as put harshly by a Swedish student,

> "The foreigners should not think that they will have a free ride in our education and steal our jobs afterwards" (Swedish male student)

The anonymous course evaluation surveys systematically underline that it is difficult or prejudicial for some local students to work with international ones. However, these comments are counterbalanced by some of the international students being critical to the lack of work motivation expressed by their Swedish colleagues. Coming to a foreign university, it is for some of them important to demonstrate their ability by achieving the highest grades, whereas "*the nationals know they will get a job whatever their results*" (international male student).

> "Here I become more compromised when working with new people, especially when they have unfamiliar cultural backgrounds to me. For several times, I spent time figuring out some suggestions on modifying project process and results, but eventually I gave them up, because I do not want to be hated for giving too much pressure on my team members. But when I worked with my country classmates before, I usually stick to my ideas unless there are more convincing ways to do" (individual assessment international female student).

The local students have often misidentified the international ones for exchange students, which is connoted as students "*spending a holiday semester abroad…*" and not worth investing during the class or socially,

> "They keep calling us exchange students, but we are not in any exchange programme, we have decided to come and study here, we have been admitted by selection and some of us paid quite a lot to be here" (international male student).

Moreover, most of the international students actually intend to stay in Sweden after obtaining their diploma and are longing for establishing contact with their national colleagues and broaden their network. "*They don't invite us to their parties, but we invite them to ours and sometimes they come*" (International mal student).

The language is another issue. It is convenient for the national students to revert to Swedish when doing project work, even if one or two of the group members are international. The latter are getting a summary of what has been said in English or are in the worst case:"*informed*" about the tasks they need to perform. As frustrating as this situation can be, "*it is tiring to repeatedly ask them to use English during the sessions, so you just give up*" (international female student).

The local students benefit of a network of older and former students with whom they discuss about the courses, the teachers, and the previous exams and assignments. This allows them to have access not only to previous tests, but also their answers. If these are shared within social media, the international students are not always part of these networks or aware of the benefits they can drag out of them; as such, they feel "*cheated*". The local students acknowledge the situation but blame it on the naivety of the teachers:

> "Today we can get everything online, all can be shared, it is just a question to know where from, but I am not sure the teachers are aware of that" *(local Swedish male student).*

The problem is that external and international students may not be aware of what they can search for in the first place. Even if the students do not notice any kind of discrimination regarding gender, the reactions of the international students towards national students' behaviours are quite strongly differentiated within the two groups.

The female students focus on cultural differences and underline their feelings of being discriminated or even excluded, while the male students display a more active and powerful attitude:

> "I rely on myself, I am taking initiative"*; or even excuse the local behaviours:* "It would be the same in my country, … I also prefer talking my own language" (international male students).

Teachers and privilege

The local students, after three years of bachelor studies at the university, are well-versed to the culture and routines of the institution. They know the rules, both formal and informal, as well as what is expected from them in terms of behaviour and delivery. This gives them a clear advantage when interacting with the teaching staff or planning and executing project work. The international students are more distant and respectful towards teachers and rules, and consequently may be disadvantaged in certain situations like taking the word or asking questions during class sessions. Likewise, local students may start whispering to each other when the internationals are asking questions, showing their lack of interest for the ongoing interaction. Unfortunately, teachers may not always be attentive and compensate for the imbalanced pedagogical outcome that may stem from these kinds of situations.

This division of "insiders " versus "outsiders" is reinforced by the teachers mostly referencing local or national projects and/or companies during the courses. These may be known to the national students, but the international ones often miss contextual information to make sense of the given examples. This situation can be attributed to a lack of attention or knowledge from the Swedish teachers. For the international teachers, however, using local references may also serve to demonstrate that they are knowledgeable about the Swedish context, which in turn contributes to their own legitimisation process as competent lecturers.

Language is an issue during the classes, when teachers build on Swedish vocabulary, slides, or assignments. As quoted by several of the international students, being told that "*they can look in their mobile for translation*", does not really feel inclusive. Bilingual students have also noticed that they tend to have longer and more complete answers from the local lecturers if they use Swedish to ask questions. So, besides feeling disregarded, the internationals' learning possibilities are also reduced.

CONCLUSIONS

It was a pleasant surprise that our students did not find examples of gendered discrimination. However, our theoretical background on privilege draws the attention to respective experiences being common among other minority identities. The use of the possessive words "our education, our jobs", underlines a taken for granted situation deserved by the local students; something to which they are entitled, and which can potentially be "stolen" by somebody who does not share the same privilege. The vocabulary used to describe the international students, delegitimises their presence in the education, and constructs them as outsiders who may jeopardise the local students' progression (Iverson 2007). There is a need to question these affirmations, as well as the way this perceived ownership of education is attributed, and to make the explanation for these levels of discrimination visible (Kimmel 2018).

The insights gained by the literature and the empirical investigation show that the visibility of privilege and the preparation of soon-to-be construction management professionals for adequately responding to minority-based challenges, need to be first tackled during their education, in the level of the classroom, syllabi, curricula, and even university policies. Listing these privileges contributes not only to creating awareness, but also gives us the possibility to identify and improve the situation of the non-privileged students, as well as implement measures to compensate for and share some of these benefits. Even if learning goals regarding ethics and discrimination are added to the curriculum, there is no follow-up, reflection, or assessment of these goals in terms of students' behaviour or practices in class - which in turn can perpetuate the blindness towards privilege.

Whereas awareness is being created around minority discrimination (e.g., with teachers trained to use gender-neutral vocabulary), microaggressions rooted in embodied privileges that might not even be visible to the ones having them, are still part of the daily life. Microaggressions can include minor and delicate instances of marginalisation, which perpetuate negative messages toward minorities and over time, build a negative attitude (Ogunyemi *et al.,* 2020). Such perpetuations are worsened when ignoring or dismissing an idea, question, or student's presence (Hinton Jr. *et al.,* 2020) - all of which can be understood as instances of privilege enactment. As such it also questions our roles and behaviours as educators.

Attention should also be drawn to instances of tokenisation, initially perceived as something positive. Being attributed specific competences or behaviours because of one's provenance, is discrimination as well - because it tends to ignore one's personal labour and investment in their skills and professional development, and rather exoticising those as something almost "metaphysical" and connected to one's ethnic and/or cultural background or origin.

Even more alarmingly, there can be instances of "diversity washing" through relevant low-budgeted programs, which may be not enough to account for serious initiatives. In this context, university-proposed solutions are bound to fail, as the organisational structure does not seriously support them.

As an endnote, other minorities (such as older students or LGBTQI+ people), should also be benefitted by the implementation of non-discrimination policies, practices, and measures combating privilege enactment. However, it seems that tackling privilege leading to minority discrimination has still a long way to go, even in the most "aware" higher education institutions. Therefore, continuous work is needed, as identifying what the privilege is, can lead to finding a way to balance it, as well as communicate it to the students. This requires though that we the educators do align what we say we want to achieve with what we do in the classroom so that we can build back wiser.

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THE COLLABORATIVE CHALLENGES OF SOCIAL PROCUREMENT

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Social procurement requires firms in the construction sector to form new collaborative relationships with organisations from government, third and community sectors which are poorly understood. Addressing a gap in social procurement research relating to the challenges of cross-sector collaboration, this paper applies theories of cross-sector collaboration and risk management to a content analysis of five focus groups undertaken with thirty-five stakeholders from the construction, government, not-for-profit, social enterprise, education, and employment sectors. Despite the collaborative underpinnings of social procurement, the results point to a low level of knowledge about what cross-sector collaboration involves and a lack of inclination to collaborate which is underpinned by a lack of collective vision for what the policies can achieve, a focus on downside risk rather than upside opportunity and resentment about the way the risks are being managed. It is concluded that project-based intermediaries such as the one studied here can help to mitigate perceived risks and maximise perceived opportunities for stakeholders involved in the implementation of social procurement policies.

Keywords: collaboration; diversity; social value; procurement; social enterprise; CSR

INTRODUCTION

Social procurement involves the strategic use of procurement to create social value Barraket *et al.,* (2016). Social value can be created in many ways through construction procurement but as Raiden *et al.,* (2019) note, most social procurement initiatives in construction focus on the creation of training and employment opportunities for disadvantaged groups which are normally excluded from the construction labour force. Such people include Indigenous peoples; youth at risk long-term unemployed; refugees and migrants; women; ex-offenders; people at risk of homelessness; and people with a disability. Social procurement has a long history which can be traced back to before the industrial revolution, but its contemporary re-emergence has occurred within the context of new public governance, which incentives innovative cross-sector collaborations between government, third and community sectors (Barraket *et al.,* 2016, McNeill 2017, Loosemore *et al.,* 2019). While the emerging field of construction social procurement research has begun to address the numerous new challenges associated with the implementation of these

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policies (see Farag *et al.,* 2016, Loosemore 2016, Petersen and Kadefors 2016, Denny-Smith and Loosemore 2017, Barraket and Loosemore 2018, Troje and Gluch 2019, Loosemore *et al.,* 2020), the question of how these new cross-sector collaborations work remains unresearched. Existing social procurement research is nearly always undertaken from the perspective of one stakeholder group, failing to reflect the new relational complexities associated with these new hybrid organisational arrangements. Addressing this gap in knowledge, the aim of this paper is to mobilise theories of cross-sector collaboration and risk management to explore the risks and opportunities of social procurement from the multiple perspectives of key stakeholders involved in the implementation of these policies in the construction industry.

LITERATURE REVIEW

Theories of cross-sector collaboration have emerged within several fields but its current pre-eminence in the context of social procurement arises from contemporary public management discourse around principles of New Public Governance (Crispeels, Willems, and Scheerlinck, 2018). The concept of New Public Governance is based on the idea of a ‘plural state’ where social services which were once considered to be the primary responsibility of government are delivered through new hybrid organisational assemblages between non-profit, business and government organisations (McNeill 2017).

The collaborative underpinnings of social procurement are based on claims of organisational efficiency, effectiveness and economic benefits that flow from cross-sector collaboration where organisations from different sectors share knowledge and resources to develop and implement innovative solutions to increasingly wicked social problems which are beyond the scope of one type of organisation working alone (Keast, 2015). Gray (1989: 5) defines collaboration as ‘… a process through which parties who see different aspects of a problem can constructively explore their differences and search for solutions that go beyond their limited vision of what is possible’. Collaboration involves a different way of thinking and behaving based on sacrifice for the collective good and strong interpersonal relationships, supported by processes and mechanisms to facilitate transformational change.

In their formative work, Thompson, and Perry (2006) define collaboration as higher-level form relational working which is distinct from cooperation and coordination where people make personal sacrifices and give away part of themselves for the greater collective good. Thompson and Perry (2006), Stout, Bartels and Love (2018) and Flynn (2019) argue that collaboration requires five key enablers: Relational governance (governance that facilitates collaboration and joint decision-making based on sharing of risk and reward and clear rules for working together); Backbone administration (processes and support structures which support collaborative decision-making); Negotiation and compromise (acknowledging and dealing with the tensions between organisational self-interests and collective interests); Mutuality (norms of trust, reciprocity and respect); and Relational competencies (such as communication, professional embeddedness, emotional awareness, personal agency and collective identity).

Loosemore et al's (2020) analysis of an ex-offender employment program which required construction firms to collaborate with organisations from other sectors such as charities, government prisons and education institutions showed that these enablers are unlikely to exist in the construction industry and that cross-sector working is risky and challenging, especially where organisations with no prior record of collaboration are being required to do so by external imperatives such as social procurement policies.

Current risk management research in construction provides few insights into how to manage these risks. While theories of risk show that it is a complex social and psychological phenomenon that has many dimensions: technical, physical, monetary, cultural, psychological, and social (Linsley *et al.,* 2019), risk management research and practice in construction has been pre-occupied with the technical aspects of risk (Edwards and Bowen 2004, Loosemore *et al.,* 2015). Furthermore, while some construction researchers, have argued for new forms of collaborative risk management involving multiple stakeholders (Bryde and Fearon 2011), construction risks are typically managed in isolation and the enablers of cross-sector collaboration discussed above are likely to be missing from the construction industry due to its fragmented structure and confrontational risk transfer culture (Ogulana *et al.,* 2019, Qu *et al.,* 2015).

METHOD

Recognising the socially constructed nature of risk and employing an interpretivist epistemology, we conducted five focus groups with thirty-five stakeholders from the construction, government, not-for-profit, social enterprise, education, and employment sectors (see Table 1 for sample details).

Table 1 Sample details (focus groups)

Stakeholder group	Participants
Constructors	Subcontractors (formwork, services x2, plumber x2, painting, Groundworks) and principal contractor.
Government	Local, Federal, Statex2, Government Agency
Employment services providers	7 Job Actives, 2 Disability Employment Agencies and 2 representatives of a not-for-profit Aboriginal Support Agency
Educational institutions	Higher education x2, Registered Training Organization x 2, trainers and mentors working in the field with youth.
Social Enterprises	Refugee employment and support, Traffic control, youth charity-based social enterprise, Group Training Organisation, Property Maintenance and Cleaning.

Respondents were purposefully sampled based on their experience of cross-sector working in a unique collaborative initiative called a Connectivity Centre© set up by a major international contractor in Australia to meet its social procurement requirements on a major hospital project with demanding social procurement requirements. In simple terms, the Connectivity Centre © was a physical space located adjacent to a major hospital redevelopment project (about AU$1 billion) to co-locate the variety of organisations involved in helping disadvantaged job seekers from the local project community find sustainable and meaningful work in the project supply chain. The approach rests on facilitating cross-sector collaborative relationships forged over numerous projects between the main contractor, client, employers on the project (including construction subcontractors and consultants), training organisations, employment services providers (called Job Actives), disability employment organisations, Indigenous support agencies, refugee support agencies, charities and community and support services organisations.

Collecting data in the context of the Connectivity Centre© was important in providing a common focus for respondents to articulate and discuss their collaborative experiences in responding to the social procurement requirements. While we recognise the limitations of single case study research (Yin 2017), as Noor and Baharel (2008, 1603) state, case studies "enable the researcher to gain a holistic view of a certain phenomenon…capturing the emergent and immanent properties of life in organisations and the ebb and flow of organisational activity." This is particularly important in exploring the concepts of risk/opportunity and collaboration which epistemologically require in-depth 'meaning-orientated' methods to explore.

Each focus group lasted approximately three hours and followed a typical focus group format with research questions, background information and aims being circulated in advance. Each focus group was recorded and transcribed, producing approximately one hundred and twenty thousand words of material for analysis. Following Guest (2012) our inductive thematic analysis involved several stages starting with: 'immersion' in the data (repeatedly reading the interview transcripts to obtain a high level of familiarity with the data); categorisation/coding (organising and generating an initial list of items/codes from the data-set, that have a reoccurring pattern as it relates to the theoretical constructs in our literature review); searching for themes (examining how codes combine to form over-reaching themes which are phrases or sentences that identifies what the data means in relation to the research questions); refining themes (continuing to search for data that supported or refuted proposed themes and connections between overlapping themes).

In line with the traditions of thematic research we present our analysis below in narrative form supported by selected quotes. Furthermore, in presenting our results we have sought to present the exact words used by our respondents without our interpretation so that readers can judge for themselves that our interpretation is correct.

FINDINGS

In terms of the perceived risks created by social procurement for key stakeholders involved in the implementation of social procurement policies, our findings indicate that construction's negatively focussed risk transfer culture (Peckiene *et al.,* 2013) is being extended into social procurement and they also reflect concerns in the field of corporate social responsibility in construction about distributive and procedural inter-organisational injustice in this process (Loosemore and Lim 2016).

> "so why are we being asked to step-up and take the costs?" (subcontractor)
>
> "There are the extra costs of supervising these people and the time involved" (subcontractor)

Subcontractors felt that this risk burden was exacerbated by their small size and by the lack of supply of suitable work-ready candidates to fill required quotas. This they felt would lead to inevitable "gaming" and "exploitation" of the policies to the commoditisation of intended beneficiaries:

> "Not being able to meet targets through lack of supply" (subcontractor)
>
> "When all the other government projects come on stream then there is going to be a massive supply problem very quickly…we are already seeing it now" (subcontractor)

Our results suggest that the concept of absorptive capacity, employed in the wider innovation literature, may be a useful analytical lens to understand social procurement policy implementation in industries like construction, particularly because it has been found to be related to characteristics like company size which distinguish construction from other industries (Zhou *et al.,* 2018).

The main risks articulated by employment services providers related to the culture and structure of the construction industry, the supply of suitable candidates, and the focus on short-term outputs as a measure of policy success:

> “so dangerous and highly regulated” (Employment Services)

> “They feel that construction is so far away that they are just not able to do it… and they get scared” (Employment Services)

Communication with a fragmented supply chain about future labour requirements was also problematic:

> “The subcontracting model of the industry makes social procurement much more difficult because the numbers of interfaces increase hugely across which Job Actives have to work” (Employment Services)

For education stakeholders’ social procurement was described as a 'sugar hit' which caused an over-reliance on temporary project-based employment with non-local employers to address longer-term systemic problems:

> “In three years’, time…some big suits will fly in here. cut the ribbon...and then the jobs will be gone…so we need to make sure that at the end of every job that we start to connect people working on these projects are starting to transfer into local governments and local businesses which depends on them being given transferable skills not just skills for this job that they need to meet their compliance requirements” (Education provider).

For social enterprises the risks of social procurement policies largely revolved around: mandatory nature of policies; policy instability; increased competition; and learning to work with the private sector:

> “It’s all very good for the government to tell companies they have to do this but if we then place a candidate and they have a negative experience then that creates a big risk” (Social enterprise)

> “These new contracts represent a big risk to us, the policies are subject to political changes” (Social enterprise)

Collaboration with the construction supply chain and between themselves in tendering for work was also seen as problematic. Reasons included: industry payment regimes; size of contracts; unionism; project-based structure; negative perceptions of social enterprises; its cut-throat culture; the pressures and risks of working on site; and the unique skills needed to work in the industry.

> “…not being able to set foot on a worksite because we don’t have an enterprise agreement with them (the union)” (Social enterprise)

> “...a lot of these tier 1 contractors pay on 40-day terms because they are big and bad enough to impose that…but we pay out wages on a weekly basis” (Social enterprise)

> "...we struggled for a while in trying to understand the difference in culture with the private sector…they are very competitive and cutthroat.... they don’t believe that our people can do the job” (Social enterprise)

These results add a collaborative and construction-specific lens to the vast body of literature on the challenges of running and scaling a social enterprise (see for example Social Venture Australia 2016) and to the limited body of research on social enterprise in construction (Loosemore 2015, Barraket and Loosemore 2018). In particular, the identification of unions as a source of resistance is new and somewhat counter-intuitive given the social justice nature of their mission and adds a potentially interesting industrial relations dimension to the social procurement debate.

When asked about opportunities offered by these new social procurement opportunities, our findings supported the warnings of Barraket and Weissman (2009) about potential distortions to markets since larger subcontractors perceived an opportunity to exclude smaller risk-averse companies from public sector projects because of the costs of complying with these policies:

> "There will competitors that will drop out because of this policy…they won't be able to comply and they will stop tendering for government work…there are lots of companies that cant set the bar that we will set" (Subcontractor).

Interestingly, the opportunity to address skills shortages widely identified as a risk for the industry (Infrastructure Australia 2021), was not seen as an opportunity, largely because the people targeted by social procurement were not seen as skilled - especially in the areas of licensed trades (plumbing and electrical services), which are facing particularly acute shortages. This supports previous research by Loosemore *et al.,* 2020a) who showed that subcontractors perceive the people being targeted by social procurement as a risk to productivity, safety, and quality rather than an asset.

Social enterprises opportunities included the chance to change negative stereotypes of social enterprises highlighted in previous research and address challenges of building scale (see Raiden *et al.,* 2019, Loosemore 2015):

> "We see these new regulations as an opportunity to be able to grow and diversify our service offerings" (Social enterprise)

> "it provides us with an opportunity to challenge and break those perceptions (of social enterprises and their clients" (Social enterprise)

For government stakeholders there was little concern for how private firms required to comply with these contractual requirements addressed their new responsibilities, and a sense that social procurement was an opportunity to transfer the risk of welfare to the private sector at little cost:

> "we don't care what companies do to deliver on the social outcomes" (Government).

Our results tend to support cynicism in some quarters about the motives of these policies (Macmillan 2013) and signal a warning for policy makers about the risks of not following the basic principles of effective risks management which state that risk should only be given to parties who have the necessary resources, information, and willingness to manage them, and which can charge an appropriate premium to do so (Abrahamson 1983).

Reflecting the commercialised and privatised nature of the employment network in Australia and the low level of interaction with this system by employers across all industries (Commonwealth of Australia 2019), Job Actives saw potentially large opportunities for their businesses and their clients, but curtailed by a low understanding of the industry, poor networks, and a sense the industry is not taking its new responsibilities seriously:

> "We have definitely seen this as an opportunity and still do…but there are many barriers, and we are already starting to see some social procurement fatigue" (Employment services).

> "The reality is that many of these companies are not taking it seriously...... these companies have no intention to create permanent jobs and because they are on projects its hard for them to do it…these projects only last for a while" (Employment services).

CONCLUSION

Set within the emerging policy debate about the role of social procurement to create positive social value through major industries like construction, and the lack of research in this area, the aim of this paper was to investigate the risks and opportunities of social procurement in the construction industry from the multiple perspectives of key stakeholders involved in the implementation of these policies. Our results contribute numerous new insights to the social procurement debate from a variety of new stakeholder perspectives. First, results point to a low level of policy awareness, scepticism, and perceptions of policy unfairness, highlighting a need for more research into what can help to foster greater policy engagement in this area.

Second, despite the collaborative foundations of social procurement policies, our research highlights a lack of collaborative intent among key stakeholders involved in implementing these new policies in construction. Our results point to little sense of a collective vision and imagination for what these policies might be able to achieve between the organisations needed to collectively implement them, highlighting a need for more research into the enabling conditions, attributes and competencies which are needed to facilitate cross-sector collaboration.

Our results also contribute a new risk management lens to the social procurement debate revealing the highly negative light in which these policies are seen in the construction sector and the perceptions of unfairness as to the way these policies are being rolled out. Worryingly, our research suggests that this will inevitably lead to opportunistic and gaming behaviours to the detriment of the vulnerable people these policies are meant to help. Overall, our findings show that the risks and opportunities presented by new social procurement policies vary from one stakeholder to the next and need to be better understood and then managed effectively if these policies are to be effectively implemented.

In terms of future research, our findings highlight the need for more research into the role of innovative project-based intermediaries like the Connectivity Centre ©. The Connectivity Centre © was widely seen by our respondents as critical to facilitating cross-sector collaboration and in mitigating collective risks and maximising collective opportunities for stakeholders involved in implementing these new policies. Such research would contribute to the very limited research into the role of intermediaries in supporting social procurement, especially in dynamic environments like the construction industry.

Finally, in recognising the inherent limitations of our single case study approach, we recommend that more research be undertaken into social procurement policy implementation in other geographical, sectoral, procurement, design, and regulatory environments to explore how the risks and opportunities of social procurement may vary between construction industry sectors and between countries.

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EXPLORING THE LIVED EXPERIENCE OF WOMEN OWNER-MANAGERS OF SMALL CONSTRUCTION FIRMS: A SOCIAL IDENTITY APPROACH

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Despite the growing number of small construction firms that are owned-managed by women, there is limited research into the lived experience enacted by these women who have direct influence over their firms' strategic direction and operational management. This paper aims to revisit the current narratives on gender prevalent in the industry from a social identity perspective. Social identity approach (SIA) posits that individuals have multiple and salient self-concepts that are defined by their social context and experiences. The exploration of the lived experiences of women owner-managers of small construction firms could shed light on how these women identify themselves. The narrative inquiry methodology will be adopted as it is an appropriate way to gather data about lived experience. Findings from this study will contribute to help policy makers and industry stakeholders go beyond examining structural barriers only when it comes to making the construction industry more attractive to women.

Keywords: women owner-managers, social identity, gender; business owners

INTRODUCTION

There is a growing number of small construction firms that are owned-managed by women (BEIS 2021a, 2021b). There is, however, a scarcity of research on the experiences enacted by these women who have direct influence over their firms' strategic direction and operational management within the construction industry. Instead, studies on women in construction tend to focus on their professional roles within large organisations, and the identification of the barriers preventing women from entering and remaining in the construction industry (Bridges *et al.* 2020). The male-dominated nature of the industry, for example, has been cited as one of the barriers that explain the under-representation of women (Akinlolu & Haupt 2020) and the difficulties that women face in the progress of their careers (Clarke *et al.* 2017). Gale's (1994) seminal work exploring why only a few women are occupied as construction professionals, is one of the first to establish the importance of contesting the industry's male-dominated culture perception.

Subsequent research, however, has anchored attention on how to improve the image of the industry and thus, it is claimed, attract more women. As a result, a lot of effort has been put into creating strategies or external approaches, but unfortunately, these have

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not delivered the anticipated results (Clarke *et al.* 2017). It could be argued that this direct focus on initiatives solely designed to attract/motivate women to join/remain in the industry has rendered women as needing motivation to join and remain in the industry.

It might inadvertently produce a counterproductive narrative about the disparity of opportunities available for women within the construction industry. Perhaps more importantly, these external initiatives that are designed to attract women to joining and remaining in the industry might have overlooked the question of whether women see their gender as a motivational factor that influence their behaviour and decision making into joining/remaining the industry.

LITERATURE REVIEW

Nevertheless, the existing literature, with its examination of the individual experience of women in construction, continues to be relevant not only to identify the barriers affecting the attraction and retention of women in the industry (Navarro-Astor *et al.* 2017) but also to identify the success factors behind the progress of some women in the industry (Francis 2017).

Hasan *et al.* (2021) reflect on the scarcity of studies which highlight the positive experiences of women and success attributes related to their employment in the construction industry. Becoming an owner-manager of a small construction firm could be perceived as a success indicator for some individuals. Therefore, exploring women in owner-managers roles within the construction industry could serve as examples of positive career development. Hasan *et al.* (2021) propose that exploring the experiences of women in construction, their successful career paths, and their contributions to the sector could potentially enable to revisit some of the current narratives on gender prevalent in the industry.

Hence, exploring women's advancement and success as leaders in their roles as owner-managers, rather than the focus on the external barriers hindering their career development, could be argued to offer a complementary perspective into the experience of women in the construction industry. Additionally, the literature suggests that concepts such as leadership and business ownership are traditionally male gendered concepts (Ahl & Marlow 2012). Hence, exploring the experience of women owner-managers who are at the top of the hierarchy of their firms; who are actively involved in the management of their organisations; and who might have fulfilled their career aspiration in the industry, might expose a contrasting view to the way women are traditionally presented in the literature.

In the existing construction literature, a significant number of studies have turned their attention to the exploration of gender relating issues affecting the experience of women in the sector (Hasan *et al.* 2021) and the discourses about gender that might reproduce their absence in the industry (Ness 2012). The literature reports the impact of gender in the career progression of women working in the industry, highlighting the differences in the career progression for women and men due to perceived gendered practices in the industry (Dainty *et al.* 2000; Francis 2017; Lu & Sexton 2010). In addition, the effects of gender in the leadership role of women in the industry is also a recurring theme which captures the specific challenges faced by women in leadership roles within a male-dominated sector such as construction (Thayaparan *et al.* 2014; Watts 2012).

Within the existing literature, studies exploring specifically women as owner-managers in construction is limited. Those studies covering women experience as owner-managers in other industries focus on the identification of the gender factors negatively affecting the experience of women in self-employment and business ownership roles, despite paradoxically women identifying business ownership as a means to lifting gender-related restrictions to their career advancement (Arenius & Kovalainen 2006; Carter & Shaw 2006). These three aspects of the lived experience of women in construction and women owner-managers: career progression, leadership role and business ownership, provide a general overview of how gender affects the experience of women in construction. There is however limited research available regarding how these aspects relate to the lived experience women owner-managers of small construction firms.

Whilst the literature reports on the effects of gender inequality (Powell *et al.* 2010), gendered perceptions (Akinlolu & Haupt 2020) and gender related barriers (Naoum *et al.* 2020) affecting different aspects of the experience of women in the construction industry, little is known about the value that women themselves give to gender. Whether women working in the industry perceive gender as a constrictor or a source of empowerment; or whether they perceive gender as having a considerable, little or no influence at all in their day-to-day experience.

It is proposed that exploring this alternative focus allows the examination of whether initiatives created specifically designed to attract/retain more women into construction might be putting a lot of effort and resources into a social idea that might not have the expected significance for women; or resonate to them as being deeply important in their decision making or behaviour. Since little is known about the experience of women owner-managers of small construction firms, they provide a seemingly 'valid research gaps' to test this empirical consideration. To test this proposition, social identity approach (SIA) is proposed as it offers a series of tools that allow the identification of whether gender is a salient self-concept for women owner-managers of small construction firms.

This paper is organised as follows. First, the proposed - social identity theoretical framing is presented, with a general overview into this approach and a review of how it can be applied to explore the lived experience of women owner-managers of small construction firms. Second, proposed research design and methods are discussed. Finally, conclusions are presented.

Theoretical Framing - Social Identity Approach (SIA)

Introduction to SIA

Social identity theory (Tajfel 1978) and its related theory of self-categorisation theory (Turner *et al.* 1987) are often jointly described as the 'social identity approach' or the 'social identity perspective'. These two distinct, but intertwined, theories have been regarded a significant theory dedicated to understanding group processes and intergroup relations (Hornsey 2008). Social identity theory (SIT) developed by Tajfel (1978) and later modified by Tajfel and Turner (1986), posits that individuals have multiple and salient self-concepts that are defined by their social context and experiences. Self-concept is defined as "those aspects of an individual's self-image that derive from the social categories to which he/she belongs" Hornsey (2008, p. 206). Social categories refer to the social groups that individuals categorise themselves (Trepte & Loy 2017). Hogg and Vaughan (2008) further describe social identity as the individual's self-concept derived from his or her perceived membership of social groups. Van De Mieroop (2015, p. 408) explains that every individual can be within several different social groups and further argues that "these groups are the result of an individual's segmentation of the social world into categories on the basis of variables such as similarity, common fate, and proximity". SIT proposes that people tend to favour members of their own social category (in-group) over members in other social groups (out-group) (Ullrich *et al.* 2005), hence causing intergroup conflict.

Self-categorisation theory (SCT) (Turner *et al.* 1987) represents a later elaboration of social identity theory (SIT). SCT moves away from the focus of SIT on intergroup dynamics and social conflict; instead, it proposes that depending on the importance of a certain situation, an individual's behaviour is driven either by social or personal identity processes (Trepte & Loy 2017). According to this approach, identity refers to "a shared set of meanings that define individuals in particular roles in society" (Stets & Serpe 2013, p. 31). Ely (1995) explains that identity is comprised of two components: (1) a personal component derived from idiosyncratic characteristics, such as personality and physical and intellectual traits, and (2) a social component derived from salient group memberships or social categories, such as ethnicity, religion, political affiliation, nationality, vocations, relationship, gender, sexual orientation, class, etc.

SCT indicates that both personal and social identities can be at work simultaneously and the self is perceived as being determined by both personal and social identities (Trepte & Loy 2017). Davis (2009) further differentiates between individual and personal identity by claiming that individuals' personal identities are constructed by individuals themselves, while their individual identities are socially constructed in terms of their different group memberships. Social identity can be perceived as the link between individuals' personal identities and individual identities. The combination of SIT and SCT has been applied in the exploration on the salience of gender as a self-concept as it facilitates the understanding of the multi-faceted nature of gender and the ways that it shifts with influences such as current motives (Bosson & Michniewicz 2013; Wood & Eagly 2015).

Hornsey (2008) explains that SCT and SIT share most of the same assumptions and methods. The two theories however can be differentiated based on their views on social and personal identity. Whereas SIT suggests a variety of interpersonal versus intergroup behaviour exists, SCT asserts that both social and personal identity processes may be at work concurrently (Hornsey 2008). For this study, the combination of these theories will be referred to as 'social identity approach' (SIA). Ellemers *et al.* (2004) explain that SIA specifies the conditions under which a particular self-definition or social identity is likely to become salient.

Haslam *et al.* (2010, p. 348) define self-category salience as "the level of self-categorisation at which a person defines themselves and the particular self-categorisation that serves to guide behaviour". Under SIA it is understood that certain group memberships tend to become more powerful determinants of behaviour than others, and salient identities are effective forces to influence motivation and behaviour (Ashforth & Mael 1989). SIA, a theoretical approach that focuses on capturing individuals' identity attachments or self-categorisation, aligns with this paper proposition to explore the perceptions of women owner-managers of small construction firms regarding specific key aspects of their lived experience that have been previously associated to gender.

SIA Applied to Women Owner-Managers of Small Construction Firms

To date, scant attention has been paid to the value that women in the construction industry themselves put into their gender identity. The fixation of the literature on the narrative that women need motivation to join and remain in the industry, might need to be re-considered by evaluating the importance that women themselves give to their gender identity. Under a social identity approach (SIA), gender is perceived as a self-concept, hence exploring the lived experiences of women owner-managers of small construction firms will shed some insights into how they identify themselves. SIA could allow exploring the significance of gender in women owner-managers' self-categorisation and it might indicate the level of relevance that these women place on their gender in the social context of the construction industry.

Hence this approach might provide a complementary perspective to re-examine traditional gender views in the industry. Condry (1984, p. 485) describes the process of gender identity as "the self-attribution of culturally bound concepts of masculinity and femininity". Although the salience of gender is maintained by many social institutions, Condry (1984) further argues that as society begins to treat the sexes more equally and as social roles become more widely shared, the value of gender is expected to decrease proportionately, and its position as hallmark of social identity is projected to recede as well.

Furthermore, literature about women business ownership often treats them as a homogeneous group (Carter & Shaw 2006). SIA allows to explore their experience at an individual level. An individual level analysis allows to focus on human actors and the identification of the characteristics of human decision making (Nau 2019). The adoption of SIA could shed light on whether there is any linkage between the 'actual' lived experience of women who own and manage small construction firms and gender self-categorisation.

In addition, it might stress which other identities these women identify themselves in their professional careers, their leadership roles, and their roles as business owners. SIA could be operationalised to explore which self-category relate and motivate women owner-managers. This could be then translated into tailored recommendations based on their lived experience. This paper proposes the need to explore women's perceptions about gender in specific social contexts and to identify the level of relevance that being a 'woman working in a male dominated industry' has to them. If gender results as a salient self-concept for these women, this might re-enforce the continuous discussion on addressing gender-related issues affecting women in the construction industry.

If instead, gender is not an important salient self-concept for women owner-managers of small construction firms, it could be then recommended for this empirical consideration to be tested with other women within the industry to assess whether recommendations to attract and retain more women in the industry might need to be re-evaluated. In either case, this study might display positive examples of career development, along with introducing the perceptions of a group of women working in the industry that has been overlooked so far by the construction-specific literature.

Examples in the construction-specific literature have used SIA to explore how the social structures at large construction sites facilitate the development of social identity among site workers and how this may affect safety behaviour (Andersen *et al.* 2015); to identify the influence of group norms on construction worker's personal standards regarding safety behaviour (Choi *et al.* 2017); and to identify the socio-psychological factors relevant to co-operative behaviour among project participants (Phua 2004). All these studies point to the richness and broad influence of this theoretical approach and its applicability to research interests such as this one, seeking to explore the effect that social identities have on individuals and the social contexts that influence motivation and behaviour individuals.

METHOD

In line with the proposal to employ SIA to develop an understanding of the lived experience of women owner-managers, a methodological approach which aligns with this aim, is narrative inquiry methodology. Kramp (2003) argues that as a methodology, narrative inquiry is as an appropriate way to gather data about lived experience. Narrative inquiry focuses on how individuals assign meaning to their experiences through the stories they tell (Moen 2006). Singer (2004, p. 438) further explains that "to understand the identity formation process is to understand how individuals craft narratives from experiences, tell these stories internally and to others, and ultimately apply these stories to knowledge of self, other and the world in general".

Indeed, there is a seemingly close linkage between identity and narratives. Within SIA, narratives are perceived as a window into the process of identity construction (Riessman 2008). Hence the use of narratives provides an entry to the identity and self-perceptions of women owner-managers of small construction firms. Riessman (2008) further argues that individuals' narratives about themselves are what they regard as their personal identities, or their identities as they themselves see them. The introduction of narrative inquiry methodology to explore the lived experience of women owner-managers is argued to be an appropriate approach which also aligns with the adopted SIA theoretical framing.

Butina (2015) explains that a defining feature of narrative inquiry methodology involves the collection of narrative (stories) from individuals or small groups. These stories tell of individual experiences that often exposes the researcher to the identities of that individual (Butina 2015). Narratives are often collected through interviews. The interviews can be open-ended and unstructured, or semi-structured and guided. Some of the techniques that relate to this approach include the narrative interview method (Hollway & Jefferson 2008), the biographic narrative interpretive method (Wengraf *et al.* 2002), and narrative-oriented inquiry (Hiles & Cermák 2008). This study proposes the use of the narrative interview method as a technique to generate stories about the research participants' experiences. The narrative interview method has been chosen as it allows to tailor questions specifically situated for certain aspects of the lived experience of the research participants, which would be more difficult with the open question nature of the biographical approach.

Narrative inquiry methodology views participants as storytellers (Smith 2010). More specifically, narrative inquiry methodology uses the stories the research participants tell as the primary source of data and is appropriate for determining meaning and aiding understanding of life experiences (Smith 2010). Many studies using narrative depend on oral accounts, such as interviews which are then transcribed. These interviews can then be thematically analysed. It is proposed the use of semi-structured interviews as a mean to derive narratives. The large qualitative data resulting from these interviews will then be analysed by employing thematic analysis using NVivo software. The coding process will incorporate the areas of experience that have been associated to gender by the literature: career, leadership, and business ownership, but offering the flexibility to discovering new themes. The analysis aims to identify common words, codes, as well as recurring self-concepts generated from the data. This exploration will allow the identification of whether gender is a salient self-concept within the experience of women owner-managers of small construction firms.

It is proposed for the participants in this study to be women and men who are owner-managers of small construction firms. The inclusion of men's experience allows the presentation of balanced view regarding gender in the construction industry and the avoidance of favouring the views of a group over the other. However, since the focus of this study is on the exploration of whether gender is salient self-concept in the experience of women owner-managers, the number of female participants could be favoured to capture a broader sample of women and gather insights into their live experiences.

The criteria for the selection of participants are twofold. First, participants must be legal business owners from consultancies or trade service providers in the construction industry and have day-to-day management responsibilities within their firms. This is to account for the interest of this research in the experience of women owner-managers in leadership roles. Second, participants come from limited construction firms with and without employees (including limited companies where only the directors/partners are 'employed' and these firms 'employ' external self-employed professionals), and sole proprietors' owner-managers or part of a partnership. The labour-intensive nature of narrative inquiry methodology accommodates the use of a small sample frame. Therefore, the initial intention of this research is to interview between 10 to 15 women and men business owner-managers of small construction firms[2]. The sample will be accessed through the researcher's personal and professional networks, online research, and the snowballing method (Snape & Spencer 2013).

CONCLUSIONS

This paper presents the need to add a complementary perspective to the traditional gender related studies within the construction literature which tend to focus on the examination of gender related barriers to make the industry more attractive to women. As an alternative this paper proposes to explore the relevance that women themselves give to their gender identities within the context of the construction industry using a social identity approach (SIA). SIA allows the exploring of the significance of gender for women owner-managers, and it might indicate the level of relevance that these women place to their gender category in the context of the construction industry. The proposal highlights the specific areas of interest within the lived experience of these women which are perceived as relevant when it comes to gender. Results from the exploration will contribute to help policy makers and industry stakeholders to go beyond examining structural barriers only when it comes to making the construction industry more attractive to women.

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HEALTH, SAFETY AND WELLBEING

APPLICATIONS OF IMMERSIVE TECHNOLOGIES FOR OCCUPATIONAL SAFETY AND HEALTH MANAGEMENT IN THE CONSTRUCTION INDUSTRY: A SYSTEMATIC REVIEW

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The construction industry contributes significantly to workplace fatalities and injuries. Recently, Immersive Technologies (ImTs) as part of a suite of industry 4.0 technologies have also emerged as a viable pathway to address poor construction occupational safety and health (OSH) performance. A literature review of 79 articles relevant to the application of ImTs for construction OSH management is conducted to gain a broader view of different construction OSH areas using the preferred reporting items for systematic reviews and meta-analysis (PRISMA) approach. The review revealed that literature has focused on applying various ImTs for OSH areas including safety training of construction workers. This review identified challenges associated with the use of ImTs including the low adoption rate of developed ImTs for construction OSH management. It is therefore recommended that investigations should be conducted to determine the possible reasons for the low adoption rate of developed ImTs for construction OSH management.

Keywords: health and safety; H&S; immersive technologies; systematic review

INTRODUCTION

Schumacher *et al.,* (2016) described industry 4.0 as the modern advancement of technology that utilises the internet and other enabling technologies to integrate physical objects, human beings, intelligent machines, production lines and processes resulting into an intelligent, networked, and agile value chain. Some of the technologies driving industry 4.0 include but are not limited to immersive technologies, big data analytics, additive manufacturing, and internet of things (Salimi, 2018). Immersive technologies (ImTs) can be defined as the 'integration of virtual content with the physical environment in a way that allows the user to engage naturally with the blended reality' (Pavithra *et al.,* 2020, p.1). For example, Truong *et al.,* (2021) observed, in a study on the use of ImTs in addressing the inadequacies of

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Babalola, A, Manu, P, Cheung, C, Yunusa-Kaltungo, A, Bartolo, P, Gao, S and Perera, S (2022) Applications of Immersive Technologies for Occupational Safety and Health Management in the Construction Industry: A Systematic Review *In:* Tutesigensi, A and Neilson, C J (Eds) *Proceedings of the 38th Annual ARCOM Conference,* 5-7 September 2022, Glasgow, UK, Association of Researchers in Construction Management, 197-206.

2D drawings in construction that ImTs could enhance collaboration and planning bringing significant economic savings and gains for the construction industry.

The construction industry is a very large industry consisting of about 7% of global workforce and contributes about 6% of the world's gross domestic product (GDP) (Adami *et al.,* 2021; Bhagwat *et al.,* 2021). Despite its huge impact on employment and the global economy, the construction industry has an intrinsic dangerous nature making it one of the most hazardous industries (Comu *et al.,* 2021). The International Labour Organisation (ILO) has evaluated that the global annual record of fatal injuries in the construction industry is over 100,000 (International Labour Organisation, 2015). The construction industry is one of the industries with the highest records of work-related accidents and diseases as it has about 3.5 times the average rate of fatal injuries to workers than in all other industries (Health and Safety Executive, 2015). Also, the average rate of non-fatal injuries in the construction industry is about 1.5 times the average rate of non-fatal injuries in all industries (Health and Safety Executive, 2015). The number of fatalities and injuries in the construction industry is very high and requires urgent intervention.

It was also noted that virtual reality (VR), augmented reality (AR) and mixed reality (MR) are the trending realities in ImTs (Pavithra *et al.,* 2020). Wang *et al.,* (2018) refers to VR as a visualisation technique for the creation of virtual environment (VE) with the use of technologies. VR is a technology that utilises computer hardware and software tools to simulate a real environment with a high feeling of presence and immersion in the simulated environment (Raimbaud *et al.,* 2021). These hardware and software tools have been used for the training of construction practitioners in a risk-free and realistic virtual construction site (Zhou *et al.,* 2012). AR, on the other hand, is a technology that complements the real world by generating computerised information such as computer images, videos and texts and superimposing the generated computerised information onto real world layouts (Abbas *et al.,* 2020). In addition, MR as a form of ImT, is "the merging of real and virtual worlds to produce new environments and visualisations where physical and digital objects co-exist and interact in real time" (Dai *et al.,* 2021, p.2).

This study focuses on reviewing the status of application of ImTs as part of a suite of industry 4.0 in addressing the occupational safety and health (OSH) challenges in the construction industry. A few reviews have been conducted on the application of ImTs, especially VR and AR for construction OSH management, but most of these reviews are often individualised owing to their focus on the application of just one or two ImTs on different OSH areas in construction (Li *et al.,* 2018). Other reviews have focused on the use of ImTs for a particular OSH area in construction such as for safety training (Gao *et al.,* 2019). There is, however, the lack of a review that provide a holistic view of the application of ImTs to various OSH areas/topics and different types of OSH hazards in construction. The lack of comprehensive academic documents makes it challenging for researchers and industry professionals to adequately examine as well as ascertain the proficiency of all approaches under all scenarios at a glance. Academic researchers and industry practitioners may therefore not have an in-depth knowledge of the limitations and gaps pertaining to the application of ImTs for addressing OSH challenges in construction due to the overwhelmingly diverse and vast nature of studies in this area (Li *et al.,* 2018). This study aims to coalesce and consolidate understanding of the application of ImTs for construction OSH management by adopting the PRISMA-based systematic literature review (SLR) approach. This implies that there is a very logical approach to the definition of keywords, database selection, articles inclusion/exclusion and research timeline, which makes it very easy for future researchers to determine the exact contributions as well as limitations of the study. The central research questions this study addresses are:

1. What is the current state of research on the application of ImTs for construction OSH management? What construction OSH areas/topics and hazard types are addressed by ImTs in the academic literature?
2. What are the challenges/limitations and future research directions regarding the application of ImTs for construction OSH management?

METHOD

The Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) approach was used to conduct an extensive systematic literature review (SLR) on the application of VR, AR, and MR for the OSH management in the construction industry. PRISMA methodology has been described as a methodology that consists of detailed items checklist and phase flow diagrams which provides transparent reports during SLRs (Qiao *et al.,* 2021). The literature search was conducted using Scopus (www.scopus.com) which is the one of the largest online, abstract and citation database of scientific literature (Gao *et al.,* 2019). The set of search strings used for the collection of articles from Scopus database is as shown in Figure 1.

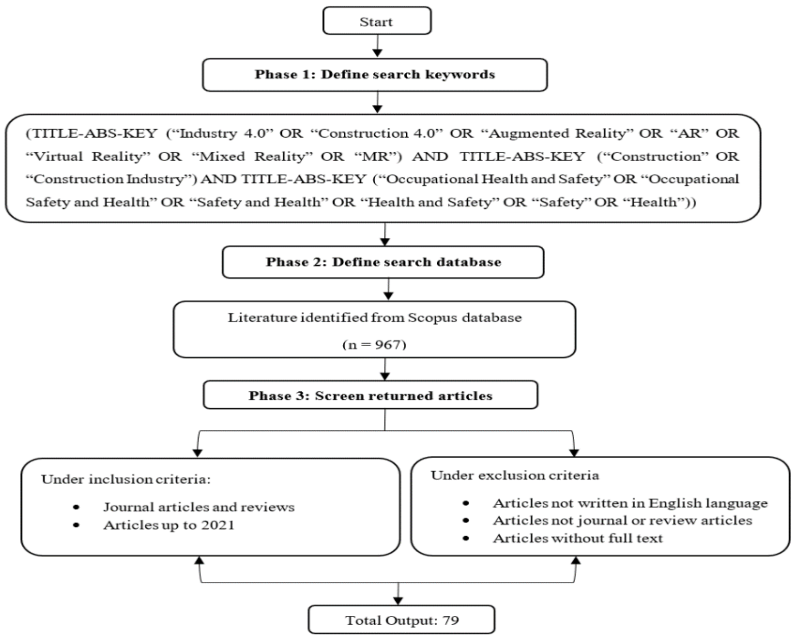


Figure 1: SLR flow diagram

As depicted in the systematic flow diagram shown in Figure 1, the initial search retrieved 967 papers from the Scopus database. The set of search strings was then limited to journal articles and reviews because they tend to provide more comprehensive information on the field of study. The number of journal articles and reviews obtained was 384 with 583 papers filtered out. The titles and abstracts of the papers were then screened and reduced to 87 as 297 papers were not relevant to the scope of study. There were 5 papers without full text leaving 82 papers. The full-text screening revealed 3 irrelevant papers to the scope of study and were therefore excluded resulting in 79 relevant papers, which were analysed for the SLR. The number of papers is sizeable enough to draw valuable insights from the literature as evidenced by other systematic reviews relating to construction management, including more specifically, the areas of OSH, ImTs and industry 4.0 technologies. Examples are the: 32 articles reviewed in a study about safety leading indicators by Xu *et al.,* (2021) and 41 articles reviewed in a study about VR by Wen and Gheisari (2020).

FINDINGS

The review of the literature clearly shows that several studies have been undertaken in the application of ImTs for the construction OSH management. The annual distribution of the 79 papers is shown in Figure 2 and it indicates an increasing trend in publications relating to the application of ImTs for the construction OSH management from the year 2017 till 2021 as 24 articles were published in 2021 when compared to the 3 articles published in 2017. It can be noticed that there was an undulating trend in the number of publications from 2012 after a 6-year gap and this could be due to the emergence of industry 4.0 concept in 2011 (Yang and Gu, 2021). The subsequent sections examine further the OSH areas/topics and the hazards addressed by the application of ImTs in construction.

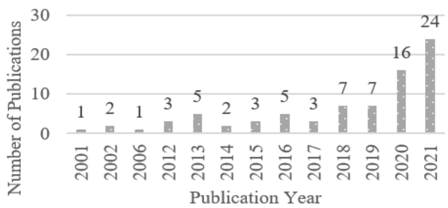
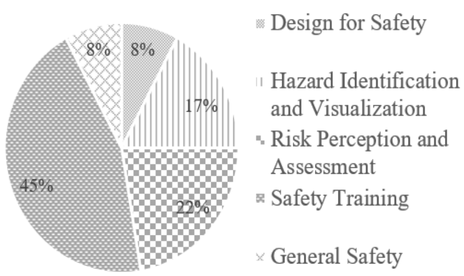


Figure 2: Annual Distribution of Papers

OSH Areas/Topics Addressed by Immersive Technologies

The OSH areas addressed by ImTs as observed in literature are hazard identification and visualisation, safety training, design for safety, risk perception and assessment and general safety. The distribution of these areas/topics across the reviewed articles is shown by Figure 3.

Figure 3: Percentage of publications within construction OSH areas



Hazard Identification and Visualisation

Hazard identification is a key factor in the development of efficient construction-site based management processes (Albert *et al.,* 2014). Kim *et al.,* (2017) proposed a vision-based hazard avoidance system which prevents accidents from occurring by allowing workers to identify hazards through the display of augmented hazard information on a wearable device. However, this AR system which consisted of a vision-based site monitoring module rendered construction site in a planar form thereby limiting the identification of other important hazards by workers (Kim *et al.,* 2017). The planar view of the construction sites has been addressed by Eiris *et al.,* (2018) with the development of an augmented 360-degree panorama of reality

(PARS) that provides a true-to-reality representation of construction sites for effective hazard identification.

Afzal and Shafiq (2021) addressed the planar view of the construction site differently as the issue was addressed with the application of 4-dimensional (4D) building information models (BIM) and VR. VR and 4D-BIM was used in the simulation of construction sites which improved the hazard identification of workers (Afzal and Shafiq, 2021). A similar study conducted by Teizer *et al.,* (2013) presented a 3-D view of primarily steel erection tasks with the application of location tracking sensors and VR for the effective identification of hazardous activities by steel workers. Lucena and Saffaro (2020) conducted a study on the application of VR for the identification and visualisation of hazards.

Participants, who were construction managers, explored the VE and mentioned hazards they identified to the instructors as VR technology provided visual stimuli to participants thereby making it easier to detect dangerous situations intuitively (Lucena and Saffaro, 2020). A similar approach involving the walkthrough of workers in a virtual construction site for hazard identification was adopted in a study conducted by Hadikusumo and Rowlinson (2002). The workers also selected appropriate precautions to the identified hazards for the prevention of accidents (Hadikusumo and Rowlinson, 2002).

Safety Training

The lack of experiential training on OSH is one of the reasons preventable incidents occur in the construction industry and this can be tackled with VR technology for OSH training to minimise incidents at construction site by improving safety awareness of workers (Xu and Zheng, 2021). This is perhaps why 45% of studies on the different construction OSH area focused on addressing construction safety training using ImTs as depicted in Fig. 3. Xu and Zheng (2021) delivered a VR safety training session with the use of VR goggles and a controller which could not enable free navigation of participants in the real world during the training session thereby reducing the realism of the immersive experience.

The effective navigation of trainees was however implemented with the use of a VR treadmill in the virtual dynamic construction site replacing the use of controllers or keyboards (Adami *et al.,* 2021). A study was conducted that compared the conventional safety training method to the VR-based safety training method which involved the collection of eye-tracking data from engineers, construction workers and engineering students (Comu *et al.,* 2021). Alternatively, a similar study conducted by Adami *et al.,* (2021) compared the conventional method of safety training to the VR-based method of safety training for the operation of a demolition robot. While Adami *et al.,* (2021) observed that there was a significant increase in the safety behaviour of workers who participated in the VR training when compared to the conventional training, Comu *et al.,* (2021) realised that different backgrounds of people such as field experience and education contribute immensely to their concentration levels during safety training sessions. Nykänen *et al.,* (2020) extended the study on the comparison of conventional safety training method and the VR-based safety training method by determining the long-term impact of the training methods as a one-month follow up was conducted on participants of the study.

Design for Safety

Designers can play a huge role in the improvement of construction OSH management with VR, a very useful tool, to aid designers make appropriate decisions leading to safety during the execution of construction works (Sacks *et al.,* 2015). Sacks *et al.,* (2015) therefore conducted pilot tests on designers and construction managers who both have knowledge on safety issues in design and construction as they interact in a virtual construction site and discovered that dialogue makes safety issues in designs more identifiable and clearer, especially for designers. Hadikusumo and Rowlinson (2002) took a different approach in an earlier study as construction practitioners did a walk-through of the VE to identify hazards inherent within the construction components and processes and to determine the necessary and appropriate measures to curb the occurrence of accidents using a design-for-safety-process (DFSP) tool.

Risk Perception and Assessment
Perlman *et al.,* (2014) compared the conventional method and the ImT-based methods through studying to understand how construction superintendents perceive and assess risks on construction sites by presenting subjects with photographs and documents while some other subjects explored the VE. Most of the subjects successfully identified hazards in the VE than the hazards in photographs and documents (Perlman *et al.,* 2014). Lu and Davis (2016) used a different approach by adopting the use of sound to understand how sounds affects the level of risk perception and assessment of construction workers by adding sound to the VR simulator for a set of subjects while the other subjects had no sound included in the VR simulator. It was discovered that participants without the sound experience communicated more to the investigator whenever they perceived risks than participants experiencing sound (Lu and Davis, 2016).

General Safety
Akinlolu *et al.,* (2020) conducted a bibliometric review on industry 4.0 technologies including VR for construction health and safety management and the review revealed that the application of these technologies has greatly improved the health and safety issues in the construction industry. It was also observed that there is an underrepresentation of the application of industry 4.0 in Africa in literature when compared to other continents (Akinlolu *et al.,* 2020). Li *et al.,* (2018) however conducted a critical review focusing mainly on VR and AR in addressing construction safety issues in academic studies. It was discovered that academic studies on VR and AR for construction safety has been conducted from various views which includes safety enhancement mechanisms and technology characteristics with proven efficiency of VR and AR in the general construction safety areas (Li *et al.,* 2018).

Types of OSH Hazards Addressed by Immersive Technologies

As observed in literature, the OSH hazards addressed by ImTs are struck-by hazards (Kim *et al.,* 2021), electrical hazards (Zhao and Lucas, 2015), fall (Bosché *et al.,* 2016) and slips/trips (Afzal and Shafiq, 2021). The various types of hazards could be the reason several studies are looking to improve construction OSH through various initiatives including proposing the use of VR simulation for safety training to mitigate the hazards owing to previously reported effectiveness of VR for construction safety training (Zhao and Lucas, 2015). The leading cause of fatalities and injuries in the construction industry is falling from elevated surface (Habibnezhad *et al.,* 2021). This explains the high number of publications that have focused on fall hazard as depicted in Figure 4. Habibnezhad *et al.,* (2021) therefore proposed a VR simulator in determining the impact of high elevation on gait metrics.

Alternatively, to address fall hazards, Bosché *et al.,* (2016) conducted a study on the use of MR technology to provide trainees exposure on working conditions at height with positive feedback from the test subjects as they affirmed that the MR system can prepare trainees for working at height conditions that they will later experience in a real construction site. A VR environment that simulates the activities of the construction and maintenance of road construction was created which exposed participants to struck-by hazards (Kim *et al.,* 2021).

The result of the study revealed that 90% of the participants became more cautious of the work environment after being struck by a construction vehicle in the virtual road construction site. A study by Dai *et al.,* (2021) was conducted to understand the potential in MR for the effective visualisation, communication, and collaboration on general construction safety issues as participants who were experienced construction workers in various roles were made to communicate on potential hazards, violations, and suggested preventive measures. Upon the conclusion of the study, it was discovered that MR has a great potential for the effective communication of general construction safety issues amongst workers when compared to communication via phone calls, emails, walking up to people and video conferencing (Dai *et al.,* 2021).

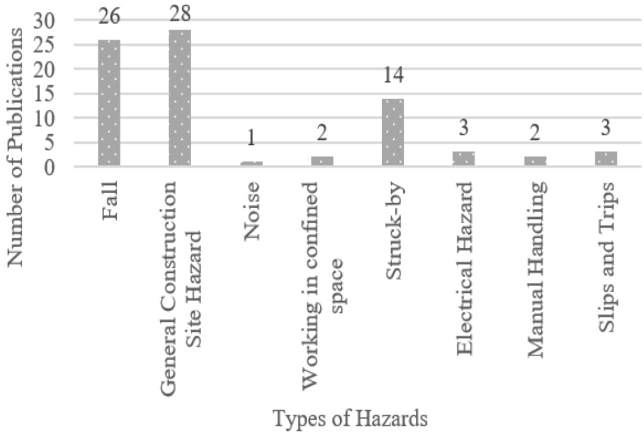


Figure 4: Distribution of publications with the types of hazards addressed

Limitations of Studies and Future Research Directions

The findings from many of the research studies are based on a relatively small number of subjects (Habibnezhad *et al.,* 2021). Some participants of studies experienced headache, eye stress, dizziness and discomfort while using ImTs (Bhagwat *et al.,* 2021). Some studies also researched students rather than industry practitioners (Jeelani *et al.,* 2020) which might therefore not be a true representation of the study outcome. Another limitation observed from the literature is that studies could not expose participants to real-life hazard types such as fall hazards (Eiris *et al.,* 2020) which could affect the study outcome. This is due to the high computational costs and long development times that are involved in simulation an absolute real-life scenario as this would require the geometrical modelling and the assembling of various construction elements in the VE (Eiris *et al.,* 2020). In addition, despite the immense benefits of applying ImTs, the industry has been very slow in adopting these technologies for construction OSH management and this, therefore, needs to be tackled to improve the statistics on construction OSH. Furthermore, as shown in Figure 4, most of the studies have focus on safety-related hazards, with very few exploring the use of ImTs to address health-related hazards.

In view of the discussed limitations, future studies should focus on investigating the transition from research to industry practice. Future studies should also examine the effectiveness of ImTs for addressing health-related conditions (e.g., musculoskeletal disorders) given their prevalence in the construction industry (Health and Safety Executive, 2015). Aligned to this, further research should also be conducted on how VR, AR and MR can be applied for health hazard identification, risk assessment and control and health training on construction sites. Studies should also be conducted to compare the relative performance and effectiveness of the various ImTs (i.e. VR, AR and MR) for construction OSH management.

CONCLUSIONS

In this study, an extensive review of the application of ImTs for construction OSH management was conducted, which identified the major OSH areas including safety training, risk perception and assessment, hazard identification and visualisation, design for safety and general safety. The review also identified the types of OSH hazards that were addressed using ImTs, including falls from heights, slips and struck-by hazards. Various technologies were used to implement the ImT environment and for the effectiveness of ImTs for construction OSH management. The review revealed immense benefits of applying ImTs for construction OSH management compared to the traditional methods commonly used by the industry. Each year, researchers are ever more interested in the use of ImTs for construction OSH management, especially in the last 6 years, as this study reveals a research increase from 2017 to 2021 with an undulating trend from 2001 till 2016. However, further works need to be done as regards research areas such as investigating the low level of transition from research to industry practice, study of the effectiveness of the use of ImTs for addressing health hazards; and studying the relative performance/effectiveness of the various ImTs (i.e. VR, AR and MR) for construction OSH management. Further works that incorporate bibliometric analysis can be done to augment the insights offered by this study. In addition, other systematic reviews could focus on the broader scope of Industry 4.0 or its sub-domains/concepts such as cyber-physical systems (CPS) and digital twins (DT) to further understand their role in construction OSH management.

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DETERMINANTS OF ALCOHOL RISK OF HARM PROFILES AMONG SOUTH AFRICAN CONSTRUCTION WORKERS

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Excessive alcohol consumption is a global public health concern. Aside of its adverse health effects, it is also associated with risky sexual behaviours and lower levels of HIV testing. Using data obtained from 450 workers drawn from 18 construction sites in the Western Cape, the Alcohol Use Disorders Identification Test (AUDIT) was used to predict alcohol risk of harm profiles as a function of demographic characteristics and sex-related behaviours among site-based workers. Logistic regression was used to determine factors associated with increased risk of alcohol harm. Determinants of alcohol risk of harm were (ordered from most to least proximal) frequency of alcohol or drug use before and/or during sex, attitude toward condom use, education, and HIV testing behaviour. The complexities associated with workplace interventions are highlighted.

Keywords: alcohol consumption; determinants; alcohol; risk of harm; site-based

INTRODUCTION

Excessive alcohol consumption has been identified as a global public health concern by the World Health Organisation (WHO 2018). In 2016, an estimated 5.3% of all global deaths and 5.1% of the global burden of disease and injury was determined to be associated with alcohol, as measured in disability-adjusted life years (DALYs). In South Africa, the burden of disease attributable to alcohol use has been estimated at 7.1% of all national deaths and 7.0% of total DALYs. Peltzer *et al.,* (2011) found that approximately 27.7% of all South Africans are frequent consumers of alcohol. Their study also showed that alcohol consumption differed by age, gender, population group, locality type, province, education, employment, and income status. Other behaviours linked to alcohol use are behaviours associated with an increased likelihood of HIV infection, such as the use of alcohol before or during sex, multiple and concurrent sex partnerships, and non-condom use (Parry *et al.,* 2010).

Health and safety is a major concern in construction. Potential hazards of working in the industry include working at elevated heights; exposure to the elements; the use of

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hand-held powered tools; as well as the operation of moving plant and equipment. The use of alcohol before or during work has been shown to cause serious accidents in the workplace and has also been linked to reduced productivity (Burnhams *et al.,* 2014). Furthermore, people who work in jobs involving physically taxing labour have been found to be more likely to have alcohol dependency problems than are persons who work in jobs that pose less physical risk (Lehman and Bennett 2002). Despite the physical nature of construction work, little is empirically known about alcohol consumption among employees in the SA construction industry. Thus, in this study, we sought to examine the predictive relationship between harmful alcohol consumption, demographic factors, and HIV-related health behaviours among workers in the South African construction industry.

LITERATURE REVIEW

Relationship Between Harmful Alcohol Consumption and HIV-related Health Behaviours

Baliunas *et al.,* (2009) investigated the association between HIV incidence and alcohol consumption, finding that, in general, alcohol consumption increased the risk of HIV infection. Specifically, alcohol consumers were found to have a 77% higher risk of acquiring HIV than did non-drinkers. Furthermore, those consuming alcohol prior to, or at the time of, sexual relations, were at an 87% increased risk. Parallel results were found in studies investigating the relationship between alcohol use and unprotected sexual behaviour among people living with HIV (PLHIV) (Shuper *et al.,* 2009). Similarly, in the construction industry, Bowen *et al.,* (2017) have found that workers reporting higher levels of alcohol and drug use also reported significantly higher levels of risky sexual behaviour.

Townsend *et al.,* (2010) demonstrated the link between harmful alcohol consumption and choice of sexual partner and found that problem drinkers were more likely to report having had at least one once-off sexual encounter in the past three months. Kader *et al.,* (2014) found that harmful alcohol consumption was significantly related to the health status of patients attending HIV clinics, with participants at medium to high risk of alcohol harm less likely to adhere to their anti-retroviral (ARV) treatment regimen. Based on this and other research evidence, the following hypotheses were postulated:

H1: Respondents that have previously had an HIV test are less likely to present with a moderate to high alcohol risk of harm profile.

H2: Respondents with a high negative attitude toward condom use are more likely to present with a moderate to high alcohol risk of harm profile.

H3: Respondents who frequently use alcohol or drugs before and/or during sex are more likely to present with a moderate to high alcohol risk of harm profile.

Relationship Between Harmful Alcohol Consumption and Demographic Factors in South Africa

Harmful alcohol consumption has been found to be associated with socio-demographic factors, including gender, relationship status, settlement type, age, occupation category, education, and income level. Nationally, the Western Cape has been identified as having the highest rates of harmful alcohol consumption (Adams *et al.,* 2014). Peltzer *et al.,* (2011) found that harmful alcohol consumption was higher among men than women across all nine South African provinces. They also noted that while harmful alcohol consumption did not differ across age groups for women, it was significantly greater among males older than 20 years compared with males between 15 and 19 years.

Peltzer *et al.,* (2011) found that harmful alcohol consumption was significantly higher among Coloured men than among Black African men. Regarding education, men who had completed primary school, but who had not completed secondary school were more likely to be more harmful consumers of alcohol than men who had only primary education and men who had completed secondary school (Peltzer *et al.,* 2011). On the other hand, in the construction industry, Bowen *et al.,* (2014) found that higher levels of education were associated with higher levels of alcohol consumption among both male and female workers. The association between marriage status and alcohol risk of harm is not clear in South Africa, but it is possible that there is a significant association especially when considered within the national context of high levels of intimate partner violence and relationship power inequity (Jewkes *et al.,* 2010).

The association between employment status and harmful alcohol consumption is mixed. Despite this ambiguity, being employed was found to be more strongly associated with alcohol drinking than being unemployed (Walia *et al.,* 2021, Ragnarsson *et al.,* 2010). Based on existing research evidence, the following hypotheses were postulated:

H4: Age is positively associated with moderate to high alcohol risk of harm.

H5: Black Africans are less likely to have moderate to high alcohol risk of harm profiles compared to “Others”.

H6: Education is positively associated with moderate to high alcohol risk of harm.

H7: Respondents who are single are more likely to present with moderate to high alcohol risk of harm profiles compared to respondents in married/long-term relationships.

H8: Workers on permanent contracts are more likely to present with moderate to high alcohol risk of harm profiles compared to workers on casual or temporary contracts.

METHOD

Instrument and Measures

Field-administered survey questionnaires were used to collect data. Table 1 lists the variables, sample items, and point of scales. The questionnaire was based on an instrument originally developed by Bowen *et al.,* (2015) and in a modified and expanded form by Yakubu *et al.,* (2021). In all instances, higher scores indicate higher levels of the construct of interest. Alcohol risk of harm was assessed using the 10-item Alcohol Use Disorders Identification Test (AUDIT) (Saunders *et al.,* 1993). Negative attitudes towards condom use were measured using a 5-item scale (Roy *et al.,* 2013), and alcohol and drug use before and/or during sex was assessed using a 6-item scale (Turchik *et al.,* 2010).

In this study alcohol risk of harm was represented by a quantitative variable and so refers to a respondent’s total AUDIT score. The AUDIT scores range from 0 - 40, with the following thresholds for level of alcohol risk of harm: 0-7 (low risk of harm); 8-15 (moderate risk of harm); 16-19 (high-risk or harmful level); and 20 or more (dependence likely). For the logistic regression, we compared low risk of harm against moderate to high risk of harm, and so the 4 categories were transformed into two categories as follows: 0-7 (low risk of harm) versus moderate to high risk of harm (8 or more).

Table 1: Demographic, behavioural, and cognitive characteristics and scale items for composite variables (n=450)

Items and Constructs	Sample items	No. of items	Response options and point of scales
1. Demographic characteristics			
Age	-	-	Years
Ethnicity	-	-	'Black' African=1; 'Other'=2
Education	-	-	No formal school education=0; Completed primary school=1; Attended high school but did not complete matric=2; Completed matric=3; Attended university or college, but did not graduate=4; Graduated from university or college=5
Relationship status	-	-	Divorced, separated, widowed, or never married=0; Married or living with a partner=1
Work status	-	-	Casual=1; Contract=2; Permanent=3
2. Behavioural and Cognitive characteristics			
AUDIT alcohol risk of harm assessment (Scale score range: 0-40); α = .89.	*'How often during the last year have you had a feeling of guilt or remorse after drinking?'* [Q18]	10	'Never'=0 to 'Daily or almost daily'=4
HIVAIDS testing status	*'Have you been tested for HIIV'* [Q64]	-	'Never tested'=0; 'Tested'=1
Attitude towards condom use (negative) (CN) (Scale score range: 5-25); α = .85	*'Using condoms makes sex unenjoyable'* [Q36c]	5	'Strongly disagree'=1 to 'Strongly agree'=5
Alcohol and / or drug use before and / or during sex (AD) (Scale score range: 6-30); α = .84	*'How often have you [your partner] used both alcohol and drugs before or during sex?'* [Q44l and Q44o]	6	'Never'=1 to 'Always'=5

Note: Question number references are given in parentheses.

Data Collection

Participants were drawn from 18 construction sites in the Western Cape, involving 7 construction firms. The purposive sample consisted of all male employees of each construction company present on site on the day scheduled for the visit by the field researchers. The survey questionnaire was available in three of the eleven official languages of South Africa, namely, Afrikaans, English and isiXhosa. These are the most-commonly spoken languages in the Western Cape region. A total of 576 questionnaires were administered and after accounting for missing data we had a usable dataset of 450 participants.

Data Analysis Methods

Confirmatory factor analysis (CFA) (weighted least square mean and variance adjusted (WLSMV) estimator) using Mplus 8 (Muthén and Muthén 2017) was first conducted to verify the factorial structure of measured items underlying the three latent variables. The WLSMV estimator makes no distributional assumptions about the observed variables. Five critical model fit indices were applied to determine the degree of model fit as follows: $\chi2$/df ratio (less than 4); the Tucker Lewis TLI (non-normed fit index (0.95 and greater)); Bentler CFI (comparative fit index (0.95 and greater)); RMSEA (root mean square error of approximation (0.08 and less)); and the SRMR (Standardized Root Mean Square Residual) index (0.08 or less). A factor loading of 0.5 is minimally accepted, with a loading of 0.7 being considered satisfactory.

Once the factorial structure had been validated, the determinants of alcohol risk of harm as a function of demographic, behavioural, and cognitive characteristics were explored using logistic regression. Unweighted scale scores were developed for each of the AUDIT (10-items: range 0-40), negative attitude to condom use (5 items: range 5-25) and alcohol and drug use before or during sex (6 items: range 6-30). Higher scale scores indicate greater levels of the construct of interest. For the scale scores of each of the negative attitude to condom use and the alcohol and drug use before and/or during sex scales, a median-split method was used to position the responses for the scale into one of two (categorical) groups, namely, values falling below the median and values equal to or exceeding the median - specifically, low negative attitude to condom use versus moderate to high negative attitude; and low use of alcohol and drugs before and/or during sex versus moderate to high use. Logistic regression does not make assumptions concerning the distribution of scores for the predictor variables but is sensitive to high correlations among predictor variables.

FINDINGS

Sample Characteristics

All participants were male, aged 18-67 years (M=35.4; Md=34). More than half (n=268; 59.6%) had at most primary school level education, were single (n=230; 51.1%), and were "Black" African (n=262; 58.2%). A majority were permanent staff (n=213; 47.3%), 182 (40.4%) were employed on a contract basis, and 55 (12.2%) were casually employed. A minority (n=128; 28.4%) had never had an HIV test, approximately half (n=223; 49.6%) held high negative attitudes to condom use, and nearly half (n=222; 49.3%) indicated moderate to high use of alcohol and drugs before or during sex.

Regarding alcohol consumption, nearly half (n=221; 49.1%) of the survey participants reported that they never consume alcohol. Including these abstainers, a total of 334 (74.2%) participants were classified according to the AUDIT thresholds as low risk (score <8). The at-risk workers were categorized as follows: 18.7% (n=84) at medium risk (score 8-15); 3.3% (n=15) at high risk (score 16-19); and 3.8% (n=17) at very high risk (score 20+). Of the 229 (50.9%) workers who reported using alcohol, 32 (14.0%) (score 16+) may be categorized as being at high-to-very high risk. In summary, 25.8% (n=116) (score 8+) of construction participants may be classed as engaging in harmful alcohol consumption

Confirmatory Factor Analysis

Output indices for the 21-item, 3-factor model indicated a good fit to the data ($\chi 2$/df ratio = 2.995; TLI = .956; CFI = .961; RMSEA = .067 CI 90% (.060 - .073); and SRMR = .086. All items loaded strongly onto their respective factors (> .7), and all factor loadings were statistically significant ($p < .001$). No modifications were necessary, and the dimensionality of the model was deemed tenable.

Logistic Regression Analysis

None of the correlations among the predictor variables were high, with the vast majority being small. Based on the hypotheses, a binary logistic regression analysis was specified and tested. A test of the full model against a constant-only model was statistically significant, indicating that the predictors, as a set, reliably distinguished between workers who had low alcohol risk of harm profiles from those with moderate to high alcohol risk of harm profiles ($\chi2 = 53.716$, $p < .001$ with $df = 12$). The -2 Log Likelihood was 295.621. The Hosmer and Lemeshow Goodness-of-Fit test ($\chi2 = 6.165$, $p = .629$ with $df = 8$) indicated a good fitting model. A summary of the testing outcomes of the hypothesized relationships is presented in Table 2.

Statistically significant unique contributions were made by education ($\chi2 = 6.282$, $p < .05$ with $df = 1$), HIV tested or not ($\chi2 = 5.049$, $p < .05$ with $df = 1$), a negative attitude to condom use ($\chi2 = 8.199$, $p < .01$ with $df = 1$), and alcohol and drug use before and/or during sex ($\chi2 = 25.015$, $p < .001$ with $df = 1$). Age, ethnicity, relationship status, and work status failed to make a uniquely statistically significant contribution to the prediction of alcohol risk of harm.

Table 2: Summary of hypothesis testing

Hypotheses	Results
H1: Respondents that have previously had an HIV test are less likely to present with a moderate to high alcohol risk of harm profile.	Partially Supported*
H2: Respondents with a high negative attitude toward condom use are more likely to present with a moderate to high alcohol risk of harm profile.	Supported
H3: Respondents who frequently use alcohol or drugs before and/or during sex are more likely to present with a moderate to high alcohol risk of harm profile.	Supported
H4: Age is positively associated with moderate to high alcohol risk of harm.	Not Supported
H5: Black Africans are less likely to have moderate to high alcohol risk of harm profiles as compared to "others".	Not Supported
H6: Education is positively associated with moderate to high alcohol risk of harm.	Supported
H7: Respondents that are single are more likely to present with moderate to high alcohol risk of harm profiles as compared to respondents in married/long-term relationships.	Not Supported
H8: Workers on permanent contracts are more likely to present with moderate to high alcohol risk of harm profiles as compared to workers on casual or temporary contracts.	Not Supported

* The association between alcohol use and HIV testing behaviour was confirmed, but respondents that have previously had an HIV test were found to be more likely to present with moderate to high alcohol risk of harm profile than were their counterparts.

The odds of being classified at low risk of alcohol harm is 2.4 times higher among male construction workers who have completed or been exposed to primary school education compared to those who have completed or been exposed to secondary or tertiary level education. A worker who has never had an HIV test is 1.9 times more likely than a worker who has had an HIV test to be classified at low risk of alcohol harm compared to moderate or high risk. The odds of being classified at low risk of alcohol harm is almost two times higher among male construction workers who hold a low negative attitude towards condom use compared to those who hold a high negative attitude towards condom use.

Finally, workers who report low levels of alcohol and drug use before and/or during sex were found to be 3.3 times more likely than workers indicating moderate to high use of alcohol and drug use before and/or during sex to be classified at low risk of alcohol harm. No significant differences were noted between the categories of age, ethnicity, relationship status, and work status in contrast to their respective reference groups in relation to alcohol risk of harm classification.

DISCUSSION

Our research goal was to develop an approach to profile male workers in terms of their alcohol consumption that is data-driven, informative for programming interventions, and potentially applicable in other contexts.

Moderate to high alcohol risk of harm was predicted by (in order of most to least proximal): a worker's frequency of alcohol or drug use before and/or during sex, their (negative) attitude toward condom use, level of education, and their HIV testing behaviour. A worker's age, ethnicity, relationship status, or work status makes no difference in differentiating between low and moderate to high risk of alcohol harm prediction profiles.

Of the five demographic factors included in the predictive model, only level of education was found to be associated with alcohol risk of harm. This aligns with Bowen *et al.,* (2014), who observed a significant predictive pathway between alcohol consumption and education among construction workers in the Western Cape.

The link between education and alcohol use warrants further investigation, however, as it is possible that higher levels of education are associated with greater levels of disposable income and so an increased ability to purchase alcohol, especially in extreme and harmful volumes. Moreover, given that this finding aligns with previous research in the Western Cape construction industry (Bowen *et al.,* 2014), a further implication of this finding is that alcohol risk of harm reduction interventions in the workplace (at least at a provincial level) need to specifically target workers with higher levels of education.

All three behavioural and cognitive factors included in the model were found to be significantly associated with alcohol risk of harm. Harmful alcohol use has been previously linked to HIV transmission in sub-Saharan Africa. A significant positive association has been found between alcohol use, risky sexual behaviour, and HIV infection across multiple settings (see Morojele *et al.,* 2013). The literature also suggests that people who consume higher levels of alcohol will be less likely to undertake voluntary HIV testing (Peltzer *et al.,* 2010). Our study confirms the association between alcohol use and HIV testing behaviour; however, it also offers an interesting insight over previous research. Specifically, we observe that workers who reported that they had previously had an HIV test were more likely than workers who had never had an HIV test to present with a moderate to high risk of alcohol harm profiles. While this association may appear to be counter-intuitive, it may be partly explained by sex-related alcohol expectancies (see Celio *et al.,* 2016).

An association was detected between possessing a negative attitude towards condom use and risk of alcohol harm. Respondents with higher negative attitudes towards condom use were determined to have higher odds of having a moderate to high risk of alcohol harm profile than did those who had more positive attitudes towards condom use. This corresponds with the findings of Townsend *et al.,* (2010).

The behaviour with the strongest effect size of association on alcohol risk of harm was determined to be the use of alcohol or drugs before and/or during sex. This corresponds with the findings of Bryan *et al.,* (2007).

CONCLUSIONS

This study has several implications for policy and practice. First, given that there are not many South African workplace interventions that address substance abuse (alcohol and drugs) and HIV in a single programme (see Burnhams *et al.,* 2013), this study provides an evidence base for an intervention formulated on the growing understanding of the nexus between substance abuse and HIV. Such interventions should include risk of alcohol harm messages embedded in a wider health promotion framework which focuses on topics such as HIV, sexual and reproductive health, and other aspects of wellness.

Second, despite the need to target 'at-risk' groups, the lack of association of demographic factors including age, ethnicity, relationship status, and work status with the measure of risk of alcohol harm, is an indication that interventions need to expand their scope beyond simply identifying and targeting at risk demographic groups. Further research is needed to examine the clustering of multiple behaviours, and in particular the association of cognitive and behavioural factors with harmful alcohol use.

Finally, the psychometric approach to evaluating alcohol risk of harm using AUDIT allows for greater confidence in the use of the scale across additional regions in Southern Africa to assess and diminish the pervasive effects of alcohol abuse.

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DESIGN FOR SAFETY ORGANISATIONAL CAPABILITY IN MALAYSIA: A MULTI-STAKEHOLDER PERSPECTIVE

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Since the introduction of Occupational Safety and Health in Construction Industry (Management) (OSHCI(M)) in Malaysia, little effort has been made to capture the current state of construction organisations' Design for Safety (DfS) capability towards fulfilling the stipulated requirements. Therefore, this paper aims to discuss the current state of six DfS organisational capability elements (i.e., competency, corporate experience, collaboration, infrastructure, strategy, and system) among key construction stakeholders in Malaysia. Based on the online questionnaire survey, the findings indicated that all 18 attributes under the six main elements are important in determining an organisation's ability to practise DfS. Additional initiatives such as incentivisation, early education; practical guidance, professional training, and enforcement were also required to enhance the existing DfS frameworks. The findings from this study have salient implications in enhancing the ability of construction organisations in Malaysia to instil DfS practices from the upstream stages of typical projects lifecycles.

Keywords: design for safety; safety and health; organisational capability; Malaysia

INTRODUCTION

The construction industry has long been suffered from the organisational inability to manage workplace safety and health as a collective endeavour. The fact that managing occupational safety and health (OSH) is a traditional concern in the construction industry, continuous efforts by governments worldwide have led to the introduction of innovative OSH practices. These efforts are reflected in the establishment of the Design for Safety (DfS) concept which is known as Safe Design in Australia and New Zealand, Prevention through Design (PtD) in the United States and Construction Design and Management (CDM) in the UK. The DfS concept has been promoted via different forms of frameworks, for instance as a legislation (where DfS is legally enforceable) such as the CDM regulations in UK and as a guideline (non-mandatory or voluntary basis) such as the Occupational Safety and Health in

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Construction Industry (Management) (OSHCIM) in Malaysia and the Guidelines for addressing occupational hazards and risks in design and redesign processes in the United States. The DfS concept is often seen as a preventive practice, where OSH risks and hazards are mitigated or eliminated in the early phases of project lifecycle. While DfS practices promote the collective prevention practice among project stakeholders (Che Ibrahim *et al.,* 2022), design organisations have specific responsibilities which is, as far as practicable in the design phase, to mitigate OSH hazards during the construction, operation and occupation phase of a building or structure (Schulte, 2008).

LITERATURE REVIEW

Although the role of organisations has been highlighted in DfS-related legislations in reducing accident occurrences (Health and Safety Executive, 2015; Gambatese *et al.,* 2017), there are still limitations and challenges that continually emerge in various contexts (e.g., concept, processes, legislation, regulatory requirements, collaboration, technologies, early and continuous education etc) that affect the organisational capability in DfS implementation. The ambiguity associated with regulatory prescriptions of competence and its assessment, have contributed to the inability of design organisations to fulfil their duties under the DfS-related legislative / guideline framework (Manu *et al.,* 2019; Che Ibrahim and Belayutham, 2020; Adaku *et al.,* 2021). The lack of clarity on the required DfS capabilities, coupled with the misconceptions, mindset, and ownership among design organisations (Behm *et al.,* 2014; Manu *et al.,* 2021), as well as the lack of competence (knowledge, skills and experience) among designers in addressing the OSH issues during the design phase (Morrow *et al.,* 2016; Che Ibrahim *et al.,* 2021) could further impede the progress of DfS diffusion.

A review of related literature has highlighted that there is a growing body of DfS research in developed countries especially UK, USA, and several countries within the European Union (Manu *et al.,* 2021), and it is still a growing area of research and practice in many developing countries including Malaysia, whereby DfS concepts remain underdeveloped. Against this backdrop, there's been significant upgrades to the existing OSH guideline in Malaysia, to better encapsulate DfS principles and practices (Che Ibrahim *et al.,* 2020). Specifically, the OSHCIM has been introduced in 2017 as part of DfS practice to enhance the capability of construction stakeholders in improving the safety performance of the construction industry. The fact that OSHCIM is relatively new to the industry, most players within the industry are still unclear about the DfS subject (Che Ibrahim *et al.,* 2020; Ismail *et al.,* 2021; Che Ibrahim *et al.,* 2022). Thus, the need to capture the state of DfS capability of Malaysian organisations in fulfilling the OSHCIM requirements highlighted in Sections 3.1 and 3.2 of the guidelines.

Although there have been several studies related to DfS in construction studies, empirical studies related to DfS capability at the organisational level is still limited. This limitation could hinder the actual capabilities in relation to DfS practices as different disciplines of professional might influence the level of specificity (i.e., task, project, programme, and portfolio) of organisational capability (Adaku *et al.,* 2021). Also, different geographical contexts (e.g., legislations, safety requirements, public procurement) might influence the dynamism of organisation to undertake OSH exercises (Oney-Yazici and Dulaimi, 2015; Goh and Chua, 2016). Although existing DfS studies on organisational capabilities (e.g., Manu *et al.,* 2019; Poghosyan *et al.,*

2020) provide a useful insight into the organisational capability landscape, the findings in these studies were mostly framed based on responses from the UK (where DfS practise is well established in CDM regulations) and, thus, these studies were limited in terms of responses from those countries where DfS legislations are non-existent or have recently been developed. Thus, to fill the identified gap within the existing body of DfS knowledge, the aim of this study is to investigate the DfS organisational capability among the key stakeholders in Malaysia.

The key elements of OSHCIM are as follows, where OSHCIM: Applies to design, construction, maintenance, and demolition phases (full cycle); Focuses on planning, design and management of construction projects; Sets the standard/objective to achieve, but not how; and Main responsibility to the client/developer, principal designer and principal contractor. OSHCIM has similar characteristics to the CDM in the UK, owing to its adaptation of CDM regulations 2015 (CIDB, 2019). This study has adopted a theoretical framework based on empirical organisational DfS capability related studies (see Manu *et al.,* 2019; Adaku *et al.,* 2021) as a foundation to construct an OSHCI(M) organisational maturity framework. A recent study by Manu *et al.,* (2019) identified six key elements related to organisational DfS capability (see Fig. 1): 1) Competence; 2) Strategy; 3) Infrastructure; 4) System; 5) Collaboration and 6) Corporate Experience. These elements went through an extensive process of validation and verification through three focus group sessions with eight UK construction and OSH professionals, as well as three rounds of Delphi survey involving 28 - 32 experts. As the UK has been implementing CDM regulations for the past two decades and has demonstrated a significant reduction in risk at the source (CIDB, 2019), the elements identified and verified by Manu *et al.,* (2019) would be a useful foundation for this DfS study.

Table 1 depicts the alignment of the key elements of DfS organisational capability with the OSHCIM principles (as stipulated in section 1.2 of the Guidelines on OSHCIM 2017) to ensure the validity of these elements on the principle of OSHCIM. All six elements can address the five OSHCIM principles.

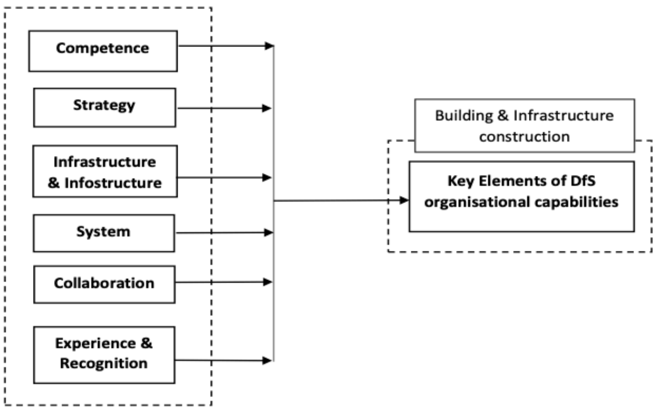

Figure 1: Key elements of DfS capability within an organisation (adapted from Manu et al., 2019 and Adaku et al., 2021)

METHOD

In view of the research aim to obtain a generic understanding of context pertaining to the knowledge gap on the current state of DfS organisational capability in Malaysia, a quantitative approach using questionnaire survey was adopted for this study. Such approach is deemed suitable because it able to elicit the perception of stakeholders against specific attributes (Fellow and Lui, 2015). An online questionnaire survey was developed and administered through SurveyMonkey platform to multiple stakeholders, using a purposive sampling approach.

Table 1: Mapping between key elements of DfS organisational capability and OSHCIM principles

Key Elements of DfS Organisational Capability	OSHCIM Principles (As stipulated in section 1.2 in Guidelines on OSHCIM 2017)				
	Risk management approach and general principles of prevention	Appointing the right organisations and people	Supervision, instruction, and information	Cooperating, communicating, and coordinating	Consulting and engaging with workers
1. Competence i.e., the competence of organisation's designer in respect of DfS	√		√		√
2. Corporate Experience i.e., Organisation's experience in implementing DfS on projects		√	√	√	√
3. Multidimensional Collaboration i.e., inter and intra organisational collaboration within the project				√	√
4. System i.e., organisation's systems, processes and procedures required for DfS	√		√	√	
5. Infrastructure i.e., organisation's physical and dynamic information and communication technology (ICT) resources required for DfS	√			√	
6. Strategy i.e., the consideration of PtD practice in organisation's vision as well as the top management support for DfS		√			√

The first section of the questionnaire was designed to identify the demographic characteristics of the respondents, while the second section included descriptions on the extent to which the respondents consider the organisational capability attributes (adopted from Manu *et al.,* 2019) as important towards DfS practice in the Malaysian construction industry in the form of a five-point Likert-scale (1 = not at all important, 2 = least important, 3 = important, 4 = very important and 5 = extremely important). In the third section, the respondents were asked to rate their level of agreement regarding the influence of each of the described factors for DfS implementation.

The initial invitation was sent to over 150 potential respondents through an industrial network of experts that have previously attended OSHCIM workshops and seminars. Out of the 150 potential respondents, 90 responses were received and 82 were useable responses. The number of useable responses is considered appropriate when compared to the number of responses from other DfS studies (e.g., 73 responses reported in DfS studies in Kuwait (Sharar *et al.,* 2022) and 46 responses reported in DfS studies in Singapore (Goh and Chua, 2016)).

The responses, collected in Excel format, were then exported to IBM SPSS Statistic 26 Software to conduct descriptive statistical analysis (e.g., frequency, mean, percentages, and standard deviation) and inferential analysis to ascertain variations in DfS attributes across organisations.

From the 82 responses received, 58.5% and 41.5% of the respondents were male and female respectively. The response also depicted that respondent possessed an average of 13 years' experience within the construction industry. The respondents have described their organisations as contractor (42.7%), government agencies (24.4%), consultant (20.7%) and developer/owner (12.2%). It is worth noting that 42% of the respondents were registered as a professional (e.g., professional engineer, architect, surveyor, and technologist) under their respective professional bodies.

FINDINGS

Key elements of DfS organisational capability

Table 2 presents the results of the questionnaire survey on the key elements of DfS organisational capability. To demonstrate variations between designers, the mean values were divided into four key stakeholders in the construction industry: G1 (Contractor), G2 (Consultant), G3 (Government Agencies), and G4 (Developer/Owner). Based on this analysis it should be noted that the top five elements of DfS organisational attributes were dominated by top management commitment, design risk management and competency-related elements. From the analysis, commitment from top management (mean = 4.402) is the most important capability. It is acknowledged that the commitment from top management is one of the most important attributes for driving DfS related initiatives (Gambatese *et al.,* 2017). Such commitment in terms of proactive leadership and higher expectation for worker safety and health could positively impact the culture of DfS practice within the organisation.

The need for an organisation to ensure that their designers are fully equipped with such knowledge, experience, and skills (identified as second, third and fourth most important capability, respectively) has been explicitly highlighted in several DfS legislative / guideline frameworks. For example, in Regulation 8 within the Construction Design and Management (CDM) regulations 2015 in the UK; Section 3 on OSHCI(M) guideline in Malaysia; Part 3 - Duties of Designer and Contractor (regulation 9) under the WSH (DfS) Regulations in Singapore; and Part 2 - Health and Safety Duties (Section 22) of Work Health and Safety Act 2011 in Australia. A recent study by Che Ibrahim *et al.,* (2020) emphasised that DfS practice requires diverse capabilities (including design, constructability, organisational, human, technologies, and life cycle management), a wider range of competencies related to construction, design, hazard and risk, as well as other factors (e.g., procurement strategy, regulations, economic and social impacts, and management practices) in order to facilitate organisational DfS implementation (Che Ibrahim *et al.,* 2022).

The capability of having proper design management system (mean = 4.293) was fifth position from the list. Researchers (e.g., Che Ibrahim and Belayutham, 2020; Manu *et al.,* 2021) have emphasised that the lack of sufficient knowledge and skills among the design professionals is significant. This evidence has led to the need to have access to prescribed design management system in managing the DfS. Such a system could act as a foundational platform for designers to follow a structured and systematic risk identification and assessment process during the design phase with a high level of constructability (Toole *et al.,* 2017). Moreover, ability to integrate such systems in the activities could provide long-term positive impacts on project cost and duration (Gambatese *et al.,* 2017). It should also be noted that the two elements of least importance are corporate experience and research and innovation. The former could be because DfS is still relatively new and real-life impact case studies from Malaysia are scarce, making it challenging for organisations in Malaysia to quantify DfS values.

Upon further analysis with ANOVA test to examine the differences in perceived importance of the DfS organisational capability elements across the four groups of organisations (see Table 2), it was found that there was no statistical difference between the 18 sub-elements ($p>0.05$). However, some notable findings (mean value less than 4.000) are worth mentioning, particularly those from government agencies, where intra and inter-organisational collaboration elements received lower responses. This suggests that those working in government-related organisations are having slightly different views regarding the significance of inter-organisational collaboration to DfS implementation, owing to their fragmented experience managing projects through traditional procurement. On the other hand, the mean value for sub-element of physical work resources for consultant is 3.647 which are slightly lower than those of the other organisations and the overall values of 4.049. Such results may imply that professionals working in design organisations may not require a physical workspace/workstation and equipment in the office to support DfS, owing to less face-to face interaction and working from home policies due to the recent COVID-19 pandemic.

Factors influencing DfS implementation

Having identified the DfS organisational capability, this study also sought to understand the factors influencing DfS implementation. The results indicated that the first key factor is the "Government should provide incentive (e.g., tax deduction, subsidise DfS training) for companies that meet the requirements" (mean =4.146). The findings indicated that having external economic incentives can motivate further the interest of organisation to practice the DfS. Such incentives could be provided not only at the national level but also through local authorities as intermediaries to stimulate further efforts in DfS (Karakhan *et al.,* 2017). The second key factor on the list is the "Inclusion of DfS lessons in the formal education of design professional" (mean = 4.085). The importance of having early DfS learning has been highlighted by scholars (Abueisheh *et al.,* 2020; Che Ibrahim *et al.,* 2021; Adaku *et al.,* 2021) as a mechanism to improve the cognitive, psychomotor, and affective development towards enhancing the DfS principles.

The need for "Industry guidelines / practical guidance or codes for DfS implementation" (mean =4.073) comes third on the list. Previous studies (e.g., Abueisheh *et al.,* 2020; Sharar *et al.,* 2022) in different geographical locations have indicated the availability of DfS guidelines as being influential to DfS implementation. The fourth key factor is the "Professional development training relating to DfS for potential duty holder" (mean = 4.049). As DfS practice is relatively new concept is most countries, such training is critical for organisations to ensure the DfS sustainability and effectiveness. Also, continuous training, whether in-house or external, could provide newly graduated or experienced professionals with a better understanding of their role in fulfilling the requirements as a DfS duty holder (Ismail *et al.,* 2021). The fifth key factor is the need for "introduction of legislation relating to DfS (e.g., mandated legislation and DfS is one of the criteria in tendering)" (mean = 3.963). Such institutional pressure is viewed as a necessary mechanism to augment the country's DfS implementation. It is argued that ignoring the legal mechanism may result in DfS diffusion failing to perform its intended function of improving safety at the beginning of the project lifecycle. It is worth noting that the ANOVA test results showed no statistical difference between 12 factors across four different organisations (p>0.05).

Table 2: The responses on the key elements of DfS organisational capability

Element	*Overall Mean* (n=82)	*Mean values for each organisation* *G1* (n=35)	*G2* (n=17)	*G3* (n=20)	*G4* (n=10)	*Standard Deviation*	*Significant p*
Competency							
DfS skills of designer	4.293	4.371	4.000	4.400	4.300	0.762	0.355
DfS knowledge of designer	4.390	4.371	4.294	4.350	4.700	0.733	0.547
DfS experience of designer	4.329	4.343	4.235	4.300	4.500	0.755	0.850
DfS continuous professional development	4.120	4.114	4.471	3.800	4.100	0.754	0.060
Designer access to competent advice	4.159	4.086	4.235	4.150	4.300	0.711	0.816
Designer recruitment and role definition	4.110	4.057	4.059	4.050	4.500	0.754	0.389
Corporate Experience							
Company/design office experience	3.927	4.057	4.118	3.500	4.000	0.953	0.143
Collaboration							
Intra-organisational collaboration	4.098	4.114	4.235	3.800	4.400	0.747	0.143
Inter-organisational collaboration	3.976	4.029	4.118	3.550	4.400	0.889	0.056
Infrastructure & Infostructure							
Information communication technology	4.085	4.143	4.000	4.000	4.200	0.773	0.839
Physical work resources	4.049	4.314	3.647	3.900	4.100	0.967	0.106
Strategy							
Company policy in relation to DfS	4.183	4.314	4.000	3.900	4.600	0.862	0.106
Top management commitment to DfS	4.402	4.486	4.294	4.150	4.800	0.799	0.160
Research and innovation	3.914	4.059	3.765	3.750	4.000	0.883	0.543
System							
Design quality management	4.159	4.200	4.235	3.950	4.300	0.761	0.555
Design risk management	4.293	4.286	4.294	4.200	4.500	0.745	0.787
Project review	4.195	4.314	4.235	4.000	4.100	0.823	0.574
Management of outsourcing/subcontracting	3.963	4.171	4.000	3.650	3.800	0.974	0.267

CONCLUSIONS

This study has provided an overview of the attributes of organisational capability for DfS implementation from a Malaysian construction organisation's point of view. This study assessed the importance of DfS organisational capability attributes and provided insight into factors influencing DfS implementation using online questionnaire surveys with four different types of construction-related organisations. The findings indicate that all 18 attributes under six main elements are important in determining an organisation's ability to practise DfS. The findings also suggest that despite the perceived DfS benefits, the government and related authorities should consider factors such as incentivisation, early education, practical guidance, professional training, and enforcement in order to further facilitate the development of construction organisations capability towards fulfilling their role as duty holders, as specified in Section 3 of the OSHCIM guideline.

Overall, the consistency of the responses suggests that the nature of the organisations may not have an impact on the capability required for DfS practise. Thus, this study contributed to corroborating the constituents of DfS organisational capability reported in literature the previous research on. It is proposed that any countries with DfS legislation that embed similar characteristics with CDM legislation could adapt this capability framework. Despite some limitations (e.g., locality, balance distribution of sampling size), further research could expand the current study to larger scales with different disciplines of organisations (e.g., architecture, civil and structural, mechanical, electrical quantity surveyor) as well as focusing on qualitative methodologies to facilitate more in-depth findings regarding the DfS organisational capability.

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EXAMINING EXPLOITATION AND ITS INFLUENCE ON CONSTRUCTION SITES IN SOUTH AFRICA

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The purpose of this study was to understand exploitation. Phenomenological research was used in the study. Participants in the interviews answered open-ended questions based on lived experiences on construction sites. Analysis of the data affirmed that exploitation harms the work environment and the image of contractors. For example, people in construction tend to react negatively to instances of exploitation by quitting their jobs when demotivated or causing a scene at work. In contrast, the theoretical argument indicates that respect for persons motivates people in construction to perform better in their work with direct implications for a healthy work environment that saves time and money. By becoming mindful, people in construction will be more aware of situations and how to prevent exploitation on construction sites. Construction managers need to embrace mindfulness and RfP as a prerequisite for safe work performance to build back the economic wiser.

Keywords: exploitation; respect for persons; site work; South Africa

INTRODUCTION

Negative attitudes and actions on a work site reduce morale and team performance. The behaviour that should be of concern to site management is negative acts that are chronic and endemic. If an individual or a team is exposed to negative attitudes, site operations can be derailed. When negative influence takes hold on a worksite, 'learned helplessness', which makes all activities problematic, can ensue (Reason, 2008; Sharman, 2019). Learned helplessness, in the context of this paper on exploitation, is a mental state in which individuals are forced to bear aversive actions or attitudes that are unpleasant because they cannot control the situation. Such situations will proliferate where negativity among workers is allowed to flourish to the detriment of both employers and the employed.

Over two decades ago, it was estimated by the U.S Bureau of Labour Statistics that organisations (regardless of sector) lose a great deal of income annually because of negative attitudes among workers (Topchik, 2001). In his book, Topchik (2001) suggests that managers must address the root causes rather than the symptoms of negative behaviours. In other words, to move forward on a construction site plagued by negativity among its workforce, underlying reasons should be uncovered and eliminated. Widely cited reasons for negative behaviours at work include lost confidence, job anxiety and feeling unappreciated or lost. Some of these reasons are

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linked to a worker feeling exploited either on a construction site or off site. For example, Sharman (2019) explained some of the reasons as follows:

- Lost confidence, which occurs when a worker experiences personal decline in confidence caused by a stagnant role with low interest (being 'in a rut')
- Feeling unappreciated, which happens when a worker is often overlooked for a promotion or upward change in status
- Feeling lost, which occurs when workers feel removed from the core operations and thus become displaced and powerless in the organisation

The above reasons, adapted from Sharman (2019), show that, on a construction site where injuries and illness rates are indicative of the working conditions, the feelings of the workforce matter. People in construction (PiC) have dignity that influences how they feel: valued or exploited. When people, such as PiC, perceive that they are not granted respect as rational beings, as Kant (2013) contended, the idea of being exploited (used) will permeate the workplace (Modarelli, 2006).

Exploitation is the opposite of respect as it involves taking unfair advantage of individuals by manipulating them as a means to an end, whereas Kant (2012) clearly says "always treat the humanity in a person as an end". It is also notable that respect takes different forms. Some people are respected for their upright character, and others for their unique achievements (Buss, 1999). For others, respect is shown because it is the right way to treat people. People want to be treated with respect, but people differ and not everyone perceives the action of respect in the same way. Thus, it is necessary for everyone (including PiC) to take into consideration how a person will perceive respect from others (Haydon, 2006). It is argued in this paper that, regardless of job title or position on a construction site, everyone deserves to be treated with respect.

It is essential to remember that all people are unique individuals, who deserve to be treated as ends (Kant, 2012). Most employees want to perform well in their job, tasks, and responsibilities. They do not want to feel unappreciated, lost or exploited. To understand the phenomenon better in the South African construction context where casualisation and poor working conditions continue to marginalise PiC (Mollo and Emuze, 2017), a descriptive study was conducted in 2020. The general trend of having a large layer of unskilled site workers hired on daily or short-term contracts exposes PiC to indecent practices such as poor payment, late payment or no payment for work done as cited by Mollo and Emuze (2017). One interviewee in the study reported by Mollo and Emuze (2017: 2021) said:

> "…one of my clients once took me to renovate his house, painting, and to install new tiles. After I completed the work, he paid me half of the agreed payment and promised to pay me the rest of the money in town. And when I arrived in the town, he instructed me to wait for him, as he was going to withdraw money from the ATM. And that was the last time I saw him, as he drove away without saying any word."

The above quote shows that some employer of casual workers in construction are exploitative. The episode may be widespread in an industry where major construction firms only retain core workforce (such as quantity surveyors, site managers, and skilled artisans) to limit overhead cost (Cottle, 2013).

Therefore, the study that is presented in this paper was undertaken to respond to the question: What is exploitation and how do PiC react to it on construction sites? The purpose of the study was to understand exploitation and explore how RfP and mindfulness can be used to chart the way forward in South African construction. The phenomenological method used in the study is outlined in the next section of the paper followed by a succinct presentation of the results. The discussion, which is focused on RfP and mindfulness, provides a platform for making concluding remarks.

METHOD

Phenomenology as a theoretical position was used to drive the reported study, where exploitation was the phenomenon. Although the various approaches to qualitative studies differ in their theoretical assumptions, in their understanding of issues and in their methodological focus, theoretical points of reference can be drawn from phenomenological considerations (Flick, 2018). A phenomenological approach to inquiry was adopted for the reported study. Traditionally, phenomenology is employed in the direct exploration of lived experiences (King *et al.,* 2019). The primary data were thus collected through face-to-face and mediated interviews. Interviews are widely used in phenomenological studies because of their emphasis on exploring how people interpret their experiences (King *et al.,* 2019). The exploratory study was conducted to describe exploitation based on the lived experiences of the interviewees. The sources of primary data were face-to-face and mediated interviews, owing to mandatory social distancing, expedited by a protocol of open-ended questions. Examples of the questions include:

1. "What are the common reasons for exploitation in construction?"
2. "What measures reduce/prevent lack of respect for people in construction?"
3. "How do exploitation or lack of respect affect work performance in construction?"
4. "What can be done to mitigate situations that might arise from lack of respect on site?"

The same instrument was used for all the semi-structured interviews to enhance confidence in the data (Huberman and Miles, 2002). A purposive sampling method was used to select project sites and the interviewees. The criteria for selection were participation in physical work on-site and lived experience of work practices in construction. The data collector was a student registered to study Quantity Surveying in 2020, who was familiar with the subject. Seminar-like training was provided for him before data collection. The training incident to the methodology classes covered site access and ethical norms. The ethical considerations included informed consent, confidentiality, and voluntary participation. The interviews were audio-recorded and the responses to the open-ended questions were transcribed before thematic analysis.

The data were obtained from people involved in on-site work in Bloemfontein, South Africa. Initial attempts were made to conduct the interviewees on purposively selected building and civil engineering construction sites in Bloemfontein. However, owing to strict COVID-19 social distancing rules, alternative ways to access the interviewees had to be followed. Accordingly, personalised e-mails were sent to six different firms. Five companies responded, and the interview questions were shared with them for approval. After securing permission from senior management of the five companies overseeing construction projects in Bloemfontein, the number of individuals who would participate in the interviews was requested. The gatekeepers provided contact for, or mediated access to, the respondents whose background information is shown in Table 1. Altogether, 60 construction professionals from the five companies were willing to make their contributions. The interviewees held various built environment job titles, which included Architects, Construction Managers, Quantity Surveyors, and Forepersons.

Table 1 shows the length of experience that the interviewees had while working in the construction industry. It is notable that most of the interviewees had between 5 and 15 years of industry engagement and could be deemed to be experienced in the construction industry. The job profile on the table show that construction managers were interviewed the most. Most of them had either a diploma or bachelor's degree to back up their work experience. In effect, they had the foundational knowledge required to practise in the industry.

Table 1: Background information of the interviewees

Profile	Frequency	Percentage
Experience		
1 to 4	6	10
5 to 9	32	53
10 to 15	13	22
16 to 20	6	10
21 to 29	2	3
30 or more	1	2
Total	60	100
Job title		
Architect	8	13
Construction Manager	25	42
Foreman	9	15
Project Manager	6	10
Quantity Surveyor	12	20
Total	60	100

FINDINGS

The responses to the opened-ended questions asked in the interviews are presented in this section.

Factors influencing exploitation on construction sites/work environment
According to the responses of the 60 individuals who participated in the interviews, the factors that influence exploitation the most on construction sites were selfishness (68%), greediness (66%), and not caring for the needs of others (56%). A notable response from one interviewee was that some people will exploit others out of spitefulness to feed their greed. Ten percent (10%) of the answers also included the factor of hatred or being very angry towards another individual for some reason.

In addition, at the organisational level, four consequences of exploitation on construction sites were identified, based on the responses. Loss of time (92%) was one of the most common responses, followed by the loss of money (88%). Relationships between employees and/or employers in the workplace deteriorated (68%) making the work environment very unpleasant. Furthermore, 65% perceived that exploitation would lead to more injuries and other health-related issues, as shown in Figure 1.

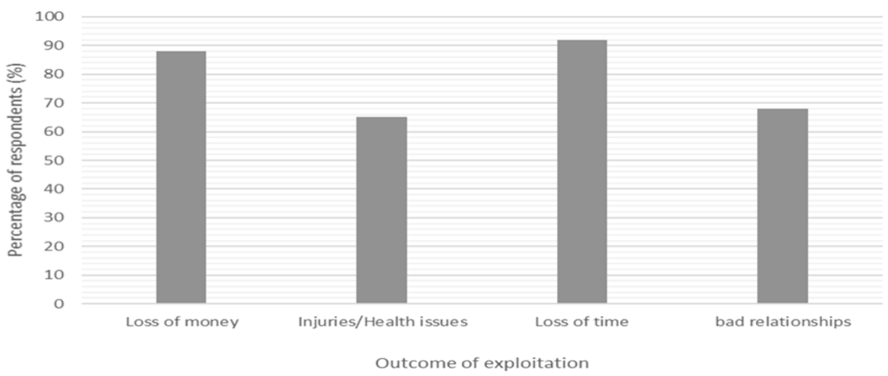

Figure 1: Effect of exploitation on work environment on construction sites

At the individual level, most of the interviewees (93%) said that exploitation will demotivate an individual or group on construction sites. More than half of the interviewees (60%) said that some operatives will react to exploitation immediately and cause a scene on the construction site, while 52% also observed that workers might quit their job when exploited. It was notable that less than half of the interviewees (45%) indicated that operatives will do nothing in reaction to exploitation.

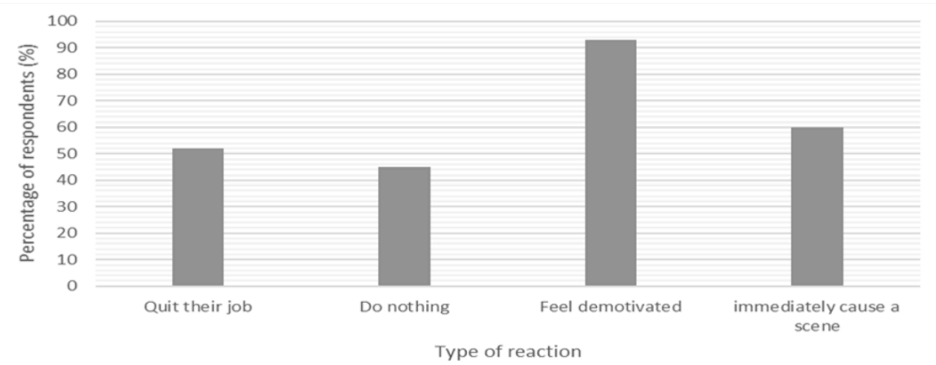

Figure 2: Reaction of employers and employees to exploitation on construction sites

Interpretation of salient points

The first key point from the descriptive study was that PiC react negatively to instances of exploitation. As shown in Figure 2, PiC will quit their job, they can become demotivated and/or cause a scene at work, resulting in anything from being rude, to verbal abuse or a physical fight. The second salient point was that respect for people motivates them to perform better in their work. Almost half of the interviewees believed respecting others makes the work environment better and peaceful for everyone. RfP boosts the image of the contractors when everyone co-operates in doing their jobs and, when respect prevails on the construction site, it boosts work performance which, in turn, saves time and money.

The third salient point from the study was that an exploited construction worker is a demotivated worker. As shown in Figure 2, 93% of the interviewees indicated that they would feel demotivated at work if they were exploited. An example used by one interviewee was that "one bad potato in a bag can make the other good potatoes bad over time". The fourth salient point addressed the consequences of demotivation. It was noted in the study that workers demotivated through exploitation are prone to make errors and mistakes in the workplace. Such mistakes have implications for the H&S of the workforce. Figure 1 shows that the detrimental effect of exploitation on construction sites. Based on the views of the interviewees, injuries or other health issues might eventuate in the life of an exploited construction worker. This view can be supported by personal observation onsite by the researcher that, when an individual is demotivated, he/she will not be fully focused on the job at hand.

Cultivating a sense of understanding and engagement on a construction site can promote the chances of sustained positive behaviours that will help to keep negative attitudes and perceptions at bay. RfP and mindfulness are potential preventive interventions in this regard.

RfP and exploitation

As alluded to earlier, and most clearly by other authors such as Sample (2003), RfP is the opposite of exploitation, which means taking advantage of people at work. The causes of exploitation cited by the interviewees fall under the concept of self-interest. Self-interest might be the result of an imbalance in power relations between workers and their managers. Self-interest is evident when one human being uses another entirely for his or her own benefit. According to Kant (2012), the moral relations between people should not be governed by self-interest. Rather, respect should be deployed to avoid exploitation. The usefulness of RfP has been explored in the construction industry, especially in the UK for example, in addressing some of its problems. The 2000 and 2004 RfP reports in the UK contained responses to issues of skills, image, equity, diversity, H&S and working conditions. In the reports it was noted that, for the industry to deploy RfP, it must change how construction practice promotes diversity, working conditions, training, H&S, and wellbeing (Emuze and Smallwood, 2018).

The superficial changes in the working conditions of PiC, which are exploitative, as revealed by the plight of migrant workers in some regions of the world, make the use of RfP imperative to either prevent or limit exploitation in thoughts and actions (Adsul *et al.,* 2011; Ghaemi, 2006). The concept of RfP propounded in this paper is Kantian as it is based on morality that is not diluted with the notion of 'business case'. To address exploitation, RfP is an effective approach to build relational trust on construction sites. The original concept of RfP will help to improve factors that influence cognitive performance such as mental state, attitudes, and moods on sites. It must be recognised in the industry that to respect people is to respect the moral rights of people. When the moral rights of individuals are upheld, instances of exploitation are less likely to occur because everyone will be mindful about such rights in social interactions on site. PiC can be mindful of situations that make workers feel demotivated and exploited, but what does it mean to be mindful?

Mindfulness and exploitation

Langer and Moldoveanu (2000) described mindfulness as paying attention to things that are new or different in an environment. It denotes the "capability to induce a rich awareness of discriminatory detail and a capacity for action" (Weick *et al.,* 1999: 82). Therefore, mindfulness is linked to situation awareness as a concept. According to Casey and Griffin (2020), when mindful, individuals will be sensitive to the environment and work conditions, open to new views, and aware of different perspectives. Mindfulness is useful in improving workplace H&S (Reason, 2008). For instance, Casey and Griffin (2020: 33) stated:

> "Mindful people are generally able to draw on greater levels of focused and directed attention; they tend to notice more risks, make less biased or automatic judgements, and can consciously control their safety-related behaviours. Mindful people may also make fewer errors. Mindfulness has been linked to improved situational awareness (put

> simply, 'knowing what is going on' and being able to anticipate what will happen in the future)".

Of the different four levels of mindfulness (individual, relational, organisational, and societal) outlined by Langer (2021), the relational level plays a critical role in protecting the H&S of the workforce in construction. Relational mindfulness implies that healthy relationships and high-quality social interactions between individuals involved in a project can make a significant difference between exploitation and RfP. The creation of a working environment of high trust, where everyone is seen as 'an end', will engender collective awareness of how to behave on site. The question is how can mindfulness be created? Figure 3 illustrates a response, as it shows five cognitive processes that could lead to mindfulness. Thus, a mindful person on a construction site will focus on failure (such as negative attitudes that might reveal exploitation), will not neglect data, will actively promote the big picture of operational terms, and defer to expertise to ensure that H&S is not compromised.

Figure 3: Five cognitive processes leading to mindful organising of tasks, Source: Schochlow and Dekker (2019)

The benefits of mindfulness described above are applicable to site management and general workers on construction sites. Mindfulness increases the ability of PiC to detect and handle unplanned events (Schochlow and Dekker, 2019). In relational terms, "mindfulness means being awake. It means knowing what you are doing" (Kabat-Zinn, 2004: 17). Knowing what is happening on a site, individually and collectively, will assist in spotting instances that could be perceived as exploitative because of effects on task completion and the wellbeing of those doing the work. Several authors have mentioned that mindfulness is a pre-requisite for safe work performance in all industries (Reason, 2008: Casey and Griffin. 2020), including construction operations. As an illustration, if mindlessness is brought to a task, there is the ever-present risk of an accident such as falls from height or struck-by objects.

CONCLUSION

Creating safety and safe behaviours within a team on construction sites is more a question of addressing attitudes and beliefs. Instead of adding layers of administrative controls or levels of compliance or adding to the number of H&S professionals on site, site management should seek to establish the right kinds of behaviours. It is based on this premise that how professionals view exploitation and its effect on PiC on sites is presented in this paper. In the paper it is shown that the concept of exploitation is viewed as taking unfair advantage of people based on selfishness, not caring for the needs of others, and greediness. In addition, as mentioned by a few participants, hatred towards another individual is a concern that should not be ignored. The factors influencing exploitation on construction sites directly affect PiC. When such incidents occur, the consequences include lost time (92%), lost money (88%), and a very unpleasant work site filled with distrust. Another consequence identified in the findings (65%) is the likelihood of more injuries and other health-related issues on sites. In summary, the cited consequences prove that exploitation influences the whole construction site in a negative way and that there is a serious need for ways and ideas to reduce and eliminate it.

The interviewees affirmed the notion that exploitation will affect employers and PiC negatively, as it will demotivate individuals or groups on construction sites. Negativity among workers will lead to a decline in work performance (Topchik, 2001; Sharman, 2019) and safety outcomes. Signs of demotivation are evident in people causing a scene on the construction site by physically or verbally abusing others. It is clear from the findings that there will be some form of reaction from employers and employees when exploitation occurs on a construction site. The reactions of people are understandable but, in most cases, there can be a better way to react and address a situation.

The findings suggest that there are ways to avoid and reduce exploitation on construction sites. Interviewees suggested weekly, open, information forum sessions between employers and workers to prevent exploitation from happening. From a conceptual argument point of view, RfP is the direct opposite of exploitation. When it is deployed effectively on construction sites, it will be difficult for exploitation to occur among the crew. By becoming more mindful, PiC will be more aware of situations that promote exploitation instead of RfP. Mindfulness can be exercised to identify low morale and prevent a slide into an atmosphere of exploitation on a site.

However, in the South African context, the reported study was exploratory and descriptive. The analysis of the data is limited regarding inferences and relationships. Initially, the study was designed as sequential, mixed-methods research using quantitative (survey questionnaire) and qualitative (interview guide) instruments. However, the hard lockdown and slow return to the 'new normal' hindered the smooth implementation of the design in 2020. The need to conclude the project within a year of postgraduate diploma study meant that only interviews were concluded. Thus, there is a need to build on the research with rigorous, multi-year studies that will provide tangible evidence of exploitation and lack of respect for PiC. Future studies should also explore how RfP and mindfulness will act as the antithesis of exploitation on construction sites. The link between exploitation, RfP, mindfulness and work performance on site should also form part of future studies that use multiple techniques to collect data.

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MENTAL HEALTH IN CONSTRUCTION: THE AWARENESS OF THE IMPACT OF STRESS ON CONSTRUCTION PROFESSIONALS' MENTAL HEALTH IN IRELAND AND THE UK

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In recent years, various Health and Safety initiatives have led to significant improvement of physical safety on site, yet initiatives to safeguard the mental health of construction professionals still fall short, particularly in smaller construction companies. Due to the often-stressful nature of work on site, the mental health of construction professionals can be affected, impacting both home and work life. The aim of this pilot study was to investigate the levels and sources of such stress on site, evaluate the impact and to investigate the uptake and success of interventions. Sixty-two semi-structured interviews anchored on 5 stressor categories- organisational, task, personal, physical and industry characteristics were conducted. The data shows that the negative impact of stress on mental health is exacerbated by factors such as stigma, lack of understanding of mental health and a lack of awareness of and engagement with mental health education and support initiatives on site.

Keywords: professionals; impacts of stress; interventions; mental health; stressors

INTRODUCTION

In 2019, 26% of construction professionals thought about taking their own lives, 97% recorded being stressed at least once (CIOB 2017) - this can only be described as a frightening statistic. Anyone can suffer from stress and mental health issues, but the incidence is significantly higher in construction sector. Factors that contribute to stress in the construction sector include moving locations, tight schedules, job insecurity and cashflow uncertainty, all of which are due to the nature of the business. Recently social and government focus has been on mental health in construction because of rising suicide numbers due to male dominated construction sites being relatively unaccepting of mental health as an issue as many men see mental issues as a topic not to be discussed openly. Even though the issue has been a hot topic in recent years, the construction industry has been slow to adapt to change and introduce solutions even though for example, over 50% of men who committed suicide in Ireland in 2013 worked in the construction industry (CIF 2013). The recent COVID-

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19 pandemic created what may be considered a 'perfect storm' of factors impacting on the mental health of construction workers due to the nature of the business and its vulnerability when the economy contracts (King and Lamontagne 2021). High stress levels can have many negative effects on the person, the site or company. Stress has many effects such as lack of concentration, avoiding other work colleagues, becoming easily agitated or moody, having difficulty relaxing or feeling low or depressed and can unfortunately lead to serious mental health issues. When such factors come together and are not dealt with correctly, they can have a serious impact on a site through lower productivity, absenteeism, and staff turnover (Greden 2017).

This investigation used semi-structured interviews and a questionnaire-led survey executed with a panel of 62 construction professionals to gather relevant information on three main themes. Firstly, the level of stress and the impact it has on the mental health of construction professionals. Secondly, construction professionals' awareness of interventions and knowledge of how they can avail of such interventions. Lastly, why the construction industry has been slow to adapt to change in comparison to other sectors. There needs to be more collaboration between the organisations within the construction industry to make a sectoral change. Some organisations are training staff as 'Mental Health First Aiders' to ensure mental health is being managed effectively on construction sites (CIOB Mental Health Week 2020). Some of the main reasons why the construction industry is yet to apply the necessary training and solutions are the cost, time, and access to supports that are available.

There appears to be a knowledge gap in that the focus seems to be on workers mental health and the responsibility of managers and professionals on site to ensure that they recognise the issue in their workforce and implement interventions to help. However, the mental health of the managers and professionals themselves in the Irish and UK construction sector seems to have been neglected. This investigation into the mental health of construction professionals is intended to raise awareness and offer recommendations that could help all the associated parties.

LITERATURE REVIEW

The National Institute of Occupational Safety and Health in the US defines stress as "The harmful physical and emotional responses that occur when the requirements of a job do not match the capabilities, resources or needs of the worker" (NIOSH 1999 p5). Generally, a good balance between peoples' work and non-work lives is an important contributor to their overall psychological wellbeing. A poor work-life balance has been seen as the primary cause of occupational stress (Industrial Society 2001; Faragher *et al.,* 2004). The construction industry is characterised by high rates of work-related accidents and challenging timelines, it also features non-permanent positions, risk of personal injury and long working hours (Campbell 2006, Heller *et al.,* 2007). These factors can accumulate to generate a stressful lifestyle for construction workers. It is suggested that in the construction industry work-related stress has become known as a problem in the workplace and is also commonly found to transfer back into family and personal lives at home, thereby compounding the negative impact. (Love *et al.,* 2010:650 cited in Hanna 2019).

In the management of construction projects, uncertainty and high risk can lead to excessive levels of work-related stress and work with experience, project size and complexity and level of education identified as factors that can affect project managers ability to cope (Haybes and Love 2004). These are not the only elements involved as stress can also be related to home-life and brought to work (Lingard and

Francis 2003) so factors other than work are involved in the formation of stress and its manifestation. A systematic review of mental stressors in the construction industry identified 5 main stress categories (Tijani *et al.,* 2020):

1. Organisational stressors can be defined as the sources of stress originating from the organisation (Leung *et al.,* 2009). Poor organisational structure entails the presence of bureaucracy and hierarchies, supremacy of rules and unjust treatment in the construction industry (Enshassi and al Swaity 2014).

2. Task stressors are ascribed to job characteristics that shape the mental state of the workers (Enshassi and al Swaity 2014). These can include project overload, tight time frames and project role ambiguity. Construction project managers often suffer from excessive project workload due to demanding time pressures and the structure of a project. On average construction workers work 60 hours per week and are subject to the nature of the construction firms and complexity of construction (Love *et al.,* 2010). Long working hours is a core contributor to work-family conflict and occupational stress, which cause high staff turnover in the construction industry (Sunindijo and Kamardeen 2017).

3. Personal stressors due to the private and personal life of the worker that may affect their mental health (Leung *et al.,* 2008). Type A behaviour can be defined as the action-emotion complex that entails hostility, aggressiveness, competitiveness, and a sense of time urgency (Suntherland and Cooper 1990). Construction professionals such as construction managers and architects are more suspectable to type A behaviour because of their competitive working environment (Leung *et al.,* 2008).

4. Physical stressors are described by (Leung *et al.,* 2009) as environmental sources of stress inherent at either home or at work. Physical stress is predicted by job certainty, co-worker support, and safety equipment (Leung, M.Y., Liang, Q. and Olomolaiye, P. 2016)

5. The construction industry is notoriously conservative, male-dominated and emphasizes performance under pressure (Carson 2019). Male-dominated culture in the construction industry creates stressors that affect the mental health of the female construction workers (Marshall 1990). Gender-related stresses include sexual harassment, gender inequality and limited job opportunities. (Sang *et al.,* 2007) states gender inequality in the construction industry results in the premature exit of female construction workers and explains the negative interaction between gender inequality and mental ill-health among female construction workers.

Work overload, unrealistic deadlines, poor interpersonal relationships, poor work environment and poor work-life balance are clear factors that cause stress and are involved in its formation and manifestation (Lingard and Francis 2003). Unfortunately, there is shame associated with middle aged men and mental health which results in a reduction in the number of men who seek help (Hanna 2019). Mental health issues within the workplace can have serious consequences not only for the individual involved but for the workplace as a whole (Janusonyte, 2019). In recent years, the industry has made large improvements in the health and safety sector focused on physical elements. The literature has shown that individuals working in the construction industry are at an increased rate of suffering from mental health conditions (Oswald *et al.,* 2019). Yet mental health has to date been the "poor cousin" to physical health and safety.

The world of work has changed over the years and has led to several new or increasingly prevalent psychological risks such as new forms of employment and intensification of work (Milczarek 2007). However, remaining in work has been shown to have a positive effect on maintaining social networks and providing a sense of purpose (Le Masters *et al.,* 2006, Damman *et al.,* 2013). Participatory ergonomics is an approach which has been shown to be successful in several industries. Previous research has shown that by using elements of participatory ergonomics such as bottom-up approach together with good management support and key stakeholder involvement, means significant benefits can be achieved for workplace, job and equipment design and healthy working behaviours (Rivilis *et al.,* 2008, Tappin *et al.,* 2016). A 2016 study demonstrated that workers can be encouraged to share ideas to improve their health at work (Eaves *et al.,* 2016). Involvement of the workforce in developing solutions/decision-making can lead to positive changes and managers and supervisors should consider ways of encouraging this.

Aside from the individual burden of common mental health disorders, work productivity in the construction industry may be critically reduced when the workers suffer from mental illness. This may lead to a higher risk of accidents and injuries on the job (Beseler and Stallones 2010; Kim *et al.,* 2009). In other words, construction workers need psychological and mental capacities to maintain their concentration and alertness to manage the variety of onsite hazards throughout the workday. These capacities are likely to be impaired when the worker suffers from mental health complaints (Boschman *et al.,* 2013). The need for recovery after work is a sign of occupationally induced fatigue and a predictor of adverse health effects, (Sluiter *et al.,* 1999) found that the need for recovery after work was significantly higher amongst supervisors and managers. (Alavina *et al.,* 2009) found that lack of job control, lack of support and dissatisfaction with work were significantly related to sick leave. Low participation in decision making and low social support from the direct supervisors are additional psychosocial risk factors for symptoms of depression among supervisors (Boschman *et al.,* 2013).

METHOD

Literature review is a common method in construction management research for advancing the body of knowledge on specific topics (Li *et al.,* 2014). A total of 39 papers, identified using key word search terms such as stressors at work, construction industry mental health, mental health interventions in construction)) across databases including Google Scholar, Web of Knowledge and Science Direct were used to analyse the topic of Mental Health in the Construction Industry. From the literature, numerous stressors associated with construction work attribute to a high suicide rate in the construction industry in comparison to any other sector. Therefore, the likelihood of interaction with a construction professional with poor mental health is quite high. Due to recent COVID-19 restrictions all one-on-one interviews guided by a suitable questionnaire were carried out over organised Zoom calls once the consent to participate were returned to the researchers. The interviews were designed to determine construction professionals' knowledge of stress and gauge their awareness of resources available to them. Since the topic being discussed is both personal and confidential, one-on-one interviews were preferable to a group discussion where participants would be slower to talk about sensitive topics.

The participants interviewed had to meet 3 main criteria - they had to be currently employed as construction professionals, with relevant on-site experience and to consent to participate. The companies engaged were all currently working on construction projects in either the UK or Ireland as either main contractors or sub-contractors. Participants were solicited through a Linked-In post looking for participants as well as through direct contact from the researchers. Participants' details were verified at the start of the interview prior to their data being included in the study. Participants could also withdraw at any time during the process. All data gathered from all individuals was anonymised and securely stored. To guide the semi-structured interview, a questionnaire with 34 questions was used to gather data relevant to the three themes as outlined in the introduction. The questions were formatted as open, multiple-choice, Likert scales or required Yes/No responses.

FINDINGS

There were 64 interviewees (60 male and 4 female) from 20 companies ranging from small companies with <10 employees up to large companies with >1,000 employees. Participants were classified as Site Manager (12), Site Engineer (14), Project Manager (18), Quantity Surveyor (8), Health and Safety Manager (3), Contracts Manager (3) and Other (6). As a general comment, even though the interviews were designed to get the most information possible from the interviewee, some answers were short, perhaps an indicator of the difficulty in discussing the topic of mental health. A very telling comment from one participant was that 'we are to report when we feel stressed, but in reality, it makes you look weak in the workplace'.

Levels of Stress and its Impact: The data showed that mental health issues were clearly a problem that everyone who was interviewed faced, with all participants, 37% of whom have worked in the industry for 10 years or more, agreeing that they regularly feel stressed at work. This mainly related to a culmination of project overload and tight time frames. Long working hours also emerged as an issue however most workers were compensated for long hours by easily receiving time off, high salaries and other benefits such as company vehicles.

Workers were convinced they have adequate time to spend with friends and family on their time off yet reported that family members do not seem pleased with their working hours, possibly due to work affecting interviewees when they are at home, sometimes due to carrying stress home, having to take phone calls or reply to emails. In relation to organisational stressors, 40% of participants scored home/work conflict the highest. It may have been interesting to investigate this topic more in relation to divorce, however this was deemed as being too personal and could have turned the participants off from completing the interview. Interestingly 77% of the interviewees with >10 years' experience stated they work through their lunch break. In their 'spare time' at home, 50% of participants reported using exercise or getting plenty of sleep as mechanisms to de-stress, while talking to others scored only 23% in total but interestingly 75% of female participants stated this as a coping mechanism. The task stressors that scored the highest were project overload reported by 33% and long working hours by 25%. Just over 40% reported that both these task stressors combined, account for some of their stress. It was found that 72% agreed that a construction professionals role consists of unpredictable working hours which can lead to ill health from factors like stress and burn-out from being overworked. Commuting to work averaged at 75 minutes however the workers home location is not usually taken into consideration when moving sites with 16% of workers travelling over 4 hours a day for their work commute. Interestingly, only 1 out of the 62 interviewed reported that in their organisation people were 'if possible, put on jobs closer to home'. Why is Construction slow to adapt? By examining stress, it became clear the reason the industry is slow to adapt is that construction professionals do not talk about the detrimental effect it has on them or highlight how bad the issue is when questioned about it - possibly due to the reticence of males to talk about issues. Findings show that older men tend not to discuss their mental health freely, with 50% preferring to say there's no issue rather than talk about it.

This was even though 70% admitted to being regularly stressed at work, with 87% of these specific interviewees saying they regularly bring their work-stress home with them. It was found that 49% of respondents found it uncomfortable to talk about their mental health issues with others while 87% of these respondents said they were affected by long and irregular working hours. It was also reported by 40% of interviewees that they have problems with superiors, with companies trying to cut costs and maintaining a reduced workforce. However, when questioned further on these topics the answers became sharp and short, some interviewees even trying to retract what they had said initially. Despite the long hours, the stress involved, and the fact family and friends are not pleased with their current roles, 75% of professionals are happy with their current role at work and would choose the same career path if they had the choice again. Even after highlighting the negatives, the interviewees felt healthy in general whilst dealing with numerous negative factors that were clearly present.

Awareness of Interventions: Since middle-aged men are slow to talk about their mental health (Karpansalo, M *et al.,* 2005), interventions need to be brought to them to show that there is help available. During the CIFs construction safety week 2020, Monday's topic was 'Mental Health, Welfare and Wellbeing in Construction'. Results showed 68% of interviewees did not participate in this event intended to help highlight symptoms and indicators for poor mental health plus identify available interventions. Awareness of interventions on construction sites was low, almost 50% were unaware of any intervention on site.

Usually, mental health toolbox talks were given by Health and Safety officers, however 30% were given by people outside the company who have experienced mental health issues of their own. When asked do mental health toolbox talks occur on site, only 45% said they did. However, when asked what interventions they were aware of on site the most common was toolbox talks. Therefore, even though the workers are aware that mental health toolbox talks are an intervention for mental health issues on site, they do not take place on over half the sites so over 30% of interviewees have no intervention available on site for mental health issues. Other interventions they were aware of include support from upper management and Pieta House (a suicide prevention charity in Ireland). A positive that can be taken from the data analysis is that 59% of professionals stated they can easily get time off work which proved to be an intervention also scoring highly in dealing with stress from work. However, when questioned on work-life balance, comments were made that included 'main contractors do not consider this as it's all about time frame and completed projects' and that 'like most construction companies they let on they provide a good work-life balance, but they don't' indicating that this is a problem within the industry.

The findings will be further examined in the discussion with some recommendations suggested for tackling the problem of mental health of construction professionals.

DISCUSSION

From a review of the existing literature and the research undertaken, there is an apparent lack of understanding of the seriousness of how stress can affect construction professionals' mental health. However, there is a correlation between participants' years of experience and how stressed they are at work. The more experience, the more stressed the workers seemed, possibly due to longer working hours and extra workload - both significant factors causing stress. Another factor was home relationships, younger more junior construction managers did not usually have the responsibility of a partner and children at home, nor were they significantly impacted when moving from site to site and as a consequence were less stressed. Investigating the mental health of construction professionals proved that stress has impacted every participant to some extent. While organisations are trying to stay within budgets and deadlines, their workers would benefit from increased support from superiors to lighten their workload and enable them to work in a less stressed environment especially during busy phases by having additional resource capacity. Tight time frames and project overloads are another reason why the construction industry is so slow to adapt as men can feel they are “too busy” to engage in other activities apart from their work.

The preferred forms of relieving stress were activities which could be carried out independently such as exercising and getting plenty of sleep. Only 23% of the interviewees stated they would talk to others to relieve stress. It was found that 72% were affected mentally by the unpredictable working hours. Days become longer and more stressful towards the end of a project, especially on projects which fall behind schedule, this can have a major toll on one's state of mind at work and at home. In fact, 40% of the interviewees stated that the task stressors which affect them the most were long working hours and project overload, a worrying fact that could easily be resolved through better scheduling and resource management throughout the project and have a significant positive impact on work-life balance.

Even though the CIOB and CIF are trying to highlight the issue and provide interventions, companies are not taking such interventions into consideration. Clear evidence found this study that backs this statement is that only 32% of the interviewees participated in Monday's topic of 'Mental Health, Welfare and Wellbeing in Construction' during the CIFs construction safety week in 2020. Companies feel they do not have adequate time to be completing toolbox talks or taking time to discuss the mental health of their employee - highlighted by the fact that the most common intervention on site was mental health tool-box talks - yet only 45% of the participants said such talks took place on their sites. Tool-box talks where an 'outsider' came to site to discuss stress and mental health issues they had suffered were seen as very effective. Seeing a middle-aged man open up about his mental health in front of a group workers he did not know helped a lot of men see that there is more to life than working 60-hour weeks. A recommendation that can be made from this investigation is to make mental health toolbox talks as important as inductions and site meetings. Another interesting was the way the participants reacted when asked questions in greater detail, in that they responded in a short, snappy way and sometimes they physically moved back or away from the screen!

The clear absence across all participants regarding awareness, availability and uptake of mental health interventions shows a need for the targeted distribution of information regarding mental health awareness in the sector. It could be argued that the construction industry unintentionally promotes poor mental health conditions by being blind to its existence, instead focussing on the development and reputation of companies delivering projects on time and within budget without due care for their workers mental health.

CONCLUSION

From the data presented above the management of stress and the mental health of construction professionals has been lacking in the past. With most interventions only really beginning in recent years, the positive affect that it is having on the workers cannot be properly measured yet. However, it seems that most of these interventions are seen as just a task to be completed on site to tick the compliance box, yet companies promote to the outside world the care they show for their workers through social media platforms - described as 'soft talk' by one participant! Consideration needs to be placed in managing the day-to-day issues which arise on site that contribute to causing poor mental health. This should include preventative measures such as better project management, resource management and communication practices through to remedial and support activities such as allowing space for mental health to be discussed and encouragement to engage with available interventions. However, a significant barrier is that seeking help for their mental state deems a person weak or unstable- this outlook held by men, and older men in particular, needs to change. It can be concluded that while supports and programmes are essential for good mental health, the approach to the provision of, and engagement with, these supports must change to have a significant impact on improving the mental health of professionals working within the construction sector.

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A SCIENTOMETRIC REVIEW OF TECHNOLOGICAL APPLICATIONS IN OCCUPATIONAL HEALTH AND SAFETY MANAGEMENT IN THE CONSTRUCTION INDUSTRY

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Poor safety performance has remained a significant concern in the construction industry worldwide. However, increased affordability and capabilities of emerging technologies could enable proactive OHS management. The paper presents a scientometric review of 151 peer-reviewed journal articles (2000-2021) on applications of various technologies in OHS management in construction projects. It identifies past and emerging research trends; primary research themes; collaborations among individuals; institutions; and countries; research gaps and future research directions. Most research has been conducted in the United States; followed by China and Hong Kong. Research was clustered around five major themes: (1) machine learning; sensors and wearable technologies; (2) virtual reality and experimental designs; (3) hazard identification and improved decision-making; (4) BIM and digital design; and (5) ergonomics. The review found less research in developing countries and a lack of discussion on legal; cybersecurity and ethical concerns surrounding technologies such as wearable devices and video surveillance.

Keywords: occupational; H&S; wearable devices; sensors; workers; scientometric

INTRODUCTION

Fatalities in the construction sector are historically high. As per the US Bureau of Labour Statistics, the annual fatalities in the construction industry increased by 13 per cent, from 937 to 1061 between 2015 and 2019 (BLS 2020). The construction industry accounts for 21% of all fatal accidents in the European Union nations (Eurostat 2016). Similarly, unhealthy lifestyles and work-related illness rates are prevalent among construction workers (Loudoun and Townsend 2017; HSE 2019). Health disorders such as hypertension and respiratory and cardiovascular diseases among construction workers were found at a rate higher than the general male population (Chung *et al.,* 2018). The high injury rates and poor health conditions affect construction workers, their families, organisations, and society.

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Ghosh, A, Jha, S K and Hasan, A (2022) A Scientometric Review of Technological Applications in Occupational Health and Safety Management in the Construction Industry *In:* Tutesigensi, A and Neilson, C J (Eds) *Proceedings of the 38th Annual ARCOM Conference,* 5-7 September 2022, Glasgow, UK, Association of Researchers in Construction Management, 246-255.

Consequently, occupational health and safety (OHS) is a widely researched topic in the construction management discipline. In addition to changes in worker behaviour and training, work design and work practices, several researchers have studied the application of emerging technologies in improving OHS in the construction industry (Adepoju and Aigbavboa 2021; Rivera *et al.,* 2021). For instance, researchers have studied design and construction OHS considerations using BIM (building information modelling) and applications of wearable sensors and devices to monitor critical health metrics to reduce workplace injuries and health disorders. Moreover, research on technological applications in OHS management has resulted in several focused research and collaboration networks among authors, institutions, and countries. However, a scientometric literature review of the current trends, research collaborations among countries and authors and cluster analysis of the major research themes is currently missing. Such an analysis could offer valuable insights into the existing research in this domain, facilitating future research efforts.

LITERATURE REVIEW

Scopus was selected as the source database for conducting a scientometric literature review on technological applications in OHS management in the construction industry. Scopus has a broader coverage of recent publications and a faster indexing process and lists (Abioye *et al.,* 2021). Moreover, it is widely used for systematic and scientometric reviews in construction management. The initial search for the relevant papers in the Scopus database was performed with the following search query:

(TITLE-ABS-KEY (("health" OR "safety") AND ("construction worker" OR "construction professionals" OR "construction personnel") AND ("technology" OR "wearable" OR "sensors"))

The period of the analysis was limited from 2000-2021. To filter out quality research outputs, the document type was refined to include only peer-reviewed journal articles, the rationale being that for science mapping purposes, journal articles represent research studies with a high impact (Wijewickrama *et al.,* 2021). After a round of manual screening of title, abstract and keywords to filter out irrelevant articles, 151 journal articles published in the English language were retained for further analysis.

Next, scientometric mapping was performed using *VOSviewer* because it provides easy mapping and visualisation of scientometric networks. It is increasingly used by researchers in the domain of construction management (Li *et al.,* 2021). The intention was to provide a preliminary evaluation of emerging themes in technological applications in OHS management in the construction industry and provide concise information on the existing research to undertake concentrated studies on emerging themes. The analysis also illustrated the major collaborative networks and research groups in this field. Additionally, it revealed information on researchers affiliated with institutions from different countries assisting research efforts in this field.

Wave of research on technological applications in OHS management in the construction industry

Fig. 1 depicts the wave of research on technological applications in OHS management in the construction industry. While very few articles were published annually between 2000-2010, the wave of research in this field has been steadily rising since 2015, with the highest number of articles (i.e., 42 articles) published on this topic in 2021. The publication trend could be explained by the increased affordability and availability of various technologies in recent years resulting in broader applications in OHS management in the construction industry.

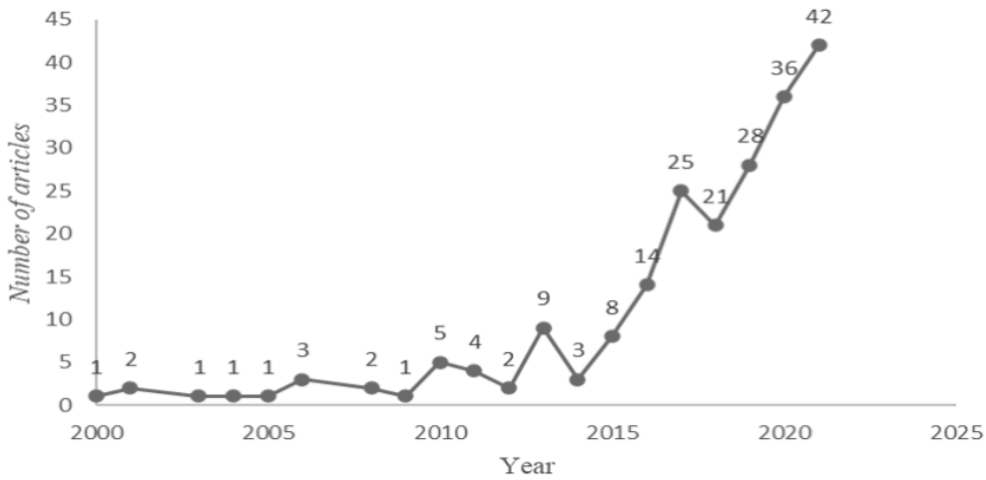

Figure 1: Year-wise publication trends on technological applications in OHS management in the construction industry (2000-2021)

The general distribution of the primary discipline source of the analysed articles revealed that most of the articles come from Engineering journals (41.6 %). Additionally, there are significant contributions from Business, Management and Accounting (10.5%), Medicine (10.2%), Computer Science (8%) and Social Sciences (8%), which demonstrate the multi-disciplinary nature of research in this field.

Leading institutes and countries

Among leading institutions illustrated in Figure 2, Hong Kong Polytechnic University, Hong Kong is the leading institute in this field with 28 publications, followed by the University of Michigan, Ann Arbor, USA, with 16 publications and Georgia Institute of Technology, USA, with 14 publications.

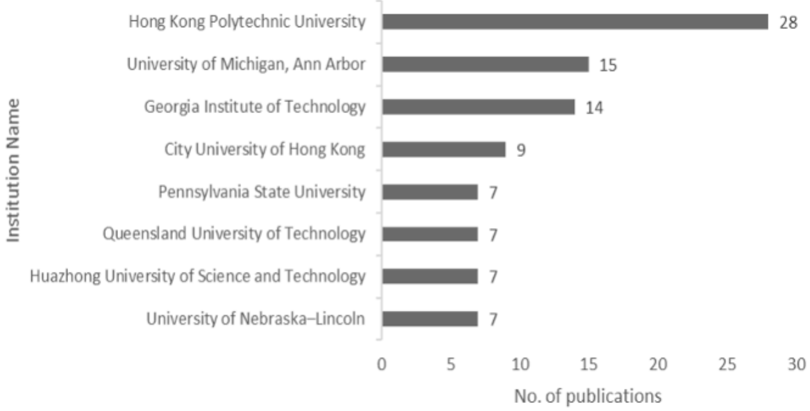

Figure 2: Prominent institutes

Among countries leading the research in this area, as illustrated in Figure 3, the US has the maximum number of publications (i.e., 97 publications), followed by China (43 publications) and Hong Kong (35 publications). It is observed that there are more academic contributions from developed countries than from developing nations which could be due to the limited financial capacity of construction organisations and the slow adoption of technological advances in developing countries (Iqbal *et al.,* 2021; Opoku *et al.,* 2021).

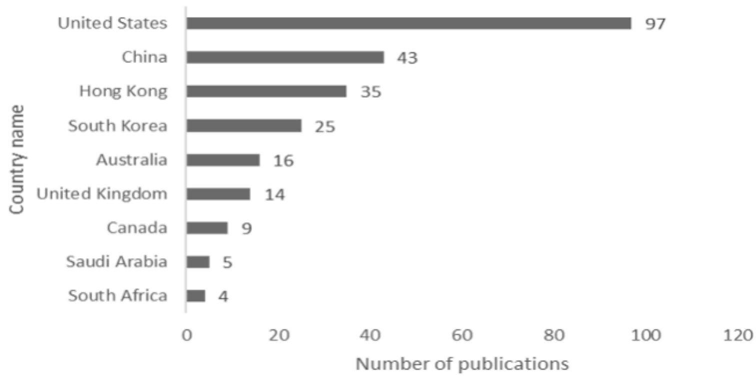

Figure 3: Prominent countries

Author collaboration networks

An analysis of author collaboration networks provided the results presented in Figure 4. For conducting this analysis in VOSviewer, the type of analysis was set to co-authorship, the unit of analysis was set to authors, and the counting method was fractional counting to determine the major authors. Of the 384 authors, 17 met the criteria of a minimum of 3 citations and a minimum of 5 documents per author.

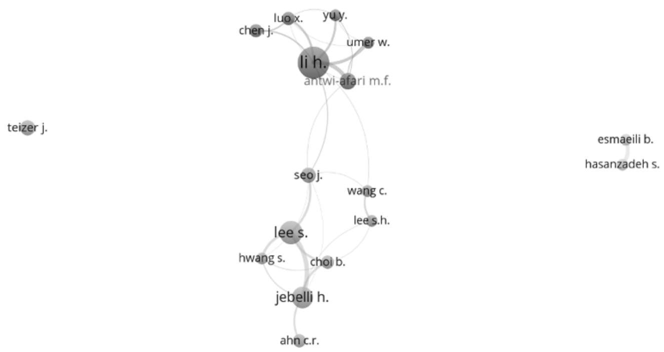

Figure 4: Author collaboration map shows the network map

Figure 4 shows the major author collaboration networks of 17 authors linked in 5 clusters through 30 links. Heng Li leads the authors in cluster 1 from Hong Kong Polytechnic University. Sang Hyun Lee from the University of Michigan, Ann Arbor leads author cluster 2, and Houtan Jebelli from Penn State University leads author cluster 3. These clusters are interconnected, which shows collaboration between authors of these clusters. Clusters 4 and 5 (isolated clusters) include authors who produced research work independently without collaboration.

Country collaboration networks

In VOSviewer, the type of analysis was set to co-authorship, the unit of analysis was countries, and the counting method was fractional counting to determine the major collaboration network between countries. Of the 25 countries, 9 met the criteria of a minimum of 3 documents and a minimum of 3 citations from a country. Figure 5 shows 9 countries grouped into 3 clusters with 19 links. One can also infer from Figure 3 and Figure 5 that the leading countries working on this topic are the United States, Hong Kong, and China. From a chronological analysis, it is observed that research on this topic has been going on in the US and Canada since 2017. A significant contribution by the United Kingdom, Hong Kong and Australia is noted after 2018. Vietnam and Saudi Arabia are relatively new in this field compared to other countries. The analysis shows 9 countries divided into 3 clusters based on their network. Cluster 1 is the biggest cluster, with the United States having the most networks and comprises Canada, South Korea, and Vietnam. Cluster 2 comprises Australia, China and the UK, possibly due to the close collaboration between academic institutions. Cluster 3 comprises Hong Kong and Saudi Arabia, which could be due to the close economic relationship between these nations. Therefore, the close collaboration among these nations could be due to successful joint grants by the authors, independent research collaboration between the authors, or country-level research collaboration agreements.

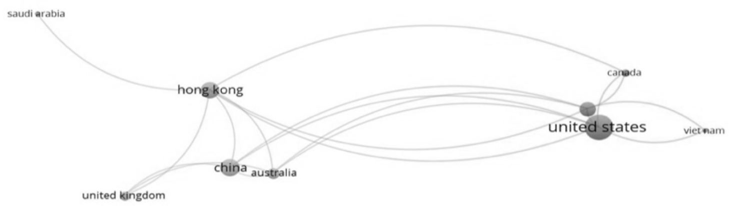

Figure 5: Country collaboration network

Keyword Cluster Analysis

For the keyword cluster analysis, the type of analysis was set to co-occurrence. The unit of analysis was set to all keywords. The counting method was set to full counting to form clusters in VOSviewer. Of 1690 keywords, 66 were selected when the minimum number of occurrences was set to 7. Some keywords were omitted due to being too generic or repetitive, such as construction industry, article, adult, humans, priority journal, construction work, construction, etc. The resulted final keyword network map was organised into five major clusters depicted in Figure 6.

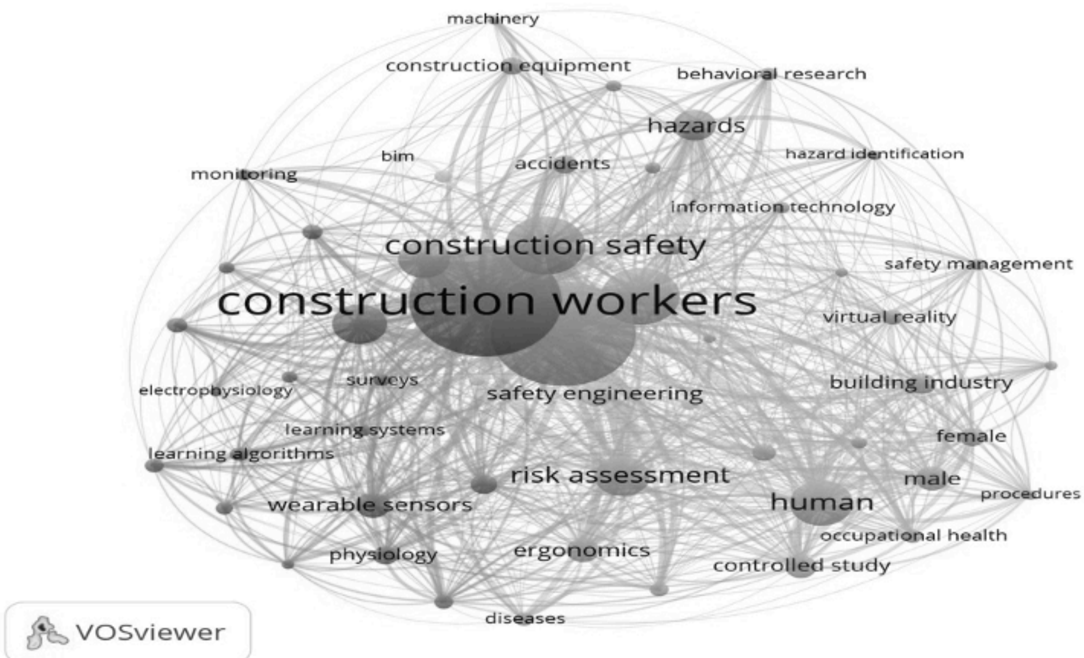

Fig. 6: Text data overlay map of co-occurrence of research areas

Cluster 1: Machine learning, sensors and wearable technologies

Cluster 1 is denoted in red colour in the text data overlay map in Figure 6. This cluster contains keywords related to the application of digital technologies in OHS management in the construction industry. Previous studies show that recent advancements in digital technologies have reduced OHS risks and increased industrial hygiene (Antwi-Afari *et al.,* 2022). Wearable sensors are now used to monitor construction workers' physical and mental health in many projects.

A strong focus has emerged on promoting industrial hygiene, especially when dealing with heavy machinery and critical construction equipment (Lippy *et al.,* 2021). For instance, electroencephalography determines the construction workers' physical and mental workload (Nguyen *et al.,* 2021). It also reveals the workers' emotional status (Noghabaei *et al.,* 2021). Additionally, deep learning and machine learning are used to analyse the physiological traits and data collected from the wearable sensors to improve OHS in the construction industry (Jeon and Cai 2021). For example, Shakerian *et al.,* (2021) propose a heat-stress risk-assessment process to evaluate heat strain based on the continuous measurement of workers' physiological signals using a wristband-type biosensor.

Cluster 2: Virtual reality and experimental designs
Cluster 2 is denoted by green colour in the text data overlay map in Figure 6. This cluster includes the keywords discussing accident prevention measures among construction workers. Previous studies show that technological applications in the construction industry have made human resource management and project management more efficient (Madubuike *et al.,* 2022). Experiments and controlled studies on construction workers have helped discover more efficient and alternative procedures to improve OHS in the construction industry (Yu *et al.,* 2021). Virtual and augmented realities have also helped make personnel training more effective. The experimental research designs act as a catalyst in implementing technology in the construction industry, highlighting their positive and negative repercussions (Harichandran *et al.,* 2021).

Cluster 3: Hazard identification and improved decision-making
Cluster 3 is blue in the text data overlay map in Figure 6. This cluster includes the keywords related to hazard identification and improved decision-making in construction sites. Innovative technologies have impacted the decision-making processes in selecting construction equipment and machinery in the construction industry (Tummalapudi *et al.,* 2022). They have also influenced risk perception in a positive way (Celik and Gul 2021). For example, timely hazard identification reduces occupational risks, prevents accidents, and increases total construction safety at construction sites (Hire *et al.,* 2022). Son and Kim (2021) proposed an integrated construction worker detection and tracking sensor-based scheme for real-time monitoring and safe operation of construction machines. Therefore, technologies used for hazard identification could significantly improve OHS management in the construction industry due to proactive risk management.

Cluster 4: BIM and digital design
Cluster 4 is yellow in the text data overlay map in Figure 6. This cluster comprises discussion regarding the use of BIM and digital design for promoting safety at construction sites (Lu *et al.,* 2021). Also, it facilitates the risk perception for different construction projects due to adequate planning for safety utilising principles of safety engineering (Park *et al.,* 2022). Hire *et al.,* (2021) discussed using BIM for planning, visualising, simulation of construction hazards, and on-site safety monitoring and control.

Cluster 5: Ergonomics

Cluster 5 is denoted in purple colour in the text data overlay map in Figure 6. This cluster consists of keywords focusing on the use of ergonomic studies on the musculoskeletal system disorders faced by the construction workers (Wahab *et al.,* 2022). Also, mitigation strategies to prevent this from developing into long-term diseases are discussed in the existing literature (Oakman *et al.,* 2022). A better understanding of ergonomics could help develop alternatives in the procedure and construction method to ensure construction activities do not stress the musculoskeletal system (Hire 2021). Technological applications, such as the inertial measurement unit (IMU), could reduce the chances of musculoskeletal disorders by early detection of improper body posture or poor work design that puts the load on the vulnerable body parts like the wrist, hips and back (Lee *et al.,* 2021). Chen *et al.,* (2021) proposed a novel posture coding scheme based on the worker's body part relative position information.

LIMITATIONS

The findings are to be considered against some limitations. First, the findings are limited by literature analysis ranging from 2000 to 2021. There might be a few studies published outside the research period considered for the analysis. Second, using Scopus as the search database has a few limitations. Using multiple databases could identify more relevant articles. A similar analysis could be conducted in databases like Web of Science, ScienceDirect or ProQuest to gauge the research trends in those indexing methods. Third, scientometric mapping suffers from certain limitations. Being a data-driven approach, it is an empirical and objective approach to analysing knowledge domains. However, there could be subjective biases while interpreting obtained results which could be minimised by consulting with independent domain experts (Li *et al.,* 2021). Finally, research quantity and other quantitative indicators used in scientometric mapping do not necessarily represent the quality of the research work. Therefore, quantity should not be considered the sole criteria for judging the research contributions of researchers and institutions active in this research area.

CONCLUSIONS

The present study aimed to enhance the understanding of the existing research on technological applications for OHS management in the construction industry. The outcomes of this study are expected to assist researchers and practitioners by providing valuable insights into research trends, collaborations, and research clusters. The study found that research on technological innovations and applications in OHS management in the construction industry is an emerging research area, as evidenced by increased research outputs in recent years. Current research in this field is attracting the attention of many researchers, as evidenced by 42 articles in 2021 alone. The multi-disciplinary nature of this field of enquiry was also observed in the analysis, indicating it is an important and relevant area of research across different disciplines. Moreover, five major collaborative clusters of researchers in this field were identified and mapped. The analysis also shows collaboration between researchers from different countries. The scientometric analysis further identified five major research clusters of technological applications in occupational health and safety management in the construction industry: (1) machine learning, sensors, and wearable technologies, (2) virtual reality and experimental designs, (3) hazard identification and improved decision-making, (4) BIM and digital design, and (5) ergonomics.

The review also identified a few gaps in the existing literature. For instance, research in developing countries such as South Asian and African nations are lacking. Since most construction workers reside in developing nations, improving OHS performance in these countries is essential and demands more attention and collaboration with researchers from developed countries. Similarly, studies on data privacy issues and ethical concerns while collecting and storing OHS data of construction workers are scarce. Recent cybersecurity breaches across different sectors suggest that similar incidents in the construction industry could have profound implications for workers and construction organisations. Moreover, most studies have examined the use of wearable sensors in controlled environments. Studies in the actual construction environment could offer more insights into user acceptance and the practical feasibility of these technologies for broader adoption.

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EVALUATING THE HEALTH AND SAFETY PRACTICES OF CONSTRUCTION SMALL AND MEDIUM-SIZED ENTERPRISE LEADERS

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The construction industry is a high-risk industry and a top-five contributor to non-fatal injuries in the UK. The industry is dependent on Small and Medium-Sized Enterprises (SMEs) and reportable accidents are most often attributable to the SME sector. This study focuses on the role of the leader (Owners/Directors) of SMEs in improving health and safety performance. An initial study with six construction health and safety experts was undertaken before qualitative semi-structured interviews with thirty-two Owners/Directors of Construction SMEs. These interviews evaluate the experience and perceptions of the construction leader's practices through a '4P', Qualitative analysis. Focusing on the leader's characteristics revealed that leaders tend to seek similar positive attitudes and behaviours within followers. It was also found that Leaders consistently try to positively change the follower's understanding and behaviour, sometimes overlooking negative behaviour due to pressures from the main contractor to comply with the programme of work.

Keywords: health and safety; leaders; performance; practices; SME; H&S

INTRODUCTION

The construction industry is unique, ever-changing (Sherratt and Dainty, 2017), one of the most complex and dangerous industries (Pan and Zhang, 2021) with frequently the unenviable record for fatalities and serious accidents. The industry is supported by an essential component of Small Medium sized enterprises (SME) and is regarded as a significant contributor to society; however, construction SMEs are a significant source for industry accidents and fatality rates (Labour Force Survey, 2016). With limited resources for developing and supporting health and safety standards and performance it is important, as identified within mature organisations, for those leading to continually improve health and safety performance (Kaassis and Bardi 2018).

Levitt and Parker (1976) identified links between the drive for improved health and safety performance and measured outcomes of exceptional safety performance as well as higher productivity. A significant business focus for construction organisations is based on performance, productivity standards and successful tendering to obtain future work (OGL, 2020). Harnessing these elements have the potential for developing greater organisational success and establishing the positive practices of

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Construction SME leaders through greater health and safety performance can influence this success.

LITERATURE REVIEW

As Pilbeam (*et al.,* 2016) identified, there are significant challenges for SME leaders in balancing operational consideration with health and safety practices. The greater impact of hazards on SME is associated with the lack of planning, availability and opportunity of reasonable controls and quick response that is required in a crisis, compared to the ability to respond by a large organisation (Herbane, 2010).

There is a significant lack of health and safety research focusing on a construction SMEs leader's practice, with previous research specific safety management practices and legislation (Unnikrishnan *et al.,* 2015) contractor compliance (Mustapha *et al.,* 2017) and safety culture and climate (Asad *et al.,* 2021). Hollnagel (2014) and Dekker *et al.,* (2016) suggested moving away from focusing on general negative aspects of health and safety, such as accident causation and accident rates, and towards a more positive focus. Consideration of building back wiser, within positive health and safety leadership practices, can create a positive community through creating resilience and capacity (Trinh and Feng. 2019).

Sullivan-Taylor and Branicki, (2011) identify that SMEs take a different approach to risk management and have a different perspective on dealing with extreme events compared to large organisations. Small and medium-sized enterprises face difficulties in implementing formal management systems (Arewa and Farrell 2012). Taylor and Branicki (2011) also recognise SMEs as being the least prepared for a crisis. Therefore, considering the existing skills, knowledge, and behaviours of directors, owners of construction SMEs which reflect industry best practices and innovation could create an altered health and safety approach.

Leadership is a relationship involving power and influence (Fielder, 1974). The construction industry has a poor image and reputation for non-collaborative culture, driven by commercial behaviours (Framer 2016), whereas implementing a collaborative management process can improve safety and productivity (Choudhry, 2015). The construction industry has been traditionally regarded as being led with a Transactional Leadership style, which is reactive, compliance-based with close monitoring by the leader for deviations, mistakes, and errors (Bass, 1985). In contrast, Transformational leadership is a pro-active and recognises the change organisations require to address adaptability and flexibility (Ismail and Fathi, 2018) where leaders motivate their followers to perform beyond expectations and beyond self-interest for the greater value of group goals. Development from a transformational leader considers a higher-level multi-dimension, reciprocal relationship process between the leader and the follower as recognised within the Leader-Member Exchange theory (LMX) (He *et al.,* 2021). Through a social exchange and moral leadership, a leader can respond to the follower's abilities and provide greater motivation than just an economic exchange (Khan *et al.,* 2020). Fiedler (1974) links the power, the leader has, to the influence within a situation based on the leader-member relationship, the task structure, and the position of power. Therefore, when the leader has developed a relationship with the follower, they will have more power and greater influence.

There is a growing interest in the theory of the authentic leader (Gardener *et al.,* 2021). An authentic leader reflects on their ability and actions with a sense of humility by way of validating their position. The leader identifies themselves as being faithful to their values and consider personal strengths as a structure for personal identity (Kruse *et al.,* 2016). For those who incorporate the role of leader within their identity, are then able to influence others in a personal manner which reflects their values, knowledge and skills and equate to one's best self (DeRue and Ashford 2010).

Kheni *et al.,* (2007) consider a broader stakeholder perspective of construction health and safety for SMEs through qualitative interviews. This research found that implementing a health and safety framework was influenced more by the fact followers/employees were extended family members of the Director/Owner. Agumba and Haupt (2009) exploratory study considers the importance of the leader's commitment and health and safety skills as an influence of culture for construction SMEs through a quantitative sampling questionnaire and methodology. However, the research did not clarify the role of the participants, or the pressures placed upon them within the decision-making process.

Adegboyega *et al.,* (2021) considers risk normalisation of health and safety within construction SMEs through a questionnaire, contemplating a broader stakeholder perspective; however, this did not provide a focused view from the leader's perspective. These studies demonstrate the dearth of knowledge and understanding on construction SME leader's practices for health and safety, and no one best theoretical framework to address the mix of topics covered in this paper. The application of a 4P analytical framework (Pressure, Partnership, Practices and Performance), from the marketing industry was applied to the construction SME leadership context (Sodhi and Tan 2016), accommodates a complex supply-chain arrangements commonly found in construction.

This research explored the construction SME leader's practices, for health and safety in the context of their actions (Thompson *et al.,* 2018), with the method in which the practices fit within the leadership process recognising enhanced health and safety performance (Kaupplia *et al.,* 2015). This focus recognises that implementing effective leader practices for health and safety fosters relationships to build upon individual and organisation resilience and community.

METHOD

The data collection method was gained from structured probabilistic interviews specifically through the lens of thirty-two (32) Directors/Owners of construction SMEs to gain an understanding of these individuals' leadership practices. All interviews were undertaken due to the specific criteria of being an Owner or Director of a Construction SME and worked within the construction supply chain. The interviews were transcribed verbatim, data coded and integrated through Qualitative Data Analysis Software (QADS) Quirkos.

Data was coded within a 4P framework model based upon the 4P marketing theory (McCarthy, 1960) with the purpose to add value in meeting customer needs and achieving company goals, and similarly within a fast-paced environment. The 4Ps adopted a conceptual framework addressed Pressures and Partnership, which were evaluated as having a significant impact on the Practices and, ultimately, Performance (Sodhi and Tan 2016). Applying such a framework provides the research with an aspect of boundary object and parameter limits (Gray *et al.,* 2017).

FINDINGS

The context of the leadership was evident in the pressures (Table 1) associated with general construction issues. The themes identified were linked to adverse traditional construction problems of staying within the programme of works which resulted in cutting corners, skills shortages that required operatives to be employed that did not have practical experience or understanding of the technical or hazards present on site.

Table 1: 4P analysis of SME health and safety leadership

Pressure	Partner	Practices	Performance
Responsibility, Reputation, Blame culture Int 1, Int 7, Int 24, Int 28,	Employee/3 rd Parties Int 7, 13.	I want to demonstrate my commitment. Int 7 leadership in our company is very visible. Int 9 leaders' vision. Int 28, We give the operatives some control we as well as understanding as to what is expected. Int 3 being very aware of yourself, but also aware of those around you. Int 19 importance of communication and feedback and engagement. Int 13	we are now looking for innovation Int 3 Show that moving toward health and safety performance improvements is the desired state. Int 9 leads by example through identifying his expectations. Int 30 the leaders vision. Int 28 to walk away from high pressure work Int 32
Commercial: Unrealistic programme. Int 4, Int 7, Int 13	Client Main Contractor Int 2, 7	you've got to learn from this and adapt and move and change. Int 7 Importance of planning and understanding the client's needs. Int 8 drivers are developed (from pressure) and important. Int 2	Greater working relationship. Int 23, Int 28, having clear objectives. Int 5 Cause of accidents Int 3 Financial reward. Int 4
Skills shortage/Social behaviour Int 7, Int 9, Int 8, Int 28	Employees Int 1, 21, 25	Importance of education and qualifications. Int 1 Improving competency. Int 2, 21 Being forward thinking Int 3, 5 Close enough to understand the operatives but not to be friends. Int 25	health and safety performance improvements are the desired state. Int 9 Importance of "Why" for performance. Int 11
Changing standards and processes. Int 2	Client/Main contractor. Int 3 External 3rd Parties Int 7	Being flexibility and allowing for authority and responsibility in the process. Int 3 we'll all probably bend the rules but not so far as to break them. Int 7 has to take on new approaches. Int 2 importance of planning. Int 5 you've got to adapt. Int 30	Use of external resources and expert knowledge (Safety consultant) Int 19 recognise good follower performance. Int 24 follower looks for and needs education, skills and knowledge and understanding. Int 28
On-site Hazards Int 3 health and safety are highlighted further with COVID 19 Int 1	Client/main contractor Int 7 Employee Int 3,14, 15, 21	Improving competency. Int 21 the leader being aware of individuals within a team. Int 3 Allow the follower or to help the leader improve Int 15 Learn from other people. Int 14 My wide is the COVID coordinator. Int 7	Use of mobile phones for on-line software and training. Int 15 Using a LinkedIn and WhatsApp page to praise workers. Int 7 Understanding the process of Hazard identification, risk control and linking this to productivity. Int 14

(Int; Interview)

Therefore, the leader's responsibility is associated with the care owed to others and the ethical consideration. The threat of damage to the organisation's reputation due to an incident and health and safety performance may affect the sustainability of work supply from a client or main contractor, where reputation is associated with a blame culture and correlates to the 'guilty until the proven innocent' structure of UK health and safety legislation (where employers must demonstrate that they have either met or exceeded the minimum legal requirement). The pressures (table 1) of leading construction SMEs were related to the personal pressure associated with the "threat of imprisonment, fines, damaged reputation" (Int 1) and the personal responsibility of injuring someone with whom an SME leader will have a close working relationship.

A “blame culture” is often associated with the construction industry and was evident with the pressure of personal experience by many interviewees. Pressure arose from the lack of full integration of health and safety costs within the commercial and time constraints and the potential for improving performance. Limited industry collaboration resulted in clients and contractors demanding varied health and safety management processes and documentation, which prevents standardisation of submission documents complicating the tendering process.

Leaders look for followers with similar characteristics and beliefs that they also hold important and are drawn to the leader, especially those regarded as having additional skills, such as being multilingual. Such an example was provided for a large Polish constituent of Joiners on site where the operative with higher skill levels and command of English drew the leader to provide more information and instruction to that individual. By applying a more reliable communication process, removes the potential of a cross-cultural communication barrier. This higher-skilled operative then cascades instruction to the other non-English speaking employees and becomes the notional on-site leader. The leader of this Construction SME was able to identify the followers' skills and apply them to support their own communication skills gap in a symbiotic dependant partnership with the follower.

Int 28 identified that social standards, expectations, and behaviours have altered within the construction industry, from alcohol consumption to illegal recreational drugs. The application and development of alcohol and drug policy and testing by large and high-risk industries restricted this SME Leader placing operatives who are known users within the main client or contractor's site - a pressure of the skills shortage for owners and directors to retain such employees. At the same time this leader is aware of their significant personal responsibility.

The leaders understanding of site hazards impacting the leader’s practices are an important method for trust to be developed. The global COVID 19 pandemic highlighted the fragile nature of continuing projects and balancing the safest work methods in line with Government guidance and limitations of construction health.

Essential partnership (Table 1) characteristics of the leader were identified as; the importance of trust, respect and honesty and closely associated with multiple leadership theories such as Transformational, LMX and Authentic leadership styles. The interviewed leaders realised the dependency on the follower as a construct of "the leader needs followers they can learn from" influence and be influenced by the follower in a symbiotic, two-way process where communication is seen to be vital in achieving the leader's organisational vision. Communication was key in providing confidence, thus allowing the follower to take responsibility, which then leads to greater independence and sharing of responsibility with the follower.

This form of delegated responsibility leads to a greater likelihood of accepted trust by the follower, where the message is clear and the follower understands what is expected, resulting in the follower not being entirely reliant on the leader and accepted responsibility. Two study participants identified that a leader must retain a certain level of detachment to the follower, as this is essential to ensure a level of command and control. By preventing a close relationship, they could ensure the ability of enforcing action when required. One participant intentionally created a barrier between themselves and the follower through their requirement to have a COVID 19 co-ordinator. An example by another participant stated that "on a Friday you cannot go to the pub with the men and be their friend and lie like a lamb and then on Monday morning run with the wolfs and discipline them" aligning with the perspective of Transactional style of leadership.

In contrast, other study participants identified the importance of the team, particularly when considering all employees or family culture with a more open relationship. By doing so leads to a better understanding of the individual needs of the employee. The principles of successful leadership were highlighted as an art form with "Leadership being related to the tempo of the leader in charge". The suggestion is that the culture created within the organisation was viewed as a "team" or having a "family feel" often creating a higher level of care within the Leader, often due to the close personal connection with the employees. For those leaders who considered the importance of creating a family feel, identified the importance of the employee's needs, to know and understand the follower and their capabilities.

The shared pattern of leadership practices (Table 1) considered that change is an essential strategy to the survival and the development of the leader, follower, and essential for organisational growth. The leaders see themselves as setting the standard through visibility and commitment as to the standard of health and safety required. Their followers are developed through competency, raising the technical ability, and understanding, through qualifications, of the construction process, hazard awareness and increased follower competency and ability. These additional skills and characteristics reinforce the development of an organisation in both the leader and follower through building confidence, evolving maturity, and creating resilience. The leaders' believed that greater health and safety integrity was established with new working and leadership practices.

One approach was to provide easy access to health and safety information through mobile phones or tablets with online access to software such as "I" Auditor and training or to the existing company to health and safety files specific to a site or client. Being innovative, leaders made it easier for site employees by providing access to online systems and updated safety information such as asbestos registers and health and safety monitoring records. Online access also raised the organisation's profile by recognising individuals' work, successfully completed work and good safety practices through social media (LinkedIn) or apps (WhatsApp). In contrast to the intrinsic importance of communication for health and safety engagement, it was suggested that leaders could hide behind communication. where there is an overload of health and safety information or restrict access to specific communication processes such as meetings and committees.

The health and safety performance (Table 1) of the construction SME is not held in isolation from the other activities of the leader. As the leader looks to develop their SME, the pressure of insufficient health and safety performance, often identified by the client or main contractors, can, become a driver to develop organisational change. Facilitating health and safety performance improvements were supported by improving skills and access to education for both the leader and followers; however, the availability of skilled and experienced operatives is one of the significant performance challenges for the construction industry (Farmer 2016). Leaders felt that they had to consider planning; however, still be flexible in their approach and amenable to "bending" (Int. 7) the health and safety rules. Such comments showed the honesty of the participants, reducing the possibility of the participant providing answers which they felt 'were required'. Safety performance was a desired state, gained through vision and innovation often with the support of external safety advisors with specialist knowledge, reflecting the SMEs specialism.

Features detrimental to construction SME's health and safety performance, was an environment not within the control of the SME and lead with less regard for health and safety standards (Int 2). The result being that operatives would work to the lower standard set by others. To combat this influence, the interviewee, suggested establishing expectations of consistent health and safety performance.

DISCUSSION

The importance of the construction SME leader's role requires integration of health and safety practice and performance with the organisations' need to survive and develop (Int 7). There is continual reflection and planning as to the situational environment, level of health and safety risk, expectation of the client and the ability/skills of the follower (Int 1) to meet those standards. The technical complexity of construction (Trinh and Feng, 2020) links the significance of competency in qualifications, knowledge, and experience for both leader and the follower to the overall organisational performance (Int 19). Having greater skills and knowledge (Rantal *et al.,* 2022) provides greater awareness and understanding of health and safety requirements in addressing risk control (Int 14).

Organisational community (Int 13) can be gained through a positive health and safety culture (Rantal *et al.,* 2022) created from a positive, supportive leadership style (Int 7,9), such as a Transformational (Bennis, 2001) or LMX (Barling *et al.,* 2011). These leadership styles are more considerate in providing justification and reasoning as to "why" (Int. 11) specific health and safety practices are implemented and therefore allow for a supportive culture, where the follower is to be able to ask "why?" without a negative reaction. This; however, does not prescribe transactional leadership style as being negative. Such a direct leadership approach provides a different culture with less potential for ambiguity of expectations or relationship. As Ismail and Fathi, (2018) identified, there is the requirement for leaders to be able to be adaptable in leadership style to address the follower's needs (Int 3), such as in times of requiring support (mental health) or situational needs such as in emergencies.

Findings which focus on the Leader's perspective reveal that leaders look for similar positive characteristics within followers; followers who show initiative, have improved communication skills and a desire to learn, are factors which reflect a Transformational Leadership theory (Bennis, 2001). Other leaders suggested decentralising health and safety responsibility, as a potential power shift to the follower. A shift in responsibility and the power balance (Fiedler, 1974) is associated with the LMX leadership theory, where a leader appraises the follower as being responsible and having the suitable ability, is trusted with greater independence, and as suggested by participants, a decentralisation of ownership for health and safety responsibility. An LMX structure provides a greater understanding of the Leader's practices for performance by enhancing the follower's understanding of "why" they are to behave in a particular manner. The construction SME Leader would then expect improved health and safety performance by providing greater certainty and clarity of health and safety, objectives associated with the LMX theory, constructed through practices of leading by example, setting expectations, and improving worker engagement.

Pressure can arise when there is conflict in health and safety standards between the SME and the Client/Main Contractor. The Client /Main Contractor generally expect the highest standard of health and safety performance within their supply chain. However, they invariably require the lowest tender cost and compliance with the work programme demands. Such demands were seen as conflicting with health and safety standards, especially as the programme developed, where time constraints were believed to be the most significant cause of accidents. One interviewee suggested that the best scenario for "improving health and safety performance would be in choosing whom they worked for and walking away from excessively low tenders with arbitrary time scale" (Int 32). Such a Pressure /Partnership conflict resulted in the most proactive and responsible leaders balancing the financial/contractual risk with health and safety and overlooking minor, adverse health and safety practices.

CONCLUSIONS

The group of Construction SME Leaders', within this research, identified and supported the opinion that health and safety decision-making practices are complex and must consider multiple factors. That the leader continually reflects on and plans the compatibility between the skills and ability of the follower to meet the performance standards of the environmental situation, the level of health and safety risk and the health and safety expectation of the client/main contractor.

A positive Leaders practice was to consider the 'pressures' of client/Main Contractors feedback as personal motivation to achieving higher health and safety standards. Pressures of construction skill-shortage often saw the need to employ operatives of lesser skills and ability. The leader would address this by seeking employees with similar attitudes as the leader and then plan to develop the required trade skills and appropriate health and safety behaviour. Such a strategy resulted in a temporary shortfall in the initial risk awareness; however, it allowed the employee to adapt and develop knowledge about the leader's expectations and required culture behaviour. Leaders need followers, with leaders understanding the mutual symbiotic relationship with the follower. These leaders' take cognisance of the follower's personality, needs and ability and balance these with the leader's practices. Ranging from a family and individual perspective, acting with empathy, moving to a wider consideration of the organisational needs and the use of power through responsibility to achieve the required health and safety performance.

Leaders realise the importance of building community and relationships with their followers in supporting a safety culture by providing an understanding of "why" specific safety procedures are implemented and must be adhered to. In recognising the importance of communication and removing the traditional leader/follower imbalance of power, leaders can create a safe social environment in which the follower can ask "why", shaping engagement and follower acceptance of the leader's practices.

Construction leaders look to combine wider access and ease of access by on site employees to health and safety information, documents, and files. This is being achieved through a significant change and innovative use of technology. Innovative online business support, with the use of health and safety specific software and training packages. Social media, was also successfully applied to publicly praising follower's behaviour, raise wider community awareness and to advertise commitment and leadership of positive health and safety performance.

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ENHANCING DIGITAL TRANSFORMATION IN CONSTRUCTION HEALTH AND SAFETY: A SYSTEMATIC REVIEW OF THE CURRENT STATE OF THE ART

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Previous studies have emphasized the need to improve the state of knowledge regarding the benefits of incorporating safety technologies to improve safety of workers. Despite the benefits that could be gained from incorporating safety technologies, its potential has not been fully realised. This paper therefore filled the gap by examining critical success factors required for implementing safety technologies in the management of construction H&S from the organisational point of view and then develop a framework for its adoption. A systematic literature review was conducted on selected articles from 2012-2022 to allow a thorough synthesis on recent literature on digital innovations and construction H&S. The success factors are attributed to strategic initiatives, organisational culture, learning capability and knowledge sharing and financial and statutory drivers. The findings from this study will be valuable to industry practitioners, policy makers, regarding strategies to enhance its successful implementation in the construction industry.

Keywords: safety technologies; industry 4.0; digital transformation; health and safety

INTRODUCTION

Numerous scholars are constantly searching for new tactics and procedures that could boost H&S efficacy in construction. An overview of current publications shows a definite trend toward the use of new inventions for H&S management (Yap *et al.,* 2021; Zhou *et al.,* 2013). These innovations can be used to suppress occupational dangers in a variety of construction activities (Nnaji and Karakhan, 2020). Research on utilising technological innovations for construction H&S has increased because of the advantages that can be derived from its adoption (Karakhan *et al.,* 2018; Zhang *et al.,* 2022). However, despite the opportunities and benefits posed by technological innovations in managing H&S hazards, its adoption and implementation is still very low.

This could partly be attributed to difficulties associated with its implementation at the organisation level (Lokuge *et al.,* 2019). Although, most research is focused on using technological inventions to mitigate health hazards in construction sites, they are unable to establish a complete approach for measuring the importance of integrating

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smart technologies (Nnaji and Awolusi, 2021). Incorporating safety technologies for construction H&S management is a continuing phenomenon with a variety of impacting parameters that may influence its implementation (Malomane *et al.,* 2022). As more technologies are developed or adapted for safety purposes, it is essential to determine ways to improve the integration of technologies within H&S management. In most cases, a technological change goes through three phases prior to becoming a standard practice in an organisation.

These phases are the adoption of the technology, its implementation and the acceptance or utilisation of the technology (Nnaji and Awolusi, 2021). Given the level of fragmentation within the construction industry and the different construction means and methods adopted among construction firms, it is necessary to determine the success factors of adopting innovative technologies and examine their level of importance on influencing overall adoption of H&S technologies in construction. Previous literature focuses primarily on evaluating the effectiveness of and assessing the return-on-investment of implementing H&S technologies (Yap *et al.,* 2021; Gao *et al.,* 2019; Khakurel *et al.,* 2018) rather than investigating critical success factors of implementing H&S technologies.

Therefore, this study will examine critical success factors for implementing digital innovations within corporate contexts. Furthermore, there is an absence of a clear integrated model, further complicating the deployment of digitalisation in construction H&S. In view of this, an implementation framework will be created to give a stronger conceptual foundation for the overall implementation process. This will allow construction firms to better embrace and implement more effective processes and change management methods because of this. A review of the existing literature on construction H&S, and digital innovations will identify the primary critical success criteria that must be evaluated for effective and efficient integration of safety technologies for construction H&S.

Safety Technologies Adoption as a Process Change

The adoption of safety technologies in construction is one of the paramount ways to reduce H&S hazards in order to protect workers and ensure the successful delivery of construction projects (Yap *et al.,* 2020). Nnaji and Awolusi (2021) mentioned that the implementation of safety technologies creates unique opportunities for construction to change from existing corporate procedures or for creating new ones. This is why it is termed as a process change enabler or process change management (Kraus *et al.,* 2022). Implementing safety technologies in construction H&S is not just about modifying software packages, but it's all about restructuring the firm in its response to matters of H&S of their workers and transforming construction processes and practices (Martínez-Rojas *et al.,* 2020).

An organisation's efforts and activities should be evaluated and improved on a regular basis. Successful implementation of safety technologies in H&S requires different approaches which involves team management, cultural change, and significant changes in the construction operations and methods (Golisadeh *et al.,* 2018). Any business process change requires a strategic initiatives where top managers define and communicate a vision of change. An organisational structure with an effective culture, a willingness to exchange ideas, teamwork, and a capacity to learn should allow the deployment of certain process management and change management method (Lines and Reddy Vardireddy, 2017) for the implementation of digital innovations in construction H&S.

METHOD

This study was carried out as a systematic literature review using the method suggested by Abbasnejad *et al.,* (2021). Qualitative research approach was used to obtain the primary data. Based on this method, the literature-based findings were extracted, analyzed, and reported using a three-stage procedure. A desktop study was undertaken in the first round to collect literature using several search databases such as Google Scholar, Web of Science, ScienceDirect (Elsevier), and Scopus. Also, English-language journals and peer-reviewed publications, conference papers on the research focus make up the literature dataset covering periods from 2012-2022. For compiling the literature, keywords such as "construction H&S" or "digital technologies" or "safety management" or "safety technologies" or "Industry 4.0" and "critical success factors or drivers or implementation or adoption or change management" were used as a basis for retrieval.

This research resulted in the collection of 225 papers which were acquired from different construction and safety management literature and related journals as listed by Wing (1997), Nasirian *et al.,* (2019), and Zhou *et al.,* (2013). The number of relevant papers and their corresponding source tiled is outlined as "Initial Number of Papers". These articles were exported to Endnote support platform to manage the bibliography. Afterwards, the papers were considered for eligibility based on; inclusion and exclusion criteria which allows redundant publications to be discarded based on the focus of the research, incomplete articles, language used, and year of publication.

This resulted in the selection of 78 papers for further investigation. Further filtering was performed on the 78 manuscripts to test for eligibility based on quality assessment which focused on the type of journal articles (peer-reviewed and of high quality with the exclusion of non-peer-reviewed papers), duplicate papers where the same author/s published in more than two conference proceedings. Also, in cases where a journal article is an extended version of a conference paper, the journal article was prioritised because journals represent more rigorous and in-depth analysis. A total number of 34 papers were recognised as meeting the requirement of this study, thus providing a suitable basis for the analysis of literature and for developing strategies to enhance the implementation of safety technologies. Content analysis was used for analysed the collected publications. The data were managed and analysed using Microsoft Excel and the synthesis of the findings is presented in the following sections. Each of the publications, with its corresponding journal, and authors are listed in Table 1.

FINDINGS

The results of this study are presented in two parts. The first part provides a summary of the journals publishing papers on safety technologies and the topics being considered. In the second part, a conceptual framework for enhancing safety technologies in the construction industry is developed and details regarding different elements of enhancing safety technologies is presented (Figure 1). This review revealed seven sources that have published more than one paper around the enhancement of safety technologies (Table 1). Some of these journals belongs to the list of top construction journals by Zhou *et al.,* (2013), including Journal of Construction Engineering and Management, Automation in construction, Construction Management and Economics, Engineering, Construction and Architectural Management, and Journal of Management in Engineering which contains 15 different papers. Famous safety management journal such as Safety Science was also included. Other journals focus on Construction Innovation, Journal of Information Technology in Construction, Technological Forecasting and Social Change.

Table 1: Search results for relevant publications

Source title	Initial number of publications	Final number of publications	References
Journal of Construction Engineering and Management	35	3	Ahn *et al.*, (2019), Karakhan *et al.*, (2018), Nasirian *et al.*, (2019)
Automation in Construction	42	4	Golizadeh *et al.*, (2018), Martinez-Rojas *et al.*, (2020), Zhang *et al.*, (2022), Li *et al.*, (2018)
Construction Management and Economics	24	4	Lingard (2013), Wing (1997), Zhou *et al.*, (2013), Shibeika and Harty (2015)
Engineering, Construction and Architectural Management	12	2	Aghimien *et al.*, (2020), Nnaji *et al.*, (2019)
Construction Innovation	8	1	Farghaly *et al.*, (2021)
Architectural Engineering and Design Management	2	1	Abbasnejad *et al.*, (2021)
International Journal of Construction Management	9	1	Akinlolu *et al.*, (2020)
Journal of Building Engineering	1	1	Nnaji and Karakhan (2020)
Journal of Management in Engineering	7	2	Lee *et al.*, (2015), Lines *et al.*, (2017)
Journal of Engineering, Design and Technology	7	1	Yap *et al.*, (2021)
Organization, Technology and Management in Construction-An International Journal	4	1	Mihic *et al.*, (2019)
Frontiers from Architectural Research	10	1	Ramilo and Embi (2014)
Frontiers in Built Environment	5	1	Swallow and Zulu (2019)
Safety Science	16	2	Badri *et al.*, (2018), Martinez-Aires and Martinez-Rojas (2018)
International Journal of Environmental Research and Public Health	2	1	Malomane *et al.*, (2022)
Computers and Education	6	1	Gao *et al.*, (2019)
Journal of Information Technology in Construction	12	2	Hare *et al.*, (2020), Miller *et al.*, (2014)
International Journal of Information Management	9	1	Kraus *et al.*, (2022)
Information Technology and People	6	1	Khakurel *et al.* (2018)
Information and Management	1	1	Lokuge *et al.*, (2019)
Technological Forecasting and Social Change	6	1	Martinez-Caro *et al.*, (2020)
Technology in Society	1	1	Nnaji and Awolusi (2021)

Framework for Enhancing the Implementation of Safety Technologies

To better understand safety technologies, a framework has been devised that incorporates the key elements that need to be considered when devising appropriate strategies (Figure 1). The four main elements of the framework are strategic initiatives, organisational readiness, financial and statutory drivers, and learning capability and knowledge sharing. Each element includes several sub-elements discussed. Each element includes several sub-elements:

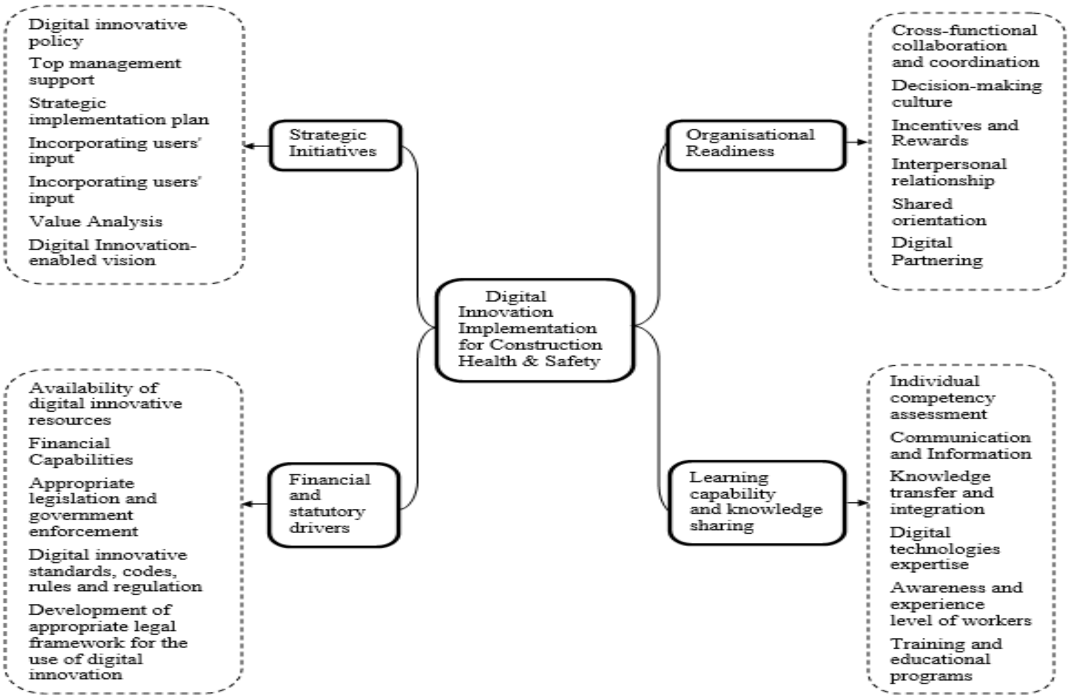

Figure 1: Framework showing drivers for successful implementation of safety technologies

Strategic Initiative

According to Table 1, one of the critical success factors for the implementation of safety technologies for construction H&S is strategic initiatives. Nnaji and Awolusi (2021) mentioned that the buy-in of key stakeholders is crucial for digital innovations to successfully penetrate the construction sector. Given the increased desire and gradual shift towards a more collaborative project delivery approach, this buy-in is becoming increasingly vital. In this process, the support of top management is crucial for the successful adoption of safety technologies for H&S management (Lingard, 2013).

The willingness and commitment of top management to provide essential resources and their involvement is vital to implementation (Nnaji and Awolusi, 2021). Digital innovative managers will need to assume tasks such as regular communication to suppliers of software, training, supervision, and developing digital policies and plans (Yap *et al.,* 2021). In addition, effective innovative policies (guidelines, standards, etc.) should be established to guide practices, and compliance should be highly established to ensure the achievement of construction H&S (Hare *et al.,* 2020). Goals and objectives, roles and duties, adoption scope, process flows, duration of the project, and supporting organisational and technical infrastructures, as well as the evaluation process, should all be included in the implementation plan (Mihic *et al.,* 2019). During the evaluation process, construction workers should be involved because they are crucial to the effective adoption of safety technologies (Yap *et al.,* 2021). Yap *et al.,* (2020) also mentioned that a detailed training program that incorporates predicted training requirements and includes generating a cost-effectiveness rationale should be produced.

Although, the cost of purchasing and operating safety technologies should not be the main driver of their adoption (Nnaji *et al.,* 2019), the influence of a technology on an organisation's bottom line is crucial to ensuring senior management's continued support. Furthermore, an enabled vision for understanding the role that safety technologies will play in the mitigating health hazards will help firms in determining performance goals and fulfilling key objectives (Nnaji and Awolusi, 2021). This idea must be compelling enough to inspire collaboration and commitment of the employees (Lee *et al.,* 2015).

Organisational Culture

Digital innovative initiatives will advance in an open and safe environment if mistakes are allowed to be perceived as improvement opportunities (Abbasnejad *et al.,* 2021). Changes resulting from the introduction of safety technologies may cause resistance (Martínez-Caro *et al.,* 2020). In this vein, efficient communication is essential, as it enables individuals to feel more involved in the implementation process while also keeping them informed about organisational practices, standards, and aspirations (Ahn *et al.,* 2019). Finally, impediments to implementation are most likely to be addressed by an organisational culture that is open to change and consists of shared common values and goals (Ahn *et al.,* 2019).

Workers and employees should also be involved as quickly as possible by management (Abbasnejad *et al.,* 2021). Organisational change agents (leaders) with the required skills, expertise, and leadership capabilities are required to effectively explain the advantages of safety technologies in minimizing or suppressing health risks (Khakurel *et al.,* 2018). Leaders must identify and analyse the sources of resistance and provide strategies to deal with them effectively to drive consensus throughout the implementation process (Nnaji and Awolusi, 2021). Digital adoption should not begin unless potential users (construction workers) develop and maintain a positive mind-set (Ahn *et al.,* 2019).

As a result, managing change initiatives is a vital enabler for implementing digital innovations. To effectively deal with exchange of information, integration, IT systems, and software difficulties, there must be collaboration among external vendors, consultants, and supply chain partners (Yap *et al.,* 2021). This will help maintain tight and trusting relationships with other entities who have valuable information about advanced technologies by providing opportunities to learn and gain expertise about the concept. Therefore, project stakeholders, organisations, professional bodies, and local governments are encouraged to collaborate to improve project organisational-related issues, such as the adoption of safety technologies to prevent potential health risks of workers.

Learning Capability and Knowledge Sharing

Successfully implementing digital innovations for construction H&S can also be achieved through learning capability and knowledge sharing (Swallow and Zulu, 2019). It is important for construction firms to develop informal learning networks for knowledge acquisition to take place. Construction employees' skills are improved, and their awareness of digital concepts and tools is expanded through effective and well-designed training and continuous educational programs (Gao *et al.,* 2019). Personal attributes, training intervention design and delivery, and training performance evaluation are some of the major categories that training, and education might follow (Miller *et al.,* 2014). Candidate competences must be identified, measured, and recorded to improve learning performance. Training performance evaluation should incorporate assessments of learning outcomes, behavioural reactions, and expectations on whether training programmes have enhanced trainee values and to what degree new knowledge and skills have resulted in improved job performance (Martínez-Aires *et al.,* 2018). Thorough training and education are critical for attaining end-user expectations, as well as supporting a long-term focus on continuous development.

Furthermore, information exchange and communication are critical in minimizing resistance to change as well as the risk and uncertainty that come with new systems, processes, and technology (Zhang *et al.,* 2022). The development of a knowledge management (KM) system for safety innovations facilitates the codification of internal routines, employee learning experiences, builds on knowledge, coordinates complex change activities, disseminates knowledge, and ultimately increases the dynamic capability of the organisation (Ahn *et al.,* 2019). Firms' ability to capture and re-use gained information and experience is hampered if they do not build an effective learning capability and knowledge management system. This means that top management of construction firms and professional bodies must place a greater emphasis on employees' training, as well as increasing their knowledge and awareness of the use of safety technologies to mitigate health hazards in construction by organising seminars, workshops, and conferences.

Financial and Statutory Drivers

These underlying factors are related to the ease of securing funding for the acquisition of digital software and its associated licenses, support from government in the form of start-up funds for construction firms, development of an effective regulatory basis to guide its implementation in projects, among others. Malomane *et al.,* (2022) recognized the challenges faced by the relatively high cost of digital software acquisition. As a result, to improve the implementation of safety technologies for reducing potential health risks in building projects, stakeholders involved must make a concerted effort and commitment to make the required funds available to help the efficient adoption of safety technologies (Nnaji and Karakhan, 2020). Also, top executives in the construction sector should be eager to make long-term investments and commitments in the execution of safety technologies that will have long-term effects (Nnaji and Karakhan, 2020). It is also critical that the government work to support small and medium-sized construction enterprises with funds and incentives to encourage them to utilize safety technologies to reduce health risks in their projects (Li *et al.,* 2018).

Considering the possible impact these innovations could have on construction workers' H&S, establishing a comprehensive strategy for facilitating the adoption and use of safety technologies has become imperative. As a result, this research contributes to a better understanding in a variety of ways. To begin with, the industry is ripe for the adoption and diffusion of safety technologies that will play a significant role in revolutionizing H&S in the construction industry, given the alarming state of safety performance in the industry and the current push to leverage innovative and effective methods to improve workers' H&S. The current research revealed the most important aspects to consider when using safety technologies on a construction project or inside an organisation.

Once digital innovations have been effectively embraced and deployed on a larger scale in organisations, practitioners can use artificial intelligence to create predictive models that can provide significant insights to designers and planners, thus enhancing the design for safety objectives. In addition, the results showed that the most significant factors for implementing safety technologies are having a knowledgeable and well-trained workforce, as well as ensuring that the technologies give relevant and usable information to end-users in a timely manner. This means that effective training and information campaigns could help to alleviate some severe worries about these technologies, such as privacy risks and data security. After identifying the crucial success elements for the successful implementation of safety technologies for construction H&S management, the main fundamental precepts for the strategic integration of these technological innovations in all aspects of the construction activity must be established.

CONCLUSIONS

Organisations' inability to realize the value of safety technologies in avoiding construction hazards is primarily due to the difficulties involved with successful implementation. The effective adoption of digital innovations for reducing health hazards on construction projects necessitates a considerable systemic reform in the construction industry's business operations. When an organisation experiences a major transformation, detailed planning and management are essential during the implementation process. This research found that organisational readiness, strategic initiative, learning capability and knowledge sharing, as well as financial and legislative factors in a collaborative network relationship, can help construction firms to successfully implement safety technologies for reducing health hazards and realizing the associated outcomes and benefits.

A greater knowledge of the observed success factors should help construction firms improve the adoption of safety technologies for construction H&S management. As a result, there is a critical need for key project stakeholders to give the safety of construction workers a greater priority, as well as equip and retrain them to keep up with the industry's current trend of innovation. The development and implementation of a suitable working strategy or model to implement digital innovations should be prioritized by top management of construction companies. It is critical for government agencies and professional organisations to work together to give necessary and appropriate subsidies or financial incentives to small and medium-sized construction enterprises to encourage them to utilize safety technologies in their workplace.

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DIGITAL INFRASTRUCTURES OF FACILITIES MANAGEMENT: HOW DATA SYSTEMS AND WORK ENVIRONMENTS AFFECT EACH OTHER

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Introducing digital objects in facility management enables professionals to coordinate operation and management tasks. However, using digital objects is not a "neutral" matter. Instead, digital objects shift the distribution of responsibilities and create new ways of visualising professionals' work performance that create frustrations and discontent among the facility managers. Building on ethnographic fieldwork and inspiration from the Science and Technology Studies field, the study investigates a case concerning the operation and management of an office building in Copenhagen, Denmark. Findings show that the operation and management professionals get frustrated when the technical and digital systems of the building cannot solve the issues experienced by the building users. Limited access to systems obstructs the professionals in their work, and the systems create distance between the building and the means to solve the experienced problems. The study suggests paying more attention to digital systems' effects on professionals' mental health within facility management.

Keywords: digital infrastructure; FM; mental work environment; S&T studies

INTRODUCTION

Digital objects have an increasingly strong presence in the facility management sector. Facility managers and other operations and maintenance (OM) professionals work with many digital objects, such as building management systems (BMS), geographical information systems (GIS), building information modelling (BIM), internet of things (IoT), and 3D visualisations (Kazado *et al.,* 2019). The introduction of digital objects creates new ways of visualising information, tracking the progress of the construction process, and shifting responsibilities (Whyte and Lobo, 2010) that may cause meaningless work routines and stressful situations for the users. Although several authors examine the development and use of digital objects in the facility management sector (e.g., Stride *et al.,* 2020; Pärn *et al.,* 2017), research has been lacking on the effects of digital objects on the mental work environment of OM professionals.

Frequently, digital strategies and development initiatives promoted by politicians and professional actors refer to these digital objects as unproblematic (Ministry of

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Transport, Building and Housing, 2019), as if the transfer or the visualisation of data happens "neutrally" without influencing the software users. However, studies from the 2010s suggest this is not the case (e.g., Whyte and Lobo, 2010; Neff *et al.,* 2010; Jaradat *et al.,* 2013). For example, Whyte and Lobo (2010) state that digital objects do not "just" convey information across professions. Instead, digital objects establish new visibilities, possibilities of control, intervention, evaluation of performance, functions, roles, and distribution of responsibility. Digital objects are not "neutral" but displace roles and responsibilities and enable new actions taken by the users. To understand the use of digital objects better, we must study the effects of their introduction into the facility management industry and their use in companies and projects. This paper conceptualises digital objects and the practices with which they are applied as "digital infrastructures" (Whyte and Lobo, 2010) in which professional practices create and share digital objects across locations, media, and time.

The point of departure for this paper is a case about the management and coordination of the indoor environment in an office building in Denmark since it, in practice, involves the use of digital objects in work. Building users no longer control the indoor environment in modern office buildings. Instead, OM professionals primarily manage it through digital systems: in this case, a building management system (BMS) and a task management system (TMS). Since the technical complexity of modern office buildings is high, many installations support maintaining a comfortable indoor environment. For example, the digital systems help the OM professionals monitor and manage the temperature, airflow, and CO2 levels. It could involve installations for ventilation, heating, cooling, and solar screening. Because of the large size of many office buildings, BMS connects the many installations in a centrally controlled system that regulates the indoor environment. In comparison, TMS helps the OM professionals handle the many tasks concerning such a complex building.

According to Forman and Sørensen (2019), there are typically four "subsystems" that form part of building automation: 1) The physical building and its installations, 2) sensors and meters that are embedded in the building, 3) servers, networks, interfaces, and algorithms that process and transform the collected data, and 4) the practices of people responding to information in the systems. The four subsystems clearly show how digital objects in the form of servers, networks, interfaces, and algorithms connect technical objects such as sensors and meters in the building with the social practices of those working with the information. What we denote as a "digital infrastructure." This paper describes the relationships between digital and technical objects and their roles in practice and, for that purpose, adopts Forman and Sørensen's (2019) approach to indoor environment management, which regards building automation as a network-based technology embedded in a heterogeneous and distributed actor-network.

As the indoor environment management in office buildings today comprises increasingly digital and technical objects, it places additional pressure on the OM professionals. As demonstrated by studies of architectural practices (Jaradat and Whyte, 2013), the demands for implementing digital objects may lead to a need for systematisation. Systematisation can be distracting from the employee's competencies and core tasks. Jaradat and Whyte (2013) show how the demands of digitalisation shift architects' professional identity and result in the loss of meaning in solving problems as part of their core tasks. According to Olsén (2008), when employees experience systematising their work as meaningless, it contributes to a poor mental work environment.

This paper draws on Olsén's (2008) description of the mental work environment. Olsén focuses on the core tasks of the professionals' work. Professionals may experience repeated meaningless deviations, distractions, or interruptions of their core tasks negatively, contributing to a poor mental work environment. This paper discusses whether the relationship between OM professionals, digital infrastructures, and technical installations possibly impacts the involved professionals' mental work environment.

Focusing on how OM professionals work with digital objects and technical installations, this paper leans on discussions within the field of Science and Technology Studies (STS) and actor-network theory (ANT) that go back to the 1980s. Within STS and ANT, several authors examine the relationship between humans and computers, or humans and machines (e.g., Ehn, 1988; Goodwin, 1993; Hutchins, 1995; Latour, 1986; Lave, 1988; Suchman, 1987).

Based on studies of the design and use of the first photocopying machines, Suchman (1987) shows the difference between humans and machines or humans and computers. Designers programme machines and computers according to "plans" - formal rules and explicit courses of events within which the machine or computer can act. According to Suchman, people also draw on plans - for example, when using recipes, manuals, or checklists. Unlike machines and computers, people act in "situated actions" (Suchman, 1987), where we sense and assess the course of events as the activity takes place and while the circumstances of the situation change.

People do not solve complex tasks individually, such as steering a naval vessel into a harbour (Hutchins, 1995). However, accomplishing complex tasks relies on the distributed action of many elements. Hutchins (1995) suggests studying "cognition in the wild," where many actors, in his case, actively participate in the successful mooring of a large naval vessel, such as trained quartermasters, maps, intercom systems, and specific organisation at the bridge. Navigation from this perspective involves a distributed and collective way of knowing across human and technical elements.

Like Suchman's notion of plans, Akrich and Latour (1992) present a group of terms that they call "scripts." The process of "inscription" is when designers (not limited to official designers but may also include other stakeholders) design machines with specific users or use situations in mind. Machines and computers contain expectations and assumptions about the user's interests, competencies, motives, aspirations, and political prejudices (Akrich, 1992). Woolgar (1990) expands the understanding of what designers "inscribe" into systems by including political and moral connotations in the design of computers. Designers "configure" (Woolgar, 1990) the users in specific ways based on usability trials, design suggestions, and development strategies. In this way, systems contain assumptions about the users and expectations of the users' practices.

Based on these analytical points, this paper focuses on understanding the relationship between indoor environment systems and the practices of OM professionals. The designers of the indoor environment systems have inscribed certain expectations and anticipations about roles, collaboration, practices, and strategies within which the OM professionals navigate their tasks and solve problems in distributed actor-networks. Based on this relationship, this paper examines how the interface between the systems and the professional practices leads to unexpected work processes that pressure the OM professionals.

METHOD

Case Description

This paper draws on empirical material that centres on the operations and maintenance of an office building in Copenhagen, Denmark. The building is owned by a prominent developer with a portfolio of properties and is rented out to a tenant organisation. The building is a traditional, modern office building with office spaces, reception, and a restaurant. The facades contain large glass surfaces that the office workers cannot open. A centrally controlled ventilation system ventilates the offices through a building management system (BMS). The BMS also controls solar screening outside the fixed glass facades. Inside, radiators integrated into the floor (convectors) heat the offices and ventilation valves in the ceiling heat, cool and ventilate the offices. The BMS likewise controls heating, cooling, and ventilation. The building design with fixed glass facades, centrally controlled heating, ventilation, and solar screening entails that the office workers cannot change the temperature or increase ventilation by themselves. On the other hand, the OM professionals have access to BMS and can change the settings.

When the paper refers to the OM professionals, the reference concerns a site manager of the building owner organisation and a consultant of the tenant organisation. An agreement between the building owner and tenant organisation dictates that the building owner is responsible for the operations and maintenance of the building components and common areas. In contrast, the tenant organisation is responsible for the operations and maintenance of the office spaces. Therefore, the site manager is primarily responsible for the technical installations integrated into the building and the building components. Meanwhile, the consultant is primarily responsible for the interior surfaces and installations in the office spaces. The site manager is responsible for the operations and maintenance of this building and three other buildings, while the consultant is only responsible for this building. It is crucial for both the building owner and tenant organisation that the indoor environment is comfortable. Office workers occupy the building, and the indoor environment supports their work. Therefore, ensuring a comfortable indoor environment is critical for OM professionals.

In addition to the BMS, the OM professionals also use a task management system (TMS) to coordinate tasks concerning the control of the indoor environment. The building owner organisation has implemented the TMS for most of the properties in their portfolio. The organisation requests tenants and suppliers to use the TMS as much as possible as the system helps them coordinate, document and plan operations and maintenance tasks across properties. In the TMS, the site manager, suppliers, craftsmen, and tenants (in this case, the consultant) can order, register, and plan OM tasks.

This analysis builds on ethnographic fieldwork (Pink *et al.,* 2010) involving three interviews with professionals from the building owner organisation (among these the site manager) and four interviews with collaborators from other organisations (among these the consultant). The interviews were audio-recorded and transcribed. As a supplement to the interview data, access to the TMS provided insight into details about the communication and coordination of OM tasks.

Empirical Observations

This study describes issues and experiences surrounding infrastructure management and control of the indoor environment, from the discontent of office workers to the work practices and systems (BMS and TMS) of the OM professionals responding to changes in temperature or airflow in the technical installations. After analysing the relations that appear among the many actors, a discussion follows on which possible effects the relations may have on the mental work environment of the OM professionals.

Experience in Indoor Environment and Indoor Environment Systems

When the office workers in the building experience drought, cold, heat, or other uncomfortable elements, they usually contact the consultant in the in-house OM organisation. Subsequently, the consultant contacts the site manager because most installations are integrated into the building. The consultant enters a task in the TMS, where the problem can be described in a short text format. Such texts could be "it is generally too warm in the room" or "suffer from draught." The consultant can add a location on a floor plan or describe where the issue seems. The site manager receives the task in his inbox in the TMS and opens the BMS to change the settings, for example, the temperature. In the BMS, the site manager looks at diagrams of technical installations, short texts with abbreviations for the BMS components, and values for the airflows and temperatures concerning, for example, how the ventilation system performs. In the BMS interface, the site manager changes a value from 24 to 23 degrees Celsius for the room's air supply temperature.

The numbers on the screen in front of the site manager are collected through sensors and meters in different locations in the building connected via cables and the internet. Based on diagrams, descriptions, and hierarchical breakdown of floors and rooms in the building, the site manager reads the location of the specific component in the BMS and the meaning of the value, then navigates (Hutchins, 1995) based on the information he reads on the screen, the message from the consultant, his familiarity with the building and the specific sensors and meters from his inspection rounds. From the screen, he gets information about the components' performance while drawing on his knowledge about potentially dysfunctional sensors requiring service.

In TMS, the site manager answers the consultant with a message. For example, "the temperature is changed from 24 to 23 degrees Celsius." The consultant gets the message in his inbox and can inform the office workers about the task's progress. In some cases, the experience of the dissatisfying indoor environment does not match up with the representation of the indoor environment in the BMS, i.e., levels of CO_2, airflow and humidity. In such cases, the two OM professionals place small mobile loggers in selected places to potentially find proof of the claims about chill or warmth. The consultant states:

> "Even though we measure and do something, we cannot get anywhere because we do not really know what we should do. Then we sometimes have placed a logger in an attempt to log for a longer period to see whether the temperature fluctuates that much. Often, it turns out actually that there is not anything to do. It is a little hard in reality."

The consultant expresses frustrations because the infrastructure does not help him solve the issue of chills or warmth. In other words: the consultant's tools, as inscribed in the BMS and TMS, do not create satisfying results and possibly affect the mental work environment of the site manager.

Business Strategies and Obstacles in System Access

A year before the fieldwork, the site manager's responsibility only concerned one office building. Under the fieldwork's mandate, the building owner organisation has provided the site manager with the responsibility of several office buildings. Initially, the site manager focused all his time and energy on the building on which this paper focuses. This presence made it possible for the site manager to talk with the consultant often. The OM tasks were coordinated and solved face-to-face instead of online across the TMS. The site manager and the consultant were satisfied with the day-to-day "chitchat." With the introduction of TMS and BMS, the building owner organisation has obliged the site manager to carry out OM tasks for more buildings than one. During the fieldwork, the site manager was responsible for three properties, including around 65.000 m2. Because the site manager needs to take care of three buildings, the primary communication between the site manager and the consultant happens through the TMS.

When the site manager was more present in the building, the consultant lost his access to the TMS. His password suddenly did not work for some reason. He contacted the building owner's helpdesk service to get help. It took weeks before the consultant gained access again. The disconnection from a system that the building owner requires the consultant to use can seem frustrating for the consultant. Likewise, the consultant also lost access to the BMS. Even though the consultant was not responsible for the BMS, he had had access to the system and, in some situations, changed the settings to accommodate a poor indoor environment. However, the consultant lost access because of an update to the software. The consultant states:

> "At one point, something needed to be reorganised in the software, and then suddenly, I could not gain access. Now, [the building owner] has tried a couple of times, and I have gained some access, but our firewall will not allow me to download the needed files. There are still some problems. I have just informed them again the day before yesterday that we have to get it fixed since it actually is quite annoying."

Data security issues continue to prevent the consultant from accessing the TMS and the BMS. The case shows how the site manager and the consultant navigate in situated actions (Suchman, 1987) based on many types of information from digital systems, loggers, office workers, and their bodily experiences of being in the office spaces. Knowing about the indoor environment for them is to measure it through sensors and meters and obtain proof confirming or denying the claims about a poor indoor environment. They are integrated into an infrastructure where their only space for action concerning solving indoor environmental issues is through technical descriptions, values, and installations. Frustrations appear when the site manager and the consultant attempt to solve problems concerning the indoor environment, but their actions within the infrastructure do not help them solve the problems. Similarly, the office workers might be frustrated because they cannot adjust to the indoor environment - the infrastructure cuts them off and allow access to the OM professionals.

The case also shows how the network around the core tasks of the two professionals has increased over time. Although they had the opportunity to coordinate and solve OM tasks in person, the increasing responsibilities of the site manager shifted their interaction primarily with the TMS. Furthermore, the many digital objects (e.g., TMS and BMS) and technical objects (e.g., sensors, meters, and installations) create a distance between the experienced issues concerning the indoor environment and the professionals' ability to affect it. Simultaneously, when the professionals lose access to the systems, they have difficulty carrying out their core tasks. The practices of the OM professionals may lead to potentially problematic situations concerning their mental work environment. The following section discusses some of these potential issues.

FINDINGS

The analysis demonstrates how rationalisation logic permeates these situations. The design of the office building is optimised to ensure a comfortable indoor environment. However, the designers obtain this through a sealed building envelope and technical systems that regulate the indoor environment, preventing the office workers from regulating the indoor environment themselves according to local needs. A TMS gathers all data about OM tasks in one place, making it easy to order, plan for and estimate future costs. However, TMS brings demands for documentation and new ways of being accountable for the OM professionals' data. It seems that the building owner organisation regards it as possible for one site manager to supervise several properties using TMS, the logic being that fewer people can handle more using the system.

However, what is the other side of the coin? Does the TMS bring information overload, new work procedures, and a need for new competencies that pressure the employees? The case shows that the response time increases drastically when the coordination goes from happening in-person to involving tasks described in the TMS. In the TMS, the tasks await the busy schedule of the site manager before he can react to them. The response time on issues increases as the consultant experiments with loggers over extended periods. The need for proof makes the process slow. A prolonged response time may lead to conflicts between impatient, discontent office workers and a frustrated consultant trying to measure and push for adjustments in the technical settings of installations.

The site manager and the consultant remain trapped in an infrastructure that only allows for specific ways of approaching the indoor environment. The designers of the building and the systems, including the site manager and the consultant themselves, inscribe (Akrich, 1992) this specific way of approaching the indoor environment into the infrastructure. The inscriptions lock the consultant, for example, in a worldview where he can only act according to measurements and suggestions for technical interventions. The control of the indoor environment becomes a “measurable discipline,” and the sensors, meters and loggers gain authority. However, when issues arise that do not fit the worldview, for example, office workers experiencing a poor indoor environment even though the consultant cannot read any negative signals from the BMS, the consultant is lost.

The office workers can quickly become “unruly” and “uncontrollable,” and the “shortcomings” in the system cannot be corrected. The measurements visualise specific aspects of the indoor environment and both reduce and amplify these aspects (Latour, 1999) while simultaneously documenting and proving the existence of certain actors, such as CO2. The consultant may experience a clash between worldviews as frustrating since he cannot locate the problem or, worse yet, solve it. Moreover, office workers may be irritated by the continuously changing reference measurements and limitations of the building design and technical installations. In their configuration (Woolgar, 1990) of the infrastructure, system builders have made no room for handling local needs for changes to the indoor environment.

As the control of the indoor environment moves from the consultant's hands and eyes (Latour, 1986) to the digital and technical systems such as BMS and TMS, it creates a distance between the operator and the operated. Instead of adjusting thermostats in specific rooms in the building, the site manager now adjusts numbers on a screen with the possibility of doing it in another building, possibly in another country. Control of the indoor environment shifts geographically and temporally and becomes more distributed among several actors. Are our facility management professionals becoming more distanced from the physical buildings they operate and maintain?

When we develop and work with digital and technical systems, are we introducing longer and longer chains of actors into the operations and maintenance of buildings? How long can the chains become before they break? Because these systems hold such power as essential nexuses of information about the indoor environment and control over it, access to these systems becomes even more crucial. Even though the examples from the case where the consultant did not have access to the systems may seem banal, if the instances repeat themselves in critical situations, it might significantly affect the consultant's stress level. Lack of access may also result in a state of helplessness. The consultant can see the problem and knows how to fix it but cannot access the systems to do anything about it. Such helplessness may result from the division of responsibility, technical discrimination from the systems, or a lack of competencies to remedy the situation.

The consultant and the site manager are "men of the system." They become part of an infrastructure of digital and technical objects that focuses primarily on measurements of the indoor environment. Knowledge about the indoor environment is distributed among the many actors, and the possibilities of actions are enhanced and limited by this network of actors. In the upkeep of a good indoor environment, the consultant and the site manager may regard the office workers and their practices as "disturbances" to the system. Potentially, there can become conflicts in the interface between the practices of the office workers and the practices of the consultant, which might negatively affect the mental work environment for all of them.

CONCLUSIONS

This analysis describes potential tensions concerning the mental work environment of two OM professionals. Their connectedness to technical and digital objects leaves them a narrow set of options when confronted with indoor environmental issues. The worldview inscribed in the digital infrastructure permeating the work of the OM professionals does not fit the worldview of the building occupants (the office workers). It may potentially pressure the OM professionals' mental work environment. Furthermore, repeated disconnections from crucial systems contribute to frustrations and powerlessness for the consultant.

This paper contributes to research with a combination of analytical perspectives based on STS, ANT and literature on mental work environments to study the work of facility management professionals. In an age where the number of digital and technical objects constantly increases in our professional work, understanding these objects' effect on people's mental health is crucial.

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DOES THE ENACTMENT OF INFORMATION AND COMMUNICATIONS TECHNOLOGY AGREEMENTS IN A DIGITAL CONSTRUCTION ORGANISATION IMPACT THE MENTAL WORK ENVIRONMENT?

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This study discusses how digital infrastructures in the Danish building industry affect the mental work environment in a project organisation, by focusing on the information and communications technology agreement as a term of reference for the division of labour and the specification of digital work. Based on interviews from a case study, namely a renovation project from a major Danish real estate owner, this paper studies the interactions between social and technical practices in a network and draws on concepts from actor-network theory to analyse the findings. The study sheds light on how the network around the information and communications technology agreement is dominated by one enactment, and it is found that displacements occur when one enactment becomes dominant. In these displacements, the mental work environment is pressurised, which leads to stressors, shifts in core activities and employees' struggle to find meaning in their tasks. However, the study also points out how digital tools can help to ensure a good mental work environment by strengthening project collaboration.

Keywords: digital infrastructure; ITC; mental work environment; S&T studies

INTRODUCTION

Technological development in the Danish construction industry has intensified in recent years, with the creation of digital tools aimed at structuring each part of the value chain in the industry and technology's growing role in agendas such as sustainability, efficiency, and economy, as described in a report from The Danish Building Research Institute about building automation: 'Significant societal agendas such as climate, energy, sustainability, indoor climate, etc. have, in recent years, challenged the construction industry'. The authors state that diverse new requirements for topics like climate management and improved energy performance have, in addition to new types of collaboration interfaces between professional groups, professions, suppliers, and users, led to a significant development in the constructions' use of technology (Forman, Sørensen, and Fredslund, 2017).

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These agendas do not only occupy the construction industry but are broad societal interests, and therefore, they increase both internal and external pressure on the construction industry. With the construction industry contributing a 30% share to Denmark's total CO_2 emissions (Klimapartnerskabet, 2019), the pressure to incorporate more sustainable construction is increasing. Digitalisation is given a central role in the conversion process, as the Ministry of Transport, Building and Housing's strategy for the digitalisation of construction from 2019 stipulates (Trafik-, Bygge-, and Boligstyrelsen, 2019). Here, digitalisation is emphasised as a means to improve the building sector's general development and sustainable conversion: 'Digitalisation can help to connect idea, design, execution and use in a way that promotes productivity, quality and resource savings and, thus, ultimately sustainable construction.'

With this, a strong connection is created to show the digitalisation of the construction industry and the solutions to the problems that the industry may face in the future. The digital infrastructures that continue to grow in complexity and are formed by the development of technology in the construction industry, therefore, play a large role for the people who directly or indirectly work with construction technologies and who experience how their work is affected by this development. In a study of the construction industry's digital infrastructures and how tools such as building information modelling (BIM) affect the existing structure of the industry, the authors conclude that the effective utilisation of digital infrastructures will have significant effects on construction in the construction industry: 'In setting out to achieve their longer-term goals, the idea of digital infrastructure suggests that practitioners need to be aware that the implementation of digital tools, such as extranets and building information models, changes the boundaries between firms, offices, disciplines, teams and roles. It shapes social relations, as it develops new practices and changes the visibility of information' (Whyte and Lobo, 2010).

Therefore, it is important to study how working within digital infrastructures affects the construction process and how the shaping of digital work can entail challenges in the mental work environment for employees within the construction industry. Additionally, a central aspect of digital work in the construction industry is the information and communications technology (ICT) agreement, a contractual document that aims to structure work using ICT and structure the later delivery of data by creating terms of reference for the division of labour, as well as specifying a digital building model and project material. The ICT agreement was introduced in 2007 as part of the law of ICT (By-, Bolig, and Landdistriktsministeret, 2013) and is applicable to public construction projects with the long-term aim to incorporate the application of IT into construction. The agreement holds uniform requirements to define the project's digital level and digital processes by which the project is governed and is a statutory contract between the client and the ICT responsible consultant. However, there is still confusion about what data to deliver at project submissions, in addition to problems with the translation of data between different digital systems.

Analytical Framework

The aim of this paper is to examine whether the ICT agreement, an agreement that regulates digital cooperation in a building project, affects the mental work environment of the project's employees via the network around the agreement as the central actor. This is done by using Mol´s (2002) concept of enactments and ontological multiplicity to study the possible effects and how this connects with the concept of boundary objects (Star and Griesemer,1989), Star´s (1999) definition of digital infrastructures as a concept for understanding the digital connections and finally are Olsén´s (2008) theory of meaningful work and core activities used for understanding the mental health.

In the study of this network that is formed around the ICT agreement, actor-network theory (ANT) is used to shed light on the processes that arise from the agreement that can affect the project employees' mental work environment. The concept of the network is not limited to seeing the network as a specific type of relationship but provides space for networks to comprise several different relationships (Papazu, Wintereik, and (red), 2021). Additionally, the size of the network is not defined in advance. Unlike the broad mindset of the sociological research tradition, the actor in ANT is not seen as someone who actively defines others rather than being defined themselves; they are seen as part of a network contributing to the actions of others and arranged in a certain way. The actor is, therefore, not limited to being a human actor; it can also be nonhuman, such as a document or technology.

To study how the ICT agreement stems from and influences various work practices, Mol's (2002) development of ANT is used to analyse the coexisting realities of the building project. Mol focuses on how different practices can coexist and challenge each other within a common relationship to a particular phenomenon via the idea that reality is multiple and exists in different overlapping versions. Mol's (2002) concepts of 'enactment' (Papazu, Wintereik, and (red), 2021) and 'ontological multiplicity'" (Mol, 2002) clarify how the ICT agreement is realised as an actor in the network and how different versions of the same reality can emerge and exist in a network. The concept of enactment refers to how something is made a reality in practice, making space for overlapping realities to continuously develop and become material. This understanding implies that each practice produces materially different versions of reality that can both vary in size and in the extent to which they overlap, but they all affect the network around them. Thus, one reality does not exclude the other; they can coexist despite their differences. Continuing this, Mol (2002) develops the concept of ontological multiplicity in connection with her study of atherosclerosis in The Body Multiple (Mol, 2002), to explain how several different enactments of the same disease can exist among professional groups in the same hospital. Over time, management selects a version of the disease as the dominant reality to manage and organise their work. If hospital management focuses on one enactment of the disease, the other enactments' legitimacy is challenged, and they risk being overlooked in practice.

Later, Star and Griesemer's (1989) concept of boundary objects, are used to explain why the dominant enactment of the ICT agreement can challenge digital work during project collaboration and weaken the ICT agreement's position as a boundary object for the digital work. Star and Griesemer (1989) describe a boundary object as an object that makes collaboration possible without the need to agree on what is being collaborated on. Further, 'boundary objects are at once temporal, based in action, subject to reflection and local tailoring and distributed throughout all of these dimensions' (Star, 2010). In this description, the ICT agreement can act as a boundary object between various digital enactments by creating a common understanding of what the client desires, what the digital work should be and what is to be delivered.

The ICT Agreement as Part of a Digital Infrastructure

Star (1999) defines an infrastructure as the invisible layer that makes things possible, such as the complex system of water pipes, pumps, the craftsman, and systems that make it possible to fill a glass of water from the tap. Infrastructures is a part of a larger technical system, exciting of different interactions and representations or as Star (1999) describes it, 'infrastructure is a fundamentally relational concept, becoming real infrastructure in relation to organised practices.' Based on this, the ICT agreement constitutes a part of the infrastructure in digital construction that connects different professions and digital objects as a structure that precedes work using building models, digital project management systems and ICT cooperation in the project. The ICT agreement is, therefore, a natural starting point for examining the effects of digital infrastructures in the early stages of a building project on the mental work environment.

Mental Health as a Concept

To justify our hypothesis that the ICT agreement's structuring of work practices can affect the project members' mental work environment, we draw on the conceptualisation from, Lorentzen (1988): 'When we talk about the mental work environment, we mean that we take a psychological point of view on the work environment in order to investigate some influences, reactions and contexts that cannot easily be accommodated in a traditional understanding of the work environment' (Lorentzen, 1988). Continuing this way of thinking, Olsén (2008) introduced the idea of studying mental health by focusing on how employees can maintain or develop a positive meaning for their work. The focus is on the tasks and what conditions are needed to fulfil the task, which is done by looking at how the subject makes the work meaningful and how changes affect the subject's core activity (Olsén, 2008). The core activity can be related to both the individual's main tasks and the organisation's overall mission, as well as the connection, goals, procedure, cooperation, conditions, feeling of professionalism, and results of the work. On both levels, the core activity is connected to individual expectations for the work and how these lead to the feeling of tasks being fulfilling and meaningful. Meaningful work is connected to whether the individual experiences meaningful connections among activities, actions, and practices, as well as within social relations. A loss of meaning can lead to discomfort and anxiety, which can cause reactions such as reluctance or resistance. Based on Olsén´s (2008) concept of the core activity and meaningful tasks, it is possible to identify areas in the network in which the mental work environment is pressurised.

METHOD

To study the effects of work with ICT on the mental work environment during the initial phases of design, the study draws on an ethnographic case study of a Danish project organisation. Through qualitative interviews with the project members who comprise the network formed around the ICT agreement, as well as observations of project meetings, the implications and impact of the ICT agreement are analysed. The case study is chosen strategically for the opportunity to study different enactments of the ICT agreement in a shared project environment and how the different professions interact with and are affected by the with same agreement.

The case is a renovation project at a Danish university, which involves transforming an existing depot into modern study areas. The study involves representatives across the entire project organisation to follow the creation and development of the requirements for ICT and how the requirements affect the work of the project members. Through interviews with the project members, observations of meetings and insight into the digital platforms used, we follow the application of ICT in the project throughout the organisation, as well as how the ICT agreement interacts with the project participants' roles.

The client has its own ICT and project management and associated client advisers. The client is responsible for a total property portfolio valued at 49 billion DKK and is, thus, one of Denmark's largest real estate companies. Internally, the organisation is organised as follows: There are project managers and a support function that supervises the project manager with ICT-specific knowledge. In addition, the client's organisation fulfils the users' requirements for the building. In this case, the users are responsible for the day-to-day operation of the building. As the ICT agreement must encompass the interests of these two parties, it reflects a negotiation between the client's standard requirements for ICT and the users' specific operational requirements.

The client's standard requirements for ICT consist of several complex documents addressed to the contractor and consultant that must ensure that the client achieves the desired standardisation across their projects and complies with the applicable legislation for ICT in public construction projects. On the other hand, the users, namely the university's facility management in this case, rely on the data delivered with the physical building, especially compatibility with the existing operating system and a data structure equal to other buildings in the portfolio. e.g., naming of the location of building parts and the format of delivery. As a combination of the two interests for the project's ICT, an agreement consists of both the client's documentary standard controls and the users' project-specific requirements for data.

The client has entered into a four-year framework agreement with an experienced Danish construction company that, as turnkey contractors, hires architects and engineers as sub-consultants. With the framework agreement, the contractor has the opportunity and the financial interest to be included in both the design and the practical handling of ICT in the project. According to the contract, the turnkey contractor is responsible for complying with the requirements of the ICT agreement but chose to appoint the role as ICT manager to the project engineer, who also has the official role of project manager. He thus bears responsibility to disseminate and enforce the ICT agreement's requirements in the project organisation as well as responsibility for the design phase and internal coordination.

Analysis of the Empirical Observations

Examining the practical use of the ICT agreement in the project, the largest shifts in the project organisation seem to occur in the various professional groups' representations of the building and how these representations affect their relationship with the ICT agreement in practice. As an actor, the ICT agreement is part of a network consisting of four professional groups, namely the client, the users, the contractor, and the consultants (engineer and architect). Despite their participation in the same project, their enactments of the ICT agreement and their representations of the building differ. The various representations of the building that coexist in the network are connected through how the project participant is related to the building in practice, and these different representations seem to affect their enactments of the ICT agreement, as it arises from and interacts with these varying practices.

For the client, the building exists as an economic representation of the physical building, focusing on budgets and costs of long-term maintenance, thus requiring information, values, and capacity. This economic representation of the building, that is embedded within the client's understanding creates a need for the structure and security of digital work, which forms the client's enactment of the ICT agreement as an attempt to create standardisation and a basis for agreement. This main function, as a standardised document to ensure that the project complies with the structure of all governmental buildings, is stated in the following quote from the client's ICT project manager:

> "There will be discussions back and forth, there will always be, but we have these standard documents and a standard paradigm for ICT agreements, which we use on all our projects, and then you can, of course, change a bit here and there. But it is, in fact, the same fixed requirements for properties in the models and the same requirements for drawing standards."

Therefore, it is clarified in the beginning that it is a standard fixed agreement, but small, project-specific changes can be made to it. Although there is a great focus on the standardisation and quality control of digital work in the client's internal organisation, the client's ICT project manager says that situations arise during which he must defend the need for digital focus in the projects to the remainder of the internal project management and, thereby, defend its position. This suggests that even though there is a focus on securing a standardised process across many different projects, the topic of ICT is still debatable within the internal organisation. This position is also evident in statements such as the following about balancing project economy and the need for digital elements at delivery:

> "There could be some discussions about whether we should do the project in a 3D model, or whether it would be enough with a 2D model. It is all in relation to the project economy, which needs to be strong enough to carry our extra demands for the ICT."

The users' representation of the building is related to the physical practices on site, including the responsibility for the operation and maintenance of the building. The users' everyday work depends on the connection between the digital representation of the building, which generates the material for operating the building, and the physical building that they must facilitate. This need for structure is reflected in the users' enactment of the ICT agreement in relation to the existing operating practices that will be applied to the building when finished. Therefore, they need the requirements in the agreement to be structured so that they comply with existing site practice. The negotiation between the client's standardised requirements and the users' need for project-specific additions will, therefore, be decisive for the operation practice of the building after delivery. This is a concern that the users' ICT manager expresses in connection with the delivery of the operating material, as the users' existing operating system is not considered in the agreement. The users' ICT manager expresses the following concern about handing over the data:

> "So, it will simply be a manual process with some Excel sheets we get in and then we must make the connection from the data we get in and enter them into the system manually. We really want the system to be able to handle that coupling by itself, so we do not have to create these couplings afterwards."

Therefore, if the ICT agreement fails to create the necessary connection between the project and the existing operating practice, there will be a risk of creating challenges for the employees who are going to operate the building.

The main contractor's representation of the building is largely based on an economic and systemic understanding of the physical building in which knowledge of the division of labour, partial deliveries and coordination is embedded. For the contractor, the ICT agreement, therefore, is perceived as a management tool for the digital aspect of the construction process through which important elements of the contractor's practice are determined, such as what digital project platform will be used to document the project during the actual construction and how the contractor will need to communicate with the remainder of the project organisation. The contractor states how this could have been a problem for them if they did not have the right resources:

> "We are such a big organisation that we have the needed experience with most digital platforms, but if we had been a small construction company with limited digital competencies, I would fear that there would be some challenges in having to change systems from project to project."

Among the consultants, there is a widespread digital representation of the building, which is supported by both the architect and the engineer's digitally anchored work practices and the common need to coordinate the work in and around the digital models. In the following statement, the architect points out how both communication and coordination between the architect and the engineer take place through the combined models:

> "Today, we have a completely different dialogue with the engineers through the BIM model than we had before, where drawings were sent back and forth between the offices. Now, there is a dialogue in the models, where we always have the same updated drawings to look at, and we can see each other's things in 3D."

The consultants (architect and engineer), who have the practical responsibility to perform ICT during the design work, enact the ICT agreement through requirements that define the scope, complexity and level of competence needed in their work. This is where the client's ICT requirements play the most significant role and where even small changes in the contractual relations can cause changes in design practices and collaboration structures, a challenge that the architect addresses in the following quote:

> "It was a requirement that the model should contain a 3D design of the basement floor and a 2D design of the other floors, but how are we supposed to document the walls in the basement floor if we do not have the walls going all the way up through the building?"

It appears from the client's ICT requirements that a full 3D model should only be created for the basement plan rather than the entire building, which does not practically correspond to the work for which the model is to be used. Therefore, the architect had to do extra work to create an adequate foundation for later model work and design. As a further example of this, the architect explains how they spend a large amount of their time feeding the IFC (Industry Foundation Classes) model with information for the client that does not make sense for either the engineer or the architect's practices or needs:

> "We have to name everything very specifically and make sure it has a keynote attached. We are used to working with keynotes, but in addition to that, we need to fill in some parameters that we have already given in the keynote so that the client can read it in the IFC file. It means that every building part must be named in three different places, so I spend a lot of my time doing that, time I could otherwise have spent on traditional architectural work, such as making a material catalogue."

The engineer stats another example of this discrepancy between the practices of the design team and the requirements stipulated in the ICT agreement is the naming of files. The engineer experienced problems with the specific naming of building parts in the BIM model, as the ICT agreement requires that the names of building parts may only be comprised of numbers, as per the Cuneco Classification System. He says, 'For people who are not so much into working with ICT, it can be difficult to sift through the contents of a file if there is not a topic in the file name.' Despite this requirement for naming documents in the project, the engineer repeatedly noticed that the client's project documents were named incorrectly, creating confusion in the project organisation, and demotivating the employees from maintaining the required naming system.

The architect and the engineer draw attention to another potential effect of the use of digital building models, is the possibility of simulating both the building and the entire construction period digitally before executing the project. Here, the traditional phases of construction and, thus, the division of responsibilities that lies in the transition between phases are pushed forward. Both the client and, in this case, the contractor get earlier access to digital models of the building and, thereby, the opportunity to initiate the decision-making processes for time and economy earlier, causing the consultants to ensure a high level of detail in the models and initiate quality assurance earlier in the design phase.

Examples like these show the client's standardised enactment of the ICT agreement and the enactments need for structure, information, and control, as well as how it leaves little space for project-specific changes and local adjustments, resulting in these dominating the network. Due to this situation, there is a risk of the client determines the dominant enactment of the project's ICT agreement and its content even before the project starts, without having knowledge of the other project participants' relation to the agreement and its content or how it will potentially affect the project work.

Despite this both the architect and the engineer also report of situations in which technologies have helped to strengthen the collaboration between the two professions and how the digital possibilities in the building models have facilitated the stronger quality assurance of the models, as the architect states:

> "As an example, there is the work with our common ceiling plans where the digital tools make a big difference for us. Previously, we got a basis from the engineer model and then drew their lamps into our model. Now, we get their model integrated as a basis for our plan. That is a big win for us."

As previously described, the ICT agreement can, under optimal conditions, act as a boundary object for digital project work by providing descriptions of and support for digital work processes and submissions during project collaboration to be integrated, thereby ensuring that the collaboration will work across the various digital practices and perceptions of the building. However, since the dominant enactment of the ICT agreement aims to standardise a process that requires flexibility and project-specific adaptations, it may affect the ICT agreement's opportunities to function as a boundary object. This is caused by the conditions for the ICT agreement to act as a boundary object not being met if the dominant enactment in the network does not allow for other enactments to be represented in the agreement, which makes the boundary object an interesting topic for future studies on the subject.

FINDINGS

The client's standardised enactment of the ICT agreement dominants the network by determine the projects detail level of digital models, use of digital systems, file naming and file structure, and the process for final delivery of the project material. This is based on the enactments needs of standardisation to control a large real estate portfolio, rather than adapting local experiences from the building operation or further analysis of the full scale of the specific project.

Tensions are reported throughout the project organisation, with members from all professions reporting everyday experiences connected to the digital infrastructures of construction affecting their work. This is not necessarily connected to the specific work task but results from displacements occurring that can lead to workarounds, meaningless work or shifts in responsibility that, together, can challenge the mental work environment.

The study shows that the standardised enactment of the ICT agreement that dominates the network affects the roles of the project employees to such an extent that they allow their professional identities to be compromised and their core activities to be downgraded to satisfy or adjust to the standardised enactment. The same stress factors can be found in the negotiation process between different enactments of the ICT agreement, which create a vulnerable position in which there is a risk that the dominant enactment causes the need for making space for experiences to be overlooked. As described in the project delivery phase, the users, who are to conduct the operation and maintenance of the building, state how the delivery of the material will be done manually, which will be time-consuming.

The possibility of simulating both the building and the entire construction period digitally before executing the project can lead to stressors for the consultants, workarounds, such as creating drawings with tags to ensure that everybody knows what is still incomplete and increasing time pressure during the design phases.

However, notably, the situations in which digital infrastructures help to strengthen project collaboration seem to benefit the mental work environment. For example, in the consultant's enactment of the ICT agreement, a document of requirement, in the section relating to the disciplines that address the design of the building, the consultant succeeded in creating a common structure around the requirements that the ICT agreement outlines for the project and used the digital building models as an opportunity for collaboration and the satisfaction of the common interest of securing a buildable project.

CONCLUSIONS

This study indicates that in the network around the ICT agreement, tensions arise among the project members due to the dependencies of the ICT agreement and the actual practices of which it is a part, which could influence the mental work environment of the employees. It is important to highlight that the study also found situations in which development in the use of digital building models, partly caused by the regulations behind the ICT agreement, seems to affect mental health positively. Specifically, the coordination and collaboration in building models across professions were highlighted as having a positive effect on project work.

The ICT agreement is shaped under an enactment of standardisation to ensure that there is an adequate structure in a large real estate portfolio and the management process across many different projects, but it fails to provide opportunities for adapting to the conditions in a smaller project or practices. This is despite the agreement originally being a flexible document intended to be adjusted to each project to secure a digital level across an entire industry.

The standardised enactment of the ICT agreement plays a significant role in the challenges that project members face, causing displacements in the division of labour, the product, and the responsibilities of the project organisation. Displacements occur when the other enactments aim to satisfy the demands of the dominant enactment by downgrading their needs. It is in these displacements that the mental work environment becomes pressurised, which leads to possible stressors, shifts in core activities and employees' struggle to find meaning in their tasks. Addressing one of these effects may not cause severe mental health issues, but the combination of effects over time can lead to real mental health problems.

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HUMAN RESOURCES MANAGEMENT

THE COMPOSITION AND CLASSIFICATION OF INTERPERSONAL CONFLICT IN IRISH CONSTRUCTION SMALL AND MEDIUM-SIZED ENTERPRISES: A CASE STUDY

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Although the adversarial environment in which the construction labour force operates is widely accepted, further analysis of the composition and types of conflict present, is absent. This paper aims to categorise the various types of interpersonal conflict (IPC) that manifest because of these relationships. This is carried out by completing a literature review, to identify the variety of categories of IPC. 20 Semi-structured interviews, based on these findings allow participants to detail their experiences with IPC. Interviews are conducted with employees of a singular Irish construction SME. Task and relationship conflict are the most prevalent forms of IPC found. The research highlights high levels of co-occurrence between conflict types due to interactions with external factors. The findings of this research supplement previous works which highlight the link between conflict types, conflict management strategies, and team outcomes. These findings will enable management to effectively categories the type of IPC present and subsequently implement the optimal conflict management strategy.

Keywords: disputes, task, relationship, interpersonal conflict, SME, Ireland

INTRODUCTION

The presence of conflict in an organisational environment is irrefutable (Barki and Hartwick, 2002). Subsequently, the academic world has produced an abundance of research over the last 70 years, to encapsulate the complexities at play (Deutsch, 1990; Wall and Callister, 1995; Barki and Hartwick, 2002; Schulze, *et al.,* 2014). As organisations expand and undertake more complex projects, Kiernan, *et al. (*2021) suggests that their reliance on diverse and multidisciplinary teams increases accordingly. Consequently, diversity in teams is on the rise and so too are the differentiating characteristics within the group, with Mauersberger, *et al. (*2019) having stated that once two or more individuals are misaligned in this regard interpersonal conflict becomes inevitable. In conjunction with this Rispens and Demerouti, (2016) described workplace conflict as being “omnipresent” and although conflict at work is not sought after, there is much research to suggest it has become common place in all work environments (Narayanan, *et al.,* 1999).

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O'Neill, T, Spillane, J P and Carmody, S (2022) The Composition and Classification of Interpersonal Conflict in Irish Construction Small and Medium-Sized Enterprises: A Case Study *In:* Tutesigensi, A and Neilson, C J (Eds) *Proceedings of the 38th Annual ARCOM Conference,* 5-7 September 2022, Glasgow, UK, Association of Researchers in Construction Management, 297-306.

In this regard, the construction industry has long been noted for its conflict burdened environment and the adversarial nature in which it operates (Vaux and Dority, 2020). The industries' ability both domestically and foreign to create disputes is unparallel (Spillane, *et al.,* 2011). The relationship between conflict and deficient performance is irrefutable and is acknowledged as a primary source of project inefficiency (Zouher Al-Sibaie, *et al.,* 2014). The litigious nature of the industry has had profound implications on projects for decades and is often used as a justification to the poor performance of the sector. The critical factors of dispute creation have been continually identified in academic studies (Brockman, 2014; Assaf, *et al.,* 2019). Meng, (2012) suggests that although commonality has been found across a multitude of studies, due to the infinite and incalculable complexities at play throughout the life cycle of a construction project, the source of disputes will inevitably vary from project to project.

Hahn, (2000) suggested that the amount of time spent by employees on interpersonal conflict can range between 25 to 50% of their day. Despite the inevitability of conflict within the industry further analysis of the types of interpersonal conflict seen in Irish construction SME's is absent. Therefore, this research aims to address this gap by categorising the various types of IPC present in Irish construction SME's. Once there is a clear understanding of the composition and types of conflict which exist, management will subsequently be able to implement the optimal conflict management strategy for individual occurrences. The importance of this can be seen in Behfar and Peterson, (2008) research where teams dealing with process conflict that employed "discussed / debate and open communication" based around fact driven conversation saw high/ increasing performance and team satisfaction. In contrast teams dealing with process conflict which employed "rotating, responsibilities and avoided / ignored" saw consistently low/ decreasing performance and team satisfaction.

Conflict Types in an Organisational Environment: A Review

When carrying out a critical review of literature about conflict in an organisational environment it is important to note that not all conflicts are equal. Mauersberger, *et al. (*2019) found that although the word "conflict" carries negative connotations, in reality the word covers a vast array of types of "incompatibilities" between parties. This is hugely important when discussing this topic as Rispens and Demerouti, (2016) suggested that persons experience different emotional responses dependant on the what the conflict is centred around. It is also of note that the word "conflict" covers an array of interactions between parties and the levels or severity of the incident may differ drastically while being encompassed under the same term. As this came to light academics sought about categorising conflict by "type" and more advanced interpersonal conflict theory ensued (Barki and Hartwick, 2002). There are three types of conflict which have been consistently highlighted as common place in organisational environments. The tri-partite classification includes "Task Conflict" being concerned with disputes emerging from disagreements stemming from task related activities (Lee and Kwon, 2001). "Relationship Conflict" of which in focused on disputes which usually emerges from personal incompatibilities between parties Amason, (1996) and "Process Conflict" categorised by discrepancies in methods and procedures team members should use.

Early studies such as Hammond, (1965) suggested that all conflict which emerged while parties were conducting tasks were strictly cognitive. Consequently, this claim meant that one could rule out any further understating of the parties' values or motivation as modern-day social scientists aim to have. As knowledge was furthered a more complete understanding of task conflict emerged. Lee and Kwon, (2001), Kiernan, *et al. (*2021), Meier, *et al. (*2013) are examples of numerous academics who found commonality in their views of task conflict, stating that it occurs when there are disagreements about the task, such as opinions or judgement. The most widely accepted holistic definition is that of Jehn, (1995), "Task conflict exists when there are disagreements among group members about the content of the tasks being performed, including differences in viewpoints, ideas, and opinions."

A study by Puck and Pregernig, (2014) suggests that although task conflict is a key indicator of performance, there is still room for debate as to the "how" and "why" this is the case. Studies have yielded a variety of results including finding negative effects, and finding positive effects (Puck and Pregernig, 2014). Although contrary to each other both findings are found in logical and practical theory. Those proclaiming a negative relationship between performance and task conflict suggest that it is inherently disruptive, resulting in undesirable emotions and substandard cooperation resulting in lower performance (De Dreu and Weingart, 2003; Vodosek, 2005). According to Puck and Pregernig, (2014) information processing theory and self-verification theory and heavily involved in the theoretical foundation of these ideals. Those presenting a case for a positive correlation argue that conflict which occurs in this regard correlates to a more detailed execution due to parties arguing a variety of points resulting in the most optimal output being found. In accordance with this Deutsch, (1973) found task conflict to be stimulating for team members, thus increasing curiosity and interest.

Negative emotions play a significant role in all interpersonal conflict (Barki and Hartwick, 2002). Regardless of the outcome, interpersonal conflict is often poignant. This is exacerbated by conflict, which can be defined as "affective or relationship conflict" as it usually emerges from personal incompatibilities between parties (Amason, 1996). According to Jehn, *et al. (*1997) widely cited definition relationship conflict is categorised by, "disagreements and incompatibilities among group members about personal issues that are not task related".

Similarly, to task conflict there is a certain level of ambiguity in the terms used when discussing relationship conflict. Relationship conflict is often cited as "emotional / affective conflict". However there has again been commonality found across a multitude of studies, with "personal incompatibility" often being referred to as being a defining characteristic with numerous studies citing these terms in their definition (Jehn, 1995; Amason, 1996; Cheung and Chuah, 2000).

In contrast to "task conflict" there is little to no research identifying any potential upside in an organisational context when relationship conflict emerges, as they are often the most difficult to resolve as it stimulates a strong emotional response from the involved parties. Perhaps the most cited fallout from the presence of relationship conflict in an organisation is the negative personal implication it has for employees. Research such as Meier, *et al. (*2013) suggest that relationship conflict indicates disrespect and is the expression of tension and rejection. This stimulates a strong emotional response from personnel, with studies highlighting the negative repercussions (Semmer, *et al.,* 2007).

This final part of the tripartite is process conflict, researchers in IPC rarely place the lens of focus on process conflict due to its similarity to task conflict (Behfar, *et al.,* 2011). However, due to the procedural heavy environment in which the construction industry operates it is common. Comparably, Jehn, (1997) and Jehn and Mannix, (2001) saw the differentiating qualities of process conflict, with Weingart, (1992) expressing the belief that employees possess the ability to distinguish between task and process conflict. Process conflict pertains to the "how" a task should be accomplished with Jehn and Mannix, (2001) defining it as, "an awareness of controversies about aspects of how task accomplishment will proceed". Similarly, to task conflict, research indicates correlations between process conflict and lower team performance (Vaux and Dority, 2020).

Table 1: Interpersonal conflict types, characteristics, and sources

Conflict Type	Definition	Characteristics	Source
Task Conflict	"Task conflict exists when there are disagreements among group members about the content of the tasks being performed, including differences in viewpoints, ideas, and opinions." (Jehn, 1995)	Disagreement over ideas.	(Amason, 1996)
		Opinion differences within the group.	(Barki and Hartwick, 2002)
		Disagreement about work being done.	(Jehn, 1995)
		Low levels of emotion	(Vaux and Dority, 2020)
		Primarily cognitive in nature.	(Vaux and Dority, 2020)
Relationship Conflict	"Disagreements and incompatibilities among group members about personal issues that are not task related" (Jehn, *et al.,* 1997)	Negative emotions.	(Jehn, 1995)
		Focused on personal incompatibilities.	(Amason, 1996)
		Not task related.	(Jehn, *et al.,* 1997)
		Personality differences.	(Jehn, *et al.,* 1997)
Process Conflict	"An awareness of controversies about aspects of how task accomplishment will proceed" (Jehn and Mannix, 2001)	Disagreement.	(Jehn and Mannix, 2001)
		Relates to resource allocation.	(Jehn, 1997)
		Task responsibilities.	(Jehn and Mannix, 2001)

METHOD

Having completed a comprehensive critique of the appropriate literature, a case study of a singular Irish construction SME is carried out. A case study is selected as this pilot study is the first study in what is to be a wider research plan. This provides opportunity to gain a valuable insight into the subject area while also seeing how interpersonal conflict interacts within an organisation as a whole. This is an invaluable insight for the competent execution of the wider research plan. The limitations of a singular case study must also be acknowledged, with Yin, (2009) highlighting the absence of methodological guidelines as an area of key concern. However, the "freedom" a case study provides, which is highlighted by Maoz, (2002) provides the opportunity to simultaneously address a gap in literature, while letting the study provide context for future research. The selected case study is an Irish registered construction SME of which deals with both domestic and commercial construction projects. The organisation directly employees between 25-40 personnel, depending on the current workload with a further 75-100 personnel through sub-contractors. This study is focused on IPC events between parties employed directly by the case study. Semi structured interviews based on, but not limited to, the tri-partite classification of IPC identified in the literature are conducted with personnel employed by the case study. Semi structured interviews are used as they provide the ability to gather open ended qualitative data while acquiring participants viewpoint, thoughts, and feelings on the subject matter. This study is inclusive of employees whose place on the internal management hierarchy varied, ranging from directors to general operatives (GO's).

This allows for a holistic in-sight into IPC within the construction SME rather than from the viewpoint of a singular management level. Due to the nature of the research and potential for sensitive information to be discussed there are no audio or visual recordings of interviews, as interviewees feel most at ease when no recording is taking place (Harvey, 2011). The participating company is kept anonymous and is referred to as 'case study' for the entirety of the paper. This is to ensure a comfortable and safe environment is created to ensure participants feel able to express their true feelings and experiences with IPC. All information from interviews is gathered through shorthand note taking and developed further post interview in accordance with (Rutakumwa, *et al.,* 2019). Shorthand note-taking allows for timely and accurate tracking of interview content such as key phrases and specific language without interrupting the process. Once the notes are developed further post interview, they are sent to the interview participant to verify their authenticity.

20 semi-structured interviews are conducted with employees of 'case study'. All interviews take place face to face at a location and time chosen by the participant. Participants are fully briefed and informed of the purpose of the research, its intended use, all their obligations, and rights. As this study is focused on IPC events which took place with parties employed by a singular construction firm participants are asked, to ensure the party of which they had the IPC event was directly employed by the same organisation. The interviewer has minimal further involvement and participants are encouraged to give honest recollections of their experience with IPC at work. The interview data is then accurately presented in a consistent manner to allow for efficient comparison. The data is then analysed and compared to the conflict types identified in the literature. This is conducted by establishing the presence or lack thereof, the defining characteristics of each conflict type highlighted in the literature.

FINDINGS

Interviews begin with a brief introduction to the participant to gain an understanding of their experience and role within 'case study'. Throughout 20 a total of 43 IPC events are discussed. These events include a wide variety of IPC of which differ drastically in severity and encompass a wide range of incompatibilities between parties. These include IPC events centred around issues such as but not limited to 'general operatives leaving site early, disagreements on quality standards, lack of progression of work, perceived lack of respect, smart remarks being made, and disagreements over construction details'. As the study progress the results indicate that categorising conflict using singular definitions would be negligent regarding representing the true composite of the IPC events discussed. Interviewees cited a total of 15 IPC events which comprise of singular conflict types. Subsequently, 65% of IPC events instead had conflict types co-occur in complex ways, because of an incalculable number of external factors. Participants use of language such as "because of", "due to the fact", and "as a result of" allude to IPC being a dynamic, complex event in which the severity and composition change according to the context in which it is occurring.

An early study by Barki and Hartwick, (2002) which attempts to conceptualise the construct of interpersonal conflict uses a Ven diagram to depict the properties of IPC. This is an effective method to demonstrate the dynamic composite of IPC events discussed in interviews. Figure 1 below depicts several findings. Firstly, the number of IPC events which can be characterised as a singular conflict type, (3 task, 7 relationships, 5 process). It also depicts the IPC events in which a co-occurrence of conflict types is present (17 task and relationship, 6 task and process, 4 process and relationship). Finally, Figure 1 illustrates the singular IPC in which all three conflict types occur.

Figure 1: Number of each IPC type identified

DISSCUSSION

This paper is focused on the classification of interpersonal conflict types in Irish construction SME's. The ability to understand the composition and categorise the conflicts which are an inevitability in the Irish construction industry is quintessential to its effective management and mitigation. It is evident throughout both the literature review and the interview process that the classification of conflict is a complex multifaceted endeavour. This is due to the vast number of variables at play and the ability for conflict types to co-occur in unique ways. To align with the thematic presentation style of the paper the discussion is broken into the appropriate themes.

Construction projects are in essence the continues completion of a series of tasks (work packages) which are pre-defined in the scope of works. Subsequently, 27 of the IPC events discussed in this study can be attributed to an isolated task or situation related to a task. Interviewees cite task related IPC including, "we couldn't agree as to how long the job should be taking him", "we had a difference of opinion on execution methods", "he wasn't doing enough". At inception these IPC are typically cognitive in nature and void of emotion, prime examples of task conflict. Three out of the 43 IPC incidents are categorised as solely comprising of task conflict. The literature is divided as to the implications of this "pure" task conflict with numerous studies yielding contradictory results (Jehn, 1995, Rispens and Demerouti, 2016).

This contrast in the literature is justified by Meier, *et al. (*2013) who alludes to task conflict being a doubled edged sword, with it leading to better insight and problem solving while also inevitably meaning someone's opinion gets challenged or disregarded. The same study suggested any positive benefits of task conflict can only be realised when there is little to no relationship conflict present. Pertaining to this, although interviewees often describe incidents stemming from incompatibilities related to tasks, these conflicts frequently escalated drastically to co-occur with relationship conflict, due to a variety of reasons; these included, "perception of bad attitude"," illogical excuses / justification", "poor existing relationship" and "reasons beyond comprehension of interviewee". This co-occurrence is highlighted; accordingly, 18 of the IPC events present in this study comprise of task and relationship conflict.

When discussing this escalation interviewees often depict the other party as being "illogical, emotional or beyond reason", often noting the other party's "pride". In the IPC incidents discussed only two participants take responsibility for the escalation of the conflict with both citing "bad mood" as the key emotional driver. Both these instances come from interviewees who place highly on the internal management hierarchy of 'case study'. A Jehn, *et al. (*2008) study suggest that employees possess the ability to detach emotional from task related conflict, in 'case study' this is more common amongst higher level personnel. When questioned about their lack of emotional involvement one interviewee states 'at the end of the day, I don't care by who or how a job is done, if its correct and within the budget'. Another participant refers to "letting it roll off my sleeve" when discussing how an event of IPC could have escalated after a negative emotion response from the opposite party to a simplistic task related issue.

Isolated instances of relationship conflict are the most cited singularly occurring type of IPC throughout the interview process, with seven out of forty-three. These IPC events arise when parties have incompatibilities around non task related personal issues and typically involve elevated levels of negative emotion. Examples of relationship conflict initiators cited in the interviews include "he was showing videos of me out at the weekend to the lads", "he wouldn't stop about my clothes being too small" or "we started messing about the hurling and it just got heated". The severity of the IPC events differs drastically.

Many of the incidents of relationship conflict are categories as minor and interviewees cite no long latest implications with one interviewee stating that 'when you are with the same crew so much a 15-minute blow out isn't a big deal and is usually over something trivial, it is usually forgotten about after half an hour'. The isolated instances of relationship conflict highlighted by participants were in the majority a result of "horseplay/ banter" aligning with the findings of Brockman, (2014) who cited this as a trigger of conflict in the construction industry. Interviewees are aligned in their view that this "horseplay/ banter" was essential for workplace moral and was "part and parcel" of the industry. One interviewee state that "sometimes you just unlucky and say the right thing on the wrong day" when discussing the potential for conflict to arise from banter. The most common conflict type present is in fact relationship conflict with a total of 29 instances.

Although process conflict does not receive equal levels of attention in the literature due to its similarity to task conflict, due to the unique nature of the construction sector it is prevalent, 16 incidents. Resource allocation is essential in construction a common trigger, "we clearly needed the load-all more than the roofers", "it wasn't possible to pour the floor with three men", " we needed the good consaw" and "he didn't understand what we were doing, sure how could he know how many men we needed". When recalling IPC events which involved process conflict negative emotions resulting in the co-occurrence of process and relationship conflict was mentioned 4 times. Jehn and Mannix, (2001) cited task responsibilities as being a defining characteristic of process conflict, due to the structure of 'case study' and the structure of Irish construction SMEs task responsibilities becomes an area of dispute. Interviewees cited numerous IPC events stemming from the classic principle of "that's not my job", with trades disagreeing on the completeness of previous works.

CONCLUSIONS

This paper contributes to the understanding of IPC composition in Irish construction SMEs. The construction sector is the most litigious industry. Inferior performance of the industry is often linked to the elevated levels of disputes, as these are lengthy, capital intensive, and tarnish essential relationships. Subsequently, the ability for management and the general workforce to both manage and mitigate conflict within the industry is essential. The best way to rectify an issue is at its source and interpersonal relationships, moreover, IPC is a pillar of all disputes seen within the Irish construction industry. Task and relationship conflict were the most prolific IPC types highlighted in this study.

Due to the nature of the construction industry labour resources are often assigned to pre-defined work packages. Subsequently IPCs often stem from task related issues. High levels of negative emotions often occur resulting in escalation. A key observation made was the ability of those who placed higher on the internal management hierarchy to express lower levels of emotion when involved in IPC, resulting in cross management IPC escalation levels in 'case study' being lower than that of the general workforce. High levels of co-occurrence were also seen as IPC interacted with external factors outside the scope of this study. This research helps facilitate construction management practitioners to employ the optimal conflict management strategy as there is a furthered understanding of the type of IPC, they are tasked with managing.

The importance of correct conflict management strategy for different conflict types was highlighted in research which demonstrated the critical links between conflict types, conflict management strategies, and team outcomes. As IPC events progress / escalate and new stimuli are introduced such as negative emotions and supplementary information, it is important to revisit the classification of the IPC as the composition can change. This will ensure the implementation of optimal conflict management strategy as the incident progresses. This pilot study has provided several theoretical findings on which the wider study plan can be built. Firstly, there is opportunity to examine the impact of external influences such as weather, personal issues, and stress on conflict within the industry. Secondly, a comparative study between management and the general workforce to analyse the level of IPC escalation. Finally, through-out the study the crossover language amongst conflict definitions and ambiguity of terms used introduces a certain level of confusion to the literature. A modern study to provide clarity and commonality to language used in construction IPC literature would allow for continued growth in the area.

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CORRUPTION IN THE CONSTRUCTION INDUSTRY: AN INSIGHT FROM THE THAI CONSTRUCTION SECTOR

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The construction industry in Thailand has significant impact upon the nation's economic growth. However, the industry has been threatened by corruption which is a major cause of Thailand's middle-income trap. The aim of this research is to explore the nature of corrupt practices in the Thailand construction industry by examining the causes and strategies for preventing corruption through the lens of the principal-agent framework. The study adopts qualitative research approach through semi-structured interview with 12 professionals from the construction industry. The result of the study shows that corruption in the Thai construction industry is caused by factors such as personal behaviour, red-tape and conflicts of laws, organisational culture etc. Improving organisational system, decentralisation, ethical training, promoting ethical culture etc. are some of the measures that could be used in fighting corruption in the Thai construction industry. The study contributes to a body of knowledge that could help mitigate the detrimental consequences of corruption.

Keywords: Principal-Agent Theory; corruption; business ethics; Thailand

INTRODUCTION

In developing countries, construction projects are generally encouraged to drive economic growth, decrease a nation's unemployment rate, and improve the quality of life. The Thai construction industry (TCI) significantly impacts the nation's economy, particularly since the rapid growth of the real estate market increased the number of overseas investors (CBRE, 2017). Some construction projects (i.e., Suvarnabhumi International Airport; Klong-Darn Wastewater Management Project) have been undermined by corrupt business practices (Yomnak, 2016). Whereas some researchers argued that corruption does not always have a negative effect on socio-economic growth, abundance of research illustrates the perils of corruption (Mendoza *et al.,* 2015). Moreover, Powell (2006) stated that some corruption costs were included in construction costs due to the ineffective Thai corruption's detection.

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The construction industry is consistently ranked as one of the most corrupt with steady flow of bribery and corruption cases to courts in many countries (Kenny, 2007). Corrupt practices can be found at every phase of the project delivery cycle; from the planning to the operation and maintenance stages (Sohail and Cavills, 2006). However, there is a dearth of research on corruption in TCI, an issue that this paper sought to explore further through the lens of the principal-agent theory of corruption where there are two principals; one of which is corrupting, and one agent who is corrupted. However, who is given the role of principal or agent may differ depending on the research. The Construction Sector Transparency Initiative (CoST) framework might be a good tool for specific anti-corruption implementation but lacks in full performance. Inappropriately, some agents are opportunists and use their position for personal gains than principals' benefits. As the complexity in construction processes, various kinds of professionals, possibilities of the agents' dysfunctional behaviours could increase and be more difficult to examine.

According to OCED (2017) any existing definition of corruption is universally incomprehensive and unacceptable. Instead, the corruption is outlined as "abuse of public or private office for personal gain" including "offering, giving, receiving, or soliciting, directly or indirectly, anything of value to influence improperly the actions of another party. Like other Asian countries, Thailand embeds corruption to some extent into its culture and politics. According to Noisuwan (2003), several forms of Thai corruption are shown as "sin nam jai" or "tips" which is a tiny amount of money expressing the offeror's kindness both with and without corrupt intentions. It was also called "tokens of generosity" and considered as norm. "Chor rat bung luang", another classic Thai word, implies officials' corruption including "literally, cheating citizens and hiding tax from the King", whiles "chor rat" means a corrupt activity that the governors do to citizens, victim of "bung luang" is the King (Chat-uthai and Mclean, 2017). Although the political system was changed to constitutional monarchy for many decades, Thai society has grown under the patronage system with hierarchy until recent times. Bribery and "hot tea fee" which is an additional service cost offered to government officials to grease red tape adds to the norm (Chat-uthai and Mclean, 2017). Whereas the global perceptions of the corruption are totally negative, it is not so in Thailand. Several academic research suggests that corruption can be conceived as either a principal-agent problem or a collective action problem (Marquette and Peiffer, 2015), However, Ugur and Dasgupta (2011) believe that principal-agent theory in corruption research is predominantly used. The principal-agent theory which shapes the understanding of how corruption impacts development underpins this research, and this is discussed in the next section.

The Principal-Agency Theory

The principal-agency theory is an economics theory explaining relationships between agents and principals (Roberts, 2004). Consequently, empowerment is an opportunity to encourage agents to take principal's benefits (Douma and Schreuder, 2012). There are many cases showing relationships between the agent and the principal like employee (agent) and employer (principal), broker and buyer, and board and shareholder, subordinator (agent) and manager (principal), and fund manager and investor in literature (Douma and Schreuder, 2012). Also, empowerment obtained from the principal came with both responsibility and risk. Therefore, agents sometimes used power to decrease personal risk by inappropriately spending the principal's budget. However, Jiraporn *et al.,* (2008) mentioned an informational case when the principal is excluded from the information loop. Khan (2008) also argued that monitoring was costly and might be collusion between an outsider who monitors the agent. In Thailand, the government acts as an agent in tax collection and investing in public facilities, however, some monies are spent inappropriately. In the private sector, construction firms are the agents in construction industry who sometimes mismanage the clients' budget (Arun, 2005). Figure 1 illustrates the relationship between the Agent and the Principal in the context of the TCI.

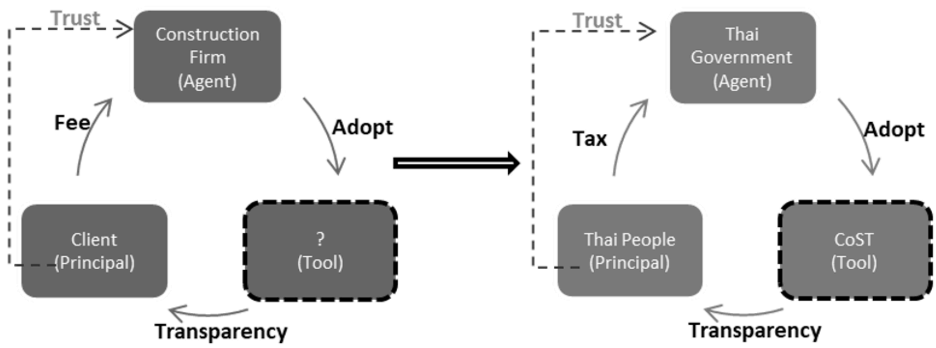

Figure 1: Agent and Principal relationship in the Thai Construction industry context

Causes of Corruption in the Thai Construction Industry

The Thai culture influence definition and boundary of corruption. Consequently, Thais usually confuse corruption's boundary with what is public good or public service (Phongpaichit and Piriyarangsan, 1999). The intertwining of Thai culture leads to several corrupt behaviours occurring in the construction industry. First, nepotism often appears in procurement as a type of "good old boys' network" (Bowen *et al.,* 2012). Secondly, collusion in bidding process bring about cost overruns of public infrastructure projects (Sayeed, 2004). Deprived of the close-knitted relationships, Thai traditional bureaucracy patronizes bribery inherently due to red tape and poor administration. Dollar and Hallward-Driemeier (2000) described this as bottlenecks of productivity rather than financial problems, whiles some entrepreneurs result to suborning government officials.

Furthermore, a determinant driver of bribery in the bureaucratic system was salary of the Thai government officials. Conversely, many Thai architects in private companies receive very low wage rates without good compensations. Virajsilp (2008) opined that Thai architectural fee was very small compared with other countries and professionals such as lawyers and doctors. However, Yomnak (2016) found bribery in materials' specifications in design process. Yomnak (2016) also noticed that cost estimation in Thailand was often done by civil engineers who were not professionally trained to be Quantity Surveyors. Consequently, the weakness of the judiciary system encourages bribery or corruption easily.

Preventing Corruption in the Thai Construction Industry

There are two strategies scholars proposed to address ambiguous corruption definitions. Firstly, Doig *et al.,* (2007) expressed that professional skills and ethical training should be provided to employees in construction firms to improve the employees' behaviours in the industry. Secondly, promoting anti-corruption in infrastructure, construction and engineering sectors by industry-led actions can help eliminate corruption (Zinnbauer *et al.,* 2009). Boeckmann (2005) also stated that promoted principles of transparency, accountability, and responsibility result in sustainable integrity, fairness, and ethical conducts respectively.

Jurkiewicz and Brown (2000) showed that leadership (i.e., top-down management) influenced organisational culture directly and are stronger and effective than policy. Svendsen and Graeff (2012) asserted that trust can reduce corruption, improve productivity, and decrease cost of inspections. Furthermore, Cheng *et al.,* (2006) demonstrated that the corporate government can mitigate internal frauds in construction firms and maintain client's confidence. It also argued that auditing is an effective way to curb corruption in the construction industry. To prevent unbalanced and collusive bids, Chotibhongs (2011) revealed that detection was a potential solution. Lastly, Yomnak (2016, p.14) noted that previous Thai anti-corruption strategies had no significant improvement as they were "one-size-fits-all" approach.

METHOD

The study adopted qualitative research methodology using semi-structured interview with 12 construction industry stakeholders with over 10 years of working experiences in the Thai construction industry. According to Silverman (2013), qualitative method is commonly used for investigating issues of reality and inner experiences through people story in the context of corruption in the Thai construction. Understanding the perceptions, beliefs, and opinions (Roulston, 2014) of stakeholders on corruption in TCI can best be addressed through qualitative research. According to Guest (2006), a sample size of twelve (12) interviews is sufficient in a qualitative study since saturation occurs beyond this point; Morse (1994) even argues that a minimum of six (6) interviews is acceptable in a qualitative study. This justifies the engagement of 12 interview participants in this study. All data were recorded during the interview and transcribed, manually analysed, categorized, and conceptualized for simplicity and consistency in the analysis process (Silverman, 2013). Interviews were conducted with professionals selected from the following 3 main types of organisations in Thailand: government, state enterprise and private companies lasting between 45-60 minutes. The interview questions revolved around the following research questions:

RQ1. What is the nature of corruption in Thailand?

RQ2. What are the causes of corruption in the Thai construction industry?

RQ3. How is the Thai construction industry preventing/minimising corruption?

FINDINGS

Table 1 presents the profile of the 12 professionals interviewed, consisting of 1 property developer, 3 project managers, 1 construction manager, 2 main contractors, 1 sub-contractor and 4 architects with the average of 14 years of working experiences in the Thai Construction Industry. The proportion of male and female, and principal and agent are 2:1 and 1:1 respectively.

Nature of Corruption in Thailand

In Thailand, corrupt behaviours and boundaries are defined to include *fraud, offer, and receive, solicit, offence, and unfairness*. Interviewees PM2 and SC believed that offering and receiving normally happened simultaneously whereas PM3 and AR2 argued that soliciting and receiving might happen separately. Interestingly, interviewee PM3 explained the difference between corruption and "*sin nam jai*", Thai norm which was defined as "*tokens of generosity*", by using the sequence of actions. Therefore, PM3 did not define corruption as receiving or offering but soliciting during work in progress by saying:

"The money received after work completed could be sin nam jai while corruption was the money or gifts solicited and received before work completed" (PM3).

Table 1: Profile of Interviewees

Interviewee		Gender*		Year	Sector**			Status***	
Job Title	Code	M	F	(Experience)	P	SE	G	P	A
Property Developer	D		•	14	•			•	
Project Manager 1	PM1	•		17	•			•	
Project Manager 2	PM2	•		17			•	•	
Project Manager 3	PM3	•		16		•		•	
Construction Manager	CM		•	10		•			•
Main Contractor 1	MC1	•		12	•			•	
Main Contractor 2	MC2	•		11	•			•	
Sub-Contractor	SC	•		13	•				•
Architect 1	AR1	•		10	•				•
Architect 2	AR2	•		17	•				•
Architect 3	AR3		•	11		•			•
Architect 4	AR4		•	10			•		•
Total		8	4	Av. = 14	7	3	2	6	6

** Male (M), Female (F); ** Private Sector (P), State Enterprise (SE), Government (G); *** Principal (P), Agent (A)*

Although the sequence of action was not directly mentioned, interviewee AR2 defined corruption as a reward gained from completed one's duty. Similarly, PM2 and SC believed that the complete corruption cycle takes place when proposers and receivers successfully agreed on a deal. Moreover, interviewee SC alluded to unfair competition when asked to give examples of corrupt behaviour in agreement with MC1 who defined corruption as unfairness. Noticeably, corruption interpreted by SC and MC1 relate to their experiences as contractors and commented that:

> "Deals lead to unfairness particularly in competitions like bidding" (SC)
>
> "It would be a fair competition if there is no corruption" (MC1).

However, MC1, MC2 and AR3 had different perspectives; MC1 and AR3 thought that corruption acts are perpetrated by government sector officials, while MC2 believed that it occurred in large organisations. With regards to the amount offered and received (i.e., money or gifts) that should amount to as corrupt act, interviewee MC1 and AR3 considered the minimum amount being 5,000 and 3,000 THB (Thai Currency) respectively. Whereas MC1, as a state enterprise employee, determined the value by his feeling, AR3 referred to the manual of Thai government officials established by National Anti-Corruption Commission in 2012 by arguing:

> "If the government officials receive any properties or benefits valued less than 3,000 THB for a personal occasion from others who are not their relatives, they are not guilty" (AR3)

Causes of Corruption in Thai Construction Industry

The research showed that the cause of corruption in the TCI were greed, organisational system, ineffective laws, red tapes, high competition, and interference resulting in the following types of corrupt behaviours: fraud, bribery, and collusion. Surprisingly, only interviewee 'D' faced fraud most often while the rest revealed bribery and collusion as the main type of corrupt behaviours encountered. Basically, bribery acts are caused by various factors while collusion is only caused by interference. However, fraud in the form of devalued materials was caused by bad behaviours of contractors who focus mainly on benefits rather than the client's interest. Interviewee 'D' said that:

> "The bad contractors use poor quality materials because of greed. High profit is the main priority rather than the quality of the construction product" (D).

Bribery, which was mentioned by most of the interviewees, happened in various construction processes. Interviewee AR2 noted that at the design stage, materials suppliers pay commission to architects for specifying products from such suppliers in drawings and considered such act as a kind of sales promotion. Similarly, CM gave an example of gratification that contractors attempted to satisfy client's construction managers to facilitate their works (i.e., quality approval).

Both AR2 and CM expressed their opinions as agents and accepting or rejecting bribes depended greatly on the individual and organisational culture. In addition, PM1 noted that:

> "There are conflicts in Thai laws and rules, and these support officials' soliciting. I usually face many difficulties when I request for the construction permission. Despite the same drawing, each officials judge differently" (PM1).

However, interviewee PM3 believed that if the officers were not opportunistic and the citizens who request the permission do not offer bribes and accept the red tape, the bribe cycle could not be completed. Moreover, PM3 interestingly commented on manual working process of organisations particularly in public sector where most activities required human discretion in judgments leading to inequalities. There was also bribery at the procurement stage on how bids were won in the current highly competitive market. Interviewee MC2 commented:

> "Today, there is a very high competition in the market. Sometimes, we have to cut our prices in order to win the bid. Also, bribe sometimes can facilitate this" (MC2).

It was interesting that all interviewees who alluded to collusion in the procurement process indicated interference as its main cause. AR3 cited a case example where material and furniture venders who were selected despite their lack of qualification.

Interviewee MC1 also revealed interfering with the procurement process of some government projects despite not being a public official. The above analysis demonstrated the various causes of corruption, but it was important to note that bribery in the TCI was mainly caused by abuse of power by officials. Power is a factor of agent problem connected with corruption in Thailand.

However, some interviewees argued that an inherent personal behaviour outweighs power. Surprisingly, neither low government officials' salary nor low architectural fees cited by Virajsilp (2008) was pointed out as a cause of corruption during the interviews. Instead, the weakness of organisational system, organisational culture and dysfunctional personal behaviours like greed was revealed as the cause of corruption in the TCI. The findings reinforced the agency theory and indicated that some agents were opportunistic and having too much power supports their corrupt behaviours. Moreover, some good agents become corrupt agents when they have power. On the other hand, some agents are moralist. These agents considered more power as more responsibility and therefore having power cannot change them into corrupt agents. For trust, although some interviewees viewed it as a motivation, it worked only for moral agents.

Preventing Corruption in the Thai Construction Industry

Trust is considered as corruption mitigation measure in organisational management. However, when interviewees were asked about their opinion on the relationship between trust and corruption, only few respondents believed that trust could reduce corruption, majority of the respondents revealed that it depended on the individuals' behaviour, disposition, integrity, and that ironically, trust supported corrupt behaviours. Although both interviewees MC2 and AR3 believed in trust, MC2 considered other corrupt prevention strategies like profit sharing, while AR3 believes in improving organisational system as a preventive measure. Interviewees PM2 and PM3 supported the idea of improving organisational system; PM3 however argued that this should start by reforming employees' attitude.

Whereas corruption preventive strategies like improved system, reforming attitude and decentralisation seem to be time-consuming, system improvement required collaboration from many people and negotiation to combat dysfunctional behaviours at organisational scale. For fraud and bribery prevention, interviewee AR2 argued that ethical training could be used for improving personal behaviour whiles CM, PM2 and AR4 strongly argued that training on ethical behaviour was useless and waste of money. Interviewee AR2 noted that:

> "Because human actions are led by their decision making, if we train our staffs on ethics and educate them how to make the right decision, corrupt act may not occur" (AR2).

Some of the interviewees who disagreed with the ethical training strategy preferred to invest in auditing systems. According to interviewee SC, if the physical auditing is implemented together with the ethics training, officers tend to work more carefully achieving better results It is noticeable that when the interviewees talked about organisational culture, prohibition and leadership were often mentioned at the same time. As stated by AR1 and CM, the leadership behaviour must be related to prohibition or policy. Thus, leadership is a crucial factor impacting on the overall organisational culture. Interviewee CM supported the assertion by saying that:

> "The action of leaders showing integrity and relating to firm's prohibition is the best communication that demonstrates the moral ethics in organisational culture. My previous boss has never had dinner with any contractor, so no one else dare as well" (CM).

Regarding the adoption of the Construction Sector Transparency Initiative (CoST) by the Thai as suitable tool for mitigating corruption in the construction industry, only interviewee D agreed with the CoST whiles PM1, PM2, CM, and SC disagreed since Thais were not ready for such approach as some used power to protest improperly. CoST is however a progressive step towards the prevention of corruption in the construction industry if successfully implemented. Again, Interviewee MC1 believed that:

> "CoST might help on projects using e-bidding that can reduce some collusions, but I don't think it covers 100% of the processes on the whole project cycle" (MC1).

The results showed that the system approach of auditing and classic step tackling of corruption was productive. This supported Huang (2017) assertion that auditing, monitoring, and detection were effective ways to curb corruption. Again, the findings indicated that decentralisation and profit sharing should be adopted as a strategy for preventing corruption as recommended by Douma and Schreuder (2012). The study showed that only few construction stakeholders used the CoST initiative for corruption mitigation and prevention in the Thai Construction Industry.

CONCLUSION

Corruption is defined as fraud, offering, receiving, soliciting, offence and unfair treatment and abuse of office hours for personal gain. Although the Thai Construction Industry (TCI) defined corrupt activities quite similarly to the internationally acceptable definition, there were some ambiguities to the degree of misconduct and values. The main causes of corruption in the TCI were categorised into behavioural and managerial factors. Behavioural factors included greed, opportunistic character, abuse of power, convenience-oriented personality, law disobeying and tempting. Whereas managerial factors were lack of transparency in procurement, weakness of bureaucratic system and jurisdiction including mismanagement of organisational culture and structure.

Preventive measures for corruption included reformation of improper behaviours and managerial systems simultaneously. Ethical training and moral education could enhance employee's behaviour, and organisational leadership's moral behaviour could serve as a role model for the followers. However, changing organisational behaviour alone was not sufficient; defensive measures such as detecting, reorganisation and employee motivation were also necessary. Significantly, mitigation and preventive measures will depend on the nature of corruption. This study provides empirical insight into the nature of corruption in the Thai Construction industry that has never been done through qualitative study; this will therefore serve as a good source of reference for the industry and policy makers in attempt to implement policies to address the problem of corruption in the TCI.

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INFORMATION MANAGEMENT

ADDRESSING DESIGN MANAGEMENT CHALLENGES THROUGH THE DEVELOPMENT OF A WEB-BASED PLATFORM

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Construction Design Management (DM) involves the coordination of design process and activity to ensure quality project design, yet it involves many challenges. This work reports on a collaborative Knowledge Transfer Project (KTP) with a Case Study Organisation (CSO) that - in the spirit of the 'Building Back Wiser' ARCOM 38 call - innovatively tackles existing DM challenges. In doing so, selected DM processes were digitalised to improve efficiency, and productivity. Mixed research strategies were employed. Qualitative analysis of semi-structured interviews with purposively identified design managers uncovered real world concerns around design coordination, and designer performance monitoring. Then, through design science research (DSR), a web-based design management prototype platform was developed. This uses typical project data to aid design coordination activity and facilitate DM task prioritisation and reporting functionalities. Its visual reporting capability enables design production to be monitored; trends in designer performance to be assessed and focus to be retained on technical queries (TQs) and requests for information (RFIs). Construction productivity and effectiveness can therefore be enhanced if supported by appropriate digital platforms.

Keywords: design management; digital; information management; innovation

INTRODUCTION

High quality asset design provides value to organisations, owners, and end users in the construction sector. Design creation involves managed interactions between project stakeholders and takes participants from an initial vague-unknown position to a subsequent known-and-desired solution. This process results in a set of collated information, involving drawings, specifications, schedules, and digital models, from which tangible assets can be constructed. Design management (DM) therefore involves the management of project-related design activities, processes, people, and other resources to enable the effective flow, and production of design information.

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However current project-delivery approaches regarding the management of design, remain problematic. One persistent concern regards the separate perspectives held by project actors around what successful project delivery is, because of various project time, cost, and quality targets.

Hence, without effective decision support systems, DM approaches may not always be focused on realizing desired project outcomes (Eynon, 2013). An additional issue revolves around how achieving such collaborative and integrated working across a temporary project organisation (TPO) has usually been a messy, and ‘analogue’ coordination process involving process waste. Bolpagni *et al. (*2022) discuss how in Industry 4.0, because of an increasing adoption of digital design through the likes of Building Information Modelling (BIM), such information-rich content could be much better managed through more digital means. In brief, BIM involves creating a digital version of what is to be built, and then using it as the basis for construction. Using specialist computer software, designers create a three-dimensional (3D) model, that is an exact, rather than approximate representation of the asset. Succar, (2009) initially suggested that BIM would provide “…technological and procedural shift" within construction, and Gledson (2016) later identified its impact as “the most prominent radical, transformative and disruptive innovation to hit the construction industry”.

Again, because of the increasing adoption of digital design through the likes of BIM, information-rich content can now be much better managed using more digital means. The aim of this work therefore is to report on the development of a bespoke digital web-based platform intended to enhance the efficiency, productivity, and ultimately the effectiveness of the design management function. It intends for better realisation of construction projects, through digitally supported design management (DsDM) functions, by way of a standalone dashboard, that uses data processing to better manage information, facilitate good evidence-based decision-making and drive project performance. Before discussing the discrete DM functions targeted by the prototype dashboard, some inherent problems in the conventional design process, the value of the design management role, and how it could be enhanced through use of project data analytics, are now discussed.

LITERATURE REVIEW

Gledson (2017) summarises various inefficiencies in design processes that, ultimately leads to inherent problems in the existing design management process. At project inception, lead designers first establish the nature of the design problem at hand be it ‘well-defined’, ‘ill-defined’ or ‘wicked’ (Churchman, 1967; Emmitt and Ruikar, 2013). To do this, they extract early non-formalised requirements through guided client interactions, to try to ensure their needs will be met. Tisani (2007), describes the information flows that occur in current design processes and identifies inefficiencies including: poor capture of formalised building requirements; rigidity of design process flow; compartmentalised decision making; lack of fidelity; minimal opportunities for design experimentation; lack of accommodation for late design changes and lack of design automation.

Dictated by selected project procurement strategy, a set order of the design activities to be carried out, before the information can be transferred down to other project participants is undertaken. This fragmented approach to managing design flow was criticised by Anumba *et al. (*2002) who notably referred to this as the 'over the wall' approach. Once each area of design has been produced, the recipient of design information must interpret the information to be able to make judgements. Because of the quality of design available to them, they may also have to make several assumptions which may lead to misinterpretations. The receivers of information will also need all the multiple project views available and correct to the latest versions to fully understand the design. Checking is done to ensure the design is ‘clear’, ‘correct’, ‘consistent’, ‘coordinated’ with the associated design information (which may have been created by another producer) and is ‘complete’: To carry out these checks properly is time consuming and requires expertise, discipline, and judgement. Such talents are rare and on fast-moving projects, fundamental mistakes are often made (Crotty, 2012). More effective digital project decision-support systems could therefore benefit the process of checking and coordinating design information.

Cidik and Boyd (2020) recently warned against the narrow, but commonly held view of design coordination involving only the integration of separate design outputs by fragmented design actors, and instead emphasise the “shared sense of purposefulness” that the design team members should have. Regardless, because several design disciplines provide input into even the most basic of design activities, their co-ordination requires much time and skilled resource. Without a dedicated design manager to ensure fit-for-purpose design quality achieved, design coordination can be inefficient and ineffective. Current means of generating and managing construction project design - even when using the likes of BIM - can therefore be inefficient and ineffective without such a dedicated role providing the necessary oversight. Whilst the focused use of BIM can facilitate improvements in conventional design processes, concerns persist around how use of such design tools enhance design quality. Therefore, greater focus on the DM role, and how it can support design quality by better use of digital project information is welcomed.

Savolainen *et al. (*2018) recently acknowledged the role in value creation that design management plays. Depending on the procurement route used, and with reference to the RIBA Plan of Work 2020, Design Managers can be substantively involved across Stage 1 ‘Preparation and Briefing’ through to Stage 6 ‘Handover’ of projects. Again, depending upon procurement mechanisms, they can be involved in activities as diverse as: preparing and monitoring design programmes, undertaking design reviews, coordinating the development of technical designs, and resolving technical and site-based queries. Recently, various researchers (Jacob and Varghese, 2018; Sutrisna and Goulding, 2019) have reviewed design processes interactions, and identified concerns around quality of information flow and information exchanges in DM processes. Similarly, Uusitalo *et al. (*2019) and Uusitalo *et al. (*2021) investigated the roles between design and design management actors in construction project contexts, specifically regarding information flow and solving design quality problems. These researchers ultimately found that project teams should look to better enhance ways of communicating and collaborating when managing design. Ultimately, much of knowledge base has hinted at how better use of project information could be enacted digitally to enhance construction practice. To that end, this specific project makes use of Project Data Analytics to better support design managers in their role.

Project Data Analytics

Various forms of project data analytics exist. These include low autonomous/intelligence Robotic Process Automation (RPA) tools such as transactional ‘bots’ to much vaunted, high autonomous/intelligence narrow/general Artificial Intelligence (AI) solutions (APM, 2022). Application Programming Interface(s) (API), also enable data analytics to occur via connections between computers and software applications. Given the range of design management processes it was identified that a range of DM functions could be digitally supported through Project Data Analytics by creating a DM solution. Specifically, this project made use of API analytics via a web-based project dashboard interface to digitally support a range of design management (DsDM) functions. In this work, we describe only a selection of these below, including opportunities to:

- Allow better coordination and management of design process interactions, as captured through Technical Queries (TQs) and Requests for Information (RFI) mechanisms
- Ensure that the design team are aware of and maintaining their design delivery programme and focusing on their critical design priorities, through better monitoring of planned design release against actual design production

METHOD

Descriptive research is to accurately portray the likes of events or situations (Saunders *et al.,* 2009). This descriptive research reports on the results of a collaborative industry-academia Knowledge Transfer Project (KTP) with a Case Study Organisation (CSO). This work involved mixed strategies, whereby survey research, was followed by design science research (DSR). To be exact, initial semi-structured interviews were held with 9 purposively identified design managers, to uncover first-hand, real world DM concerns and validate these against challenges identified in the knowledge base. Data from these interviews were analysed using Nvivo Software (See Table 1 for Themes). Then, by way of DSR, a web-based design management platform was developed. This tackled some of the identified challenges of the DM role by digitalizing selected design management processes to better manage data and information, facilitate good decision-making, and improve the efficiency, and productivity of this role. The specific results of each stage are reported separately below.

FINDINGS

Qualitative interviews

At the outset of the collaboration and to obtain funding, various supporting statements were obtained from design management or DM adjacent practitioners to justify the project. One important statement advised: “Design management plays an increasingly important role in projects as it uniquely crosses the boundaries between the quantitative/process related issues dealt with by project management colleagues, and qualitative design related issued being delivered by the design team. The benefits to the user that a central dashboard where project decisions can be made and presented to the client provide [include those of] challenging the delivery programme by utilizing data, and [of] digitizing analogue processes”.

This reveals that better project data analytics can assist the design management function. After project award and following an initial ‘Situational Awareness’ phase (Project Stage #1), ‘Problem Definition and User Requirement gathering’ (Stage #2) activities occurred. This involved a review of the knowledge base, followed by online interviews with 9 design managers. A mass of qualitative data was obtained from these interviews, which were then thematically analysed. As evidenced in Table 1, several interrelated DM challenges were revealed, however this present work focuses only on some of these, which were ultimately addressed by specific functions within the web-based design management platform. These being the creation of: digital

TQ/RFI systems (to support challenges of communication, coordination, information flow and decision making), and the digital tracking of designer performance in the production of their project deliverables (similarly, to support challenges of coordination, information flow, efficiency, and value):

Table 1: Identification of DM Challenges arising from interviews quantified via CAQDAS

Process	Parts.	Refs
Information Flow	9	112
Coordination	9	72
Decision Making	9	71
Communication	5	31
Efficiency (i.e., accomplishing output, minimising waste).	3	7
Trust	3	5
Value	3	5

The challenges of design coordination and information management
Participants revealed how better coordination and improvements in the management of design process interactions as captured via conventional 'Requests for Information' are needed: Participant 9 discussed one specific element of works on one of their projects was affected by this: "I've had 250 RFIs on site that I've had to deal with. Had, 20 days of site delay, and we've had to make 25 changes on site, to er, cable and drainage, and such". The impact of such, seemingly difficult to manage: "…you are sitting there, dealing daily with a million RFIs that are coming in from your site managers … I don't know how many days on site have been wasted, and I don't know how many RFIs have been generated from it…" (Participant 9).

Participant 4 also revealed the need for better digital management of project RFIs: "As an example, if I asked for a schedule of RFIs from a project, 'tell me how many there are', it will probably take them two weeks to extract those RFIs into an Excel sheet, [that] won't give you very much, whereas if I could get and use that data to influence and understand it, I can then link it to things like programme or whatever we need to do with it." Participant (#4) also understood how project data analytics could further aid the production process: "[Regarding] outstanding RFIs, TQs, from subcontractors, clients or whatever it is, if we can see those outstanding issues on a dashboard and their dates … if we can get everybody to think about the priorities in relation to time, and they can see those clearly through a dashboard … we can build it properly". Across the interviews, challenges of communication, coordination, information flow and decision-making concerned DM practitioners. These were ultimately addressed through the creation of a digital RFI system, as discussed in a below section.

The challenges of ensuring design team maintain their design delivery programme
Regarding the production of design programmes, existing situations were outlined: "I would ask the consultants to produce a list of deliverables, whether drawings, specs, whatever they are for each construction package and when they need to be released". (Participant 2). These are incorporated into an agreed design programme, or an Information Release Schedule (IRS) which is set out with activities and timings, "…then that would be monitored by the architects and myself. I would speak with the architect every 2 weeks [for a] progress update (Participant 1). This is then monitored: "If it's as the plan, everything's fine. If they're slightly behind we need to monitor the impact of that on the design coordination, making it all fit, which then

goes on to procurement … we then must monitor that and make sure procurement is linked into build.” (Participant 1).

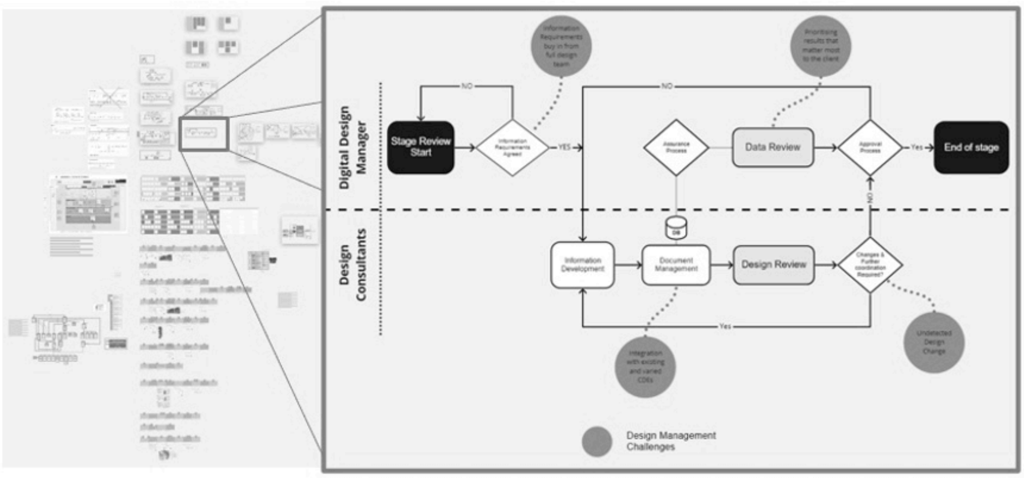
Once design information released: “…it would be a simple case of just going through the [common] data repository that they would upload it to, and it would be a simple matter of just going through and checking that those drawings and those schedules or specs have been received (Participant 2). As to any problems with existing process, designer performance in terms of design release against agreed design programmes was a frustration: “… and the day comes and the deadline comes and next Friday turns into Monday, turns into sort of Wednesday and by the next Friday … erm, if they’re late, that’s recorded.” (Participant 1). Using current existing process, the design manager is often in a reactive state, whereas participants would prefer they were able to be more proactive: “The biggest challenge we’ve had consistently for the past two years has been design managers not being process managers, not really [being able to] actively influence procurement or design programme progress.” (Participant 4).

Ultimately, what participants wanted was to be able to better track and manage designer performance: “I want to see [visibility from] the design manager, the key challenges they’re having on the project. I would like to see how the design and procurement programme and the project programme is working, against the [designers] own actions, what they’re doing, and I’d like to see [from designers], erm an element of compliance, (Participant 4). Again, across the interviews, challenges of coordination, information flow, efficiency and value creation concerned DM practitioners. These were ultimately addressed as discussed in a below section, through the creation of a digital system, for better tracking of designer performance in the production of their project deliverables.

Results of DSR: Platform Development

Following the prior ‘Problem Definition and User Requirements’ stage (#2), the present ‘Problem Solving, System Design and Development stage (#3) occurred. The main activities in this stage involve the design of the DsDM process itself, and the iterative and agile design and evaluation of the bespoke DsDM platform, its functionalities and user interface occurred. Summary details are here provided. Regarding process review, and design of the DsDM, over the duration of the project these aspects were continually storyboarded and refined using online collaborative tools such as the Miro service. Figure 1 illustrates this 'design mapping', which ultimately identified ‘what’ needed to be done in the design and development tasks.

Figure 1: Extract of Design Manager User Journey from Design Mapping



Thereafter, 'how' the DsDM platform would be iteratively designed and developed was determined. Indicative system architecture for this is evidenced in Figure 2. The developed DsDM platform draws upon relevant project data to aid design coordination activity and facilitate DM task prioritisation and reporting functionality. It enables useful visual reporting capability that, in turn: allows focus to be retained on priority Technical Queries (TQs) / Requests for information (RFI), and enables design production to be monitored, and trends in designer performance to be assessed.

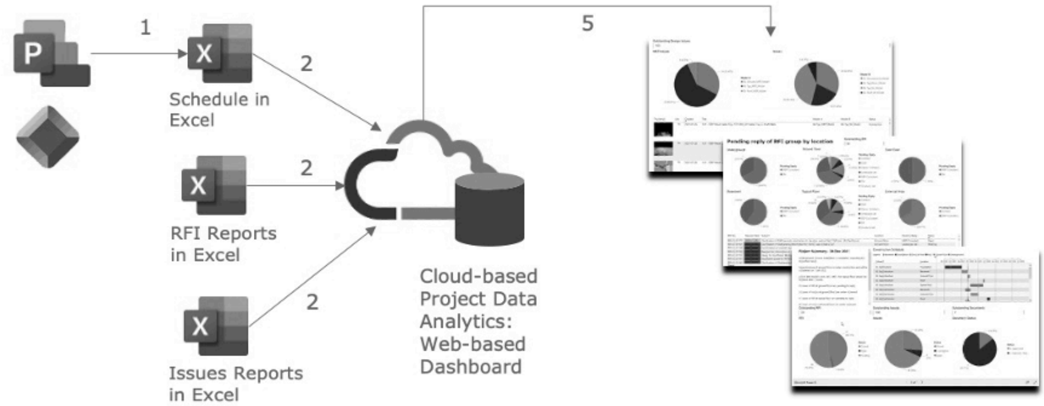


Figure 2: Indicative System Architecture

Addressing challenges of design coordination and information management through managed RFIs

Currently, individual RFI's (and/or TQs) are generated and issued in many different formats (e.g., by typed word docs, or handwritten memos etc). The key contents of these are then typically captured and aggregated via excel-based registers by DM personnel. The DsDM web-based dashboard allows for uploading of these summary reports to a project Common Data Environment (CDE), so as to host and visually present key information from these for review, onward routing and ultimately addressing. However, the web-based dashboard does not just host conventionally created TQs/RFIs. On this project the team also developed a new web-based form and associated cross-platform mobile app that allowed for electronic queries to be created 'on the go' (e.g., whilst on the jobsite), and uploaded to respective TQ / RFI schedules via ubiquitous computing tools such as a laptop computer or mobile cell phone device. Post issue, an autogenerated email is sent to advise the Design Manager of new queries, who in turn can route these on to the best placed project actor(s) to address the particulars. Using a programmed workflow to automate the task, total TQ/RFI data ultimately gets synthesised within respective schedules schedule overall so that better management and control of all project TQs and RFIs occur. Figure 3 gives an indication of this, showing how via analytics, Stage 5 RFI data is presented visually, and therefore more meaningfully in the web-based dashboard so to add value to the design management process.

Addressing challenges of design delivery programme

Presently, although design programmes are routinely prepared on projects, the accurate monitoring of designer performance in terms of if/how targeted design release dates are met by designers is unsatisfactory. Similarly, because of a long subsequent chain of activities following design release, project-decision makers are too often unaware of the impact upon the project of poor performance by designers in terms of the planned vs actual design release dates. This is because, after design release is achieved there follows various: design approval(s); subcontract package procurement; subcontract award; and subcontractor lead-times; before trade contractors start their work packages on site.

Therefore, without being explicitly aware of these logical relationships it can be difficult to see how dates that are missed by designers, can impact upon planned start on site dates several months later.

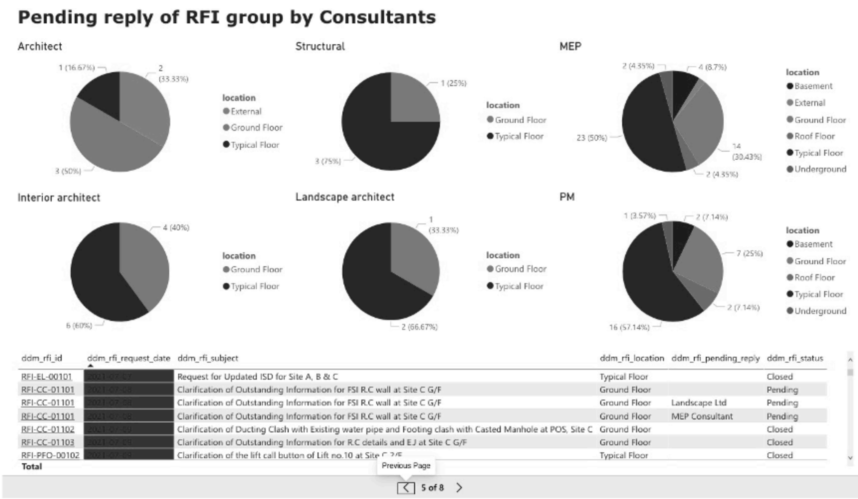


Figure 3: Indicative constructions stage RFI analytics

Current approaches to tracking performance against Design Programme do not clearly reveal this impact, or indeed longer-term highlight trends of continually missing dates. These often involve tracking via excel based ‘Information Release Schedule’ (IRS) forms. The DsDM web-based dashboard corrects this by using such excel based data to better visually presenting such information for trend analysis and uses programmed workflow to semi-automate this activity. Figure 4 gives an indication of how via analytics, such data is presented visually, and therefore more meaningfully in the web-based dashboard so to add further value to the design management process.

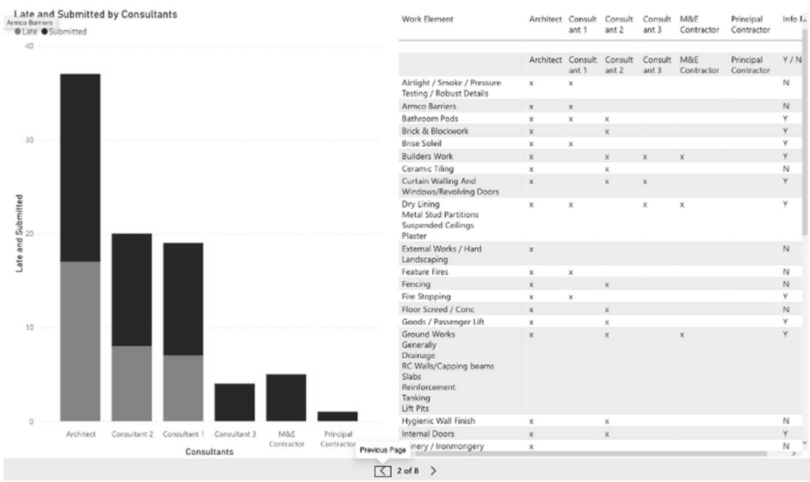


Figure 4: Indicative design programme monitoring analytics

Plans to enhance these functions via the web-based platform were shared back with various participants (amongst other targeted users), who acknowledged the value these would add to the DM role: “A monitoring system like that is really good […] that’s really powerful, because that’s the sort of thing that as a design manager I would have loved to have had." (Participant 9), and: "I think, having something like that is a huge benefit. You just get a better view, and the design team manage it a lot better, and they're being overseen. From a [project] control perspective, that's quite important." (Participant 8).

CONCLUSIONS

This work has reported on the development of a web-based platform, produced as part of the current progress of a collaborative industry-academia Knowledge Transfer Project (KTP) with a Case Study Organisation (CSO) designed to tackle some of the challenges of the DM role. Across the work, mixed research strategies were employed. Purposively selected design managers were interviewed to further uncover real world DM concerns against those found in the knowledge base. These revealed how problems of design coordination, and designer performance monitoring remain key challenges worth addressing.

Then, in digitalizing selected design management processes, a web based DsDM prototype platform was developed to uses project data to aid design coordination activity and facilitate DM task prioritisation and reporting functionality. Specifically, it enabled dashboard analytics to provide visual reporting capabilities enabling monitoring of design production, assessment of designer performance, and better management of design stage technical queries and construction stage RFIs. This work therefore reinforces how better integration and use of project data can be used for analytics in digital platforms and tools to address real concerns in construction practice. The final steps of the KTP project are now being enacted that involve final 'Solution Implementation' (#4) and 'Commercial Launch (#5) stages. Further knowledge contributions via additional academic output discussing a fuller range of DM functions addressed within the dashboard will follow this interim work.

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ENGAGED ONTOLOGY DEVELOPMENT TO BRIDGE FRAGMENTED DIGITAL REALITIES

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Fragmented knowledge bases in construction are the result of varying views on how to capture and represent knowledge. For asset management of utility infrastructure, knowledge is often either stored implicitly or in heterogeneously structured data models. Consequently, it becomes difficult to connect and implement the different data models coming from numerous individual asset owners. To unify these various knowledge representations of utility infrastructure data, we adopt the computer science concept of the 'ontology'. By using a design science-inspired research approach, we demonstrate the development of an ontology with the intent to cope better with the fragmentation in the utility infrastructure sector. We further demonstrate that the co-development of an ontology with domain professionals may emerge into a shared conceptualisation of the domain. Based on this process, we claim that engaged ontology development can play an important role in bridging the fragmentation between digital realities, in turn making digital modelling concepts such as digital twins more likely to become adopted by the utility construction sector. Future work is required to assess the impact of the ontology once applied on a larger scale.

Keywords: digital twin; fragmentation; representation; ontology; utility infrastructure

INTRODUCTION

The construction industry increasingly digitizes the life cycle of construction assets by defining concepts, attributes, and their relations (El-Diraby and Osman 2011). Digitisation is typically done through the creation of virtual representations of physical counterparts in, for example, Building Information Modelling (BIM) and Geospatial Information Systems (GIS) environments. Digitisation is further supported by the rapid development of technologies like artificial intelligence (AI), big data, the internet of things (IoT), cloud computing, wireless sensor networks, and the fifth-generation cellular network (5G) (Lu et al., 2015; Syafrudin et al., 2018). Altogether, these digital advancements nowadays drive state-of-the-art engineering and problem-solving in the construction industry.

A yet to explore issue in the construction context is the fragmentation of knowledge bases. Prior research shows that nations, organisations and even individuals may portray varying views on how to capture and represent the knowledge relevant to a construction asset's life cycle (Azhar 2011; Ter Huurne and Olde Scholtenhuis 2018;

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ter Huurne, R, Olde Scholtenhuis, L and Dorée, A (2022) Engaged Ontology Development to Bridge Fragmented Digital Realities *In:* Tutesigensi, A and Neilson, C J (Eds) *Proceedings of the 38th Annual ARCOM Conference,* 5-7 September 2022, Glasgow, UK, Association of Researchers in Construction Management, 328-337.

Voordijk et al., 2022). Such knowledge is namely either implicit or stored in heterogeneously structured data models (Figure 1). Consequently, it becomes difficult to align and connect the different data models coming from numerous individual asset owners. Such distinct and self-centred knowledge bases confuse, fragment, and ultimately delimit collaborative asset management practices (Ter Huurne and Olde Scholtenhuis 2018). Accordingly, the literature argues that uniformity of knowledge bases is necessary before the alignment of digital practices and their data models can be achieved (Turk 2001). This insight stresses the relevance of defining a shared domain understanding in the current - and most likely expanding - realm of digital construction practices.

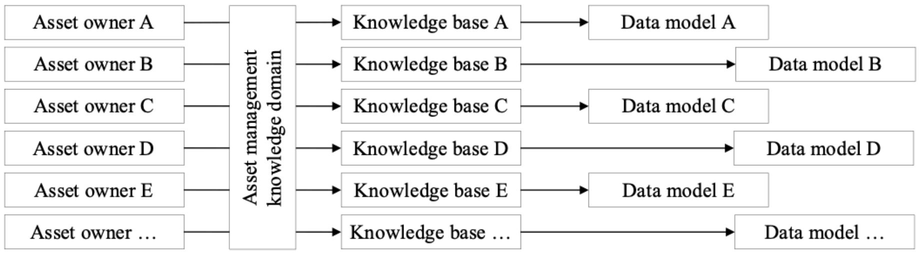

Figure 1: Heterogenous data models in construction describing the same knowledge domain

This study explores the concept of an 'ontology'. Ontologies provide the metadata that describes domain knowledge, bridging any varieties that may exist between distinct knowledge bases and their subsequent data models. This allows practitioners to understand both the content and structure of a knowledge domain (El-Diraby and Osman 2011). One sector in the construction industry that exhibits many varying data models - yet of which no one intends to be an ontology - is the utility sector. Utilities are the (typically below-surface) cables and pipes that transport services like water, gas, electricity, and telecommunication. Data models in this sector differ greatly between application domains, utility disciplines, geographical districts, and organisations.

The objective of this study is twofold. First, we demonstrate the co-development of an ontology with domain professionals with the intent to cope better with the fragmentation in the utility infrastructure sector. Specifically, we explain our efforts in attempting to conceptualize a shared domain understanding by adopting a design science-inspired research approach. Second, we reflect upon the ontology's implications regarding the future digitisation of construction environments and discuss its potential impact on the design context. Therewith, this study contributes to the construction management literature with an exploratory study of an ontology development process and expands our understanding of how ontologies may play a role in unifying fragmented data models in future digitisation efforts.

Fragmented digital practices complicate the forming of shared conceptualisations. Prior research provides evidence for the co-existence of multiple distinctive knowledge bases as the result of varying views on how to capture and represent domain knowledge (Azhar 2011; Ter Huurne and Olde Scholtenhuis 2018; Voordijk et al., 2022). This is likely to result in many heterogeneous structured data models. In turn, asset owners use these data models in their adopted information technology. Consequently, little uniformity in knowledge representation exists. This hampers the sharing of knowledge, information and data, whereas the concepts modelled are more prone to misunderstanding and misinterpretation (Turk 2001). Therefore, alignment and connection between the distinct knowledge bases and their data models become difficult. Altogether, this hampers collaborative engineering practices and complicates software interoperability (Lu et al., 2015).

This notion of 'varied knowledge representation' is expected to further increase in the modernizing and increasingly digital and virtual construction environment. In response to a greater focus on the operations and maintenance of construction assets, asset owners now increasingly enrich their existing knowledge bases and data models. This is illustrated by the recent introduction of the 'digital twin' in the construction domain (Opoku et al., 2021). Digital twins "facilitate the means to monitor, understand, and optimize the functions of physical entities, living as well as non-living, by enabling a seamless transmission of data between the physical and the virtual world" (El Saddik 2018). Digital twins are used to describe and monitor an asset's entire lifecycle via the use of sensor data, analytical and predictive models, and visualisations. The insights derived from the digital twin are then used in real-life to make decisions about the physical asset. Although still in their nascent phase, digital twins are considered amongst the most promising advancements to further modernize digital and virtual construction environments and their processes (Khajavi et al., 2019).

Based on these insights, knowledge needs to be unified to achieve the collaboration benefits of data models before 'going digital' (Gustavsson et al., 2012). This can provide a solid basis for the sharing and exchange of data models like digital twins. Literature on computer sciences advocates the use of ontologies to represent knowledge domains. Ontologies describe the world as seen by a group of people at a certain time according to a school of thought that is based on a set of fundamental propositions or world views (El-Diraby and Osman 2011). An ontology can be defined as formal and explicit specifications of shared conceptualisations (Sure, Staab, and Studer 2009). Conceptualisation refers to the universe of discourse. Shared refers to the multiple views an ontology should be able to represent. Formal and explicit refers to the fact that the concepts within the ontology should be described in a clear computer-interpretable format. Once adopted and shared amongst practitioners, ontologies are thus used to represent knowledge in a unified, simplified, and consistent way.

Brachman and Levesque (2004) describe the logic behind such knowledge representation as "the field of study concerned with using formal symbols to represent a collection of propositions believed by some putative agent". Knowledge representations are thus the internal representations of such an agent (Jakus et al., 2013). This means that representing knowledge through ontologies requires thought about phenomenology - a branch of philosophy that deals with how to take things for what they are and what it means 'to be' - and hermeneutics - a branch of philosophy focussing on interpretation. Intention and interpretation are relevant when capturing 'realities' because their meanings can be shaped both by the authors and users of ontologies (Turk 2001). Ontologies thus rely on consensus amongst the domain professionals using it to enable shared conceptualisations of the knowledge it captures and represents.

To date, ontology development efforts to bridge fragmented realities have received limited attention in construction management literature. Considering this research gap, this study showcases the development of an ontology with the intent to cope better with the fragmentation in one construction sector in particular: the utility sector. In this development process, we explain our efforts in attempting to create a shared domain understanding by adopting a design science-inspired research approach. We then zoom out and discuss the ontology's impact on its design context, while providing an outlook on the role of ontologies in the future digitisation of construction environments.

METHOD

To develop the ontology and assess its impact on its design context, we adopted Hevner's (2007) three-cycle view of design science (Figure 2). We chose design science as our research approach since it explicitly focuses on creating knowledge and understanding of a problem domain by building and designing an artefact. Furthermore, this approach supports both the development (combination of the rigor and design cycle) and the assessment of the impact of the ontology on its design context and application domain (the relevance cycle).

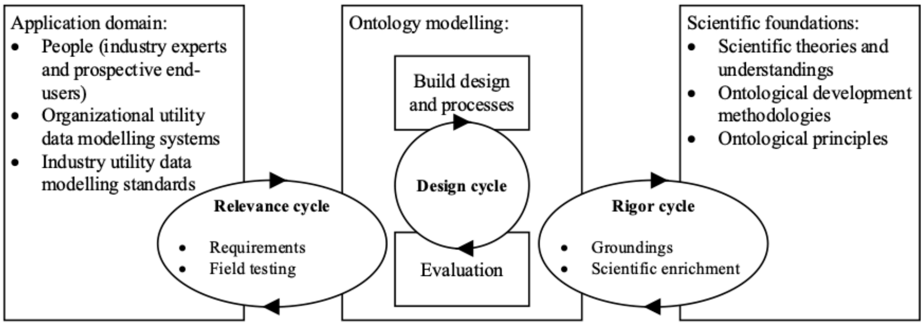

Figure 2: Adopted design science research approach (adapted from Hevner, 2007)

To build the ontology, we adopted a hybrid approach of existing ontology development principles and methodologies as scientific foundations. In specific, elements of the studies by Corcho *et al. (*2003), Noy and McGuinnes (2001), López *et al. (*1999), Sure *et al. (*2004), Gasevic *et al*., (2009), Jakus *et al. (*2013), and Pinto *et al. (*2009) were used and integrated into the design science cycle. We investigated the application domain of the ontology, defined the ontology's requirements, designed, and build the ontology, evaluated the ontology, and performed a field test. This entire process was conducted iteratively over a two-year timespan.

To align the potential varying intentions and interpretations of domain professionals, the ontology was co-developed in close collaboration with industry experts and prospective end-users. They were mainly involved in the requirements engineering and evaluation phase of the ontology. Specifically, over twenty industry meetings were held, either with groups or individuals. Further, utility data models (including models such as CityGML Utility Network and INSPIRE), existing utility design guidelines and real-life sources of domain data (obtained through observational case studies of the digital modelling practices of twelve major utility owners) were inspected to get an understanding of the knowledge represented in the distinctive knowledge bases.

The ontology was modelled by using a hybrid approach of top-down and bottom-up modelling. A top-down approach starts building with the most generic concepts. A bottom-up approach starts building with the most specific concepts. The proposed hybrid approach has the benefit of grasping the generic concepts of the domain, while at the same time being able to connect these with the detailed aspects of real-life practices. The concepts of the ontology were modelled in the Unified Modelling

Language (UML) which is an often-applied language in class modelling due to its graphical notations. We further adopted the typology of Gasevic *et al. (*2009) to communicate and describe the ontology design. This topology comprises the three main elements of an ontology, being taxonomy and hierarchy, vocabulary and terms, and semantics. The taxonomy and hierarchy refer to the hierarchical categorisation of the concepts within the ontology. The vocabulary refers to the set of terms and names that are used in the subject area captured by the ontology. Semantics refers to the linguistic meaning of these applied terms and names.

Given the iterative nature of the design cycle, simultaneous to its development evaluation of the ontology took place. Four evaluation techniques were applied: assessment against sources of domain data, assessment against competency questions, assessment against modelling rules, and assessment against end-user and expert input. The ontology was also implemented as a field test in a simulated utility operations and maintenance case. During this field test, we assessed once more whether the ontology could satisfy the 'competency questions' (questions the ontology should be able to provide the knowledge for to answer). Altogether, the various evaluation measures helped to assess the ontology against eight ontology evaluation criteria: accuracy, adaptability, clarity, completeness, computational efficiency, conciseness, consistency, and organisational fitness. Ultimately, eight versions were developed before the ontology was considered capable of satisfying all evaluation measures, and therewith, creating a shared domain understanding.

To assess the ontology's impact on its design context, a semi-structured plenary session was held with the prospective-end users and industry experts. The ontology and its intended aim were presented in combination with a demonstration of the field test. Specifically, the participants were asked to express their thoughts about how the ontology would implicate their current digital modelling efforts, as well as their current asset management practices.

An Ontology for Utility Asset Modelling

The ontological model presented in this study is an empirically grounded ontology whose targeted use lies in the management of the operations and maintenance of utilities during their lifespan. The ontology applies to the following utility disciplines: electricity, oil, gas, chemicals, sewage, water, thermal and telecommunication. The use of the ontology has no geographic boundary but is based on utility networks of developed countries. The ontology models utility networks, their subnetworks, and their superordinate networks. Utilities can be modelled both in two and three dimensions. The next sections provide an overview of the developed ontology's design. The complete ontological model and its accompanying documentation are available from the corresponding first author upon reasonable request.

The ontology describes the entire chain of knowledge represented in a utility asset management context. The model describes the interplay between actors, projects and processes, physical objects and knowledge items, and how these are described through their spatial characteristics, functions, attributes and performances. This is visualized in Figure 3.

Concepts and their attributes in the model are related to one another through different types of relations. We used the relation types of UML to represent whole-part, parent-child, and one-to-one relationships. For each of the concepts as presented in Figure 3, the ontological model allows the representation of a variety of instances. We illustrate some of its instances in Table 1.

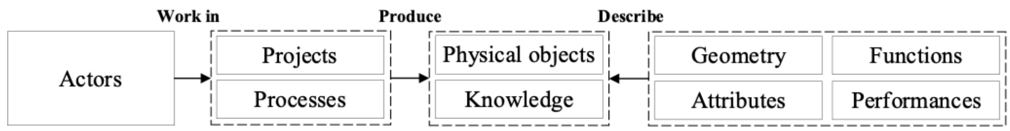

Figure 3: Concepts modelled in the ontology

Table 1: An example of instances from the ontology

	Example instances from the ontology
Actors	Owner, manufacturer, contractor
Projects	Rehabilitation of utilities, maintenance of utilities, replacement of utilities
Processes	Inspection, surveillance, corrective maintenance
Physical objects	Distribution component, controller component, protective shell
Knowledge items	Maintenance report, localization guidelines
Spatial characteristics	Geometry, construction area, project boundary
Functions	Network function, network usage, object roles
Attributes	Object material, electricity operating voltage, network status
Performances	Safety performance, engineering performance, financial performance

Table 2 illustrates how these relations were applied.

Table 2: An example of relations from the ontological model

	Instance 1	Relationship description	Instance 2
Whole-part	SubNetwork	is part of	Network
Parent-child	ElectricityCable	is a	DistributionComponent
One-to-one	PerformanceProperties	is associated to	NetworkFeature

The vocabulary and terms of the concepts within the ontology were carefully chosen in close collaboration with end-users and domain experts. An additional catalogue of all used terms was also developed to prevent semantic issues such as differing interpretations during the sharing and exchange of information.

Additionality, the ontology was implemented in a simulated utility operations and maintenance field test. Specifically, two utility types were modelled in a renovation project of street works on a university campus. We posed competency questions to verify whether the knowledge captured and represented by the ontology was deemed sufficient for its design context and application domain. Examples of asked questions are: "What is the state of operation of a utility network?", "What is the nominal flow of a commodity through a distribution line?", and "When was the last maintenance activity performed?". The ontology was able to satisfy the requirements of the engineering tasks required and assessed as relevant by the involved domain professionals.

The developed ontology was positioned as an intermediate that provides the metadata for all those concepts modelled in the current distinctive knowledge bases of utility asset owners (Figure 4). Compared to the the-before-situation (Figure 1), the introduction of an ontology does not necessarily mean knowledge bases or data models are integrated into one singular model. Instead, the developed ontology provides a basis for the sharing and exchange of, in this regard, utility asset information. This allows heterogeneous data models to share and exchange their information with one another, as to how they capture and represent their knowledge is unified through the ontology.

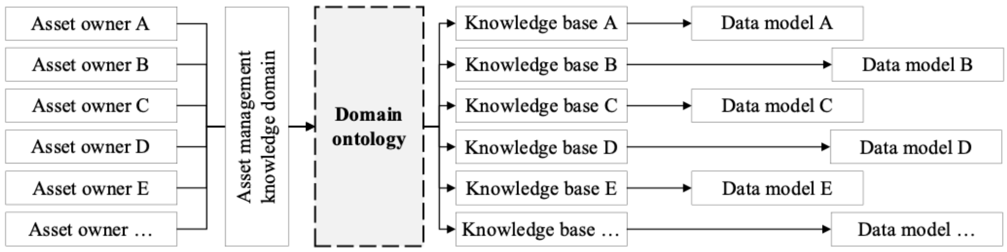

Figure 4: The ontology as an intermediate to heterogeneous data models

When assessing the impact of the ontology on its design context, the industry experts and prospective end-users first acknowledged that the ontology could stimulate the sharing and exchange of information in digital and virtual construction environments. Second, the ontology was considered helpful in the future co-development of digital models by multiple asset owners. Third and last, the richness of the knowledge represented by the ontology was considered supportive for data-driven engineering and smart reasoning. Especially for those asset owners currently working with less rich and digitized asset data models, the ontology was deemed helpful in further digitisation efforts. In the next section, we reflect upon the role ontologies may play in future digitisation efforts of construction environments.

FINDINGS

This study demonstrated the development of an ontology with the intent to cope better with the fragmentation of digital practices in the utility infrastructure sector. We demonstrated, by adopting a design science-inspired approach (Hevner 2007), the efforts undertaken to establish a shared understanding of the knowledge domain. Subsequently, we reflected with domain professionals on the impact of the ontology on the design context. Based on this process, the contributions of this study to the construction management literature are twofold.

First, this study demonstrates that an engaged ontology development process can emerge into shared conceptualisations of a knowledge domain. The perceptions of human beings - including the modellers of ontologies - are incomplete and bounded by rationality, resulting in various viewpoints on the to-be-modelled reality (Olde Scholtenhuis and Hartmann 2015). Therefore, developing an ontology that meets everyone's perception of this reality is considered a highly complex task (Turk 2001). In this study, we experienced that co-developing the ontology with its prospective end-users and industry experts stimulates a consensus-seeking behaviour that helps to align different realities. Based on this, we claim that the co-development of ontologies plays an important role in establishing shared conceptualisations, and in turn, in bridging distinct digital realities. However, future work is required to assess the ontology's role once applied on a larger scale.

Second, this study argues that the co-development of an ontology with domain professionals may form a solid basis for the future co-development and adoption of exchangeable data models. New data models continuously enter the construction environment in, for example, the form of the recently emerging digital twin (Opoku *et al.,* 2021). In this context of a modernizing and increasingly digital and virtual construction environment, where fragmentation is expected to only further increase, we claim that co-developed ontologies and data models help in bridging fragmented data realities. In turn, such co-developed models may improve inter-organisational communication, cooperation, and coordination (Adriaanse *et al.,* 2010; Peansupap and

Walker 2005). However, also here, future work is required to assess the ontology's impact on the development and adoption of co-developed data models once applied on a larger scale.

This study further provides opportunities and recommendations for future work. First, we argue that an ontology development process itself is not sufficient in a continuously evolving industry such as construction. Knowledge domains and domain professionals and their preferences and perceptions may change over time. This implies maintenance and alignment to these altering knowledge domains are needed to ensure developed ontologies are still capable of establishing a shared conceptualisation of the domain. Based on this, we emphasize that standardisation of knowledge representation in the form of ontologies is most likely an ongoing effort. We urge scholars and practitioners to take this notion into account in their future adoption or studies of ontologies.

Second, the ontology in this study was implemented as a field test in a single simulated case study. Although this test did provide evidence of the ontology's capability of generalizing the necessary knowledge of two utility disciplines in a specific context of use, further work is required to investigate whether the ontology can generalise the entire knowledge domain it was intended for to capture. As explained by Gruber (1995), the generic nature of ontologies is a key requirement of ontologies to enable the representation of entire knowledge domains. Yet, the dynamics of real-life environments between utility disciplines may significantly differ from simulated environments. This could display deficits in the current design of the ontology, requiring additional design cycles of most likely both the design and relevance cycle (Hevner 2007).

CONCLUSIONS

This study demonstrated the development of an ontology with the intent to cope better with the fragmentation of digital realities in the utility infrastructure sector. By adopting a design science-inspired research approach, we explained our efforts to establish a shared understanding of the knowledge domain. Via an engaged ontology development process in close collaboration with prospective end-users and industry experts, we abstracted concepts from distinctive knowledge bases and industry standards. Through a combination of multiple evaluation measures and a partial field test of the ontology in a utility asset management case, the ontology was considered complete and suited to its design context and application domain.

Contributions of this study are twofold. First, we provide to the construction management literature an exploratory study of an engaged development process. We demonstrate that such co-development of an ontology with domain professionals is more likely to emerge into a shared conceptualisation of the domain. This can form the solid basis of exchangeable digital models of public space. Second, we contribute to construction management literature the notion that engaged ontology development may play an important role in bridging fragmented realities in digital and virtual construction environments. This, in turn, makes asset management concepts more likely to become shared, exchanged, and adopted by the utility construction sector, engaging collaborative asset management practices. This insight stresses the relevance of an ontology in the modernizing construction sector, where the development and application of digital models like digital twins will only increase over time. However, future work is required to explore the impact of the ontology once applied on a larger scale.

Data Availability

Some or all data that support the findings of this study are available from the corresponding first author upon reasonable request. This includes the complete ontological model and parts of the supporting documents of the case studies and industry meetings.

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ATTENUATING DISRUPTIONS IN KNOWLEDGE FLOWS IN CONSTRUCTION PROJECTS

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Attenuating disruptions in knowledge flows during the delivery of construction project is beneficial for problem-solving; relationship-management; and reflexive practice in the project environment. There are however limited studies that have examined the role of knowledge-brokering and relationship management in construction project delivery. Knowledge-brokers are often beneficial in attenuating disruptions in knowledge flows; in-graining positive relational dynamics and encouraging healthy team culture across project teams. This research presents a conceptual framework for visualising the mechanism of knowledge flow across different levels (i.e., individuals; teams; and project) in a construction setting to enhance project performance outcomes. Using an inductive case-study method; we collect triangulated data through questionnaire surveys; focus-groups; and semi-structured interviews on an Australian construction project that engaged a facilitator as knowledge-broker between construction teams. This research found that the intermediate role of the facilitator was instrumental in shaping how problems were identified and efficiently resolved. The novelty of this study is that alliance principles of knowledge-brokering are being applied in a fixed-price lump-sum contractual arrangements, which typically tends to be adversarial and hinders effective knowledge flow between parties in projects.

Keywords: facilitator; knowledge-broker; knowledge flow; relationship management

INTRODUCTION

In recent times, attention to relationship management as a means of enhancing project success in construction project delivery has gained prominence in the literature (Daboun *et al.,* 2022). However, the responsibility for ensuring proper relationship management tends to be devolved to the project manager as well as senior management team (Davis and Love, 2011). The PMBOK (2017) provides some guidance on the role of project managers in relation to planning, leading, organising, and controlling teams but does not specify the competencies of project managers in nurturing relationships within project teams. Consequently, it is observed that the flow of knowledge is stifled because of the adversarial relationships in the project environment (Ahiaga-Dagbui *et al.,* 2020). Previous research by Kelly *et al.,* (2013) reported that 51% of technical staff believe that knowledge flow occurs spontaneously through conversation and team-working. In many construction projects, it is generally

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assumed that appropriate channels exist to facilitate the flow of knowledge within and across teams (Hartmann and Doree, 2015). However, the recurrence of contractual disputes in construction projects attests to the prevalence of relationship breakdowns in many project-delivery context (Fuller *et al.,* 2011). The dearth of expertise in relationship management within mainstream construction discipline has subsequently led to the evolution of knowledge-brokers who are external to the technicalities of construction projects but whose skills are invaluable in maintaining and nurturing positive relationships in projects (Holzmann, 2013).

To provide some context, the contractual environment and governance structures associated with competitive tendering and low-profit margins often perpetuate adversarial behaviours within project teams (Ahiaga-Dagbui *et al.,* 2020). Ahiaga-Dagbui *et al. (*2020) further note that traditional lump-sum contract environments generally set the commercial drivers that define the strategic goals of clients and contractors on a collision course. In an alliance framework, the organisations involved are generally more willing to share information and collaborate to identify and jointly solve problems as their remunerations are linked to the joint success of the entire alliance (Davis and Love, 2011). Alliances are thus driven generally by win-win mentality, joint problem ownership and best-for project principles (Ahiaga-Dagbui *et al.,* 2020). The key departure of this research is that the project facilitation model was implemented within a traditional design-bid-build project environment instead of an alliance. The decision to opt for a traditional procurement approach rather than an alliance arrangement lies in the economic efficiency of the former. Furthermore, against the backdrop of previous alliance projects, there were possibilities that behavioural and trust expectations could be leveraged to translate some alliance principles to future projects delivered using traditional procurement approach.

Knowledge-brokers are equipped in encouraging learning, stimulating participation, fostering knowledge-creation, and enhancing healthy project teams (Pemsel and Wiewiora, 2013). Langeveld *et al.,* (2016) recounts that knowledge-brokering is being embraced to ensure a strategic focus on enhanced knowledge flows and robust stakeholder engagement in projects. The diversity of knowledge-brokering roles in the literature includes 'orchestrator', ‘knowledge-broker', ‘lessons-learned champion', 'boundary-spanner’, ‘maestro’ and 'project facilitators' (Tokede *et al.,* 2022). More specifically, project facilitators are equipped for creating the right conditions for reflexive activities in a project, thereby, encouraging problem-solving and innovation (Fuller *et al.,* 2011). Facilitators are also able to function at both an individual and team level; and to engage in problem-solving in the project environment. Furthermore, facilitators could be fundamental in breaking down rich and complex situations to accelerate the speed of learning within project teams (Sergeeva and Roehrich, 2018). In addition, facilitative approaches could complement traditional project management roles in achieving a flexible, intuitive, and spontaneous access to knowledge in the project environment (Kelly *et al.,* 2013). This research presents a conceptual framework for visualising the mechanism of knowledge flow across different levels (i.e., individuals, teams, and project) in a construction setting to enhance project performance outcomes. The novelty of this study is that alliance principles of knowledge-brokering are being applied in a fixed-price lump-sum contractual arrangements.

Knowledge Flows in Projects

Knowledge flows between projects and organisations is becoming more difficult, as the planning, implementation and delivery of projects comprise of many knowledge-intensive activities that require different types of knowledge (Jiao *et al.,* 2019). Hartmann and Dorée (2015) conclude that the problem with project-based organisations is that knowledge accessible in projects remain as "messages in bottles" without translating into catalysts for organisational improvements. Attenuating disruptions in knowledge flows in projects will require new competencies and organisational capabilities within and between project teams.

The most widely accepted distinction of knowledge forms in the construction sector are still explicit and tacit knowledge (Oluikpe, 2015). Explicit knowledge is regarded as factually and technically correct prescriptions that address a specific design, process, or decision towards reducing or eliminating a potentially negative result (Addis, 2016). On the other hand, Oluikpe (2015) describes tacit knowledge as a construct that an individual has but which cannot be articulated. Van de Hoorn and Whitty (2019) also added that tacit knowledge is a contextual and subjective knowledge which is difficult to recognise. Oluikpe (2015), however, concluded that despite evidence on the value of tacit knowledge to construction organisations, there are limited frameworks to effectively explicate tacit knowledge in construction projects.

The implications for recognising the explicit and tacit nature of knowledge relates to the continuum of knowledge management processes adopted in construction project delivery (Tokede *et al.,* 2022). In instances, where there is more emphasis on explicit knowledge, logical rationality is privileged over context (Addis, 2016), and thus predictability is emphasised over uncertainty management (Ahiaga-Dagbui *et al.,* 2020). Also, in situations where tacit knowledge is prioritised over the explicit dimension, empirical frameworks are insufficient in steering the knowledge management process (van der Hoorn and Whitty, 2019). An integrated knowledge management model is, therefore, needed to facilitate the flow of explicit and tacit knowledge in project delivery processes.

Knowledge Brokering

Knowledge-brokering is a relatively emerging discipline and has become increasingly important based on the challenges with stimulating knowledge flows in projects (Holzmann, 2013). Fundamentally, knowledge-brokering can be accomplished by individuals or teams within an organisation, or by external actors contracted to be part of the project team for the sole purpose of managing the interface for knowledge-creation and exchange in projects (Langeveld *et al.,* 2016). Knowledge-brokering activities are social processes with the broker participating in the interactions and establishing connections between communities by introducing elements of one practice into another (Holzmann, 2013). Knowledge-brokers are fundamentally equipped to accomplish interactions between different communities of practice (Fuller *et al.,* 2011), and can support the creation of knowledge in cross-functional teams. Knowledge-brokers also assist in the structured collection of explicit knowledge, which can be beneficial for improving lessons-learned initiatives in projects (Fuller *et al.,* 2011). It has also been recognised that knowledge-brokers can assimilate diverse information and convert them into useful strategies leading to exchange of tacit knowledge (Hering, 2016).

Within a project, knowledge-brokering can take place at several levels during construction (e.g., organisation, team, and individual) (Ayub *et al.,* 2019), and, therefore, if performance improvements are to be realised, then triumphs and setbacks that materialise need to be shared and communicated as soon as they are identified to enhance the delivery of future projects. Emerging knowledge can be effectively utilised to acquire new, or modify existing knowledge, behaviours, skills, values, or preferences of the project team (Waheed and Ogunlana, 2019). This accumulated new knowledge can then be immediately and in the future applied to practice. The discovery of explicit and tacit knowledge can be used to provide the groundwork for a much-needed backdrop for reflexive practice to be engendered in construction projects (Hering, 2016).

It is, however, acknowledged that identifying knowledge-brokers early in the project can enhance the performance of the project (Waheed and Ogunlana, 2019). Despite these realisations, many organisations still fail to have a mechanism for identifying the nature of knowledge-brokering required in their projects (Holzmann, 2013). Perhaps, more challenging is assessing the effectiveness of knowledge-brokering in construction settings (Langeveld *et al.,* 2016). Pemsel and Wiewiora (2013) cautioned that incompetent knowledge-brokers could be detrimental to effective project delivery. Consensus, however, exists that knowledge-brokers can add value to projects by attenuating disruptions in knowledge flows within cross-functional teams and instituting healthy team dynamics (Hering, 2016).

METHOD

An inductive case study research approach was adopted to examine the experiences of a public sector authority that engaged a project facilitator during the delivery of a significant piece of critical construction project. Case study research is particularly appropriate when the phenomenon and its context are not readily distinguishable and when a deeper understanding of practical issues on how things work is required (Terry *et al.,* 2017). The case study used for this research is the Colac Water Supply Upgrade (CWSU) completed in the state of Victoria, Australia. Early cost estimates indicated the project could cost about $AUD19 million. The project was eventually delivered at $AUD14.3 million.

This case was selected for the facilitation approach, due to it being classified as a high-value and high-priority asset by the client, who anticipated a significant number of change requests during delivery. This was because the design stage of the project was fast-tracked to meet the accelerated timeline to operationalise the project. Triangulated data was sequentially collected from surveys, focus group interaction, semi-structured interviews, and content analysis of the documents from the facilitation program. Given the limited space allowed for this paper, only an overview of the data is provided here. *Table 1* shows the post-project review survey results and the mean scores, rated on a Likert scale of 1 - 5, where 1 indicates poor performance and 5 is excellent performance.

The survey was administered to project team members from all four Principal Contractors (PC's), the Design Contractors and the Client to solicit quantitative and qualitative information on the project. The survey in *Table 1* provided a snapshot of key issues that contributed to the list of agenda for the next stage of the data collection - focus group interactions. Eight (8) focus group sessions, involving 35 participants drawn from across the entire delivery team were held. This generated 12 hours of audio data (1.5hr x 8). This was followed by a series of 27 semi-structured interviews with project participants to further explore some of the issues identified in the focus group sessions. The interviewees (P1 - P27) included a variety of personnel including Project Managers, Site Supervisors, Design Engineers, Safety Quality and Environment (SQE) Manager, Project Delivery Managers and Construction Coordinators. Overall, over 30 hours of interview data were collated and were transcribed verbatim for analysis in NVivo 12 plus. Archival records, documentary materials used by Facilitator and the lessons learnt register compiled by the Client's Design Team were crucial to understanding the background and delivery context of the project. Twenty-four (24) different documentary records of the facilitated workshops held between the PC's and Client were carefully reviewed to understand the mechanism of facilitation in the case study.

Content analysis was undertaken by coding the data derived from the focus group interactions, interviews and documentary sources using NVivo 12 plus. The qualitative data analysis occurred simultaneously with the data collection, the detailed interpretation and sense-making process. The analysis involved theme identification, word frequency assessment, concept mapping, and thematic coding. Terry *et al.,* (2017) suggests that there are two critical stages in the thematic analysis (1) eliciting lower-level ideas in texts; and (2) identifying themes in coded string. This process allowed the researchers to move away gradually from the descriptive level of the initial coding toward an increasingly more analytic level; and (3) identification of conceptually consistent first-order themes and constructs. At this stage, the researchers sort to also ascertain recurring patterns and connections between the themes and concepts while also exploring the evidence for the "why?" behind these constructs.

FINDINGS

In this paper, the mediating role of a project facilitator is examined in a construction project delivery process. The data collected through survey questionnaire, focus group workshops and semi-structured interviews have been distilled into the key dimensions - tacit (behavioural), explicit (operational) and an integrated explicit and tacit (technical). The survey in *Table 1* indicates that the project team performed very well in relation to incident management, innovation, positive relationships between the client and Contractors, and delivery of the project on time and budget. Areas that received relatively poor scores (i.e., lesser than 4) include design team involvement in the project, Request for Information (RFI) management, project commissioning, design completion and constructability review.

Comparatively, the overall average score of the project facilitation process and relationship-based outcome is 4.5 and 4.4 out of 5 respectively. While the average is a crude assessment, it gives us a sense of where the project outcomes were at least above average. Based on the focus-group workshop and semi-structured interviews, it was deduced that the facilitator utilised constructive interactions and strategies for transforming complex situations into stratified events that can be more readily comprehended and responded to appropriately. Given these, some of the issues in Table 2 addressed in the project were used to scaffold the dynamics of knowledge flow accomplished by the intervention of the project facilitator within the project delivery team. In summary, the facilitator stimulated knowledge flows and achieved healthy team-dynamics by fostering collaboration, joint problem-solving and problem-ownership.

Table 1: Post-project review survey on the issues identified in the case study project

	Post-project review	Rating
	Section 1: Involvement and project outcomes	
a	The design team availability and involvement were adequate for the project	3.27
b	Incidents were managed promptly and effectively	4.00
c	RFI process was managed promptly and effectively	3.67
d	Project innovations were effective in providing benefits to the project?	4.08
e	The contract requirements were clear and consistently administered	3.83
	Section 2: Relationship-based outcomes	
a	There was a high level of commitment to relationships between Asset-owner and contractor of the project	4.69
b	There was a high level of commitment to involvement from the Asset-owner and contractor's project managers	4.17
c	Landowner relationships were managed very well on the project	4.46
	Section 3: Project Facilitation Process	
a	Overall importance of the workshop	4.42
b	Usefulness for clarifying needs	4.50
c	Effectiveness of outcomes for honest communication	4.50

Table 2: Tacit dimensions of the behavioural issues in the CWSU project

Post-project review	Rating
Identify Narratives	"Facilitation is effectively what it is; it's to facilitate a relationship…an understanding of how we work, how others work, and to establish some ground rules and like a frame of reference for having conversations" [P1].
	"…being able to work out a compromise that meets enough of my requirements, that it's moral and legal, and meets enough of their requirements that they can keep going and be more efficient, that's, to me, what I think about 'best for the project'"[P21].
	"A good independent gauge, like a health check on the project that provides an understanding of how we work, how others work, and to establish some ground rules and like a frame of reference for having conversations. It also enabled difficult conversations to take place" [P1].
Build Trust	"Got to be able to make a connection with everyone they're speaking to. So, there's a level of trust between the parties"
	"let everybody have their say and air their grievances"
	"Ensuring that the contractor is aware of all the expectations"
Cultivate Mindsets	"On previous projects, there was a "them versus us" mentality that came from both sides and the relationships were really hostile. Whereas this [project] was completely different"[P8].
	… "If you've got an issue, don't jump straight in there and tell a sub-contractor or a worker it's an issue, unless it's an immediate safety issue" …[P4]
	"Can definitely see areas where the conversations around reaching a conclusion probably would have taken a bit longer," [P9].

Table 3 provides an overview of knowledge that were captured in the post-project review and facilitation meetings. These lessons include (1) promoting the use of prompts on sites, and (2) developing checklists and prescriptive guidelines for the code of practice. Other key lessons involved adjusting the times for specific activities and exploring the potential for innovative technologies. In summary, the facilitator's role was considerable in highlighting the key operational issues impacting the project by instituting jointly developed protocols within a framework for accountability.

Figure 1 provide the conceptualised framework of the knowledge flow in the project environment and summarised some of the crucial knowledge-brokering outcomes delivered through the facilitators' role as a mediator. The conceptual framework recognised that knowledge-creation occurs at different levels in construction organisations - individual, team, and organisation. Each of these levels embodies different dynamics in the knowledge-creation capabilities. However, both explicit and tacit knowledge are explicated across all levels of learning in construction settings.

Table 3: Explicit Knowledge captured for problem-solving in the CWSU project

	Additional Details	Project Phase	Actionable Items	Updated in Standards
Initiatives by the contractor to promote the use of Start Card Resulted in Start Cards being better utilised.	Prompt in large bold letters: "Have You Completed Your Start Card?". This acted as a reminder for in site personnel to complete the card.	Construction	Construction team to be asked to promote prompt on-site sign in form.	Construction - Contractor Performance
Confusion about what level of detail is required in Activity Method Statements (AMS).	Client staff unsure about the expectation of contractors about AMS	Construction	Develop toolbox presentation clearly outlining requirements for AMS.	Construction - Contractor Performance
Many RFI's at the start of construction.	Early meeting should be organised between contractor and design consultant to clarify contractor RFI's	Construction	Modify standard kick Off Meeting agenda to include prompt to organise a meeting between project teams	Templates/Forms
Provide TIN file to contractors at the start of a job as part of the tender documentation.	TIN file would have been useful for contractors to determine earthworks and cut/fill volumes.	Procurement	Tender checklist to be developed	Delivery - Contract
Commissioning Kick-Off Meeting occurring too late in construction	Commissioning meeting late during construction leaves little time for proper preparation for commissioning	Commissioning	Specify commissioning kick-off meeting ahead. Suggested 2 weeks into construction program?	Construction - Contractor Performance
Fortnightly Construction Meeting agenda improvements	The meetings created a culture of openness and proactive problem solving as a team.	Construction	Review facilitated meeting agenda in conjunction with project manager/s	Construction - Contractor Performance
Contractor initially cut into the incorrect pipe for a final tie-in.	Final connection of pipeline was to tie into Colac water supply. The wrong pipe was identified in service checking and carried through to design.	Construction	Investigate with Survey team the technology available to non-destructively identify live water pipes.	Design Guide - Pipelines - Water

In line with our research objectives, our study highlighted the benefits of a knowledge-broker in excogitating both explicit and tacit knowledge. In our work, explicit knowledge directly attributed to the intervening role of the facilitator include the development of best practice strategies for information sharing and optimal policies to support quality assurance. Equally, tacit knowledge accrued in the project included a renewed sense of psychological safety, joint problem-ownership, and the development of a virtue system of ethics. It was observed that both explicit and tacit knowledge flows were creatively stimulated in the project, due to the presence and input of the project facilitator. Jiao *et al. (*2019) surmised that this shared knowledge among team members enhances the team's ability to resolve conflict and misunderstanding. A proactive stance towards problem-solving also translates into tangible benefits of improved team culture and resilience. While the project managers may be able to support the technical and tangible delivery of projects, the knowledge-broker or in this case, the 'facilitator' is pivotal in serving as a glue that holds the team together through creating and nurturing healthy relationships and enhancing the team dynamics.

It must, nevertheless, be acknowledged that knowledge flow in a project environment tend to be dynamic and emergent rather than systematic, uniform, or organised (Kelly *et al.,* 2013), and skilled facilitators are well-positioned as knowledge-brokers to encourage knowledge flows in construction project settings. Fuller *et al.,* (2011), for instance, noted that facilitators can be brokers, but there is still a need to have boundary objects and forms of interactions between different communities of practice. Our experience, however, depicts that a skilled and versatile facilitator can leverage on the diverse competencies within the team and create useful interactive activities in the project environment.

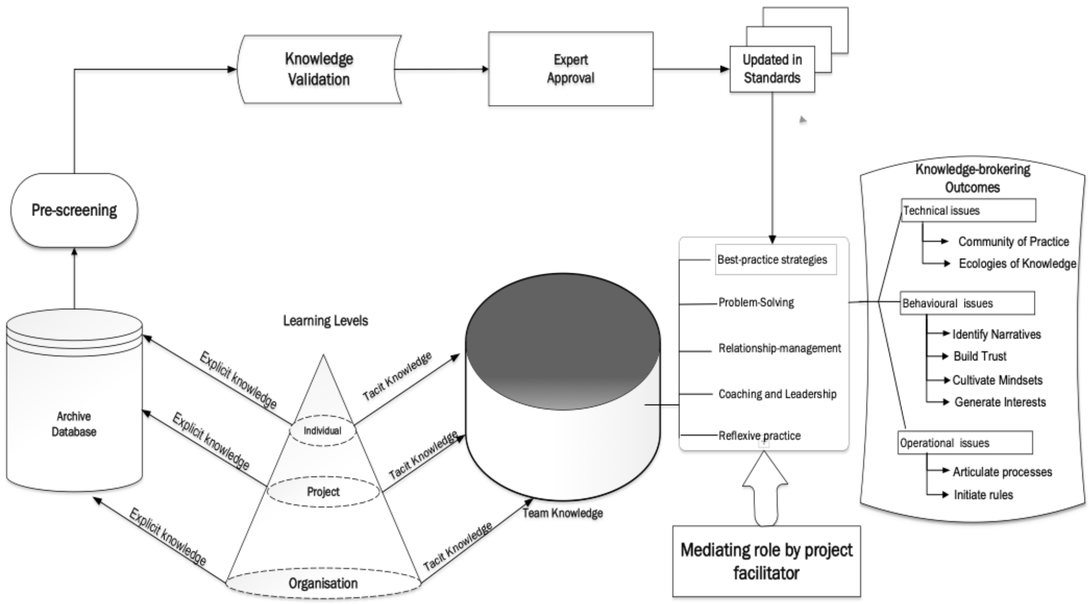

Figure 1: Conceptualised framework of the mechanism of knowledge flow in the project environment

In the CWSU project, there was evidence for robust interface management at the design, construction, and commissioning activities, during the project delivery process. Davis and Love (2011) also corroborated those transformative experiences and bonding through informal events, could develop deep-rooted dialogues within teams and enhance the flux of knowledge flows within and across the project teams. Rather than rely on contractual prescriptions to resolve tensions (Daboun *et al.,* 2022), the facilitator demonstrated transformational leadership and practised idealised influence, inspirational motivation, intellectual stimulation, and personalised consideration (Ayub *et al.,* 2019) to defuse tensions as well as shaping how problems were identified and efficiently resolved.

CONCLUSIONS

This paper presents a conceptual framework for attenuating disruption in knowledge flows in a construction project setting. Using a triangulation approach, we utilise a questionnaire survey, focus-group workshops, and semi-structured interviews to collect data on an inductive case study of a significant public sector project in Australia. The facilitator achieved high scores on relationship-based outcomes and stimulated knowledge flows across and between team. The conceptual framework depicts that knowledge flows in construction projects occur at different levels and that explicit and tacit knowledge flows can be stimulated across all levels of interaction in the project environment.

The conceptual framework also portrays the connections between the explicit knowledge captured in databases and the tacit knowledge embodied within the project team. The novelty of this study is that alliance principles of knowledge-brokering are being applied in a fixed-price lump-sum contractual arrangements, which typically tends to be adversarial and hinders effective knowledge flow between parties in projects. It was found that the intermediate role of the facilitator, as a knowledge-broker in a project was instrumental in shaping how problems were identified and efficiently resolved. Specifically, the role of the knowledge-broker is pivotal in uncovering the intricate processes and agencies associated with the flux of knowledge flow in the project environment. In our work, the knowledge-broker was funded by the client and contractors were paid to participate in the monthly facilitation sessions. To have an impartial knowledge-broker, each party might be willing to bear the cost. It is, therefore, recommended that future studies could evaluate whether co-payment by both client and contractors will affect the viability of the process and perceived conflict of interest of the client-funded knowledge-broker.

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INFRASTRUCTURE DEVELOPMENT

OPTIMISM BIAS IN TRANSPORT PROJECT COST APPRAISAL: A REVIEW OF THE CURRENT BODY OF KNOWLEDGE

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Optimism bias has been considered an important cause of cost underestimation in transport infrastructure project appraisal in recent project management literature. However, little research has critically examined the current understanding of the nature, dynamics, and impact of this cognitive bias in the context of transport cost appraisal. This systematic review provides a timely assessment of the extant journal articles in this research area. The findings of this review suggest that the presence and nature of optimism bias in the organisational setting of transport project cost appraisal are understudied. The phenomenon needs to be validated in the project planning phases. The interactions between optimism bias and other cognitive biases as well as their synergetic impacts on transport project appraisal, also require further investigations. The nuanced relationship between political pressure and optimism bias in the complex institutional environment in which transport project cost estimating is conducted should be carefully dissected.

Keywords: optimism bias; behavioural decision-making; cost underestimation

INTRODUCTION

The production of early cost estimates for major transport infrastructure projects is a challenging task. Large-scale transport infrastructure projects are often beset with many risks and uncertainties (Love *et al.,* 2021; Miller and Szimba 2015). Many of these risks arise from the time-consuming and complex organising, planning, and implementing processes of major transport projects (Cavalieri *et al.,* 2019). The risks and uncertainties derived from the lengthy and complex nature of transport infrastructure have led to frequent reports of budget overruns on transport projects around the world. Drawing from the data of completed rail, bridge, tunnel and road projects in North America, Europe, Japan and 10 developing countries, Flyvbjerg *et al.,* (2002) found that 86% of the projects experienced cost overruns. More recently, Terrill *et al.,* (2020) reported that AU$34 billion more was spent on transport infrastructure projects in Australia between 2001 and 2020 due to cost overruns. In

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the UK, the new London Crossrail Project was completed more than three years late and cost nearly £4 billion more than the initial forecast (Topham 2020).

The cost performance of a major transport infrastructure project can make a substantive impact on a region's economy. For instance, Allport (2008) records that in Singapore, the Philippines, and Colombia, the budgets for inter-city rail projects before any cost spike account for as much as the annual budgets for multiple central government departments. Currently, countries such as Australia are encouraging the increase of public spending on transport infrastructure provisions and the acceleration of the project schedules to relieve the national economic stress caused by the COVID-19 pandemic. These practices can increase the risks of transport project cost overrun and benefit shortfall because rushing into an expensive transport provision commitment without a robust feasibility study stating a clear scope definition and reliable preliminary cost estimation often heightens the risk of cost and schedule overruns (Love *et al.,* 2014). It is imperative to facilitate the conceptual analysis of the causality of transport infrastructure cost underestimation and provide the basis for using robust empirical methodologies to validate and expand the existing knowledge on the factors and conditions underlying misaligned project forecasts.

LITERATURE REVIEW

Extensive research effort has been devoted to unravelling the causes of transport project cost underestimation. The phenomenon has been explained by: project-specific causes such as changes in the project scope (Love *et al.,* 2014) and political-economic causes such as leadership foul plays (Wachs 1989) and project planners' strategic misrepresentation (Flyvbjerg *et al.,* 2002). A recently popularised explanation is optimism bias, the behavioural tendency to "overestimate the likelihood of positive events and underestimate the likelihood of negative events" (Sharot 2011: 941). Optimism bias is found in individuals' overly optimistic judgments about the chances of experiencing future negative events such as divorce and a heart attack (Weinstein 1980), the length of time for new curriculum developments (Kahneman 2013), the short-term future returns of the US stock market (Ben-David *et al.,* 2013) and the effectiveness of newly discovered cancer treatments (Chalmers and Matthews 2006). Transport project planners are perceived to suffer from the same bias when they underestimate the total cost and overestimate the financial and social benefits of a project under consideration (Buehler *et al.,* 1994, Du *et al.,* 2019, Flyvbjerg 2008, Kutsch *et al.,* 2011).

An initial search of the literature on behavioural decision-making in infrastructure projects reveals several papers that review the concept of optimism bias in the context of transport projects. Cavalieri *et al.,* (2019) and Denicol *et al.,* (2020) organise systematic literature reviews to summarise a large number of determinants of cost overruns and poor project performance in the delivery of transport infrastructures. These reviews acknowledge the potential influences of optimism bias on major infrastructure project cost underestimation among other behavioural, project-specific, and political-economic causes. Stingl and Geraldi (2017) systematically review the theoretical foundations and the negative impacts of a wide range of cognitive biases on general project decision-making. They show that decisions in projects, including the cost forecasts for capital works, are complex and should be explored from the lens of multiple behavioural theories. However, the consulted literature is "fragmented and draws only on a fraction of the recent, insightful, and relevant developments on behavioural decision making" (Stingl and Geraldi 2017: 121).

An elaboration of the previous reviews indicates that there is still a lack of review in the extant literature that critically examines the current body of knowledge about the nature, the dynamics, and the multifaceted impacts of optimism bias in the context of transport infrastructure project cost appraisal. Against this backdrop, this study aims to offer a timely review of what is collectively known about optimism bias in the context of transport project cost appraisal and highlight aspects of the current body of knowledge that are understudied. To achieve this aim, the study adopts a systematic approach to searching, selecting, and analysing literature pertinent to the causal relationships between optimism bias and transport infrastructure project cost underestimation. The systematic literature review enables the integration, parallel consideration and evaluation of the theoretical assumptions, methods and findings presented in the chosen literature, and "foster cross-fertilisation, new ideas and the overall development of the field" (Stingl and Geraldi 2017: 122). By using this review method, this paper contributes to deepening the academic discussions on the issue of optimism bias in the early cost management of transport infrastructure projects.

METHOD

The introductions of the political and psychological causal explanations of transport project cost underestimation open fresh opportunities for multidisciplinary researchers to explore the underlying causes of this perennial issue. What are some of the opportunities? Have the opportunities been adequately addressed in existing transport project cost underestimation research? This study will respond to these questions using a systematic literature review method detailed below.

The systematic literature review process consults the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines (Moher *et al.,* 2009) and follows the examples from Cavalieri *et al.,* (2019) and Denicol *et al.,* (2020). The systematic review process was completed on the online workflow platform Covidence. The process involved five main steps.

1. A scoping stage that lists the central research themes. The themes are summarised in three keywords: transport infrastructure project, estimate and optimism bias
2. A planning stage that develops a protocol to improve the search quality. The protocol outlines keyword identification, databases selection, synonyms brainstorms and relevant subject area categorisation to improve the search quality.
3. A searching stage that conducts on Scopus, Web of Science and ScienceDirect. The search strings were used in combination with synonyms (for example, transport* AND underestimate* AND optimism bias). The search results were limited to peer-reviewed journals published in English by April 2022.
4. A screening stage that stores the search result. Titles and abstracts which did not address optimism bias and infrastructure project management were deemed irrelevant and were removed.
5. A full-text review and data extraction stage that finalises the selection of texts for data extraction. Adapting from the Cochrane Data Extraction and Assessment Template, the lead author extracted information about the research aim, hypotheses, study design, projects concerned, theories consulted, interventions (if applicable) and outcomes.

The search returned a total of 1079 papers in the three databases. After the removal of duplications (n=65), 71 articles met the criteria for the title and abstract screening (941 papers deemed irrelevant) and were assigned to full-text reviews. The full-text review process led to the removal of an additional 50 papers. Among them, 31 studies examine optimism bias in settings other than transport infrastructure project cost appraisal, 14 studies focus on transport project cost underestimation causes other than optimism bias and 5 studies focus on the statistical characteristics of transport project demand shortfalls. In the end, 21 papers were selected for quality assessments and data extractions. The five-step process, along with the outcomes of each step, is visually summarised in Figure 1.

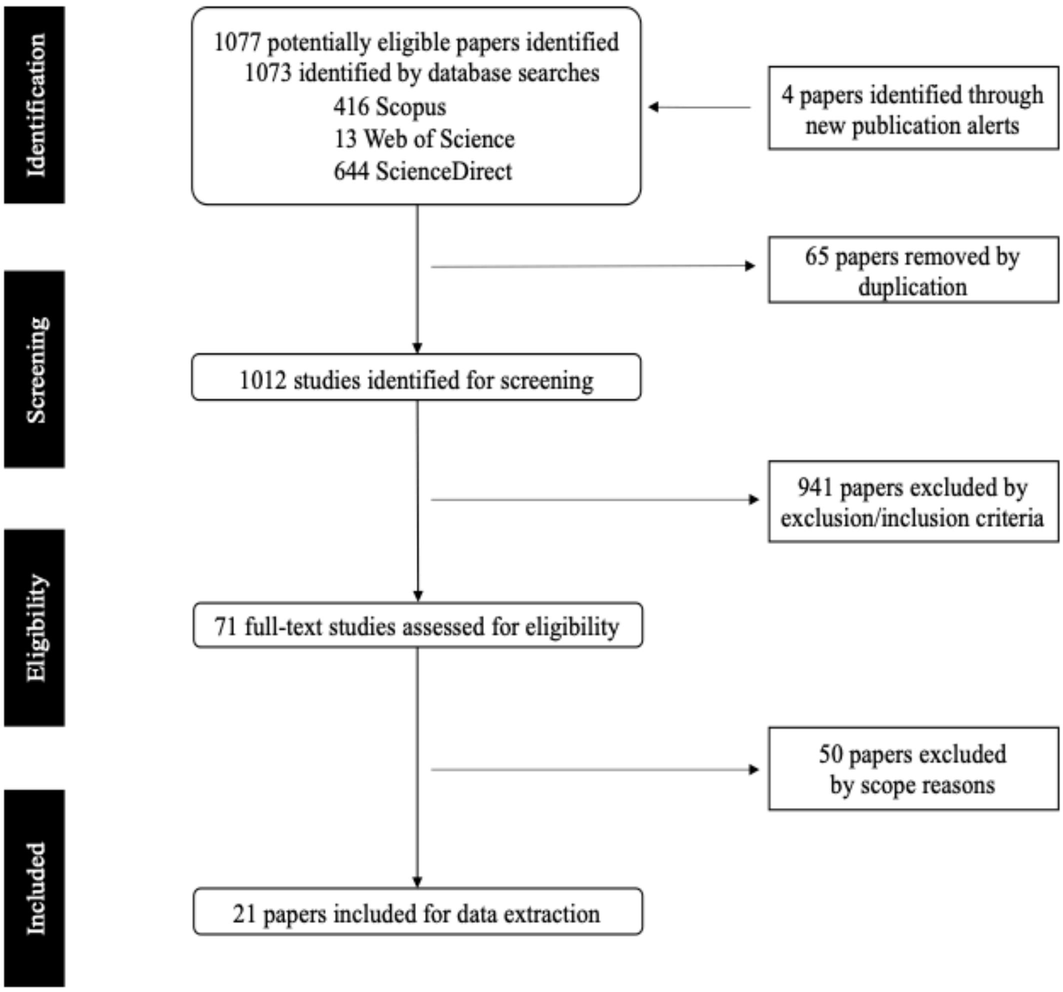

Figure 1: A summary of the systematic review process conducted on Covidence

FINDINGS

Information extracted from the selected literature facilitates the identification and synthesis of the key findings of this review. The following findings will be discussed in this section. Firstly, the presence and nature of optimism bias in the organisational setting of transport project cost appraisal are understudied. Secondly, the interactions between optimism bias and other cognitive biases and their synergetic impacts on early project appraisal in the context of transport infrastructure development requires more comprehensive investigations. Thirdly, the nuanced relationship between optimism bias and strategic misrepresentation is indicated in the literature but clear articulations and methodological innovations are needed to uncover a deeper connection between these two cost underestimation causes.

Optimism bias in the organisational setting of transport project cost appraisal
As identified in the introduction, optimism bias has been widely cited as an important cause of transport project cost underestimation. However, Love *et al.,* (2016, 2021) and Du *et al.,* (2019) maintain that the presence of optimism bias in transport project cost appraisal is still not well supported by empirical evidence. In particular, while optimism bias is well studied at the individual level (Weinstein 1980, Ben-David *et al.,* 2013, Chalmers and Matthews 2006, Lovallo and Kahneman 2003, Seaward and Kemp 2000), evidence of its presence and impacts at the group level, which better reflects the organisational setting of transport project cost appraisal, remains scarce (Du *et al.,* 2019, Ika and Pinto 2020, Love *et al.,* 2021). Du *et al.,* (2019: 45) claim that "[t]hus far, little has been done to address the group level optimism bias in capital projects, measured as the delta between group judgement and statistically realistic judgement".

It is unclear that the findings of over-optimistic judgements about future events at an individual level are valid in the transport project planning setting. At a minimum, the cost appraisal of a major transport project involves a project control group (which consists of internal project planners and external consultants) to estimate and verify budget forecasts and a project governance team to decide upon design options and funding strategies (Berechman 2018, Du *et al.,* 2019, Love *et al.,* 2021, Siemiatycki 2009). Other research that documents the early decision-making procedures in case studies of transport infrastructure has shown that opinions from project sponsors, external consultants and professional engineers and estimators are considered, and decisions are generally made carefully in the planning phase (Farooq *et al.,* 2018, Gil and Fu 2021).

The literature reviews conducted by Stingl and Geraldi (2017), Cavalieri *et al.,* (2019), and Denicol *et al.,* (2020) did not highlight this gap in the extant research. The absence of empirical evidence of the causal relationship between optimism bias and cost underestimation has significant implications for the credibility of any policy that introduces a debiasing strategy to the early cost forecasts of transport projects (Flyvbjerg *et al.,* 2016, Allport 2011). Policies safeguarding the cost and social performance of publicly funded infrastructure projects must follow sound and accountable empirical evidence (Fridgeirsson 2016, Siemiatycki 2009, Love *et al.,* 2021).

Optimism bias and other cognitive biases in the appraisal process
Among the reviewed articles, Love *et al.,* (2021), Flyvbjerg (2021), Winch (2013), and Leleur *et al.,* (2015) explicitly acknowledge the potential impacts of cognitive biases other than optimism bias in transport project cost underestimation. Love *et al.,* (2021: 6) highlight that the influence of other cognitive biases on transport project "cost contingency (and estimate)" is not well studied. One such bias underlined by both Flyvbjerg (2021) and Winch (2013) is the escalation of commitment. This bias concerns the tendency for project sponsors to "justify increased investment in a decision, based on the cumulative prior investment, despite new evidence suggesting the decision may be wrong" (Flyvbjerg 2021: 532). Winch (2013) demonstrates through a case study of the Channel fixed link between France and the UK that committed escalation is a significant factor in the budget and schedule overruns. Leleur *et al.,* (2015) introduce overconfidence bias to the inquiry of overly optimistic

cost estimates in transport infrastructure investments. The paper suggests that "people in general (including experts) are unaware of their lack of capability to indicate a complete range of variation" (Leleur *et al.,* 2015: 368-369).

Developing upon Stingl and Geraldi's (2017: 133) call for "a more critical examination and exploration of the pluralism of theories" in behavioural decision-making research, this review specifies that future transport infrastructure research should pay more attention to the dynamic interplays between optimism bias and other cognitive biases and their synergetic impacts on project appraisals. While escalation of commitment and overconfidence bias indicate different human tendencies in project management, both suggest incentives to underestimate the costs of transport projects. Nonetheless, it should be noted that different combinations of cognitive biases could cause a very similar phenomenon. The difficulties in pointing out "which specific behavioural bias is causing outcomes in a given situation" and establishing a clear distinction between cognitive biases such as overconfidence and illusion of control are recognised in the wider behavioural decision-making literature (Thaler 2015: 295, Shore, 2008).

Understanding overly optimistic estimation in the context of strategic misrepresentation

In addition to the influences of other cognitive biases, special attention should also be given to considering the impacts of strategic misrepresentation on overly optimistic transport project cost forecasts. Based on the definition described in the review of the causal landscape, Flyvbjerg (2021) considers strategic misrepresentation a political bias. The relationship between strategic misrepresentation and optimism bias has been portrayed as a "complement" (Flyvbjerg 2008: 6). This is built on the arguments that both explanations contribute to project cost underestimation and that strategic misrepresentation is more impactful when the political and organisational pressures in project appraisal are higher (Flyvbjerg 2008, Love and Ahiaga-Dagbui 2018).

Nevertheless, a review of the pertinent literature shows that the relationship between strategic misrepresentation and optimism bias is potentially more nuanced than the proposition summarised in Flyvbjerg (2008) and Cavalieri *et al.,* (2019). For instance, Winch (2013: 730) evaluates the Channel fixed link project and states that the sustained mutual suspicion between the project's financiers and construction contractors and the strong persuasions by politicians for continued investment by the financiers are the two factors facilitating "escalation of commitment in the context of strategic misrepresentation of the original business case".

In this example the author scrutinises the chain of events that leads to project cost underestimate in a complex institutional environment. This approach can be more effective for ascertaining the presence and nature of a cognitive bias than using the deductive methods such as simple questionnaires to collect segmented and superficial responses and establish plausible evidence. An inductive inquiry that utilises contextual sensemaking and narrative analysis of the transport infrastructure decision-making process, project changes, and project risk impact on process and product has been proposed by Ahiaga-Dagbui *et al.,* (2015, 2017) to substantiate the implied interactions of optimism bias and strategic misrepresentation.

A further review of the research design of the chosen articles finds that similar in-depth investigations are used by Odeck and Kjerkreit (2019), Hayasaka *et al.,* (2018) and Love *et al.,* (2017). However, the review also observes that Chadee *et al.,* (2021) and Du *et al.,* (2019) use Likert scale questionnaires to extrapolate the exhibition of optimism bias in project planners. Whilst current researchers are experiencing a shift from technical and engineering-managerial causal explanations to psychological and political explanations in transport cost underestimation causal investigations (Kelly *et al.,* 2015, Salling and Leleur 2017), a methodological shift towards true-experimental research designs to elicit more robust and insightful conclusions should also be encouraged (Fridgeirsson 2016, Love *et al.,* 2019).

CONCLUSIONS

A systematic literature review of the peer-reviewed journal articles pertinent to optimism bias and transport infrastructure project cost underestimation was undertaken in this paper. The review aims to take stock of the current body of knowledge about optimism bias in the cost appraisal of transport projects and identify the areas of weakness and future research opportunities. The review shows that the presence and nature of optimism bias in the organisational setting of transport project cost appraisal are largely understudied. The interactions between optimism bias and other cognitive biases and their synergetic impacts on transport project appraisal require further investigations. The relationship between political pressure and optimism bias in the complex institutional environment of the cost appraisal phase of transport projects is more nuanced than indicated in the existing research.

Building on the discussions about the causal relationships between optimism bias and transport infrastructure project cost underestimation, future research should help to test methodologies that are more capable of gathering empirical evidence for verifying optimism bias and contemplating the deep connections between political pressure and optimism bias at the organisational level in complex project planning. An option could be using inductive research methods instead of traditional deductive methods, such as standard surveys, to contextualise the complex chain of events in the project cost estimating decision process. Additionally, it is necessary to pay extra attention to the systemic and multiple root causes of cost underestimation commonly seen in major infrastructure project deliveries.

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DEVELOPMENT OF A FRAMEWORK FOR SELECTION OF A TUNNEL LINING FORMWORK SYSTEM

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Tunnels are considered special structures because of their uniqueness in analysis, design, and construction. During the construction of the tunnels, it is desirable to optimise the lining formwork system for the rapidity with quality, safety, and economy. The requirement of the tunnel leads to the change in the structure of the lining formwork system. However, the selection of lining formwork system is comprehensive and requires years of experience. This necessitates the development of a novel framework to select a lining formwork system for tunnelling projects. Therefore, this study attempts to develop a framework for selecting a lining formwork system using the Delphi method. For this purpose, guidelines of the Delphi Method are modified to select the experts based on their qualifications and experience. Then, ten experts are elected as a panellist. Subsequently, a total of 11 factors and 43 sub-factors are identified from the existing literature. Out of these, eight factors with their sub-factors are shortlisted using the Delphi method. Afterwards, Cronbach's alpha is determined for the remaining eight factors to test reliability. The proposed framework can help practising engineers to select and optimise the lining formwork system.

Keywords: tunnel; lining formwork; Delphi; geometry; quality; safety; economy

INTRODUCTION

Tunnels are different and special from any other civil engineering structures, as they are structures that are not worked out in typical day to day constructions. Tunnels serve numerous functions in civil engineering constructions like road and rail networks, hydropower generators, mass rapid transit systems, crude oil storage, water supply systems, and sewage systems. For example, India has been making a huge investment in various infrastructure construction projects, which involve numerous tunnel construction (Sharma 2021). Further, Sharma (2021) presented the number of tunnelling projects proposed or in various construction phases in India. The number of tunnels is 1641 spanning 3445 km long pipeline construction project, 30 for the Siang hydropower project, and seven major tunnels on different highway projects. Moreover, India's upcoming metro rail project has 10% of its construction work is underground. In this connection, engineers and practitioners in India have the challenging task of ensuring the stability of tunnel construction.

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Generally, the construction of the tunnel consists of reinforced concrete (RC) lining works, which mainly comprise formwork, rebar, and cast in situ concrete. However, out of these three-element, formwork is considered the most important because its structure changes with the change in the tunnel requirements (Jha 2012). The formwork of the tunnel project is generally called a tunnel lining formwork system. A formwork system is an essential non-standard component for the secondary lining during tunnel construction. Markewitz *et al.,* (1972) stated that non-standard components include a horizontal formwork component and two vertical formwork sections that are both bending resistant, with the vertical formwork portions moveable relative to the horizontal formwork portion.

In this connection, Pintado and Barragán (2009), Huang *et al.,* (2011), Peng *et al.,* (2011), Jha (2012), and Gaofei Group (2019) have respectively described the four types of tunnel lining formwork: (1) Simple lining Trolley/ formwork loop wheel machine (Double arch Tunnel); (2) Modular Tunnel Deck formwork; (3) Fully Hydraulic Automatic Walking Lining Trolley (Arch and Floor-to-arch transition formwork); (4) Truss Frame Lining Trolley (Universal-Rod Steel-Shuttering Jumbo for Tunnel Lining). Thus, selecting the tunnel lining formwork system is essential, as it fulfils various aspects such as quality, safety, productivity, and economy of the tunnel construction. However, selecting an appropriate tunnel lining formwork from the four types is a comprehensive and challenging process and requires years of experience.

Furthermore, there are no such studies available in the literature in order to identify the influencing factors. Therefore, this necessitates the development of a novel framework to select a lining formwork system for tunnelling projects. In this regard, the research sets the objectives to; (1) identify the potential factors and sub-factors that are required to be considered for the selection of a lining formwork system and (2) develop a hierarchical framework for selecting an optimized lining formwork system. To achieve these objectives, the paper proceeds with the following section. The paper first summarizes the literature review to understand better the formwork selection process used in different construction projects. Then, sections include the research methodology and data collection and analysis. Finally, the last section presents the concluding remarks.

LITERATURE REVIEW

Formwork is a structure whose aim is to stand on its weights and support the freshly placed concrete and live load, including material, equipment, and workers. Therefore, selecting an appropriate formwork system is critical in any construction project. In the last four decades, several studies have explored the selection of formwork systems for construction projects. Hanna (1989) identified 38 factors prompting the selection of formwork systems for building construction projects, and then, based on expert opinions, those identified factors were grouped into four categories. He also proposed selection criteria for formwork alternatives like a conventional column or wall form, ganged form, slip form etc. Further, Hanna and Sanvido (1990) proposed a methodology to select a vertical formwork system using a knowledge base experts' opinion. Hanna *et al.,* (1992) developed a rule-based system to guide practitioners in selecting the most appropriate formwork system for building projects. Further, Hanna (1999) integrated the additional factors, such as labour force and labour productivity, into the relevant literature. Proverb *et al.,* (1999) evaluated the critical factors affecting formwork selection and evaluated the degree of association between the selection factors for contractors from the UK, France, and Germany. In addition to the above-selected factors, Krawczyńska-Piechna (2016, 2017) added new factors such as flexibility, durability, compatibility, safety, and weights for the formwork selection in building construction projects. Some studies in the Indian construction industry (Loganathan and Viswanathan 2016; Pawar *et al.,* 2018; Lohana 2018; Rajeshkumar and Sreevidya 2019; Rajeshkumar *et al.,* 2021) have identified the factors influencing the selection of formwork in building projects.

In the tunnel lining formwork system, Pintado and Barragán (2009) have explained the importance of self-compacting concrete (particularity of mix design) and floor to arch transition gantry for tunnel lining work. Huang *et al.,* (2011) have considered the lining formwork design criteria to use the formwork system with required security arrangements so that the project is done with quality and speed for improving construction efficiency. Peng *et al.,* (2011) designed Universal-Rod Steel-Shuttering Jumbo (URSSJ) to customise the tunnel's shape and size with less repair and maintenance. Eventually, the literature explores that most of the studies mentioned above have identified the factors for selecting formwork systems for residential, commercial and industrial construction. Further, most of these studies (Hanna 1989; Hanna and Sanvido 1990; Hanna *et al.,* (1992); Proverb *et al.,* 1999; Loganathan and Viswanathan 2016) have used the knowledge acquisition process to select the formwork based on the identified factors for selecting horizontal and vertical formwork for building projects. However, no such studies are available on identifying the factors affecting the selection of the tunnel lining formwork. Therefore, there is a need to identify factors and develop a framework that can help to select an appropriate tunnel lining formwork system.

METHOD

Based on the review of literature, the research methodology is framed to identify and shortlist the factors influencing the selection of tunnel lining formwork systems using the Delphi method. Hallowell and Gambatese (2010) described the Delphi method as a "well-designed research technique used to acquire the opinion of independent experts on a specific topic". The Delphi method is more precise than other standard simple survey methods, as it allows users to keep control over biased feedback acquired from competent experts (Hallowell and Gambatese 2010). Owing to these, controlled feedbacks found during multiple rounds can help to accomplish consensus among the experts. Thus, to achieve this study's objectives, the procedure of the Delphi method is outlined in seven steps, and it is shown in Figure 1. A brief description of these steps is as follows.

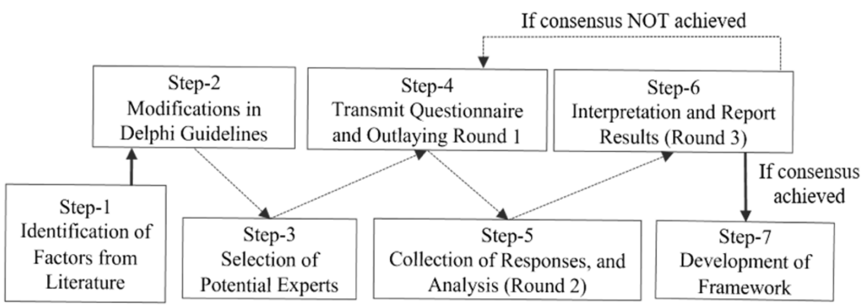

Figure 1: Research Method

In step 1, potential factors influencing the selection of tunnel lining formwork systems are identified from the literature. In step 2, guidelines are required to define for selection and certification of the respondents as experts (panellists'). In this connection, Hallowell and Gambatese (2010) have already presented the sample guidelines and recommend to modified them based on the requirement of the studies. Therefore, the present study modifies the guidelines as described in Table 1.

Table 1: Modified guidelines for the Delphi method

Characteristics	Minimum requirement adopted in this study
Identifying potential experts	Experts must satisfy at least one of the following criteria:
	1. Member or chair of a nationally recognized committee.
	2. Participated in expert-based research studies on tunnelling systems.
	3. The person with the number of handling projects and publications in the relevant field.
	4. Person in charge of design and Fabrication of Tunnel lining formwork system
Qualifying panellists as experts	Experts must satisfy at least three of the following criteria:
	1. Minimum three years of work experience in tunnelling or academics.
	2. Minimum four years of B.E./B.Tech. Civil Engineering degree from a renowned University/Institute OR Advanced or Master's degree in CEM, Structural Engineering, Tunnel Engineering or any related course to Formwork System.
	3. Professional registration such as Registered Engineer, Licensed Engineer
	4. Primary or secondary writer of at least three peer-reviewed journal articles.
	5. Invited to present at a conference or training program.
	6. Member or chair of a nationally recognized committee, society/council
Number of panellists	10
Number of rounds	3
Feedback for each round	Round 1: Data from existing literature, personal judgment, interview with experts, or archived data (if available).
	Round 2: Median response from Round 1.
	Round 3: Median response from Round 2 and reasons for outlier responses.
Measuring consensus	Absolute deviation (median) (AD), coefficient of variance (CV), range of data

Note: B.E./B.Tech. = Bachelor of Civil Engineering; CEM = construction engineering and management;

This modification is based on the requirement of Indian tunnel engineering. In step 3, the modified guidelines are used to select and certify the qualified experts in the panel. In step 4, the first round of the questionnaire survey is performed using a two-point Likert scale where 1 for satisfaction and 0 for un-satisfaction. The questionnaire is used to verify the factors identified in step 1 with the help of the panellists' responses.

In step 5, second round of the questionnaire survey is conducted using a six-point Likert scale where, extremely unimportant = 1, unimportant = 2, somewhat unimportant =3, somewhat important =4, important = 5, and extremely important = 6. However, Lad *et al.,* (2021) supported that the 'Neutral' should not be considered in the Likert scale to have a convenient response without cognitive efforts. Further, to judge whether experts have reached the required consensus, the statistical parameters such as mean, median, standard deviation (SD), absolute deviation (AD)-mean, AD-median, coefficient of variation (CV), and range of data are computed. Cut-off values for these statistical parameters can be set as per the requirement of the study in order to shortlist the factors (Patel and Jha 2017). In step 6, the third round of the Delphi method is conducted, wherein experts are asked to observe the results of the second round and shortlisted factors in order to develop the required framework. However, if an expert is not satisfied with the results, then the expert is asked for its justification. If other experts are satisfied with the justification given by that expert, then all three rounds are to be performed again. Finally, in step 7, if all the experts agree with the result of the second round, then the framework is developed that helps to select an appropriate tunnel lining formwork system.

FINDINGS

Data collection and analysis of the different steps of the research method are as follows:

First, as per the process described in step 1 of the research method, a total of 11 factors with 44 sub-factors, essential for selecting the tunnel lining formwork, were identified from the existing literature (Hanna 1989; Hanna *et al.,* 1992; Pintado and Barragán 2009; Huang *et al.,* 2011; Peng *et al.,* 2011; Jha 2012; Krawczyńska-Piechna 2016, 2017; Rajeshkumar and Sreevidya 2019). Then, 15 probable respondents were identified, and out of them, 10 potential experts were selected as the panellist based on the modified guidelines (Table 1). Of these 10 experts: three are from metro rail corporations; two are consultants; one is a private contractor; four are academicians/researchers. The average experience of the 10 experts in tunnelling projects/ research is approximately 13 years. Then, the first round of the survey was performed with the questionnaire as mentioned in step 4 of the research methodology. The four experts suggested to remove the sub-factors, namely: (1) Salvage Value, (2) Dewatering Time, and (3) Ventilation, as these factors were not required in the selection of the lining formwork system. In contrast, some experts advised to add the sub-factors: (1) Uplift of Form and (2) Contract Administration. Hence, a total of 11 factors and 43 sub-factors are finalized in the first round of the Delphi method, and they are described in Table 2.

After that, the second round of the Delphi method was performed with the questionnaire as described in step 5 of the research methodology. The responses obtained in the second round of the Delphi method are then analysed, and their statistical parameters are determined and shown in Table 3. Subsequently, the cut-off values for the parameters AD- Median, CV, and Range of data were set to be less than 0.75, 0.249, and 3, respectively. The criteria were decided on variations in data and previous studies (Hallowell and Gambatese 2010; Patel and Jha 2017). Three factors: (1) Cycle Time (F6), (2) Dewatering (F9), and (3) Construction Sequence (F10), exceeding the limit stated for AD- Median, CV, and Range of data (Table 3). Therefore, these three factors and their respective sub-factors were eliminated from further study. The eight factors and their corresponding 32 sub-factors were shortlisted, and then they were taken for validation using a reliability test. For this, Cronbach's alpha was calculated for the shortlisted 11 factors, and their values are shown in Table 4. Hair *et al.,* (2018) advocated that the value of Cronbach's alpha should be greater than 0.6 to have better reliability and internal consistency among the factors and their sub-factors. Thus, Table 4 shows that the value of Cronbach's alpha value of the "Organisational Support (F11)" factor was 0.147. However, Hair *et al.,* (2018) recommended that one can improve the value of Cronbach's alpha by eliminating irrelevant sub-factors. Therefore, the factor "Troubleshooting Experience (F11.4)" was eliminated from the study, and the improved Cronbach's alpha is recalculated and shown in Table 4 (in the bracket).

In the third round of the Delphi method, all experts were asked to observe the results of the second round and confirm their consensus on the results. Thus, all the experts agreed with the second-round results; therefore, no further modification was required for the shortlisted factors and their corresponding sub-factors.

Table 2: List of factors and sub-factors for selecting tunnel lining formwork

Factors	Sub-factors
F1 Geometry	F1.1 Shape of Tunnel, F1.2 Crown Height, F1.3 Thickness of Lining, F1.4 Tunnel Length and Alignment
F2 Economy	F2.1 Initial Investment, F2.2 Repair and Maintenance, F2.3 Stripping Cost, F2.4 Reusability
F3 Quality	F3.1 Mix Ratio of Concrete, F3.2 Compaction of Concrete, F3.3 Surface Finishing, F3.4 Cold Joints/Combing Defects
F4 Work Safety	F4.1 Safety Induction, F4.2 Risk Assessment, F4.3 Primary Lining, F4.4 Working Environment, F4.5 Degree of Supervision
F5 Project Complexity	F5.1 Company Practices, F5.2 Uplift of Formwork, F5.3 Site Characteristics, F5.4 Flexibility in Design, F5.5 Formwork Expertise
F6 Cycle Time	F6.1 Installation Time, F6.2 Crane Time, F6.3 Speed of Construction, F6.4 Stripping Time
F7 Labour Management	F7.1 Resource Requirement, F7.2 Resource Available, F7.3 Scheduling and Controlling
F8 Geological Conditions	F8.1 Topography, F8.2 Geology of Soil and Rock Mass, F8.3 Engineering Behaviour of Soil and Rock
F9 Dewatering	F9.1 Dewatering Technique, F9.3 Dewatering Time, F9.3 Seepage and Drainage Control, F9.4 Freeing and Thaw
F10 Construction Sequence	F10.1 Method of Construction, F10.2 Exposure to Dust, F10.3 Tunnel Monitoring
F11 Organizational Support	F11.1 Available Capital, F11.2 Contract Administration, F11.3 Hoisting Equipment, F11.4 Troubleshooting Experience

Table 3: Results of statistical parameters in the second round of the Delphi method

Factors	M	SD	Med	CV	Max.	Min.	R	ADM	AD Med.	V
F1	5.8	0.42	6	0.073	6	5	1	0.32	0.00	0.16
F2	5	0.47	5	0.094	6	4	2	0.2	0.00	0.2
F3	5.6	0.52	6	0.092	6	5	1	0.48	0.00	0.24
F4	5.2	1.14	6	0.218	6	3	3	0.96	0.00	1.16
F5	5.1	1.10	5.5	0.216	6	3	3	0.9	0.50	1.09
F6 *	4.8	1.23	5	0.256	6	2	4	0.88	1.00	1.36
F7	4.7	0.82	5	0.175	6	3	3	0.62	0.00	0.61
F8	5.4	0.70	5.5	0.129	6	4	2	0.6	0.50	0.44
F9 *	4.5	1.65	5	0.367	6	1	5	1.3	1.00	2.45
F10 *	3.9	1.37	4	0.351	6	2	4	1.12	1.00	1.69
F11	4.8	0.63	5	0.132	6	4	2	0.48	0.00	0.36

*Note: (1) For the name of factors F1 to F11, refer to Table 2. (2) M-Mean, SD-Standard Deviation, Med.-Median, CV-Coefficient of Variance, R-Range of Data (Max.-Min.), ADM-Absolute deviation (Mean), AD Med.- Absolute Deviation (Median), V-Variance. (3) * symbol indicates that factors are eliminated from the study.*

Finally, the results from the Delphi method were utilised to develop a hierarchical framework, where eight main factors and 31 sub-factors were shortlisted. The hierarchical framework is shown in Figure 2. Thus, the shortlisted eight factors are discussed as follows: (1) Geometry primarily indicates the different shapes of the tunnel-like circular, oval, rectangular, etc. With it, the shape of tunnel lining formwork is required to mould. (2) Economy is one of the vital factors because the experts stated that the selected formwork system incurs approximately 60-65% cost in the tunnel construction.

Table 4: Cronbach's alpha of factors

Factors and Sub-factors	Cronbach's Alpha
F1 Geometry	0.744
F1.1 Shape of Tunnel, F1.2 Crown Height, F1.3 Thickness of Lining, F1.4 Tunnel Length and Alignment	
F2 Economy	0.747
F2.1 Initial Investment, F2.2 Repair and Maintenance, F2.3 Stripping Cost, F2.4 Reusability	
F3 Quality	0.693
F3.1 Mix Ratio of Concrete, F3.2 Compaction of Concrete, F3.3 Surface Finishing, F3.4 Cold Joints/Combing Defect	
F4 Work Safety	0.829
F4.1 Safety Induction, F4.2 Risk Assessment, F4.3 Primary Lining, F4.4 Working Environment, F4.5 Degree of Supervision	
F5 Project Complexity	0.716
F5.1 Company Practices, F5.2 Uplift of Formwork, F5.3 Site Characteristics, F5.4 Flexibility in Design, F5.5 Formwork Expertise	
F7 Labour Management	0.885
F7.1 Resource Requirement, F7.2 Resource available, F7.3 Scheduling and Controlling	
F8 Geological Conditions	0.971
F8.1 Topography, F8.2 Geology of Soil and Rock Mass, F8.3 Engineering Behaviour of Soil and Rock	
F11 Organizational Support	0.147 (0.8)
F11.1 Available Capital, F11.2 Contract Administration, F11.3 Hoisting Equipment, F11.4 Troubleshooting Experience*	

Note: *symbol indicates that factors or sub-factors are eliminated from the study

Therefore, the selected tunnel lining formwork system look for less initial cost, minimum repairs and a high reuse cycle. (3) Quality of formwork impacts the quality of the tunnel structure. (4) Safety during the moulding of the formwork system can reduce the hazards and risks associated with the progress of the tunnel lining work. (5) Project complexity of constructing tunnel also creates a challenge for the moulding formwork system too, as it is based on various aspects such as company practices, site characteristics, etc. (6) Labour management is decisive in terms of resource identification, resource requirement, resource availability, and resource control through its staffing and levelling. The lining formwork requires special attention and skilled labour (Jha 2012); therefore, the availability of necessary labour and their staffing is crucial in selecting the lining formwork system. (7) Geological factors, such as ground conditions, location of the water table, soil bearing capacity, and rock strength, decide the suitable module of formwork. These sub-factors play a vital role in designing and fabricating the heavy parts of the tunnel lining formwork system. (8)

Organisation support is essential to sustain financial investment for the tunnel lining formwork from the initial to the completion stage of the project. Therefore, the proposed three-level hierarchy structured framework qualitatively helps the tunnel engineers and practitioners in selecting an appropriate tunnel lining formwork system.

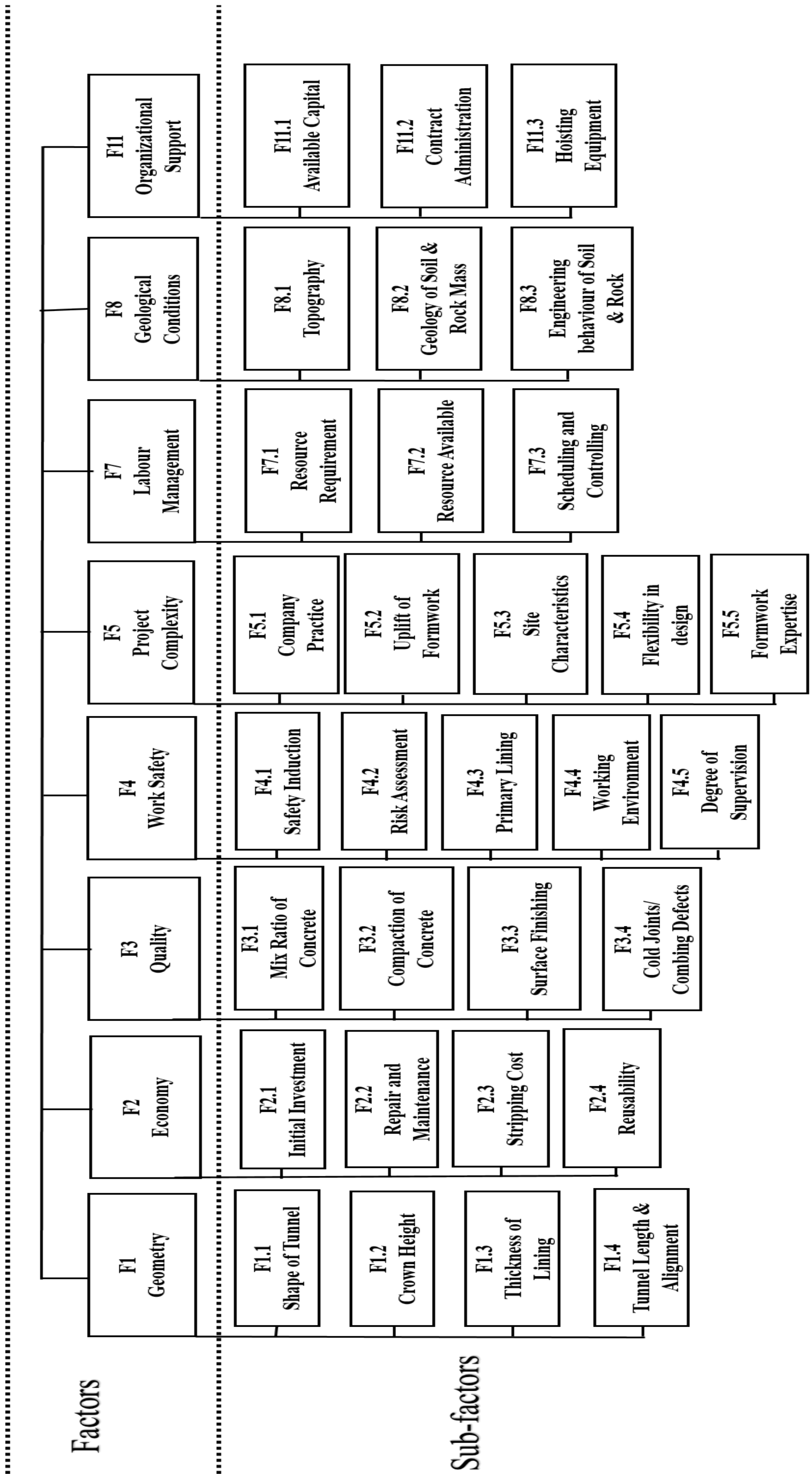

Figure 2. Framework for selecting tunnel lining formwork system

CONCLUSIONS

The proposed study aims to develop the framework for selecting the tunnel lining formwork system using the Delphi method.

First, the existing literature was used to identify factors and their sub-factors affecting the selection of tunnel lining formwork. Then, in the first round of the Delphi method, the experts' opinions were taken to confirm the identified factors and sub-factors. For shortlisting, the statistical parameters, AD-median, CV, and Range of Data, were determined, and their limits were set to be less than 0.75, 0.249, and 3, respectively.

Based on these statistical parameters and their limits, eight factors and their corresponding 32 sub-factors were shortlisted in the second round of the Delphi method. The consent was taken from all experts for agreement on the results of the second round. Then, the value of Cronbach's alpha is determined for each factor, which shows that one of the factors, "Organisational Support", had less value than the required (i.e., 0.6). Thus, the sub-factor, 'Troubleshooting Experience', was eliminated to have better reliability and internal consistency for this factor. Therefore, the final eight factors and their corresponding 31 sub-factors were used to develop a framework for selecting an appropriate tunnel lining formwork system.

The proposed framework represents the potential factors and sub-factors that can be used for selecting the formwork system. The limitation of the present study is that the developed framework is only applicable to tunnel construction. Before the framework could be used to assess and select the formwork system quantitatively, it is essential to determine the relative weights of the eight factors and their sub-factors.

For this, further research is required to propose a quantitative approach for selecting the formwork system for the tunnel lining work. An index can be developed in order to rank the factors and sub-factors.

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RISK ALLOCATION ON TRANSPORT MEGAPROJECTS: A CASE FOR AN INSTITUTIONAL THEORY LENS

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This paper explores institutional theory as a novel lens to examine the praxis of risk allocation on transport megaprojects. A case study of Australia's largest transport megaproject, Suburban Rail Loop Project, has been conducted using institutional theory to provide a better understanding of the dynamics and decision-making process in relation to risk allocation on megaprojects. The research findings identify how institutional instruments were used to shape the front-end of a transport megaproject and allocate risk. An example is the creation of a new and dedicated Minister for the Suburban Rail Loop Project, resulting in the approval powers to streamline and sometimes fast-track the decision-making processes. This paper contributes to the extant knowledge of megaproject management by providing a novel perspective on the praxis of risk allocation on transport megaprojects through the lens of institutional theory.

Keywords: front-end; institutional theory; risk allocation; transport megaprojects

INTRODUCTION

Australia, the geographical focus of this study, is currently experiencing a 'transport infrastructure boom' due to unprecedented transport infrastructure investment. In the 2020-21 Australian Commonwealth budget, a record $110 billion has been committed to the land transport infrastructure program over the next ten years as part of ‘Securing Australia’s Recovery’ (Commonwealth of Australia, 2020). Despite the Australian government's willingness to use transportation infrastructure as a stimulus tool, numerous projects have encountered significant cost overruns for the public and private sectors (Love *et al.,* 2020). According to a study published by the Grattan Institute, Australian governments have spent $34 billion more on transportation infrastructure than expected over the last two decades (Terrill *et al.,* 2020). A damning response by the Australian Contractors Association in 2020 states that "the infrastructure industry is facing a crisis.

The way infrastructure is currently procured and delivered is not sustainable… The government's response to this - transferring even more risk to the private sector - is making the situation worse" (Davies and Laslett, 2020). Consequently, the construction sector now wants governments to be responsible for more risks that lead

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Moore, T, Ahiaga-Dagbui, D, Shrestha, A and Debnath, A (2022) Risk Allocation on Transport Megaprojects: A Case for an Institutional Theory Lens *In:* Tutesigensi, A and Neilson, C J (Eds) *Proceedings of the 38th Annual ARCOM Conference,* 5-7 September 2022, Glasgow, UK, Association of Researchers in Construction Management, 369-378.

to some individual projects costing more than expected (Terrill *et al.,* 2021). In research conducted by Love *et al. (*2020), it is emphasised that State governments have a proclivity to adopt procurement approaches that allocate too much risk onto the contractors, and in turn, unforeseen costs are not included in their accepted bid. Thus, Love *et al. (*2020) go on to note that there is a growing perception that risks are 'deflected' onto tier-one contractors, which places an unreasonable financial burden on the sector. Ryan and Duffield (2017) found that while shifting more risks to the construction sector may appear to benefit the public sector in the short term, and it continues to harm the construction industry as projects grow larger and private sector losses become unsustainable.

A deeper examination of the systemic deficiencies associated with project management theories employed on megaprojects has identified that a growing corpus of academics is advocating for more novel and progressive approaches to megaproject management. Transport megaprojects are elaborate, complex, temporally backed sociotechnical undertakings embedded in institutional frameworks (Biesenthal *et al.,* 2018, Esposito *et al.,* 2021). Compared to traditional projects, organisational issues within megaprojects are significantly more complex (Li *et al.,* 2019). Therefore, they cannot be planned and executed in a predictable world where cause and effect are evident (Alfalla-Luque *et al.,* 2015). Thus, reliance on the application of technical project management principles fails to address the complex institutional and organisational pressures that need to be considered in megaproject management (Li *et al.,* 2019). Accordingly, it is becoming increasingly clear that the challenges encountered by these projects extend beyond technical concerns; they must also be viewed as sociotechnical endeavours rooted in complicated institutional frameworks (Biesenthal *et al.,* 2018).

A rising body of project management research emphasises the importance of moving beyond the application of traditional project management techniques and considering the broader institutional environment in which megaprojects are conceptualised and delivered (Biesenthal *et al.,* 2018; Dille and Söderlund, 2011; Matinheikki *et al.,* 2021; Morris and Geraldi, 2011). Accordingly, examining the praxis of risk allocation on transport megaprojects through the lens of institutional theory will help us understand how projects can build back wiser and more cost-effectively. This research seeks to answer the following question 'How can institutional theory provide a more holistic understanding of the praxis of risk allocation on transport megaprojects?' The exploratory nature of this research has been addressed through a critical literature review with a focus on the underpinning theoretical background. Insight into traditional project management theory is provided by examining the inherent limitations in its application to megaproject management. The literature review also examines institutional theory and highlights the benefits of this theory in megaproject management by responding to the institutional environment.

Traditional Project Management Theory

We live in an era of megaprojects, in which the ambition, scale, cost, and risk exposure of projects on a global scale have all expanded dramatically over time (Chapman, 2016). According to Flyvbjerg (2014, 9), megaprojects are "large-scale, complex ventures that typically cost USD 1 billion or more, take many years to build, involve multiple public and private stakeholders, are transformational, and impact millions of people". The performance of megaprojects has a long history of being problematic in terms of being delivered within budget and to schedule, with many studies questioning whether they even deliver their intended benefits (Brookes, 2015; Terrill *et al.,* 2020).

Ahiaga-Dagbui *et al.* (2017, 88) offer insight into that "major infrastructure projects, particularly those funded by the public sector, routinely make news headlines, not for being remarkable engineering accomplishments that will support and stimulate economic growth and social integration of communities, but rather for being poorly managed and often over budget". Megaproject failure is not a new field of study, but it has not moved very far beyond this initial focus, with the idea that correcting structural flaws would increase the likelihood of future project success (Pelham-Bomar, 2019). Traditional project management theories tend to focus on the technical application while failing to adequately address the complex institutional environment in which they are shaped and delivered (Biesenthal *et al.,* 2018; Dille and Söderlund, 2011; Engwall, 2003).

Furthermore, project management research has frequently been criticised for handling projects in isolation and uniformly, with prominent researchers arguing that more imaginative and novel approaches to project management research are required (Biesenthal *et al.,* 2018; Engwall, 2003; Morris and Geraldi, 2011). Thus, there is a renewed focus on exploring more progressive and novel project management approaches to advance the body of knowledge in this area. Notably, the application of institutional theory is gaining interest in megaproject management research with recent publications seeking more innovative approaches to project management by exploring the institutional environment in which megaprojects are delivered (Biesenthal *et al.,* 2018; Dille and Söderlund, 2011; Esposito *et al.,* 2021). Engwall (2003) investigated the view that project management theories are intrinsically dominated by a singular perspective on projects, treating the unit of analysis as a lone entity. Consequently, this closed system thinking fails to consider the broader context in which projects are delivered. Morris and Geraldi (2011) have acknowledged project management theories in their research 'Managing the institutional context for projects' by taking a deeper examination of the first principles of project management. This investigation proposes that project management theory can be defined in three contexts:

1. Technical - Operational and delivery orientated
2. Strategical - Managing projects as holistic organisational entities, including their front-end development and definition with a focus on value and effectiveness
3. Institutional - The institutional level at which management is focused on fostering and supporting projects, both within the parent organisation and in the external environment

The key findings draw the project management community to consider the institutional level at which management is focused on fostering and supporting projects, both within the parent organisation and in the external environment. Thus, this philosophy argues that project management practices need to consider the external context in which projects are delivered (Morris and Geraldi, 2011).

Institutional Theory and Megaprojects

Institutional theory and analysis address the processes by which social structures, including both normative and behavioural systems, are established, become stable and undergo changes over time (Scott, 2012, 27). In essence, institutional theory investigates the external influences that lead organisations to adopt specific organisational practices. According to Scott (2005), contemporary institutional theory has attracted the attention of a diverse spectrum of social science scholars and has been applied to systems ranging from micro interpersonal interactions to global macro frameworks. Tina Dacin *et al. (*2002, 45) notes that "institutional theory has risen to prominence as a popular and powerful explanation for both individual and organisational action. Institutional theory is predicated on the assumption that institutions are influenced by other organisations and is used to examine how institutions respond to external pressures". Thus, institutional theory examines the external influences that cause organisations to adopt organisational practices.

Institutional theory in organisation studies is sometimes referred to as neo-institutionalism or organisational institutionalism and is increasingly being used in research on project management (Matinheikki *et al.,* 2021). According to Meyer and Rowan (1977), institutional theory assumes that organisations are not rational production functions but rather seek social acceptance (i.e., legitimacy), and so their behaviour is influenced by socially built and frequently irrational institutions. Accordingly, institutions shape organisational behaviour because organisations must appear legitimate to a variety of referent audiences (e.g., clients, competitors, regulators, statutory authorities, non-governmental organisations, and the public) to succeed and survive (Matinheikki *et al.,* 2021).

According to Scott *et al.,* (2000), an organisational field consists of three constituents: (a) actors, which include both individuals and organisations, (b) institutional logics, which include the values and norms, ideas, beliefs, and meaning systems that guide actor behaviour, and (c) governance structures, which include the regulative and normative frameworks that exert control both within individual organisations and at the field level. Yang and Su (2014) propose that institutions are viewed as the repository for the 'rules of the game'. Thus, understanding the institutional environments enables firms to compete effectively in the market. Megaprojects are exposed to a dynamic and highly complex institutional environment that has the potential to impact a project's progress severely. According to Qiu *et al. (*2019, 425), "institutional complexity stems from both external environments (macro-level) and internal actors (micro-level environments), and consists of regulatory, political, and social complexity".

According to Biesenthal *et al. (*2018), institutional elements must be carefully managed in megaprojects due to their complexity, the multitude of their logic, and, on occasion, the dishonesty of its entrepreneurs. Furthermore, a clearer understanding of how different actors within megaprojects respond to institutional complexity is also needed. Qiu *et al. (*2019) suggests that actors within megaproject organisations choose different responses when faced with different types of institutional complexity. To this extent, Esposito (2021) argues that actors can utilise various institutional instruments that contribute to the growth of the megaproject (Table 1). Participants in megaprojects might employ these instruments to execute various types of institutional activity that help shape the front-end of a transport megaproject.

METHOD

A case study examination of Australia's largest transport megaproject, the Suburban Rail Loop (SRL) Project, has been completed. A case study approach was chosen because it allows for a deep, contextual investigation of institutional theory to support a narrative account of how this novel lens will provide insight into the praxis of risk allocation. Case study research is especially applicable as it focuses on one aspect of a problem, the problems drawn will not be generalised, but related to one event (Naoum, 2003, 46). Gerring (2016) also notes that case study research is appropriate where an in-depth knowledge of an individual example is more useful than ephemeral and superficial knowledge about a larger number of examples.

Table 1: Institutional Instruments

Institutional Instrument(s)	Utility and Application
Defining	Through a defining process, actors can change the regulatory environments in which they operate and build new institutions. Defining can thus be viewed as an institutional process of "macro-shaping," in which non-business actors create demand, as well as the megaproject itself, by establishing the overarching policy framework, time frames, and available resources.
Embedding and Routinizing	Embedding and routinising is a type of institutional work in which actors intentionally infuse an institution into the participants' daily routines and organisational processes. Through the employment of agreements, actors' megaprojects can be integrated into national actors' day-to-day routines and organisational practices. These agreements are eventually utilised to set the working agendas of other megaproject actors.
Enabling	The focus of enabling work is on actors engaging with formal rules to enable, augment, and support institutions. This may include overriding local government planning powers to expedite planning approvals and fast-track construction works.
Policing	Policing is a type of institutional work employed to preserve and reproduce institutions in megaproject shaping. Compliance and enforcement through auditing and monitoring.
Disconnecting Rewards	This purposeful use of legal tools to derail megaprojects possesses significant shaping potential. Local communities within the vicinity of megaprojects may have the ability to influence and shape execution through support or overt opposition and resistance.

Informed by Esposito *et al.,* (2021).

This case study explores, using publicly available data, how a transport megaproject traversed the early stages of the institutional environment to inform the risk allocation process. This was accomplished by mapping the institutional environment and assessing the institutional logic and regulatory mechanisms that shaped the project's front-end. In response to the research question "how can institutional theory provide a more holistic understanding of the praxis of risk allocation on transport megaprojects" the following analysis has been completed: (a) examination of SRL's front-end timeline mapped against the institutional environment; (b) analysis of the regulatory framework to identify instruments used by project actors to inform the institutional environment; and (c) an assessment to determine how institutional shaping can inform the risk allocation process.

Case Study - Suburban Rail Loop Project

The Suburban Rail Loop is a city-shaping transport megaproject providing a polycentric solution to Melbourne's radial network that will transform travel around Melbourne. The 90 km rail line will link every major rail line from the Frankston line to the Werribee line via Melbourne Airport, better connecting Victorians to jobs, retail, education, health services and each other. Stage 1 of SRL (SRL East), Cheltenham to Box Hill includes the construction of six stations, one stabling yard and approximately 26 km of a twin-bore tunnel with a $34 billion budget announced in the government's Business and Investment Case. SRL was chosen because it is Australia's largest transport megaproject. In addition, the scope of this project necessitates an ambitious start from initial concept, business and investment case development, design development, approvals, and construction delivery commencement. Furthermore, SRL is exposed to a rich environment of stakeholders and is being delivered in a diverse institutional setting.

Thus, effective front-end planning is critical as many projects fail because of the decisions made during the early stages of development (Beckers *et al.,* 2013). Responding to this environment at the front-end phase is essential in shaping the project and presents opportunities to inform the risk allocation decision-making process. According to Locatelli (2018), ineffective risk allocation contributes to megaproject failure, noting that risks are frequently underestimated and assigned to parties lacking the necessary knowledge, resources, and capabilities to manage them effectively during project delivery. Consequently, SRL pursued regulatory mechanisms to ensure the project had sufficient power to traverse the institutional environment and inform the risk allocation decision-making process. Notably, in 2021 Parliament of Victoria passed the Suburban Rail Loop Bill 2021. This Bill facilitates the following (Bailey, 2021):

- Establishes a new statutory authority to develop and deliver the Suburban Rail Loop Project
- Makes several essential modifications to the Major Transport Projects Facilitation Act 2009 (Vic) and the Planning and Environment Act 1987 (Vic) to improve and streamline the planning and execution of current and future Victorian Government transportation projects.

FINDINGS

An analysis of front-end risk allocation and project shaping on the Suburban Rail Loop project revealed the following findings:

Complex Institutional Environment

Megaproject professionals (actors) must deal with a variety of institutional logic and drivers to achieve successful project coordination, including national laws, legal agreements with funding firms, municipal legislation, and company hierarchies (Esposito *et al.,* 2021). Figure 1 provides a visual mapping of Suburban Rail Loop Authority's (SRLA) key milestones and institutional environment characterised by competing political, regulatory, and social logic. It highlights the extensive regulatory environment comprised of municipal councils, accredited rail operators, asset owners and statutory bodies - all of which have approval mechanisms to cause potential project delays. As a result of this complex institutional setting, SRLA encountered conflicting logic among key stakeholders who opposed certain project planning decisions. For example, Kingston City Council opposed the Delta site location proposed to be used for a train stabling yard, instead expressing council and community expectations of the delivery of a long-waited Chain of Parks[2].

Institutional Shaping Analysis

Esposito *et al.,* (2021) suggest that actors involved in megaprojects struggle to exert influence over final decision-making outcomes within administrative and legal processes. The research findings for this paper suggest that if a megaproject is proactive in macro-shaping the front-end to respond to institutional complexity, actors are well positioned to exert influence over the final decision-making outcomes. SRLA achieved this by recognising the inherent institutional complexity faced by the project and implementing institutional instruments to support effective decision-making. Morris and Geraldi (2011) highlight the importance of the two-way interaction between actors and their environment in shaping the enterprise's structure, designing processes, promoting its practices and behaviours, shaping policy and standards, and influencing stakeholders and decision-making with the objective of

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[2] https://www.kingston.vic.gov.au/council/news/latest-news/bold-vision-for-suburban-rail-loop-advanced-by-kingston

improving project management practices. The key findings in Table 2 (below) highlight the prominent institutional instruments used during the front-end shaping process.

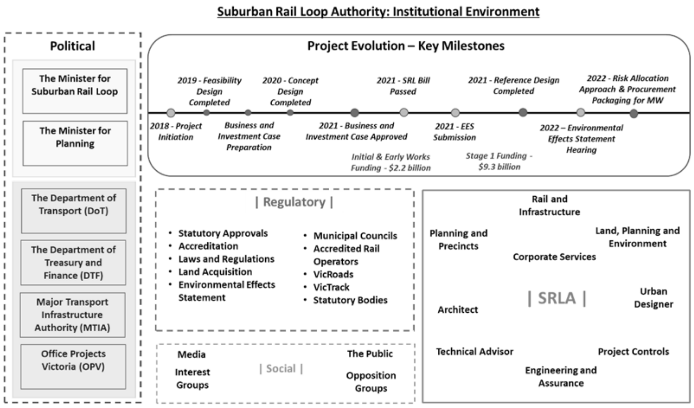

Figure 1: SRL's Institutional Environment (developed by the author)

Table 2: Institutional Shaping Analysis (developed by the author)

Institutional Instrument	Mapping	Front-end Shaping	Attributes That Aid in The Praxis of Risk Allocation
Enabling	Part 7 of the Bill	SRL was established as a Statutory Authority, providing SRL with the power to act as a Planning Authority. Minister for Suburban Rail Loop appointed.	Overriding statutory approvals to streamline the process. A dedicated Minister introduces greater decision-making power.
Enabling	Part 3	Provides the Suburban Rail Loop Minister with the power to declare areas of land that are proposed to accommodate the Suburban Rail Loop infrastructure and related precincts as Suburban Rail Loop planning areas	Access to critical land can be streamlined. Interface risk exposure is reduced as land will be available for Construction delivery.
Defining	Part 4 of the Bill	The Suburban Rail Loop program will be planned, developed, and delivered progressively in stages.	Project risk exposure can be progressively managed. Facilitates risk allocation and procurement staging.
Embedding and Routinizing	The Bill	Governance arrangements for the new Authority, including the Board of Directors, Chief Executive Officer (CEO), corporate planning requirements and financial cost control.	Sound governance positions the organisation to effectively respond to institutional logics.

'Enabling' was used to override local government planning powers to expedite planning approvals and fast-track construction works. This was achieved by making essential modifications to the Major Transport Projects Facilitation Act 2009 (Vic) (MTPFA) and the Planning and Environment Act 1987 (Vic). Furthermore, a Suburban Rail Loop Minister was appointed, who has specific powers under the Bill, introducing greater decision-making powers. To our knowledge, this is the first time such a role has been created anywhere in Australia to facilitate the delivery of a transport megaproject. This enabling function potentially allows SRL to reduce its risk exposure and uncertainty, especially in relation to interface definition, land access, and statutory approvals.

'Defining' was used as an institutional process of "macro-shaping" by facilitating SRL to be delivered progressively in stages. For example, the procurement of an Initial and Early Works Package to conduct essential enabling works prior to main works on SRL East. Notably, the Initial Works, which include minor road modifications, service relocates and site establishment, can be conducted prior to the Early Works, which are subject to approvals as part of the Environmental Effects Statement assessment. This approach means risk exposure can be progressively managed and facilitate effective risk allocation decision-making and procurement approaches. 'Embedding and

Routinizing supported SRLA to quickly establish organisational governance, allowing the Statutory Authority to effectively respond to institutional logic.

Institutional Shaping Can Inform the Risk Allocation Process

When investigating the function of risk allocation, Xu *et al. (*2018, 20) suggest that "effective risk allocation aims to compensate the Contractor for potential losses incurred during the project's implementation, thereby reducing the Contractor's opportunistic behaviour". Common perceptions of contractual risk allocation are predicated on a harmonious, effective, and efficient construction project (Loosemoore and McCarthy, 2008). However, this is rarely the case, given that most megaprojects experience cost blowouts and schedule overruns resulting in adversarial behaviour. Xu *et al. (*2018, 16) note that "a proper risk allocation scheme suggests that the owner is willing to share risks with the contractor in the implementation of a project and that the owner is not forcing the contractor to take all the risk". As discussed in the introduction, the construction sector is now pushing back on the amount of risk they are willing to accept following a series of megaproject failures and financial losses (Terrill *et al.,* 2021).

Accordingly, SRLA's approach to reducing uncertainty and institutional complexity through the application of institutional shaping has positioned the project to be more informed when allocating risk to the construction sector. SRLA, for example, has performed extensive upfront geotechnical investigation work to inform the reference design and provide the construction sector with a higher level of confidence than is common on a transport megaproject. An optimised geotechnical baseline report also limits the Contractor's risk exposure to geotechnical uncertainty through contractual measures.

The findings of this case study reveal that SRLA actors institutionally shaped the project's front-end phase via regulative mechanisms. These instruments enabled the project to have greater decision-making power and expedite upfront works. This institutional shaping is arguably a critical phase in the project that has facilitated detailed upfront investigations and design. In turn, this facilitated SRLA to be more effective in its ability to allocate risk by enhanced decision-making power, thus reducing the need to deflect risks onto the construction sector. However, this strategy may elicit objections from statutory authorities who believe their approval mechanisms and ability to influence the project have been undermined.

CONCLUSION

The critical literature review highlights that institutional theory is gaining interest as a theoretical lens to examine megaprojects. The case study provides useful insight into the critical front-end phase of a transport megaproject and how institutional instruments informed the risk allocation process. Thus, this paper makes a case that institutional theory can help us understand the praxis of risk allocation on transport megaprojects as a novel approach to megaproject management. Given the early nature of this research, it is acknowledged that industry engagement is required to conduct detailed case studies and interviews with industry professionals to gain further insight into the topic.

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THE TOXIC TRIANGLE OF SMALL AND MEDIUM-SIZED ENTERPRISE HOUSEBUILDING: A REVIEW OF THE UK HOUSING INDUSTRY'S DILEMMA

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The UK housing industry is currently facing a crisis owing to housing shortages. Nonetheless, the continued housing shortage has brought much public scrutiny towards the government's over-reliance on volume housebuilders and policy constraints on Small and Medium-Sized Enterprise (SME) housebuilders. This study therefore identified the key barriers that currently limit the shared burden of housing delivery by SMEs and the state-of-the-art in related government policies. An integrative literature review on government and scholarly publications revealed that the role of UK SMEs has been diminished due to deep-rooted policy barriers on supply. The current planning system, access to finance and viable land availability were diagnosed as a "toxic triangle" of three-fold barriers, given they are inter-related and mutually reinforcing. Next, an integrative review of government policies for their influence on the toxic triangle revealed the need to focus on the opinions of SME builders as current policies have overlooked tailored solutions for different demands of SME categories. These findings could help to improve the UK government's ex-ante policies to eliminate the toxic triangle effects on SMEs' housing delivery.

Keywords: housing policy; constraints; housebuilders; SMEs; toxic triangle

INTRODUCTION

In the last four decades, the fluctuation of real home prices in the United Kingdom has been among the highest in the Organisation for Economic Cooperation and Development rankings due to underlying housing sector issues (Remøy and Street, 2018). On the other hand, the UK housing shortage is also a major concern. From 1969 to 1989, almost 4.7 million houses were constructed in England, but from 1994 to 2021, less than 3.9 million houses were completed (Department for Communities and Local Government [DCLG], 2021). As a result, expanding social housing backlogs, soaring rents and house prices, precarious leases, congestion, and deteriorating quality have been cited as some of the issues that define the current housing industry in the UK (Nazir *et al.,* 2020; Robertson 2016). Among the numerous negative features that may describe the current UK housing industry, the housing crisis has become a cornerstone in many government programs. The current

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condition of the UK housing sector was not the same as during the WWs (Wilson and Barton, 2022).

However, the Lyons Review (2014) highlighted the dominant takeover by high-volume housebuilders in the UK housing industry, which allowed them to influence the industry and resulted in fundamental changes because of the UK government's plan-led planning system in 1990. It is estimated that three volume housebuilders alone supply 25% of all new homes in the UK, with the eight largest housebuilders accounting for more than 50% of all newly built homes in the country (Archer and Cole, 2021). The DCLG (2017: 06) explicitly acknowledged the declining position of SMEs in the UK housing sector and their importance in addressing severe housing shortages as "we will diversify the housing market, opening it up to small builders...". The Farmer Report (2016) also revealed that the role of SME housebuilders has increasingly declined because of deep-rooted and structural restrictions on housing supply.

The FMB Survey (2021) found out that the most significant restraints for SME housebuilders are the present planning system, a lack of access to land and money, resulting in these inter-related concerns. As a result, to meet the nation's housing delivery objectives while diversifying the housing industry, the UK government has responded by enacting several policies aimed at promoting the role of SMEs. However, the impact of these regulations on housing supply has not been extensively studied concerning SMEs, which is an important context to explore if the UK government is to bridge the necessary housing shortage. Therefore, the purpose of this study is to examine the influence of the UK government's policy measures on the constraints for housing delivery by SME housebuilders.

Given its political importance, the UK housing industry has seen both a rise and a decline during the last century (Robertson, 2016). As a major player in both WWs, history has shown that the UK was able to meet its immediate housing needs despite severe labour and material shortages. However, looking at the countless recent government publications focusing on this topic, it is evident that the housing crisis in the UK has resurfaced since the beginning of the twenty-first century. Ministry of Housing, Communities and Local Government [MHCLG] (2018) states that despite its peak of 352,540 housing completions in 1968, the UK housing industry has barely managed to supply houses at around one-third of that level in recent years. The Labour Government claimed the net supply of 107,870 houses in 2010-11 was the lowest level of housing industry performance this country has ever seen since the Great Depression of the 1920s (Robertson, 2016). As a result, housing is now ranked as the fourth most critical problem confronting the UK, the highest-ranking since 1974, with only Brexit, healthcare, and the economy ranked higher (Wilson and Barton, 2022). The Lyons Review (2014) reiterated this issue, proclaiming housing has not been significantly addressed in party manifestos since the 1960s, implying that while the government prioritises concerns such as health and the economy, housing has bubbled beneath the public consciousness. Coupled with the decline in housing supply is the ever-increasing demand for homes, which has exacerbated the UK's present housing crisis (Europe Economics, 2014). Wilson and Barton (2022) warned that the growing population in England alone would result in a 1.75 million increase in the number of households during 2016-2026.

However, the DCLG (2017) stated that the average household size is anticipated to decline from 2.35 people in 2014 to 2.21 people in 2039, suggesting that the number of houses required in the UK is growing faster than population growth alone. Authorities would argue that the UK has more years to prepare for this catastrophe, yet a government white paper stated that "this is neither a future crisis nor a looming danger that will become a problem if we do nothing. We are already living in it" (DCLG, 2017: 15). This regrettable reality was acknowledged further by the UK government in its White Paper August 2020, which continued the target of providing 300,000 homes per year in the 2017 Autumn Budget as redemption for decades of undersupply of houses and predeceasing governments' negligence in undermining this social catastrophe (Wilson and Barton, 2022).

The current UK housing crisis has resurfaced not just due to the negligence of UK governments. Turner *et al. (*2017) discovered that the existing composition of the UK housing industry does not encourage the increase in home supply that the country requires as well. As noted in the previous section, some government policies, such as the plan-led planning system, have created routes for large national housebuilders to dominate the housing industry and hence determine how it functions (Lyons, 2014). The OFT (2018: 56) argues that volume housebuilders would not risk saturating the market with desirable housing supply to maximise profits, stating that "housebuilders deliver new homes as fast as they can sell them, not as fast as they can build them". Although this is reasonable commercial behaviour, it does not tally with the best interests of the country. Hence, the House of Lords (2022) emphasised that the housing market cannot improve to meet the country's demands without the support of a dynamic, well-resourced number of SMEs. Nonetheless, the UK government recognises that there is insufficient competition and proposes policies to support various segments of the market, including SME housebuilders, to achieve this step-change in creating a more vibrant and diverse market that is more responsive to actual demand and, as a result, builds more houses (House of Lords, 2022). However, before any SME-targeted policies are reviewed, it is critical to consider the specific nature and features of SMEs that the subsequent sections are aimed at.

Turner *et al. (*2017) classified SMEs as micro, small, or medium-sized enterprises, while the European Commission (2019) further extended this by defining them by staff headcount (SH) or turnover (TO) (i.e., Micro: SH<10 or TO ≤ € 2 million, Small: SH<50 or TO ≤ € 10 million, Medium: SH<250 or TO ≤ € 50 million). SMEs are defined by a set of distinct features that set them apart from major corporations, such as their structure, culture, and ownership (Valenza, Caputo and Calabrò, 2021). Further to Valenza *et al. (*2021), features of SMEs include flexibility and adaptability, but Monteiro *et al. (*2020) claim that SMEs have inherent resource and talent limits. Carson and Gilmore (2018) underlined the importance of these specific limits in the high failure rate of SMEs, with many failures in a short period. The business demography in the UK confirms this since 75% of firms that start small remain the same, but over a decade, around 80% of these firms will no longer exist (Hutton and Ward, 2021). According to Robertson (2016), a primary government policy priority for the next two decades is to promote and stimulate SMEs, particularly by strengthening their competitiveness.

Although this resulted in the introduction of SME-targeted policies, their indicated aims often clash with the policy demands that are required by the industry (Westman *et al.,* 2022). Ehsan (2021) identified that to boost the competitiveness of SMEs, policymakers have been more aggressive in assisting small businesses. Although adopting public policies for SMEs may sound simple, in practice, forming a policy that is conducive to SMEs while also fulfilling the concerns of other key stakeholders may be challenging. As a result, it has been proposed that SMEs be fundamental to the design of government processes by being included in the setup, implementation, and assessment of policies, given their importance to the economic system (Monteiro *et al.,* 2020).

The Department for Business Energy and Industrial Strategy [DBEIS] (2021) found out that there were 5.58 million UK private sector SMEs, implying that SMEs constitute the backbone of the UK economy. DBEIS (2021) reinforces this, stating that these SMEs have generated a turnover of £2 trillion for the UK economy by 2021. In the context of housing, SME housebuilders are those who develop fewer than 2000 units per year (i.e., small house builders: 1-100 units per year; medium housebuilders: 101 -2000 units per year) (Savills, 2021). Although SMEs play an important part in the UK economy, their influence on the housing market appears to be shrinking (Hawthorn, 2022). In support of this, Robertson (2016) argues that the housing industry has always leaned toward consolidation, restricting competition, and thus creating an oligopoly in a market that is critical to the country's economy. According to the Home Builders Federation [HBF] (2020), the number of active small housebuilders has decreased by 80% over the last three decades, while the number of medium housebuilders has decreased by 54% over the same period. Robertson (2016) suggests that the financial crisis in 2008 had a catastrophic influence on the number of active small builders in the industry. This is seen in the findings of DCLG (2017), which recorded 44,000 active small housebuilders in 2007, but this had fallen to 18,000 within eight years, a drop of 60%. Inevitably, this has resulted in a structural change within the housebuilding industry, which now relies on fewer financially strong companies to deliver houses, as evidenced by the UK's ten largest housebuilders accounting for 60% of new private homes alone, indicating that the housing landscape is shifting (Archer and Cole, 2021).

METHOD

A comprehensive, focused literature review was conducted using an integrative method to identify the barriers faced by SME housebuilders in the UK and the influence of current policies on them. The justification for using an integrative method is that it gives a more rigorous form that introduces fresh perspectives on the existing issues by enabling creative synthesis and critical analysis (Synder, 2019). In contrast to systematic or general literature reviews, the integrative method allows for the gathering, comparing, and evaluating of individual and noteworthy pieces of literature focused on a specific research problem without heavily relying on the selection process. The goal of adopting an integrative method on established themes like UK housing context is to evaluate the body of knowledge, compare, perhaps re-conceptualise, and expand on the theoretical underpinning of the specific theme as it grows (Synder, 2019).

The selection of the relevant literature (i.e., journal and conference publications, UK government publications, industrial committee reports) was done by using the keywords: "small and medium-sized (SME)", "housing industry", "housebuilders", "housing policies", and "United Kingdom (UK)" on Google Scholar and Scopus databases. The qualitative content analysis method has been adopted since this study is more into deductive reasoning, beginning with the UK housing industry and ending with its specific policies towards SME house builders. As a result, retrieved literature from databases gave an in-depth overview of the history of structural change within the housing industry, and it was analytically deduced how such structural change can be compared against the decline of SMEs through an integrative method. The review was expanded further to emphasise the key barriers to entry and growth for SMEs, with such barriers being evaluated against recent government policies through an integrative method. Thus, this study attempted to draw conclusions to determine if the policies can diversify the housing industry by increasing the prevalence of SMEs.

FINDINGS

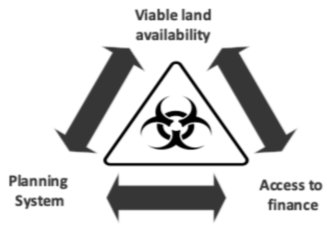
Barriers to Entry and Development for SME Housebuilders

House of Lords (2022) recognised the need for a housing industry environment that allows SMEs to thrive, giving the government a better chance of meeting the comfortable living standards of its citizens. Farmer (2016) also recognised that to develop additional houses, barriers that exist in the housing industry for SMEs must be identified and overcome. Wilson and Barton (2022) believe that, while there is agreement on the long-term undersupply of housing and the need to address it, there is less consensus within the sector on how SMEs should be facilitated in achieving the required step-change in supply. The most recent Built Environment Committee Report (House of Lords, 2022) noted the housing sector's sensitivity to skills shortages as a barrier to both entry and development of SMEs. The construction industry witnessed the second-highest redundancy rate of any trade during the latest recession, peaking at 3.2% in the first quarter of 2009 (House of Commons, 2017). Despite evidence of economic recovery, such as increased project volumes, the UK housing sector has a serious and imminent skills shortage, which looks to be worsening (Farmer, 2016). Furthermore, as rising demand continues to outstrip housing supply, material shortages have been identified as a barrier, with a reported total of 1.4 billion bricks required to address the housing shortage (House of Lords, 2022). Furthermore, the Built Environment Committee Report (House of Lords, 2022) and FMB (2021) have identified three major challenges that SMEs face constantly compared to countless other challenges: The existing planning system, land availability, and finance. Turner *et al.* (2017) perceives those barriers as mutually reinforcing and inter-related, resulting in toxicity for SME housebuilders. The following three areas, illustrated in Figure 1, emerged as the main barriers for SME housebuilding from the review, which this study refers to as the "toxic triangle".

Turner *et al.* (2017) believes that the imbalance in housing supply compared to demand cannot be addressed without significant increases in land availability. Payne *et al.* (2019) also identified land as the most critical element for the development of housing in the UK. The Lyons Review (2014) determined that England itself possesses 132 billion square metres of land, of which only 10% has been developed. Baker (2004) recognised the availability of land nearly two decades ago, also stating that it was apparent that the UK did not lack land; yet an effective planning system needs to bring forward land and unlock it for housing constructions. Payne *et al.* (2019) predicted that if all remaining public lands were unlocked, there would be enough room for up to 2 million additional houses.

However, every land will not be ideal for SME house builders (i.e., the larger sites need more resource requirements), for whom the availability of small development sites and self-commissioned new houses is most important (House of Lords, 2022). The Lyons Review (2014) identified particularly conventional government practises, such as releasing land to the highest bidder, rather than exploring more inventive ways, such as achieving long-term returns on investment. Accordingly, when larger lands are offered, a single sale will inevitably disqualify SMEs where the dividing of such lands into smaller slots and being managed by a "master developer" would provide the long-awaited collaboration between large housebuilders and SMEs.

Figure 1: Toxic triangle of SME housebuilding in the UK



The UK planning system dictates that any change in land use, which is legally defined as a "development", needs specific planning approval. This process may require the submission of detailed information as well as payment to necessary specialists, which can be costly for SMEs without a guarantee of success (MHCLG, 2021). This is a difficulty for SMEs that are living hand-to-mouth because financing for developments may not be accessible without planning approval. However, the expenses of obtaining planning permission are significant and require loan financing (Perry, 2021). It has been stated that the existing planning procedure is likely to incentivise developers to build up land banks while acting as a barrier for market entrance, thereby harming competition in the housing industry (Payne *et al.,* 2019). According to Turner *et al. (*2017), limited competition, as well as incentives for developers to build up land banks, are expected to have a significant impact on constraining housing supply. Payne *et al. (*2019) identified that land value is crucial in housing, with 70% of the financial worth of a home consisting of the land on which it is built. Robertson (2016) argues that this has resulted in housebuilders being made or broken based on their land purchases rather than the quality or efficiency of their production, resulting in the latter being overlooked. It has been proposed, however, that focusing simply on the planning system would avoid the issue of the UK's extremely concentrated and opaque patterns of land ownership (Perry, 2021). Faulkner, Murphy and Scott (2019) identified housebuilding's vulnerability to recessionary pressures and cyclical variations in the market, with the 2008 financial crisis having a significant influence. This was demonstrated by the fall of 46% in housing completion between 2007 and 2010 by private companies (Wilson and Barton, 2022). The ongoing soaring inflation and expenses crisis in the UK has been identified as another peril for SMEs' existence (Young, 2022). These findings show that SME housebuilders are more vulnerable to economic shocks and lack the potential to "bounce back." This is because capacity cannot be restored when housing demand picks up again since many SMEs may no longer be in business or be able to afford the soared material prices and employees may have relocated because of the recession's aftermath (Archer and Cole, 2021). Since the financial crisis, the uncertain and unpredictable nature of residential construction has influenced SMEs, portraying them as an unattractive proposition to potential lenders. Most SME development funding for a project is normally accessible from traditional lenders at a nominal rate of roughly 60% loan-to-cost (HBF, 2020). This is in sharp contrast to the situation before the 2008 financial crisis, when SMEs could receive loans of up to 90% (Turner *et al.,* 2017). The remaining finance must then be generated from the SME's equity. According to Archer and Cole (2021), this presents cash flow issues for SMEs because the withdrawal of a developer's equity and profit on a development scheme is completely backloaded and is realistically only tangible following the sale of the last units of a scheme. The FMB

(2021) expressed concerns that low loan-to-cost offers from banks limit SMEs' capacity to recycle financing into subsequent projects but acknowledged that enhancing available credit conditions is a viable solution.

Influence of Government Policies on Barriers for SME Housebuilders

When the government expects its housebuilding industry to change often to satisfy the needs of the country, it is unavoidable that SMEs find it difficult to overcome barriers and constraints. Governments frequently establish policy measures aimed towards the creation and growth of SMEs owing to the perceived benefits they provide, such as increased competition, job creation, and economic vibrancy (Turner *et al.,* 2017). Without a difference, the UK government also recognises the value that SMEs provide to the housing industry and has implemented measures aimed at overcoming the "toxic triangle" to stimulate their housing supply.

The government launched the Accelerated Construction Programme in 2017 and entered the delivery phase in 2018 (DBEIS, 2021). This initiative is intended to address the undersupply of new housing by assuring rapid site preparations, as well as to assist SMEs by parcelling existing sites to make developments more accessible to them and to solve challenges with access to land. Aldridge (2018) explains that this programme paves the pathway for the government to focus on non-major builders and ensures that excess public lands are used as a vehicle to enhance the supply of new housing. Furthermore, this programme encourages the establishment and development of SMEs by using the government's land as equity rather than requiring upfront payment, ultimately minimising barriers to access to financing and land. According to the government, the scheme would "speed up housebuilding on public land through partnerships with private developers" (DBEIS, 2021). However, Rogers (2017) identified that, for this initiative to be successful, councils' views regarding SMEs must evolve. This is because councils, who have borne the brunt of austerity cuts in recent years, frequently lack the manpower and endurance to deal with many smaller, less experienced builders, and may still choose larger developers as a 'one-stop' solution (Homes England, 2018). Perry (2021) expressed a similar viewpoint, adding that resource restrictions in planning departments have made finding and designating small sites for projects more difficult, exacerbating uncertainties and delays in moving sites forward.

The Lyons Review (2014) advocated introducing "redline" applications to minimise upfront expenses borne by housebuilders before approval in principle was granted. It was claimed that this would provide a more balanced approach to planning applications for minor sites by de-risking and expediting them. This was recognised in the Housing and Planning Act, which was enacted in 2016. One important reform included in this Act is the implementation of Permission in Principle (PIP), which became effective in the middle of 2018 (House of Commons, 2016). This is offered for developments of 10 units or less and provides a more simplified planning approach aimed at decreasing the need for upfront information while lowering expenses for homebuilders (MHCLG, 2021). Once this has been granted, the technical details' consent is necessary before the development may proceed. Bevan (2017) identified this policy reform's capability to speed up the supply of housing, boost development participation, and support SMEs. The FMB (2021) survey found that only 3% of SME housebuilders believed this policy change was not useful to their firms, demonstrating that this step-change has been well received within the sector.

Local governments have seen reductions of up to 50%, with the capacity of services such as local authority planning departments severely decreased, making keeping up with developments more difficult (Remøy and Street, 2018). According to Bowie (2016), these budget cuts undermine local planning authorities' capacity to verify that developments are an acceptable response to local requirements. While Bevan (2017) believes the policy helped the government discover appropriate sites, it has also been acknowledged that the policy's implementation may result in choices on affordable housing being made too late, exacerbating the difficulties with the planning system. As a result, the RTPI (2018) has cautioned that the enforcement of policies has decreased, but not eliminated, planning risks and delays for housebuilders. The government continues to have recognised the present financial restrictions faced by SMEs by endorsing and announcing new long-term financing to support the construction of more homes. The housing delivery fund, established in 2018, consists of Homes England and Barclays collaborating to give £ 1 billion in financing to improve access to finance for SMEs (Barclays, 2018). Loans ranging from £ 5 to £ 100 million were made available to SMEs that match the eligibility requirements, which include developments of at least 10 houses, as well as proof that the development would not proceed without the finance (Homes England, 2018). MHCLG (2018) supports this approach, claiming that the available finance should increase overall investment for a development project, allowing SMEs to increase their equity and hence increase their potential to create additional houses. According to the FMB (2021), such efforts might achieve this goal due to the real benefits seen by SMEs by establishing a loan-to-value ratio of 80% compared to the existing standard offer of 60%, which could assist their production practically double.

CONCLUSIONS

Former UK government policies have either purposefully or fortuitously weakened the importance of SMEs in this prolonged housing dilemma, which has lately been recognised as a focal point. Although there does not appear to be a silver bullet solution to the intrinsic and numerous barriers faced by SMEs, three key areas (land, financing, and planning) have been often identified, which this study refers to as the "toxic triangle". The reviewed literature reveals the self-reinforcing nature of these areas and the need for them to be improved for any influence on housing delivery to be coherent. The UK government's initial actions demonstrate their determination to overhaul current practises to resolve issues prevalent within the housing industry. However, to ensure the policies have a tangible impact on the ability of SME's to grow, the issues presented by the "toxic triangle" must be dealt with simultaneously to ensure failing in one area does not impact on another.

Lastly, there appears to be an uncertainty as to whether the existing policies would resolve or further impede housing supply issues for SMEs in overcoming the "toxic triangle." Therefore, the impact of policies on housing supply delivered by UK SMEs has yet to be investigated in the actual SMEs' context. This is because the identified policies in this study have proven to lack a direct target audience as the government has mostly applied a "one-size fits all" approach. Hence, this study calls for the implementation of sub-policies that are tailored for each category of SME builder to accommodate their divergent needs, which appears to have been overlooked by the government so far. Further, this study demonstrates that the UK government's attention to the housing crisis as a cornerstone of policies has substantially departed from late 2019 onwards, largely owing to the COVID-19 global pandemic. Hence, this research believes that it is the right time to refocus on this exacerbating housing crisis.

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OFFSITE CONSTRUCTION

EXPLORING THE ADOPTION OF PLATFORM-BASED DESIGN FOR MANUFACTURE AND ASSEMBLY IN THE UK CONSTRUCTION SECTOR: A STAKEHOLDER PERSPECTIVE

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Platform-Based Design for Manufacture and Assembly (P-DfMA) is identified as the future of offsite construction and potentially a panacea to achieving the UK's construction 2025 target. However, the general understanding of P-DfMA's processes, techniques, methodology, and design is still in the infancy stage. The paper aimed to investigate the rate of awareness, benefits, and barriers of adopting P-DfMA within the UK construction sector linked to the construction 2025 targets. A triangulation mixed method was deployed using a quantitative online survey as the primary data collection instrument complemented by qualitative semi-structured interviews to corroborate and reinforce the credibility of the findings. The questionnaire revealed that 31% knew about P-DfMA, though only 6% had ever used it. The interviewees also lamented the lack of awareness. Therefore, stronger implementation strategies from the government plus stakeholders' awareness initiatives are recommended to facilitate adoption and success rate and maximise the benefits of the technique.

Keywords: BIM; construction 4.0; DfMA; lean; platform design

INTRODUCTION

The construction industry is often compelled to embrace approaches from the manufacturing industry to derive a better value. But there is little scope for substantial improvement in the current trajectory of technology and delivery process. Most of the designs are unique and require bespoke solutions. Although many components and elements of it can be standardized and automated. We generally know the requirement of space, material and typical layout of any school or hospital. Then why not generate standardised design to enhance safety, productivity, and efficiency (Kier 2019).

Design for Manufacture and Assembly (DfMA), evolved from the automobile industry aimed at improving manufacturability and assemblability. Lately, the concept of standardized platform system is visualized for the construction industry, blended with the DfMA approach to achieve ‘Platform approach to Design for

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Manufacture and Assembly' (P-DfMA). The term was initially coined by Jamie Johnston (Bryden 2017b). However, understanding the essence of competitive platforms is essential to consider the competitive trends of digital economies. In the year 2020/21, the UK government allotted around £37bn for the procurement of infrastructure and construction projects (IPA 2020). According to Construction Manager (2020) P-DfMA has the potential to meet these demands and accelerate innovation if adequately engaged.

P-DfMA are specially designed kit of parts combined to form an object (Mosca, *et al.,* 2020; Carlisle and Webb 2021). Hence same element(s) of a module or assembly can be replicated and used for different kinds of projects viz., Prison, Hospital, Residential building, etc., and curtails the need to design new components every time for a new building. Beaumont (2019) concluded that if Prisons are built on a platform approach, then it could save 33% cost and trim the construction time by 50%. Additionally, it can minimize CO2 emissions by 50% and improve the import-export trade gap by 50%. IPA (2018) and Alfieri *et al.,* (2020) also emphasized that P-DfMA can boost onsite productivity and minimize waste approximately by 90%.

However, P-DfMA presents some challenges and barriers. First, the boundaries of each platform must be defined to maximise the applicability of the component parts on platform projects. However, if the project is too complex and has too many specific components, the platform approach may be difficult to actualise (Bryden 2018). However, P-DfMA would be successful if implemented at a larger scale (Cao and Hall 2019). For this, the pipeline of projects should be stable to allow a mass production and standardisation of components (Construction Manager 2020).

LITERATURE REVIEW

Evidently, there are sufficient literature on DfMA and how it helps the construction industry in various ways. However, literature relating to 'Platform approach to DfMA' is still in infancy, being a new technique. Even though literature seem to reiterate the potentials of P-DfMA in achieving the Construction 2025 targets, it's only been implemented in very few UK government projects. Perceiving the current lack of knowledge and information about the technique amongst industry practitioners regarding its success, adoption rate, and associated challenges to help relevant stakeholders make adoption decisions. The paper attempts to breach this gap by investigating the rate of awareness, benefits, and barriers of adopting P-DfMA within the UK construction sector linked to the construction 2025 targets. Findings will contribute to the argument on adopting the technique and support the emerging discussion on enablers, drivers, and strengths of this techniques now gaining momentum within the industry.

The UK construction industry contributed £117bn to the economy in 2018 (HM Treasury 2020) but is seen to be quite a low performing as compared to other industries (ONS 2021). It was identified that the construction industry of UK added around 200 million tonnes of waste and 50% of total carbon emissions in 2014 (NBS 2018a). Around 30% of building materials and 40% of man-hours are wasted during construction adding up the construction cost of building (NBS 2018c). Fragmented process and adversarial way of working have affected the client organisations (Latham 1994), due to which the product is left with a diluted value (Bryden 2020). Earlier, Egan (1998) had asserted that the industry needs to get rid of Silo-mentality and accept change to adopt emerging technologies. A series of reports published on the nature of industry highlighted issues like cost overrun, insufficient information, reduced quality, and low productivity (NAO 2001). Farmer (2016) reviewed the UK construction industry and highlighted strong issues such as lack of collaboration, low predictability, and dysfunctional delivery model of the construction industry.

As the industry shifted to the fourth generation, manufacturing approaches became relevant to the construction process (Arashpour *et al.,* 2015; Cao *et al.,* 2021). Farmer (2016) insisted on the use of Offsite Manufacturing (OSM) methods for project delivery to create a dynamic market for innovative technologies. It was also supported by IPA (2018), HM Government (2018) and Cabinet Office (2020). Conversely, Farmer (2016) argued that the construction industry has not even shifted properly to Industry 3.0. Latham (1994) had previously stated that there was a good scope for improving the construction industry through standardisation.

Government being the major client for the UK construction industry looked for ways to modernize by 'Standardisation' (HM Treasury 2020). Cabinet Office (2020) published 'The Construction Playbook' where it embedded the adoption of MMC and OSM, where prime focus was given to standardisation. The need to magnify standardisation as highlighted by many reports became necessary to increase productivity and reduce the cost of construction. Parallelly, Construction Innovation Hub (2020) had already started working with the government and industry to develop a standardized approach called 'Platform based DfMA'.

Anecdotal evidence suggests that P-DfMA can address the concerns of Poor productivity, Labour shortage, Design, and Coordination issues, etc. It can create standardisation at a component level apart from the design flexibility at an asset level (Carlisle and Webb 2021). To summarise, the construction industry of UK is seen as resilient. But in this unprecedented time of COVID-19 pandemic, embracing technology that provides digitalisation apart from a safe working environment is essential. With P-DfMA in place, projects can be tracked effectively with low wastage of time, less labour on-site, minimal coordination and increased performance (HM Treasury, 2020; Cao *et al.,* 2021). Despite the many advantages presented in P-DfMA not much information regarding its awareness, benefits, and barriers of adopting the technique to assist stakeholders such as the government being the major clients or contractors, private sectors, etc, make adoption decision. The next section presents the methodological design adopted in this study to investigate these issues.

METHOD

The research adopts a pragmatic philosophical position which sits well with the mixed methods selected for the study. Pragmatism was selected because it allows the use of pluralistic methods to investigate a phenomenon, and considering that DfMA is a new technique, it would be helpful to deploy a robust technique to capture the reality of the subject from different stakeholders. Firstly, a critical review of the literature was conducted to explore the subject of awareness, benefits, and barriers of adopting P-DfMA. Sources of the secondary data were derived from books, government reports, peer-review journals, and conference proceedings certifying their reliability for the study.

Emerging themes from the review are presented in Tables 1 and 2 respectively. The main benefits of adopting P-DfMA as revealed in the literature are health and safety, sustainability, labour, cost, productivity, time, and quality. On the other hand, the main barriers of adopting P-DfMA are project pipeline, government assistance, skills, standard guidelines, procurement, and resistance to change. Themes from the review were then designed into the questionnaires and interviews that were conducted for further investigation. A convergent triangulation mixed method was deployed using a quantitative online survey as the primary data collection instrument complemented by qualitative semi-structured interviews to corroborate and reinforce the credibility of the findings.

The online questionnaire was designed using google forms, and a link to complete the questionnaire was published on a professional social media platform. The study adopts a non-probability quota sampling technique, and the population targets are professionals within the construction sector, mainly architects, engineers, contractors, and clients, and sixty-four responses were received in total. In addition, four semi-structured interviews were conducted with highly experienced professionals identified via a snowballing sampling strategy. The snowball technique is a purposive sampling strategy and helps identify hidden population (Gray, 2018). This is justifiable because PDfMA is a new technology, and very few people are aware of it. Hence, targeting the unaware professionals was of no use in the qualitative data collection.

FINDINGS

Online Survey

The link to the survey questionnaire was posted on a social media platform, therefore there were few respondents out of the UK, even though it was highlighted that the survey is only for UK construction professionals. 64 responses were received but only 53 responses were UK based which was considered for this study. Respondents were asked to mention their level of education to understand the intelligence and reliability of the responses. 12.5% of the total respondents were PhD qualified, 39.1% were Master’s degree holders and 34.4% had Bachelor’s degree depicting that respondents were highly qualified personnel. Respondents were asked questions relating to their job title and the sector they worked. Results revealed 20 respondents were architects, 20 engineers each, 14 were contractors, 9 were clients and 1 fell under the others category. In summary, majority of respondents were architects and engineers working in the consultancy and engineering firms respectively. Others were educators, planners, builders, QS working for contractors and client's organisation. In terms of experience, only one quarter (16) of participants had less than 7 years of experience in construction field. 19 (29.68%) respondents had 8 to 15 years and 16 to 25 years of experience respectively. Moreover, 13 (20.31%) participants had 26 years of experience indicating that highly experienced individual completed the survey, and their responses can be trusted.

Awareness and Adoption of P-DfMA

61% (n=39) participants were unaware of P-DfMA approach. 8% (n=5) respondents expressed uncertainty by selecting ‘Maybe’. Perhaps, they were aware of the typical DfMA only and not P-DfMA. Furthermore, 31% (n=20) participants indicated their awareness of P-DfMA as depicted in Figure 1. However, more than three-quarter of the professionals who were aware do not use it or have not yet adopted it. 16 out of those 20 were "just aware" and remaining 4 have adopted this innovative approach in their organisation.

The question therefore acted as a checkpoint designed to end for the ones who selected ‘NO’ or ‘MAYBE’ because surveying respondents without an awareness of P-DfMA approach will not be beneficial for this study. Hence, the survey continued only for those who were aware, i.e., 20 participants who responded ‘YES’.

Table 1: Benefits of adopting P-DfMA

Theme	Benefits And Literature Sources
Health and Safety	Platform approach improves H&S at both on-site and offsite construction Increases safety on-site; Minimized manual lifting onsite keeps workers safe; Improved H&S due to offsite construction; Reduces the need to work at heights
	(Oti-Sarpong and Burgess 2020); (Bryden 2017b; 2020)
Sustainability	Pre-tested and quality-controlled components prevent on-site waste generation; Environmental impact is reduced due to less CO2 embodied components; Considerable reduction in embodied carbon per square metre; Supports low carbon designs; Will help in achieving Net zero well before 2050; Greenhouse gas emissions are reduced
	(Bryden Wood, 2017b; 2020); (Carlisle and Webb, 2021); (IPA, 2018)
Labour	Setting manufacturing hubs in underprivileged areas can address skill deficit by utilizing local workers; On-site labour-intensive work is reduced; Less requirement of on-site skilled workers
	(Bryden Wood, 2017b); (Carlisle and Webb, 2021); (IPA, 2018)
Cost	P-DfMA follows Design to Value; Cost-saving due to manufacturing mindset; On-site skilled labour is more expensive than off-site low skilled labour
	(Bryden 2017b; 2020); (Carlisle and Webb, 2021)
Productivity	Improved productivity: The logistics of the supply chain are streamlined; Highly efficient manufacturing and on-site productivity
	(Bryden Wood, 2017b); (Carlisle and Webb, 2021); (IPA, 2018)
Time	Components arrived on site can be installed quicker with snap-fit or plug; Embracing Lean construction facilitates JIT delivery with no breaks in the supply chain; Increased speed of construction
	(Mosca *et al.,* 2020); (Bryden, 2020); (IPA, 2018)
Quality	Using common standards and platforms improves the quality of material produced
	(Bryden, 2020)

The survey however prompted respondent who answered "just aware" with a follow question to probe their use of contemporary construction methods. Results reveals 43.75% (n = 7of 16) respondents of these respondents were still stuck on traditional methods and only 25% (n=4) and 18.75% (n=3) were using typical DfMA respectively, and 12.5% (n=2) used componentised panelised solutions. The results therefore indicates that just awareness does not translate to use, or adoption as traditional methods of construction are still predominately in use.

Strengths of P-DfMA linked to Construction 2025 goals

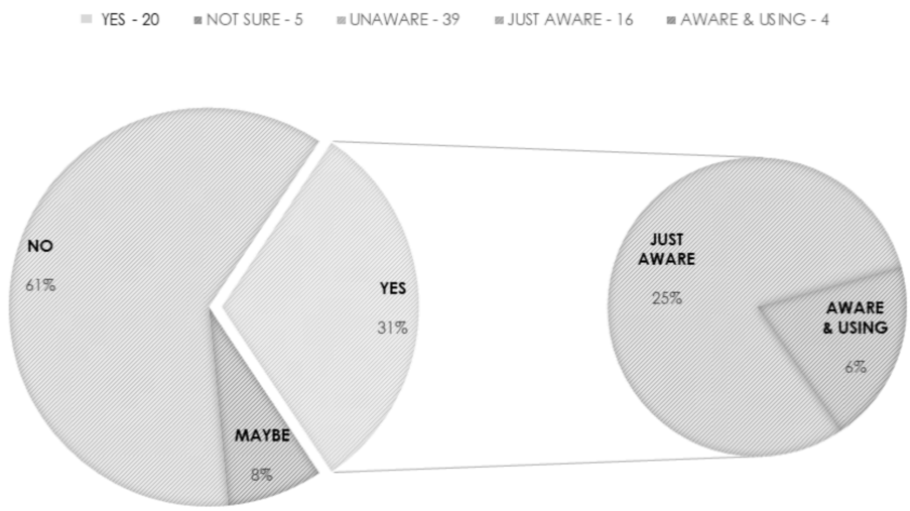
Only the 20 participants that indicated their awareness of P-DfMA were allowed to answer further question relating to the methods ability to attain the four Construction 2025 goals. The 20 participants were asked to rate their agreement to individual goals of Construction 2025. Each goal was measured on a five-point Likert scale to determine the level of agreement where '1' represents 'Strongly Disagree' and '5' represents 'Strongly Agree'. The first goal is termed as 'Cheaper', the second as 'Faster', third as 'Greener', and fourth as 'Better'. Statistical Package for Social Science (SPSS) and MS Excel were used to analyse the 'Frequency Distribution', 'Central Tendency' i.e., the mean and standard deviation and 'Variance/Dispersion'. The central tendency and variance of the distribution results indicates that "Cheaper" had a mean of 3.85, "Faster"3.84, "Greener" 3.65, and "Better" 2.70. It is notable that all four goals have mean ranging from 2.70 to 3.85, which indicates that the agreement levels range from moderate to near high level of agreement. On averaging

(3.51) all four aspects, it can be deduced that respondents agree that P-DfMA can help achieve the Construction 2025 goals.

Table 2: Barriers to adopting P-DfMA

Theme	Barriers And Literature Sources
Project Pipeline	Long-term pipeline of work is required; Clear and coordinated plan is required by the government; Requires a huge pipeline and scale
	(IPA, 2018)
Government Assistance	The results must be awarding enough to take risk; Intellectual property rights need to be defined; Government needs to regulate intermediate authorities' agenda to adopt this at a wider scale
	(IPA, 2018)
Skills	Contractors need to upskill existing or hire new workers with manufacturing knowledge; Different job skills in the labour force; On-site tasks of assembly require new skillsets
	(IPA, 2018); (Oti-Sarpong and Burgess, 2020)
Standard Guidelines	Open-source standards are required for everyone's contribution; No information about warranty and insurance of products makes it risky to buy; Planning process like RIBA needs refinement to accommodate DfMA approach; Components should be highly repeatable to be manufactured by a wider supply chain
	(Bryden Wood, 2017b); (Oti-Sarpong and Burgess, 2020)
Procurement	Traditional procurement does not seem to work with the P-DfMA approach. Hence, new procurement method is required
	(IPA, 2018); (Oti-Sarpong and Burgess, 2020)
Resistance to change	Convincing contractors who are risk averse is difficult; Due to financial issues, Client and Supplier may hesitate to change; Radical change is required within organizations to adopt P-DfMA (Mosca *et al.,* 2020); (Bryden, 2020); (IPA, 2018)

Figure 1 Awareness and adoption of P-DfMA



Benefits and Barriers of P-DfMA

Apart from the strengths, participants were asked to select top five benefits of P-DfMA. Figure 3 shows that all 20 participants aware of P-DfMA selected 'Minimized Waste' as one of their top benefits. As expected, "reduction in capital expenditure" was also selected almost by all (17). The remaining top benefits are Lower requirement of onsite workers (13), Increased productivity (12), and Improved H&S (9). Similarly, respondents were asked to select the top five barriers preventing the adoption of P-DfMA to understand the problems of non-adopters and adopters alike. Results are revealed in Figure 1 and indicates that "Lack of awareness" is a major barrier. Even though awareness does not usually translate to adoption as indicated earlier. Stemming from the fact that only a tiny percentage of those who claim to be aware of the technique are using it in reality. Many (19) expressed their concern on "requirement of project pipeline" for adopting P-DfMA, followed by "Lack of government assistance" (18), "Lack of government guidelines" (15), and "Lack of available training" (15), as a major barrier to adopting the technique.

Interviews

Four interviewees were interviewed in total. Demographics shows that two participants were a design manager and director with approximately 20- and 25-years industry experience. The other two were client relationship officer and computational designer with approximately 10- and 5-years industry experience respectively. Similarly, interviews were asked questions relating to adoption, benefits, and barriers to corroborate the findings from the survey. Emerging themes from the thematic analysis adopted are constraints, acceptance, and competence. For anonymity, respondents were denoted with Design Manager (AR), Computational designer (EN), Director (CO) and Client (CL).

Competence

All the interviewees agreed that the process saves considerable cost and time and is therefore very valuable. 'AR' exclaimed "This is a superfast process". However, 'EN' had an argument here- "The design process with P-DfMA took longer than the traditional way…But…Manufacture and Assembly phase ended before schedule". With respect to sustainability, there was a consensus that there is enormous reduction in waste, which was not so surprising as it was seen in both literature and questionnaire survey (IPA 2018; Alfieri *et al.,* 2020).

Constraint

Participants were questioned of any negative impacts of implementing P-DfMA. Based on nature of work, both 'AR' and 'EN' expressed their fear of structures looking very standardized in terms of aesthetics. Basically, their concern was to keep design very flexible and less prescriptive. 'CL' pointed out his fear saying, "few job/roles will be vulnerable to this change in approach". But later claimed that "…it will be mitigated with requirement to new roles". As expected, 'CO' was concerned with the blockage of capital cost and wishes a strong pipeline of projects where risk is worth. Interviewees expressed that this could be mitigated by government assistance. Though 'CL' disputed that Planning and building control bodies would need high level amendments to accommodate this. 'AR', 'CO' and 'CL' asserted also that government funding and incentives may help. Also, all of them mentioned that training and upskilling is highly required.

Acceptance

Participants were questioned about the success rate of this approach in terms of both awareness and adoption. There was consensus amongst all four respondents claiming that the awareness itself is very low. 'CL' emphasized that "…not a single client…has an existing knowledge about such thing". Keen to know what motivated them along with the changes and duration required for this implementation, productivity issue was raised. 'EN' and 'CO' highlighted their individual issues like lack of collaboration and repeated waste of time in coordination were the major reason that motivated them to change. 'CL' was convinced by an architect for his project estate as he had series of them upcoming. 'AR' reported that it took them nearly six months only after examining their internal organisational standards. He added, “We…implemented partially…it keeps on evolving over time”. Similarly, the organisation where ‘EN’ works embraced it quite rapidly. As ‘CO’ and his company were involved with the design of platform components, it took them 2 years in adopting it effectively. Incentives was highly concerning to all four respondents. ‘AR’ expressed that “…the risk is worth” if they get incentives for every project. “…incentives are required to lower risks”, ‘CO’ asserted.

CONCLUSIONS

A robust research investigation has been deployed to investigate the subject matter and fill the gap identified in the literature. After a thorough analysis, the awareness and adoption of P-DfMA approach is remarkably low and critical steps need to be taken to increase usage. There were surely some challenges and barriers observed in the literature and primary data, but many of them can be mitigated and the government has a critical role to play in actualising the wider use. The benefits of P-DfMA however cannot be over emphasised as demonstrated in the triangulated methods adopted and could help contribute to the delivery of the construction 2025 goal. A major recommendation, however, is a call for a stronger implementation strategy from the government plus stakeholders' awareness initiatives to facilitate adoption and success rate and could be a significant step in achieving the UK's build back better agenda if taken seriously.

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BARRIERS TO THE IMPLEMENTATION OF MODULAR CONSTRUCTION IN IRELAND: A CASE STUDY FROM AN IRISH SMALL AND MEDIUM-SIZED ENTERPRISE PERSPECTIVE

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Traditional construction has begun to struggle with societal demands. Modular construction and pre-fabrication have been studied, providing clear insight into their capabilities. An absence of research based on modular construction in Ireland is evident. The aim of this study is to identify the factors that are inhibiting modular construction adoption in Ireland. A qualitative research method is applied, using 6 semi-structured interviews with the target case study. The firm is based in the southwest of Ireland, with an annual turnover of €10 million, with 55 staff employed. Findings from this pilot study show that the barriers are varied yet subjective to the firm. It is evident that education and knowledge is a core solution to overcoming these barriers. It is recommended that modular workshops should be implemented for academia and industry to fully comprehend what volumetric modular is and its capabilities.

Keywords: constraints; innovation; off-site production; prefabrication

INTRODUCTION

Modular construction is a technique that can transfer the construction process into an off-site setting allowing work to concur in a parallel form. The benefits of modular construction are widely researched and reported, highlighting significant gains in projects such as increased productivity, reduced life cycle cost and accelerated construction pace (Wuni and Shen 2020). Furthermore, empirical studies have established that modular construction is more environmentally friendly when compared to traditional construction techniques (Mao *et al.,* 2013). These benefits are recognised across the construction community, with modular construction projects being incorporated across the world in areas such as Spain, Australia, Hong Kong, and the United Kingdom (UK).

Modular construction can be categorised in many different techniques such as prefabrication, preassembly, off-site production, volumetric modular and other ranges of off-site and onsite construction methods (Rahman 2014). For the purpose of this investigation, volumetric modular will be the construction method examined.

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Primarily looking at the barriers preventing it from being integrated in Irelands construction industry, specifically within Small and Medium sized Enterprises (SME's). The purpose of solely investigating volumetric modular is due to the fact that this is a relatively new concept within the Irish industry. The study also focuses on SME's due to them making up majority of the construction firms in Ireland (92.4%) (Central Statistics Office 2014). A small enterprise is defined as a company that does not exceed €10 million annual turnover and has less than 50 employees. Similarly, a medium sized enterprise is defined as a company that does not exceed €50 million and has 50 to 249 employees (Enterprise Ireland, 2022).

In volumetric construction projects, modules are fully fitted with walls, ceilings, floors and all furniture, fittings, and equipment (Hwang *et al.,* 2018). In addition, these modules are transported from the manufacturer to the project site for installation. This type of construction thrives on projects with design features that are repetitive such as prisons, hotels, schools, and hospitals (Hwang *et al.,* 2018). Despite this, countries such as Japan have adapted to the constraint of its design. Linner and Bock (2012), identify that Japan has one of the strongest construction industries globally, producing approximately 150,000 housing units per annum that are constructed in an off-site setting. Furthermore, their research identifies that approximately 15% of Germanys housing output is prefabricated while Austria's prefabricated housing output is 33% (Linner and Bock 2012).

Academic research on Irelands modular construction sector is limited. The traditional construction technique still thrives in Ireland despite the often-inadequate results that it produces. PricewaterhouseCoopers (2019), report on the National Children's hospital, highlights that the project expenditure has increased by 450 million euro. Additionally, the project timeline has increased by a minimum of 16 months. This example provides a very brief insight into the traditional construction methods that take place in Ireland. Subsequently, the purpose of this study is to explore the constraints that prevent contemporary construction techniques such as modular construction from being used in Ireland within SME's.

It is critical to question why these methods are not being adopted despite the success of modular construction in neighbouring countries like the UK. Taylor (2020) has demonstrated that the UK's modular sector is growing at a slow but steady rate. In 2010, the value of the sector was 6.5 billion pounds (Taylor 2010); however, the sector in 2020 was approximately 6.78 billion pounds (Taylor 2020). A significant element in the adoption of modular construction in the UK was a government backed mandate on the use of modern methods of construction. In this mandate, the UK Government is providing financial support of £2.5 billion to support builders who use modern methods of construction (Ministry of Housing, Communities and Local Government, 2019). The improvements that have developed in the UK and Europe unfortunately, have not taken place in Ireland. Previous studies have looked at the barriers towards modular construction in countries such as the UK, United States, China, and Europe, however, studies based on SME's particularly in Ireland are lacking. Thus, this pilot study, which is at the beginning of a wider research project, aims to identify the factors that restrict modular construction adoption within SME's in the Irish construction industry.

Barriers Towards Modular Construction

Barriers that prevent modular construction from being adopted in the construction industry is an area that has received a considerable amount of research. However, research into this area within the geographical location of Ireland is scant. Nonetheless, regions such as the UK, China, Japan, and the USA have experienced significant research despite very little research being conducted specifically on SME's. Upon completing an extensive literature review, six key themes are identified that are seen as major barriers to the adoption of modular construction. These barriers are identified as; Financial, Design, Knowledge and Skill, Transport and Storage, and Technology.

Financial

When analysing the barriers, costing appears to be an issue that emerges frequently. Rahman (2014) explains from a manufacturing point of view, how the cost of initial set up is extremely high. Furthermore, he states how the construction cost per unit can become expensive if the demand for modular components is low. A fluctuating market is not a fitting environment for start-up manufacturing. Wuni and Shen (2020) state that the early upfront financial commitment compromises the SMEs ability to compete in the industry despite these firms dominating the construction industry. Furthermore, Wuni and Shen (2020) consolidate the issue of the hard-to-achieve economies of scale based on the high initial capital investment. Modular construction can appear to be more expensive initially; however, Zhai *et al. (*2013) states that decision criteria used by firms is primarily cost based rather than value based. Furthermore, the study identifies houses built by modular practices tend to be observed as low-income options which effects the marketability of modular construction (Zhai *et al.,* 2013).

Design

Design flexibility within the traditional construction methods is attractive for architects and clients alike. Modular construction has been associated with the attributes of monotonous design, limited flexibility, and complex maintenance (Zhai *et al.,* 2013). Hwang *et al. (*2018) conducted a case study on a modular project in Singapore. In the research, it states that the project only allowed for limited opportunities to change design. Furthermore, design and planning had to be finalised before any work commenced leading to a lot of additional work (Hwang *et al.,* 2018). Polat (2008) identifies from his study that 62% of designers agree that prefabricated elements somewhat restrict their architectural creativity. These remarks are contradictory as modular construction is excellent from a design perspective for projects such as prisons, hotels, schools, and hospitals where the design is repetitive. Despite this, Rahman (2014) consolidates the views that modular construction is exposed to an inflexibility for late design changes and an early design freeze amongst stakeholders. Albeit these are noted as barriers within the research, opportunities may be available to the construction community to use these scenarios to their advantage.

Knowledge and Skill

The lack of in-house and industry experience surrounding modular construction is an issue that has been widely reported. Jaillon and Poon (2010) conclude that these are major limitations to the modular construction process from an architect's perspective. Furthermore, Rahman (2014) illustrates that the lack of adoption of modular techniques is due to the lack of experience and skills surrounding them. Many construction workers in the industry have little or no experience working with modular construction techniques. Potential clients incorporating modular construction may have to front load a project while also investing in training for operatives. This financial burden has the capability to change a client's route to a more conventional construction technique.

Azhar *et al. (*2013) present in their findings a critical constraint which is "owners' wrong conception". This barrier links with design and cost as clients who do not fully understand how modular techniques perform will delay design and generate a larger outlay. Moreover, the sustainable development of the modular sector may suffer due to the current workforce being transferred from traditional techniques to modular practices (Cheng and Ma 2020). This concern delves deeper by explaining that these professionals will not have the capacity to enhance the modular sector due to them not being taught the practices at a more fundamental level, which displays the need for education systems to upgrade their curriculum.

Transport and Storage

The transportation and storage of large construction elements can be an expensive undertaking. Studies identify that transportation and storage of modular elements to be a huge concern and barrier towards its adoption. Jaillon and Poon (2010) establish that precast element storage accounts for approximately 22% of a sites floor area. This is a significant amount of storage space needed on site, particularly if building within cities or congested areas. Additionally, Hwang *et al. (*2018) identifies the requirement of approval from transport authorities in Singapore to transport their modules. The approval is required 3 days before the intended day of travel. This requirement combined with congested urban areas leaves stakeholders with additional costs and additional burden. Just-in-time delivery is suggested as a solution to this dilemma; however, relying on local authorities to provide passage can be unpredictable. Polat (2008) states that the cost of transportation is directly proportional to the number of truckloads used for delivery and the cost per unit for delivery. Furthermore, Polat (2008) confirms the constraint of transport authorities' regulations with regards to allowable weights capacities, load sizes and tunnel and bridge restrictions. These are indirect factors which may not be initially investigated when choosing construction technique and could potentially lead to higher unforeseen costs footed by the client.

Technology

Technological issues are systems that are not in place or have been altered from the traditional process to serve the modular construction technique. Blismas and Wakefield (2009) indicate in their study that the low levels of information technology integration in Australia has hindered off-site adoption in the industry and has made it uneconomical to use off-site construction processes. Interfacing between components is a constraint which has been highlighted in numerous studies. Wuni and Shen (2020) describe that modular construction requires complex interfacing between modules. The study also explains that technological barriers are generally seen in developing countries, while countries such as the UK, China and Australia rarely encounter these technological issues. Rahman (2014) identifies that if modular practices are combined with traditional techniques, then interface issues are inevitable. This is due to the high tolerance procedures used in factories compared to in-situ practices on-site, causing interface issues when attempting to integrate both components on-site. Additionally, Cheng and Ma (2020) state in their research how an information integration system is vital within prefabrication projects. This can be achieved by incorporating systems such as Building Information Modelling (BIM) within the project. Taking this into account, the issue of BIM adoption and level of maturity within Ireland is cause for concern.

METHOD

This pilot study is at the beginning of initial research, to evaluate the validity of the research topic for further examination, which aims to contribute to both academia and industry. This research paper as part of a wider research project has received ethical approval from the research ethics committee in the University of Limerick. To analyse the barriers that prohibit modular construction from being adopted by SMEs in Ireland, a qualitative research method is selected. The research method is founded initially on an informative literature review. This is followed by a case study which encompasses six semi-structured interviews with industry professionals. The case study has been in operation for over 40 years in the rental prefabrication sector. The firm is now servicing the volumetric sector for over 12 months. A semi-structured interview process is adopted due to the flexibility that it provides to the participants, as it allows a focused investigation of previously identified factors yet allowing participants to identify issues that are not yet disclosed in the literature (Brooks *et al.,* 2016).

Furthermore, this method allows questions to lead from one to the next, providing the interviewer with as much information as possible. The interviews are conducted face-to-face. An open-ended format is used which generated in-depth discourse about prominent issues that faced the SME industry when trying to adopt modular construction. Questions are developed from the literature, taking themes from studies completed in different countries. However, the participants lead the discussion into areas and topics that they felt are of significance. Participants are selected based on criterion selection; minimum of 1 year of current experience working within the Irish modular construction sector, minimum of 10 years' experience within the construction or manufacturing industry, and status of the company they are currently working for (SME).

The interviewees provide their opinion on the barriers that prevent modular construction from being implemented within SMEs in the Irish construction industry. The identities of the participants involved will remain anonymous and confidential information is not revealed. To ensure non-bias, each interview follows the same process, ensuring that instructions provided is identical, provided in the same order and with equal meaning, providing comparable data. The interviewees are all male, who have worked a minimum of 1 year within a modular sector, with minimum of 10 years' experience in construction or manufacturing. Each interview is transcribed once completed. Data is extracted by analysing each response and subsequently identifying any themes provided by the interviewees. The themes are coded, and any key terms and similarities are organised and listed below.

FINDINGS

The interviews commenced with gaining general background information on each participant followed by a discussion on the modular sector in Ireland, its constraints, and the issues they face as a company. All the resultant data from each interview is amalgamated and thematically analysed. Keywords, themes, and topics are identified for discussion. A summary of all the key issues is illustrated in Table 1. The results illustrated are specific to this case study, thus should not be seen as a generalised view of the industry. However, this study provides a foundation for further investigations to be carried out on the issues that surround modular construction in Ireland.

DISCUSSION

The data and subsequent analysis have been able to provide insight into the barriers that hinder the progress and implementation of modular construction in Ireland. Much of the existing literature in this area comes from sectors outside of Ireland; however, the data gathered did not coincide with all the literature reviewed. Nineteen key factors are derived from the interviews with "Lack of knowledge of modular construction in Ireland" and "Keeping a continuous schedule of projects" being among the most prominent.

Financial

A notable issue that is discussed at length is the continuity of pipeline of projects that the company must sustain. Rahman (2014) holds the view that the small market demand controls the capacity of manufacturers, thus effecting the cost of production. Fortunately, the company is currently delivering for a public sector contract that allows them to plan 6 months ahead. This provides them with a comfortable lead time to work to. Both interviewee B and C note that weekly meetings are held to ensure an appropriate number of projects are scheduled.

Table 1: Factors and Interview Results

		Interview A	Interview B	Interview C	Interview D	Interview E	Interview F
Financial	Capital cost of firm overheads	X		X		X	
	Capital cost of manufacturing	X		X		X	
	Variations in design prove costly					X	
	Keeping a continuous schedule of projects	X	X	X			
	Fixed price contracts not sustainable currently	X				X	
Design	Fire rating of the modules is difficult to achieve		X				
	Residential sector too intricate to enter		X	X			
	Certification system can impede design		X				
	Stakeholders do not like standardisation				X		
	Trying to achieve standardisation within design and manufacturing		X	X	X	X	
	Transport restricts design				X	X	
	Material selection restricts design				X	X	
Knowledge and Skill	Lack of knowledge of modular construction in Ireland	X	X	X		X	
	Stigma surrounding the modular system by clients		X	X		X	
	Skilled labour shortages		X			X	
Technology	BIM disruption with smaller jobs	X			X		
	BIM diffusion is low in Ireland				X		
Transport and Site	Restricted site access						X
	Underground services cause disruption to module installation						X

The manufacturing director explains that in times of low demand they begin manufacturing modules that are 50% finished and then stored until a contract is initiated. The modules are then completed as per clients' specifications (Education, healthcare, pharmaceutical etc.). This allows manufacturing to remain at a stable rate and prevent a stop-start scenario as is the case with many construction projects. Furthermore, "Capital cost of manufacturing and firm overheads " was an issue that was raised. The participants state how this cost is a determining factor for a company to prosper or collapse. The case study uses their rental business as a backup if the cashflow from the modular division is reduced. This safety net is a unique scenario that other companies do not have the opportunity to obtain. Major costs for a modular company are the factory and machinery (Rahman 2014). The case studies facilities were already acquired reducing the capital cost, allowing them to focus on other key areas. Additionally, the current cost of materials is stated as a massive barrier, however, this may be seen as a barrier across the entire construction and manufacturing industry.

However, this cost rise has created a scenario where fixed price contracts are no longer suitable for projects. Interviewee B and E states that the fluctuations in materials and labour cost are too volatile to sign a fixed price contract. Furthermore, variations in the design are a costly expense which interviewee E expresses as a concern. The solution to this is a standardised design which uses the same materials and components continuously.

Design

Overall, seven issues are highlighted with regards to design. To begin with, interviewee B notes how the certification system in Ireland may inhibit their design capabilities. They are currently certifying the modules through the BCAR (Building Control Amendment Regulations) system which allows them flexibility within their design by certifying each individual element that they use in the module. They are considering achieving an NSAI Agrément cert, however this solidifies their design removing the flexibility they achieve with BCAR. The BCAR system must always be used for certification; however, an Agrément cert treats their module as a whole entity that has been tested accordingly and gives confidence to the client. This certification is expensive to ascertain and removes adjustability of the module. The participants note that they are weighing the positives and negatives of the certification and will decide on it once they develop their module further.

Furthermore, fire rating regulations in Ireland are enforced by fire officers in each county. Interviewee B notes how they encounter a scenario where different fire officers interpret the technical guidance documents (TGD's) differently regarding fire rating within the modules. This is difficult for the manufacturing division, as the fire rating is subjective to the fire officer in charge at each project. The difficulty arises when modules arrive to site and the fire rating is deemed unsatisfactory, leading to re-work, lost time, and additional costs. The frustration with trying to achieve a solid standardised design and construction system is heightened with this issue. Standardisation within design and manufacturing is noted in the interviews as one of the key goals they want to achieve. Currently, interviewee C believes they provide too much flexibility to their clients, which curtails their modular process. If they could achieve a standardised design with modules, they would increase their productivity and construction time whilst reducing variations. This is intriguing as Zhai *et al. (*2020) notes the lack of flexibility is a barrier for modular construction.

However, it is apparent they are working out the trade-offs with design and manufacturing, determining which solution works to their business model best. It is stated that that the case study wants to ensure the client has control over their project, yet they want to limit variations and scenarios that increase construction time and cost. This is particularly difficult as the client's design teams are noted for not being in favour of standardised elements. Finally, interviewee B and C both agreed that the residential sector is too intricate to enter for them currently. The design and manufacturing of the modules would only be successful if it consisted of a large project with 3 or 4 house designs. This type of project permits economies of scale to be achieved. However, the manufacturing capacity required for this size of a project far exceeds what this case study company can obtain currently. The participants note how other sectors such as healthcare, pharmaceutical and commercial are much more applicable to their modular systems. This is ultimately due to the design of the modules, as these sectors utilise spaces with large open areas.

Knowledge and Skill

The case study participants continually state how the lack of knowledge surrounding modular from a client's perspective hinders their marketability. The main time advantage that modular offers is lost through lengthy discussions on what modular construction can achieve for the client. This view is seen in Azhar *et al. (*2013) study where the wrong conception of modular is established as a key barrier. Furthermore, the participants state that clients want to use modular as a construction technique, but they do not know why they are choosing modular. This creates extreme time delays and often removes the advantage of using modular construction in the first place. All participants agree that a government led approach, like the UK, would benefit the industry immensely. Interviewee's B, C, and E states that "Stigma surrounding the modular system" is a cause for concern. This issue is stated by Zhai *et al.,* 2013 study, as modular systems can be seen as options for the low-income demographic. It is stated that this is an issue which will develop for the company as they begin to service private contracts. Both interviewees A and B agree that they have witnessed clients assuming that these systems are "shoddy" and "flimsy". To counteract these perceptions, knowledge and education is required as is indicated in Hwang *et al.,* 2018 study where owners and developers do not fully understand the capabilities of modular construction.

Technology

Building Information Modelling is a process that the case study uses regularly in their design, manufacturing, and construction process. BIM 360 and Navisworks are the primary software's that are utilised within the company. Interviewee's A and D state that they experience disruption to their BIM process when servicing much smaller jobs in rural Ireland. This issue is highlighted by Wuni and Shen (2020) as they note the lack of synergistic information platforms challenge collaborative working among stakeholders. Interviewee's C and D states that BIM level 2 is not being achieved at all in their experience. Furthermore, BIM diffusion in Ireland is stated as extremely low, while the lack of in-house experience across architects and engineers is evident.

Transport and Site

Interviewee D describes that the fundamental barrier which restricts volumetric modular is the sizing of the modules. Bridge heights, road weight capacities and module sizes are the definitive constraints that reduce the design and constructability of volumetric modular. The design elements of the module also restricts its marketability. Hwang *et al. (*2018) note in their study that design is limited by transportation restrictions which is evident in the case study. The module cannot be constructed from mass concrete as it would over the legal weight limit for haulage, however it must be a robust system that can undertake a significant amount of stress. Achieving this balance is challenging. Furthermore, Interviewee F states the difficulty in working with congested or restricted areas. Underground services prove troublesome for the installation, while organising crane and haulage is a task that requires significant planning among all stakeholders.

CONCLUSIONS

This exploratory study focuses on the barriers that impede modular construction in Ireland with regards to SME's. The case study provides an essential glimpse into the industry and the constraints that they encounter. Even though traditional construction is still thriving in Ireland, modular techniques are on an upwards trend. From the analysis carried out, nineteen key constraints are identified with "Lack of knowledge of modular construction in Ireland" and " Keeping a continuous schedule of projects " being among the most highlighted. The case study data suggests that the problems associated with utilising modular construction are varied and subjective to the company. The company in question is unique due to them being involved in prefabrication for the past 40 years, allowing them to ascertain valuable knowledge about the industry. The interviews provide insight into key concerns and limitations that are subjective to them, such as their efforts to achieve fire rating or their intention to obtain an Agrément certificate and the ramifications that may have on their design capabilities.

Despite these issues, one of the main concerns that was highlighted was the lack of knowledge and education Ireland obtains with regards to modular construction and its potential. It is recommended that to combat this lack of knowledge, companies such as this case study should target educational institutions. Workshops that provide essential information on what modular construction is, its capabilities, and the issues surrounding it, would help overcome many of the issues highlighted above. Overall, the key contribution of this study highlights that many of the issues faced are subjective and complex to the firm, however, this study only focuses on one company, reducing the overall geographical area covered. A wider array of participants and case studies is necessary to obtain a better analysis of the Irish modular industry which is the next stage of the research. The data provided in this study provides support for further research to evaluate the modular industry. Furthermore, this study aims to provide insight for academia and industry into the barriers that are constraining the modular industry in Ireland.

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MANAGING INTERFACES BETWEEN OFFSITE AND ONSITE CONSTRUCTION

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Discrepancies such as tolerance mismatches during the incorporation of offsite components into onsite construction can give rise to buildability problems. This results in considerable rework and subsequently causes delays and cost increases. Improving current knowledge of these discrepancies could help reduce buildability problems. One important challenge in this regard is related to effective knowledge exchange across structural and organisational boundaries in construction projects. This study explores how knowledge in these boundaries is activated and exchanged. Distributed Situation Awareness (DSA) theory, as a sociotechnical tool, was used to focus on knowledge distribution between project parties. Semi-structured interviews with construction participants managing offsite construction projects in the UK were carried out. The preliminary findings show that different trade specific standards from suppliers can give rise to tolerance mismatches. The expected contribution of the study is on practical project management insights into ways of designing and managing interfaces in offsite construction to facilitate knowledge exchange related to discrepancies.

Keywords: offsite; tolerance mismatch; buildability; distributed situation awareness

INTRODUCTION

Offsite construction (OSC) offers a sustainable approach in solving time, cost and waste challenges and leads to improvement in quality and productivity (Goulding *et al.,* 2015). However, there is slow uptake of OSC and one of the contributing factors is argued to be buildability problems arising from discrepancies (such as tolerance mismatches). The challenges of fitting offsite components with each other and/or with in-situ construction cause delay and rework (Arashpour *et al.,* 2020).

Buildability problems may also in turn negatively impact on building performance in-use relating to, for example, the ongoing robustness of joints between the physical components to ensure aspects such as watertightness, fire safety, airtightness and a range of other performance aspects throughout the building life cycle (Tang *et al.,* 2020). While buildability and long-term building performance are related, the particular focus here is on how well offsite components fit together with onsite construction during the construction process.

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Improving current knowledge of organisational and technical interfaces between offsite and onsite construction can help reduce discrepancies that cause delays and cost increases. One key area is by exploring how distributed and embedded knowledge can play a critical role across project teams (Bosch-Sijtsema and Henriksson, 2014; Liu *et al.,* 2022), when offsite products are being incorporated into onsite construction. Drawing on Distributed Situation Awareness (DSA) theory, the study explores how knowledge related to discrepancies that effect buildability problems is activated and exchanged between the designers, manufacturer, main contractor, and subcontractors. DSA is used to allow for the mobilisation of a sociotechnical approach and focuses on knowledge distribution and interaction or coordination between the different parties involved. Considering practitioners' lived experiences in projects as knowledge, its exchange to turn into distributed awareness has been examined.

LITERATURE REVIEW

Buildability is mainly concerned with the dynamics of the building works and solutions to putting together a complex of building materials, elements, and sub-assemblies. Ferguson (1989) defines buildability as the capacity to construct a building efficiently, economically and to agreed quality levels from its constituent materials, elements, and sub-assemblies. He highlighted that special attention should be given to interfaces because of the connection challenges which could result in project delays and high costs.

Referring to Ferguson's point, interfaces in offsite construction (OSC) are problematic and less forgiving in comparison to traditional construction because of the associated tolerances (Shahtaheri *et al.,* 2017). Construction tolerances are described as the allowable variations of materials and components from nominal values/design specifications (Ballast, 2007). Tolerances ensure that the interfacing physical components fit together reasonably well taking into consideration buildability aspect (minimising the need for costly remedial work and quality issues) and future building performance (water tightness, air tightness and fire safety). In traditional construction, tolerance issues are handled element by element, and there is the opportunity to control and correct the tolerances as building progresses. OSC products/elements have highly restrictive construction tolerances and the points where tolerances can be controlled are fewer.

If tolerances are not properly understood and coordinated in OSC, tolerance problems can rapidly accumulate (Shahtaheri *et al.,* 2017). Arashpour *et al.,* (2016) through a simulation of two construction projects argued that the integration of offsite and on-site construction can cause deviations from plans and delays. The authors' research was derived by a study of Australian house building projects. These authors, based on the Australian Bureau of Statistics (2015), indicated that the average house completion time had not been shortened, despite using offsite manufactured elements. Arashpour *et al.,* (2016) claim that one of the main contributing factors in this is related to tolerance management between offsite elements/products and onsite construction.

Similarly, Killingsworth *et al.,* (2020) studied one construction project in the USA and found that practitioners' unfamiliarity with the specifics of offsite manufactured structural frames led to tolerance mismatches between the frames and the in-situ concrete podium. The connection between manufactured structural system to the concrete slab required the slab to be perfectly flat, which, according to the practitioners on site, was difficult to achieve. This led to delays in the project programme due to the remedial work to the concrete podium to accommodate the manufactured structural system. Tolerance mismatches have long existed in construction with various causes. Talebi *et al.,* (2021, p.10) studied two UK construction projects to identify the causes of tolerance mismatches and found factors such as fragmentation of tolerance information in the specifications, inadequate tolerance information for interfacing components in the reference documents and poor communication and coordination of tolerance information between project participants.

The construction process in offsite-onsite interface typically involves a variety of project participants i.e., manufacturer, main-contractor, and subcontractors, etc who need to coordinate tolerances by exchanging appropriate knowledge (Arashpour *et al.,* 2020). Rausch *et al.,* (2020) argue that the complexities of tolerance specification and uncertainties during project delivery triggers the onsite team to use reactive measures to manage tolerance issues. Mainly, this is because the burden of meeting designer-specified tolerances is passed down to the construction team, who are tasked to correct tolerance mismatch issues (Milberg and Tommelein, 2020). This implies that project participants exchange buildability knowledge as they interact or coordinate to exercise their problem-solving measures. However, the actual interaction or coordination of project participants in OSC remains to be explored as much focus is on adaptation to industrialisation and strategies concerning business, production, and products (Lessing *et al.,* 2015).

Interestingly, Goulding *et al.,* (2015) argues that problems in OSC can be reduced by focusing on people, process, and technology as one to understand project team interaction and how knowledge is exchanged. Liu *et al.,* (2022) further develops these ideas, arguing that maintaining strong informal relationships and increasing task dependence among project team members could facilitate knowledge exchange connections in OSC.

What the current debate demonstrates is that effective interaction or coordination between project participants in OSC is required to exchange knowledge for problem solving when discrepancies arise on site. However, how knowledge related to these discrepancies such as tolerance mismatches in OSC is activated and exchanged between project team members is yet to be explored. Exploring how knowledge is activated and exchanged between the designers, manufacturer, main contractor, and subcontractors will shed light on buildability problems in offsite construction and what actually happens in the offsite/onsite interface. Such research calls for an analytical framework in which knowledge related to discrepancies being exchanged and coordinated across project teams can be analysed. Distributed Situation Awareness (DSA) theory offers a potential platform to examine this phenomenon of interest as it focuses on how information and knowledge is distributed across sociotechnical systems.

Distributed Situation Awareness (DSA) Theory as a Theoretical Background

Distributed situation Awareness (DSA) is described as activated knowledge for a specific task, at a specific time within a sociotechnical system (Stanton *et al.,* 2006). In other words, DSA model is focused on the awareness that is distributed across human and nonhuman agents of a system. Examples of nonhuman agents would be artifacts such as tools, documents, and displays. In the present study, two elements of DSA namely compatible SA and SA transactions were mobilized in the analysis of the data.

Compatible SA deals with the content of awareness. More specifically, it acknowledges that although team members may access the same information in a system, they hold different perspectives of the situation. This is mainly because of the factors such as individual roles, goals, tasks, experience, training, and schema are different for every individual (Stanton *et al.,* 2006). The team members may have the awareness of their tasks within each situation for their specific task but are also cognisant of what other team members need to know.

SA transactions explain how agents within a system can facilitate and enhance the awareness of each other through SA transactions. Team members exchange information with one another (i.e., through requests, orders, and situation reports) leading to knowledge being developed and maintained (Stanton *et al.,* 2009). DSA theory emphasizes that SA transactions are mediums for coordinating teamwork, and such transactions lead to improved task performance (Stanton *et al.,* 2009).

Reflecting on the aim of the study using the lens of DSA and considering the incorporation of offsite products into onsite construction as a sociotechnical system, this research is an attempt to answer how roles and tasks of project team members are related to reduce discrepancies effecting buildability problems during offsite and onsite construction integration. The approach to answer the question is explained in the method section.

METHOD

Using the lens of DSA theory, the focus of the study is on how knowledge related to buildability is distributed and embedded across the agents (designers, manufacturer, main contractors, subcontractors, and nonhumans). Data from semi-structured interviews were used to capture participants' experiences of buildability problems relating to onsite/offsite integration. By using active interviewing (Cicmil *et al.,* 2006), the participants were encouraged to share their reflection and accounts of the discrepancies they encountered while performing project tasks. The human agents of the study were selected based on their position in the project or contractual responsibilities and duties. In addition, they were required to have more than 2 years of work experience in offsite construction. Table 1 outlines the profile of the selected participants (anonymised).

Table 1: Profile of participants

Interviewee Position	Organization	ID
Product Manager	Main Contractor	K1
Director	Modular Manufacturer and Installer	M1
Assistant Site Manager	Main Contractor	Z1
Technical Leader – Structures	Manufacturer and Contractor	P1
Structural Engineer	Manufacturer and Contractor	D1
Senior Design Manager	Steel Manufacturer and Installer	V1

Interviews with 6 participants (average duration 35 minutes) were recorded and transcribed verbatim. To examine the data through the theoretical lens, reflexive thematic analysis (Braun and Clarke, 2006), was carried out in NVivo 12 Pro. The coding of the transcripts of the interviews was developed based on several elements of the DSA theory. Importantly, the coding scheme focused on the DSA elements defining the SA transaction dimensions including coordination, communication, and interaction. It also focused on compatible SA dimensions, including roles and tasks. An extra layer of coding for the sources of interaction used by the human agents for each transaction dimensions was included to cover artefacts and interactions with other members of the project team (either manufacturer, designer, or contractor). An important limitation of this study is the small number of informants - however, this was a scoping exercise, and the intention is to explore individual's experiences and perspectives (Creswell, 2014) rather than to generalise the findings.

FINDINGS

In the interviews, two incidents of buildability problems in the integration of offsite and onsite construction were identified. These two incidents were based on the information provided by the product manager working in a main contractor organisation and the senior design manager working in the steel manufacturer and installer organisation. (K1 and V1). The first incident happens in a housing project completed in 2021, which involved the interfacing of the in-situ concrete roof slab and a glass reinforced plastic (GRP) tank. The second incident is of a commercial building and involves a manufactured framing system.

These incidents involved multiple 'agents' engaged in undertaking interdependent tasks. The analysis focuses on SA transactions and compatible SA. SA transactions centre on interaction, communication, and coordination between human and nonhuman agents to capture collective knowledge regarding buildability problems and how knowledge was developed and changed. Compatible SA focuses on the relations between roles, and tasks of the human agents and how knowledge of the situation is activated and managed on the same piece of information.

Incident 1: Product Manager's (K1) perception

The Product Manager (PM) working for the main contractor explained that they had a project which involved installing a very large offsite manufactured GRP tank on the in-situ concrete slab flat roof. The main contractor subcontracted the works to two companies: 1) subcontractor for in-situ concrete slab roof; and 2) Mechanical, electrical and Plumbing (MEP) subcontractor for the water tank installation works. The MEP subcontractor subcontracted the tank installation to a tank manufacturer. This meant that the main contractor had no direct relationship with the tank manufacturer. After the tank was put into position, filled with water and the building was commissioned, the tank cracked and eventually failed, leaking all its water throughout the building. This resulted in considerable physical damages, including time delays and addition remediation costs of the associated reworks. The project team established that the reason for this was the tolerance mismatches between the GRP tank and the concrete slab. From the PM's perspective, the slab wasn't flat and well levelled, and this caused distortion and cracking in the tank structure, and eventual failure. The tank manufacturer has specific tolerances that are very precise requiring the tank to sit on a base that is very flat. The tank manufacturer had not communicated this piece of information either to the MEP subcontractor nor to the main contractor. Hence, the concrete slab subcontractor was not aware of the precise tolerance information required for the tank installation, the PM explained:

> "What we got was what we got because no one communicated anything. It also wasn't checked on site. The tank supplier should have been on site to do the survey of the slab before erecting the tank and say this is not acceptable for us. But ultimately, it's not their responsibility to make sure that the slab is within their tolerance, but they assumed that someone else had checked that for them".

The PM suggested that to avoid such incident in future, there should be effective coordination between the parties to accommodate different trades standards for the specific tolerances.

Relationships between roles and tasks of different agents in the system
The tank and concrete installation describe the requirements of different agents in the system. The concrete slab required specific tolerances to accommodate the tank. However, the transaction of knowledge on specific tolerances did not take place. In this incident, the main contractor, MEP subcontractor and roof subcontractor were not knowledgeable of the requirements for specific tolerances to successfully interface the slab and the tank. This information on tank tolerances was with the tank manufacturer whose task was to install the tank. Indeed, the tank manufacturer was aware of the specific tolerance for the tank but not of the slab. The manufacturer's knowledge of this interfacing tolerances had not activated as there was missing SA transactions on specific tolerances between the tank manufacturer and the roof subcontractor. Although the main contractor, MEP subcontractor, roof subcontractor and tank manufacturer were using the same information (drawings of the roof and tank), their awareness was different based on their own requirements and tasks.

Role of nonhuman agents in SA transactions and compactible SA
The interaction between the tank and the slab led to the awareness of the main contractor, MEP subcontractor and roof subcontractor about incompatible issues. The failure of the tank resulting in water spillage was a form of non-verbal communication that enabled SA transactions (i.e., knowledge on specific tolerances) between human agents. Had the tank not cracked and failed, the non-verbal communication signal to the human agents would have been 'everything is perfectly fit'.

The explanation of the PM on the Building standards highlights their importance on facilitating SA transactions (specific tolerances) for the right information to be passed to the right agent at the right time. Building standards are important to achieving compatibility among different trades involved (Product Manager K1). In this aspect building standards are storage and provider of information, which enables the construction system to perform. However, from the explanation of the PM, there are different standards of specific trades, which requires coordination to avoid the adverse effects of tolerance mismatches onsite. This suggests that the differences in trades tolerance specifications may lead to inappropriate SA transactions (i.e., inadequate, missing, and incomplete information) and SA incompatibilities causing buildability problems on site.

The experience of the PM indicates how SA transactions and compatible SA plays an important part in accommodating tolerances. The missing communication link between the main contractor, MEP subcontractor, roof subcontractor and tank manufacturer demonstrate erroneous assumptions about responsibilities for coordination in this interface.

Incident 2: Senior Design Manager's (V1) Perception

A Senior Design Manager (SDM) working for the Steel Manufacturer and installer explained the situation in this incident. His role involved studying 3D models and coordinate between the manufacture and the project team to ensure that there is no liability with the manufacturer due to any discrepancies in the drawings. In one instance, he sent two emails to the architect and project engineer explaining that there were several clashes based on the clash detection. In his perspective, the high number of clashes was because certain manufacturers and subcontractors had been exempted from the use of BIM by the main contractor because of the costs involved in having BIM.

SDM noted that despite the checks, discrepancies typically arise in the project because of the complex offsite products being installed by different subcontractors and the exemption of the other parties from the use of BIM. An important issue is that every manufacturer or subcontractor will have a set of tolerances unique to their products. These tolerances are typically included in contracts requiring the specialist subcontractor to build within those limits, or to rectify their work to the set tolerances. The SDM explained, "during the execution of the tasks in this project more than 7 different subcontractors are in a single area, all trying to prioritize their own tasks. Later, when there are connection problems, the manufacturers and subcontractors involved point fingers at each other in the meeting for delaying one another and incurring costs".

Relationships between roles and tasks of different agents in the system
This incident describes that the agents (architect and engineer) despite using the same model, had different perspective on the model based on their goals, roles and tasks that they were required to undertake. The Senior Design Manager was provided with SA by the system to plan, check and coordinate the two 3D models, whilst the architect and project engineer who undertook the works depended on the communication (about drawings not matching) from the Senior Design Manager to have adequate levels of knowledge to undertake their required tasks efficiently. Upon receiving the two models from the architect and project engineer, the Senior Design Manager checks and communicates for any discrepancies within the models. Since the roles were clearly defined at this stage, when SA-related knowledge was required, the agents involved knew what was going on and where to get the information.

Although at the factory level there could be adequate SA transactions and compatible SA, the findings suggest that this is not the same when the building elements from different manufacturers are interfacing onsite. The involvement of complex interfaces i.e., different manufactures' offsite products and subcontractors require that the agents involved understand specific information elements (i.e., tolerances) related to the subsequent tasks involved. Interestingly, after activating the SA related- knowledge (i.e., tolerances, connection problems), the agents (main contractor, manufacturer, and subcontractor) held meetings to solve the incidents which indicates the emergence of new project practices due to this formal interaction or coordination.

Role of nonhuman agents in facilitating SA transactions and compatible SA
The interaction between the human agent (Senior Design Manager) and nonhuman (drawing models) enabled the Senior Design Manager's knowledge to be activated resulting in SA transactions (i.e., information not matching) facilitated by emails (nonhuman) to achieve compatibility of the architect and engineers' drawings. The role of the Senior Design Manager, after interacting with the models, was to ensure that there is a common understanding between the agents. Again, the contract has been explained as the place where information on specific tolerances resides. The role of the contract is to inform the interfacing agents (specialist subcontractors) to build within the specified tolerances or rectify the works to the set tolerances. However, according to the findings, there seem to be a shortfall of SA-related knowledge to check the different manufacturers' or subcontractors' tolerances. This leads to clashes or connection problems. This finding suggests that interface design intended to

support offsite and onsite integration needs to encourage usability, ease of use of the system and reduction in interaction time to search for information and tools required.

In this study, DSA theory which adopts a sociotechnical system perspective, was used as a lens to study how knowledge related to buildability problems in the integration of offsite and onsite construction is activated and exchanged among construction participants. Importantly, how knowledge is distributed between the 'agents' to identify and solve discrepancies effecting installation problems is the contribution of this paper to offsite construction project management. The research focused on DSA elements namely SA transactions and compatible SA to identify what information was needed, who needed it, how it was provided and when it was required (Salmon *et al.,* 2009). The nature of planning and execution of construction activities in OSC depends on different agents with different requirements and roles. These agents require different types of information, or they use the same set of information differently. Importantly, the agents are vital sources of knowledge for understanding the current situation and anticipating any installation problems. This displays a need for agents to pay close attention to their knowledge needs and the ways in which knowledge can be activated and exchanged at the interface of offsite and onsite construction.

The results illustrate that different manufacturers' offsite products require specific attention to interaction and coordination between the parties involved. This is to reduce the adverse effects of tolerance mismatches. In addition, there may be assumptions among the participants in the interface of offsite and onsite construction which contributes to inappropriate SA transactions (i.e., inadequate, missing, and incomplete information) and SA incompatibilities (i.e., unclear link between roles and subsequent tasks). These assumptions may arise because other important human agents are either exempted from the modes of information exchange adopted (e.g., in the use of BIM in incident 2), or are not integrated early (eg.in the case of the manufacturer in incident 1).

The incidents above highlight that knowledge gaps were only addressed when things went wrong during task performance. A clear understanding of the likely situations to cause installation problems may substantially improve the project participant's interaction to exchange the required information in OSC. This may prompt the project participants to actively seek and exchange knowledge from the project environment, rather than passively waiting for the knowledge to emerge.

The findings also show that the information exchange practices happening during the interaction or coordination methods (i.e., face to face meetings, emailing) resulted in the emergence of more formal practices. For instance, in the incidents, the meetings conducted to find solutions shows how interaction or coordination formalises such meetings into series of meetings to analyse and solve the incident. This is in line with Bygballe *et al.,* (2016) who argued that new project practices emerge as project participants coordinate in new ways. Thus, knowledge is subjected to both formal and informal coordination (Jacobsson, 2011). This explains that pre-specified construction management system design in OSC evolves as the agents give sociotechnical meaning to the project structures through interaction and coordination. More importantly, the finding suggest that unforeseen challenges may not be excluded altogether (Jacobsson, 2011). These unforeseen challenges may require effective knowledge exchange practices if OSC delivery is to be enhanced.

CONCLUSION

Interaction or coordination is important for knowledge exchange between offsite and onsite construction interfaces. To reduce discrepancies effecting buildability problems in OSC, various interaction or coordination methods are used. The effectiveness of these interactions can be improved by exploring how knowledge related to discrepancies is activated, exchanged, and managed. The DSA model shows that different manufacturers' offsite products and different trades standards in OSC demand that the human agents interact or coordinate to exchange knowledge to reduce buildability problems. The analysis showed that there were missing communication links between the project parties in the interface creating room for a lot of assumptions. This suggest that the information systems and interfaces that facilitate information and knowledge exchange between agents in OSC need to support SA transactions. More importantly, the preliminary findings highlight that the human agents may also need to be flexible in their interaction or coordination procedures.

Future work will extend the DSA three-part model of knowledge elicitation, extraction, and representation (Stanton *et al.,* 2006), by considering the social, task, and knowledge networks to illustrate how knowledge related to discrepancies is activated and exchanged between offsite and onsite interfaces.

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PLANNING, PRODUCTIVITY AND QUALITY

CHALLENGES OF ORGANISATIONAL LEARNING IN A NETHERLANDS PROJECT-BASED ORGANISATION

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Project-Based Organisations (PBOs) in the Dutch construction sector face continual challenges to become more adaptable and increase their performance. Whilst there are several cultural and procedural issues that need to be addressed to fully overcome these problems, this research explores the possibility of Organisational Learning (OL) as a theoretical lens for overcoming some of the inherent concerns and to aid the industry in the quest to create, disseminate and apply new knowledge for the common good. Semi-structured interviews were conducted with seven construction managers and leaders from a high-level Dutch construction case study firm. Primary and secondary research results reveal that many construction PBOs fail to effectively practice OL, as most learning stays within project boundaries due to a lack of organisational learning mechanisms (OLM) that would institutionalise learning. Furthermore, the project-based manner of working prioritises short-term project objectives instead of improvements that are associated with learning. Barriers that impede OL include project uniqueness, geographical dispersion, fragmentation, the dissolvement of project teams, the temporary nature of projects and decentralised organisational structures. Increasing the organisational commitment of project team members and priority towards learning can improve OL.

Keywords: organisational culture; organisational learning; the Netherlands

INTRODUCTION

The Dutch construction industry is continually under pressure from external factors to improve performance and adapt to new policies and regulations imposed by the Dutch Government. Recent regulatory impositions, such as, a move to a circular economy by 2050 (Ministry of Economic Affairs and Climate Policy, 2021) and tightened nitrogen and PFAS regulations in favour of the environment (Ministry of Agriculture, Nature, and Food Quality, 2019) have a significant impact on new and current construction projects according to a report by ABN AMRO (2020). On top of these pressing challenges are further criticism of the Dutch construction industry with regards to their underperformance, cost-overruns, and failure costs (ABN AMRO; 2019, Economic Institute for Construction, 2011).

Whilst there are several cultural and procedural issues that need to be addressed to fully overcome these problems, this research explores Organisational Learning (OL)

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as a theoretical lens for overcoming some of the inherent concerns and to aid the industry in the quest to create, disseminate and apply new knowledge for the common good. OL fosters a culture of learning and increases strategic flexibility, effectiveness, and efficiencies in an ever-changing environment. However, learning from projects, especially in the construction industry, has been identified by multiple authors as troublesome. (Carrillo *et al.,* 2013; Chiponde *et al.,* 2022). Unlike traditional organisations, the temporal nature of construction projects inherently results in newly acquired knowledge not being captured, transferred, and retained and therefore allowing mistakes to repeat itself in new projects (Graham and Thomas, 2008; Newell *et al.,* 2006;).

The aim of the research is to explore organisational learning within a selected Dutch construction Project-Based Organisation and make recommendations for improvements. The organisation selected is representational of businesses in the Dutch construction industry. The study primarily examines matters of Organisational Learning (OL) and closely related subjects, such as Knowledge Management (KM), Lessons Learned (LL) and project leaming.

LITERATURE REVIEW

The basic concept of OL is grounded in the collectivity of individual learning. It is the ability and culture of the organisation in enabling learning for continuous improvement, innovation and creativity that will determine the extent to which OL is successful (Wang and Ahmed, 2003). Crossan *et al. (*1999) framework challenged previous theories on OL and introduced the concept of 'strategic renewal'. He claims that learning happens on three levels; individual, group and organisation and can be attained through the 4Is process, Intuiting, Interpreting, Integrating, and Institutionalising. Learning is subsequently captured through several inputs and outputs (See Table 1).

Table 1: Learning/Renewal in Organisations: Four Processes Through Three Levels

Level	Process	Inputs/Outputs
Individual	Intuiting	Experiences, Images, Metaphors
Individual	Interpreting	Language, Cognitive Map, Conversation/Dialogue3
Group	Integrating	Shared understandings, Mutual adjustment, Interactive systems
Organisational	Institutionalising	Routines, Diagnostic systems, Rules and procedures

The model suggests feed-forward (exploration), and feedback (exploitation) processes exist in a field of tension, as new leaming(s) constantly float from the individual to the organisational level and existing learning can feedback from the organisational level to the individual. The model, however, is criticised for its limitations in implementing it in a practical context (Sun and Scott, 2003) and, in a project context, Swan *et al.,* (2010) noted that it: "does not explore in detail the mechanisms which link institutionalisation" suggesting that learning is not returned to the organisational level for dissemination for future projects (Swan *et al.,* 2010, 327).

To translate learning from individuals and groups into organisational learning, Popper and Lipshitz (1998, 2000) introduced the notion of Organisational Learning Mechanisms (OLM), "[…] structural and procedural arrangements that allows organisations to systematically collect, analyse, store and disseminate and use information relevant to the performance of the organisation and its members" (Popper and Lipshitz, 1998, 171). OLMs function as the bridge between the different learning levels as described by Crossan *et al.,* (1999) and attribute some sort of learning capacity to organisations (Lipshitz *et al.,* 2002). OLMs are categorised by Popper and Lipshitz (1998) as integrated or non-integrated and designated or dual-purpose mechanisms. Integrated mechanisms are intertwined with task performance and exploited by the same user. Non-integrated mechanisms are, for example, strategic plans, because they are exploited for their benefit by someone else other than the creator. Designated mechanisms are those where learning and task performance are carried out at different time intervals and separate places. Dual-purpose mechanisms are those where learning takes place at the same time with task performance (Lipshitz *et al.,* 2002; Popper and Lipshitz, 1998).

The most studied project OLMs in construction literature are post-project reviews (PPR) They allow organisations to systematically improve performance, capture knowledge from previous projects and to interpret the knowledge to enhance future projects and the organisation itself (Anbari *et al.,* 2008). However, multiple authors point out there is a gap between the theorised benefits and advantages of PPRs and lessons learned and their utilisation in practice in projects (Swan *et al.,* 2010). Often argued by authors is that PBOs and construction companies do not systematically use OLMs and efforts made to improve learning appear to be fruitless due to several barriers (Duffield and Whitty, 2015; Hartmann and Doreé, 2015). However, OLMs on their own are not enough to facilitate OL (Popper and Lipshitz, 1998). Lipshitz *et al.,* (2002) proposed a multifaceted model of OL, in which OL is most likely to be most productive.

The model consists of five facets, which influence each other: Contextual facet, Policy facet. Psychological facet, Cultural facet, Structural facet. All the facets are not a necessary condition for learning, but Lipshitz *et al.,* (2002) hypothesize if each facet is positively linked, they will increase the likelihood of productive OL. Research from Chiponde *et al. (*2020) expanded on the work of Lipshitz, and specifically in the construction sector. Mahdiptura similarly (2007) analysed several articles relating to enabling conditions that benefit OL (Kriegesmann *et al.,* 2007) and found 13 different enabling conditions spread across Influencing, Leaning, and Facilitating factors that that can benefit OL. Chan *et al.,* (2005) states that Organisational Learning (OL) in Project Based Organisations (PBOs) requires a different approach from traditional functional organisations. Projects are described as vehicles for learning because they constantly require project members to solve new problems (Swan *et al.,* 2010; Koskinen, 2012).

Yet, conversely, many challenges are acknowledged in construction projects, such as short-term objectives and the long-term development-oriented nature of organisational learning processes, unsupportive organisational cultures, the inherent nature of projects and social people factors. (Carrillo *et al.,* 2013; Duffield and Whitty, 2015; Grabher, 2002; Murray, 2003). Construction projects add extra difficulties to the project learning dimension and differ from other PBO sectors (e.g., IT, manufacturing, aviation) as they are geographically dispersed, and suffer from fragmentation (Kasvi *et al.,* 2003). The geographical dispersion makes it difficult for interaction between different project teams and the organisation (Wiewiora *et al.,* 2009a). The fragmentation raises issues as many people work in a silo environment with less opportunities for social interaction and the high specialisation of people makes it more difficult for people to learn together (Carrillo *et al.,* 2013). This is especially an issue as studies by Styhre *et al.,* (2004) and Carrillo *et al.,* (20 I 3) indicate that an important aspect of learning in construction projects is through personal contacts, communities of practice and personal interaction.

The literature highlights a disconnect between the functional organisations that most theoretical models refer to, and the PBOs of the construction industry. Based on the literary findings of the research and building on models and theories of Lipschitz *et al. (*2002) and Crossan, *et al. (*1999) the following framework has been developed to show the expected process of effective OL in the context of a construction PBO (Figure 1).

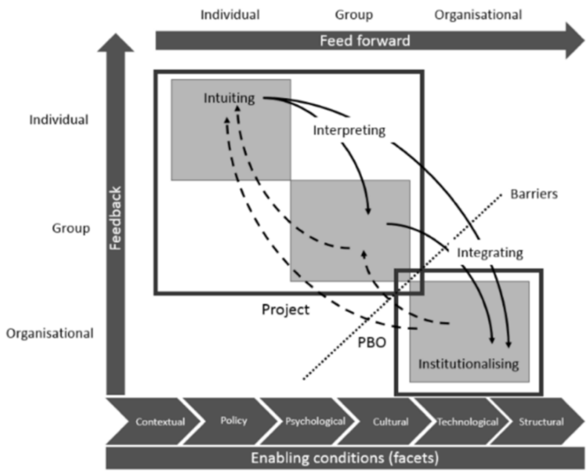

Figure 1: Process of effective Organisational Learning in the context of a construction Project Based Organisation

METHOD

This exploratory research aims to establish how organisational learning within Dutch construction Project-Based Organisations can be improved. Learning is very much perceived as a social undertaking, and as such an interpretivist approach focusing on exploring the complexity of social phenomena to gain an interpretive understanding means that the philosophical position of the research leans towards the phenomenological paradigm of the continuum. The main research question "How can organisational learning from construction projects be improved in Dutch Project-Based Organisations?" was broken up into three different sub questions: "Why do Project-Based Organisations fail to effectively practice organisational learning in construction projects?", "What are the perceived barriers to organisational learning from construction projects?", and "What conditions constitute towards successful organisational learning from construction projects?".

The research investigates the experiences, insights, and approaches of individuals to gain an understanding of the current level, barriers and enabling conditions to organisational learning from construction projects in PBOs. OL is a concept deeply connected with the experience and insights of individuals and has proven difficult to pursue in numbers, thus the focus of the research is on words and their implications. Semi-structured interviews were undertaken to understand certain processes, structures, and systems within the organisation. The interviews were audio recorded to support accurate transcription and analysis of the data. The population of interest were construction managers and leaders employed by a high-level Dutch construction PBO.

To be more specific: 3 project leaders, 2 superintendents, 1 director and 1 manager continuous improvement of the project company were interviewed. These seven were spread across a total of three different projects and central office within the same firm.

Owing to small sampling size, the participants were carefully selected based on their position. The population of interest contained a possible influence and impact on the concept of OL in their organisation, as they possess a certain degree of authority over the way of working. Questions focused on key concepts such as OL, lessons learned, learning from projects and OLMs. After conducting interviews, the data were transcribed and then analysed using NVivo 12. Thematic-analysis was aided by the SWOT-method on the interview transcripts, which was used as a framework for identifying attitudes and relations to OL. Data was coded according to the types identified by Corbin and Strauss" (1990), to ensure systematic analysis.

FINDINGS

In answer to the research sub-question 1 "Why do Project-Based Organisations fail to effectively practice organisational learning in construction projects?" Respondents indicated that there is a reliance on informal, non-integrated mechanisms "I think people have a tendency of doing their own thing" "Right now, you get ideas informally from your colleagues, but then you are very dependent on the person on the project" Other respondents also noted that if they don't know something they usually resort to calling or asking a colleague from their personal network indicating that systematic collection, transfer or dissemination is not present. These findings support the literature that suggest that there is a lack of formal structures to support the high amount of informal learning in projects (Grabher, 2002; Swan *et al.,* 2010) and that most people in construction projects learn from the knowledge and experience of other people (Swan *et al.,* 2010; Wasif *et al.,* 2010). Even though individual and team learning are considered important prerequisites of OL (Crossan *et al.,* 1999), the research highlights that it does not necessarily mean OL takes place. Like other studies on (construction) projects (Carrillo *et al.,* 2004; Swan *et al.,* 2010), the results suggest the usage, transfer, and dissemination of evaluations is not systematically pursued, which also confirms that institutionalisation in the framework of Crossan *et al. (*1999) is not effectively achieved. Respondents also gave more intangible reasons as to why OL is not effectively practiced, such as defensive behaviour towards negative feedback and failures, stubborn 'know it all' attitude (proudness) of colleagues towards learning and lack of perceived value in learning.

Furthermore, the results indicate that the people working in projects are very much focussed on the project-objectives, however, they do not seem to perceive the same priority and value to achieve the longer-term learning goals of the organisation, suggesting a lack of commitment to the organisation. Grabher (2002) also suggests the long- term processes of learning are conflicted with the short-term objectives of projects. A lack of perceived value on learning was also found by Carrillo *et al.,* (2013) due to the unique and highly contextual nature of construction projects The unwillingness to learn from other projects was attributed to the organisational culture and the attitudes of the wider project team members who purport that: "construction contractors we have the excuse that every project is unique and different" inferring that there is no benefit from learning from other projects. Perhaps in relationship to these factors is the stated unwillingness to learn and negative attitude towards feedback of individuals, which are cited to impede learning moments. Similarly, Duffield and Whitty (2015) also identified the people and culture factor possibly to be the most detrimental factor in organisational learning.

(Sub-question 2) "What are the perceived barriers to organisational learning from construction projects?" the main contributing factor was the uniqueness of projects and that as a result people do not value the learnings as being applicable to the next project. Similar findings were found by Carrillo *et al.,* 2013 and Newell *et al.,* 2006, which resulted in a lack of priority given to learning tasks. Secondly, geographical dispersion is indicated to result in reduced opportunities for interaction between knowledgeable individuals, thus meaning people miss out on opportunities to learn. This confirms findings from Kasvi *et al.,* (2003), Wiewiora *et al.,* (2009a) and Wiewiora *et al.,* (2009b), as project-based working inhibits opportunities for social interactions. This is especially obstructive in the light of construction projects, where most learning happens through informal social moments between individuals (Styhre *et al.,* 2004; Swan *et al.,* 2010).

Thirdly, in accordance with Carrillo *et al.,* 20 I 3 and Wasif et al.2010, the dissolvement of project teams because of the temporary and phased nature of projects are indicated to impede OL. The results show that after closure of a particular phase or at the end of a project, teams dissolve, move on to a new project, and 'forget' to reflect or evaluate.

Contradictory to some of the literature (Swan *et al.,* 20 IO; Wiewiora *et al.,* 2009a), the results indicate time pressure does not act as a barrier to OL. Carrillo *et al.,* (20 I 3) suggests time is always a challenge that hides other issues, which resonates with answers of various respondents. What the results indicate is that instead of issues with time, people do not prioritise learning practices enough. The project results are prioritised by project teams above learning, like findings from Hartmann and Doreé (2015). If tasks do not contribute directly to the progress of a project it prompts people to abandon these activities (Swan *et al.,* 2010).

Lastly, the organisational structure of the PBO is indicated to be a barrier to OL. Respondent 6 explained to have difficulties with implementing systems to generate 'objective' feedback from projects. Like findings from Bresnen *et al.,* (2004), the decentralised organisational structure seems to have an impact on embedding new management practices. Contradictory to the findings, Nonaka, and Takeuchi (1995) explain project team autonomy as a prerequisite to learning, because teams have the freedom and ability to pursue new knowledge. However, the results and Bresnen *et al.,* "(2004) indicate high autonomy can have implications when new management practices are introduced, because project managers could resist these changes or interpret and incorporate them differently.

(Sub-question 3): What conditions constitute towards successful organisational learning from construction projects? Like Lipshitz *et al.,* (2002) and Mahdiptura (2007), culture and a safe environment, expressed through the ability to speak freely and admit mistakes, openness, transparency, and the willingness of people to learn were identified as enabling conditions. The results indicate that if mistakes are not allowed to be made or talked about, reflection and evaluation seems unlikely to be productive. The possibility to speak openly and have discussions is important in facilitating the process of interpreting and integrating to create shared understandings and take coordinated actions (Crossan *et al.,* 1999). In accordance with the findings, Lipshitz *et al.,* (2002) notes organisational commitment as an important enabling condition. Respondents frequently noted people's unwillingness to learn and focus on short-term results. Additionally, this is exacerbated due to the project- based way of working and lack of organisational commitment created by the PBO itself, with personal goals being put before that of the organisation (Lipshitz *et al.,* 2002).

The data suggests, aside from the existence of OLMs, they need to be well-designed in order to be effective. A systematic approach, the timing, frequency, and early usage of OLMs are indicated to be important to enhance their usage. The correct use of OLMs is necessary to link learning in organisations to learning by organisations (Lipshitz *et al.,* 2002), and to be able to reach the organisational level described by Crossan *et al.,* (1999). Incentives were suggested by the respondents to help stimulate more reluctant individuals to take part in the learning processes. Supported by the literature, incentives, can motivate and help tie individuals to the goals of the organisation, increasing organisational commitment (Carrillo, 2004; Swan *et al.,* 2010). Additionally, the results indicate a plan is required to increases the urgency to take part in learning activities and thus increase organisational commitment (Hartmann and Doreé, 2015). Respondents frequently state the overload of information and impracticality of databases as detrimental to its effectiveness, like findings from Carrillo *et al.,* (2013).

(Main research question): How can organisational learning from construction projects be improved in Dutch Project-Based Organisations?

The results indicate the need for an integrative holistic approach to OL, that aims to establish and facilitate the processes proposed in the framework of Crossan *et al.,* (1999). The need to consider the facets proposed by Lipshitz *et al.,* (2002) in the context of PBOs in the construction industry is especially highlighted by the barriers that are identified. The results suggest there is a distance between the central organisation and the people working in projects. The people in projects are indicated to lack organisational commitment to the central organisation, because of the low prioritisation towards learning, and the focus on the short-term goals. The focus point of improvements is therefore suggested to be best aimed at increasing organisational commitment and the priority towards OL. To achieve this and to overcome the barriers imposed on project-based working, consideration for improvements surrounding the structural, psychological, cultural and policy facets are likely to be the most effective solution.

CONCLUSIONS

The aim of this research was to explore and establish how organisational learning within Dutch construction PBOs can be improved. The analysis reveals that increasing organisational commitment of project team members and priority towards learning can improve OL from construction projects. An integrative holistic approach is necessary that addresses the existing short-term, project-centred culture in the PBO and moves towards longer-term goals and processes of learning set out by the central organisation. Like findings from other studies, results indicate that OL in PBOs is reliant on informal non-integrated mechanisms, which lack the step towards institutionalisation in the organisation. In addition, focus on short-term goals in projects seem to aid the of lack of perceived value in learning and unwillingness to learn. The combination of these factors seems to conflict with the long-term processes of learning.

From the results the following perceived barriers are concluded as most significant to OL in construction projects: the uniqueness of each project, geographical dispersion, fragmentation, the dissolvement of project teams, the temporary nature of projects and decentralised organisational structure. Results suggest that, to overcome the barriers imposed on project-based working, considering improvements surrounding the structural, psychological, cultural and policy facets are likely most effective.

Integrated formal OLMs that establish feedback loops and institutionalise learnings, the involvement of project members in earlier phases, senior management support, and leadership are indicated by the results as part of these facets to be conducive to organisational commitment and the priority allocated to learning. Both rhetoric and actions that increase the priority towards learning and that express the need for learning are required to become a learning organisation. Project teams should identify more with the organisation when working on projects, aligning with the organisation's goals and values and making no distinction between promoting its interests and their own personal ones (Lipshitz *et al.,* 2002).

Practical Implications, Limitations and Recommendations

The research has three practical implications to improve OL from construction projects. First, structural changes should be aimed at establishing feedback loops between projects and the central organisation to achieve institutionalisation. OLMs (such as post-project reviews) need to become a part of the ongoing work processes and conducted more frequently to overcome team dissolvement. Furthermore, the lessons from the OLMs should be embedded in existing institutionalised documents used at the start of new projects or phases in the project, which could increase the priority and perceived value of conducting learning tasks. Additionally, involving people earlier from later phases in the project could further strengthen the feedback loops due to overcoming the difficulties with storing tacit knowledge.

Secondly, management support should focus on aiding the proposed structural changes and create motivational factors through policies. Creating incentives, allocating resources to learning initiatives and evaluating longer-term learning goals over short-term goals are suggested to have a positive effect on increasing organisational commitment. Additionally, creating a vision and strategy towards learning can potentially increase ownership, organisational commitment and shift the focus from short-term to longer-term goals. Lastly, the research shows leadership from managers in projects is required to tackle the existing culture and psychological environment in projects. Leaders are frequently cited to have the ability to influence existing cultures, and the beliefs and behaviour of individuals. Without an environment that is open and transparent and in which mistakes are not allowed to be made OL is unlikely to be productive.

It is recognised that using a case study research approach and smaller sample size limits the generalisability of the results. Further research using a similar approach is suggested to validate that the results are not unique to the used organisational context. Another limitation is the focus on the temporary organisation (project team), which influenced the perspective of the research. Further research should examine the different phases before and after the realisation of the construction project, as it could provide different insights on establishing more effective OL.

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DEVELOPING AN IMPROVED PROCESS MODEL FOR FORENSIC ANALYSIS OF CONSTRUCTION PROJECT DELAYS

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Forensic Delay Analysis (FDA) is an activity of specialists in extracting, presenting evidence to contractual claims, disputes that relate to project delays. The most frequently stated problems with FDA are the time-consuming, costly tasks of information retrieval, confusing multiplicity of delay analysis methods, and difficulty of presenting complex evidence. There is a growing body of literature that recognises the importance of Building Information Modelling (BIM) or Artificial Intelligence (AI) in addressing the above problems; however, their integrated approach within FDA has been under-researched. This project has two primary purposes: a) to explore the impact of an integrated approach within FDA, and b) to propose an improved FDA process model. The approach consists of three stages: i. preparing a descriptive model of the current process, ii. designing an improved, prescriptive model under the guidance of the protocols, and iii. transforming it into a working, normative model based on real-world project workflows and emerging advances. The findings show that introducing an improved process model will supplement, inform existing FDA activities, and enhance the current process.

Keywords: artificial intelligence; BIM; dispute resolution; forensic delay analysis

INTRODUCTION

Yaseen *et al.,* (2020) point out that time predictability in construction projects can be impacted by various factors due to their dynamic, complex, and interdependent nature, factors that may be aggravated by others such as inefficient organisation of human resources (Olaniran *et al.,* 2015) and lack of collaboration among project participants in developing the project programmes (Antunes and Poshdar 2018). Adverse deviations in project timelines (referred to as 'delays') may result in disputes over their extent, causation, impact, and, importantly, responsibility. A study by Arcadis

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(2021) shows the global average time to solve a construction dispute as 13.4 months and their global average value is US$54.26 million.

These insights show that the analysis of delays is crucial and has created a specialist niche requirement for consultants to undertake what is now commonly termed Forensic Delay Analysis' (FDA). The expert delay analyst might need to deal with many challenging and time-consuming tasks (Brando *et al.,* 2013). The present study is part of an investigation into the impact of new technologies on the existing FDA process, and it aims to reduce the most frequently stated problems with FDA (i.e., the time-consuming and costly tasks of information retrieval, confusing multiplicity of delay analysis methods, and difficulty of presenting complex evidence) by proposing an improved process model. Previous studies with similar interests support the rationale for an improved FDA process are systematically reviewed with the outcome briefly discussed in the following section. The background to the research and the research design are then presented, followed by the findings of the study, which are discussed. Finally, the conclusions and future ambitions of the study are presented.

LITERATURE REVIEW

The existing literature on FDA is extensive and primarily focuses on different techniques to choose the most appropriate analysis method, in addition to the challenges and shortcomings of these methods. Systematically, a review of both theoretical literature and empirical research, which have aimed to give guidance on some of the common delay analysis methods, has revealed that interest in FDA methods is not recent. Early examples include Arditi and Patel's (1989) proposal for using forensic scheduling concepts in developing an expert system that can prevent and resolve time-related construction disputes, and Alkass and Harris's (1991) integrated computerised system that aided the analysis of claims resulting from delays. In more recent studies, researchers such as Braimah (2013), Parry (2015), and Keane and Caletka (2015) have discussed different types of FDA methods, offering a step-by-step explanation of each, and examining their accuracy, reliability, practicality, and popularity.

The existing literature on delay analysis methods has highlighted the endeavours of many researchers who focused on reducing the complexity and increasing the efficiency of the existing process. A notable example of these endeavours is the proposal of Birgonul *et al.,* (2015) for an integrated approach to mitigate the shortcomings of FDA by setting sets of rules. There is a consensus among researchers (e.g., Chou and Yang 2017, Gibbs 2017, Chen 2020) that every FDA method requires three main steps: (i) the sourcing of evidence, (ii) its analysis, and (iii) its presentation. At each step there might be challenges and shortcomings. Vidogah and Ndekugri (1997) considered the information retrieval step as the most time-consuming and costly of all aspects of claims preparation. Keane and Caletka (2015) pointed out that the analysis stage was complex and confusing because of lack of guidance on standard methodologies and tools. Despite the recent work of the Society of Construction Law (SCL 2017) and the American Association of Cost Engineering (AACE 2011) to mitigate the confusing multiplicities and variabilities of FDA methods, their proper application is still entirely dependent on adequate supporting project information. In addition, the communication of the findings as evidence has been identified by Gibbs *et al.,* (2017) as another major challenge due to the difficulty of presenting complex information to decision makers who are unfamiliar with it. In addressing the above problems, recent attention has focused on opportunities presented by emerging technical advances.

Two areas, Building Information Modelling (BIM and, more broadly, digitisation of information) and Artificial Intelligence (AI), are of primary interest. The capabilities of BIM in collection, processing and presentation of data have been recognised by various researchers, and their efficacies (and especially the power of 4D BIM - combining a time dimension with the 3D-model) in the existing FDA process have been assessed in their studies. The important examples of the studies which have explored the potential support of BIM in FDA include the following researchers: Al Shami (2018), Valavanoglou *et al.,* (2018), Ali *et al.,* (2020), Marey *et al.,* (2020). Overall, these cases support the view that BIM offers significant support in the retrieval of information, analysis of programmes, and clear representation of the analysis to overcome the challenges and shortcomings of FDA. This view has been particularly supported by Vacanas *et al.,* (2015) from a more specific perspective of BIM by stating that *"*a BIM model analysed in time (4D) can act like a witness because it is a large and important source of record information*".*

The construct of 4D BIM in FDA was first articulated by Coyne (2008) who performed schedule delay analysis using 4D BIM and presented the outputs of the analysis. Other researchers have supported this initiative and further examined it with several case studies. The notable and recent examples include Valavanoglou *et al.,* (2018), Ali *et al.,* (2020), and Guévremont and Hammad (2021). Another primary interest area of the study is the adoption of AI algorithms and techniques into the existing FDA process. The first serious discussions of the use of AI in the existing FDA process emerged in a study by Riad *et al.,* (1991) in which an AI-driven knowledge-based expert system for time-based claim management was developed. This attempt has been followed by other researchers who explored adoption of AI to overcome the challenges and shortcomings of existing FDA. These include Barnett and Treleaven (2018), Cheng *et al.,* (2019), Catelain (2019), Gondia *et al.,* (2020), Chen (2020), Bagherian-Marandi *et al.,* (2021), Hassan *et al.,* (2021), and Egwim *et al.,* (2021). Although all these studies might remain narrow in focus dealing only with a particular part of the entire FDA process or attempting to overcome specific challenges, their thorough review lays the groundwork for the present study to introduce an improved FDA process model.

METHOD

The research methodology of the present project is designed in three key stages as shown in Figure 1: (i) preparing a descriptive model of the current FDA process, (ii) designing an improved, prescriptive model relating to the work of the SCL (2017) and the AACE (2011), and (iii) transforming it into a working, normative model based on real-world project workflows and emerging advances.

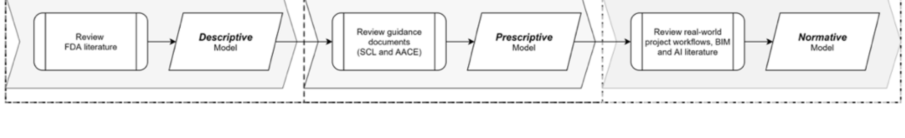

Figure 1: Three-stage methodological approach to design an improved FDA process model

The process symbols at each stage in the methodological approach indicate how the existing FDA process transforms into a normative model through potential improvements and overlay of potential technologies across the process. As a first step toward achieving this aim, the literature in areas of FDA, BIM, AI (relating to construction) and their contributions was evaluated and taken into consideration at each stage of the methodological approach. In stage I, to identify the existing FDA process and generate a descriptive model, relevant FDA literature was reviewed. This stage primarily benefitted from studies of different delay analysis methods and factors affecting the selection of these methods. In stage II, the guidance documents of the SCL (2017) and the AACE (2011), are used to capture the complexities of the FDA methodologies and to reduce the subjectivity involved in the entire process, consequently, to generate a prescriptive model. In stage III, the process is transformed into a normative model through review of two different sources: a. case-studies from the industry, such as subject expert reports from construction law specific journals, etc., and b. all the relevant BIM and AI literature.

FINDINGS

Using the output of the three-stage process described in the previous section the FDA process model is generated. A simplified version, showing only the main steps of the process, is shown in Figure 2.

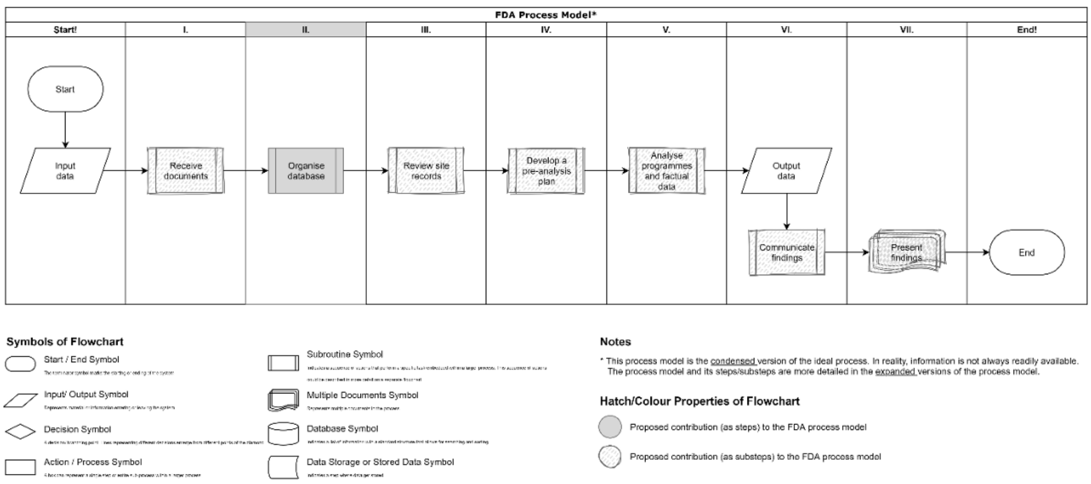

Figure 2: Simplified version of the FDA process model

An expanded version is shown in Figure 3. The sub steps and sub-sub steps are discussed in detail in the following paragraphs.

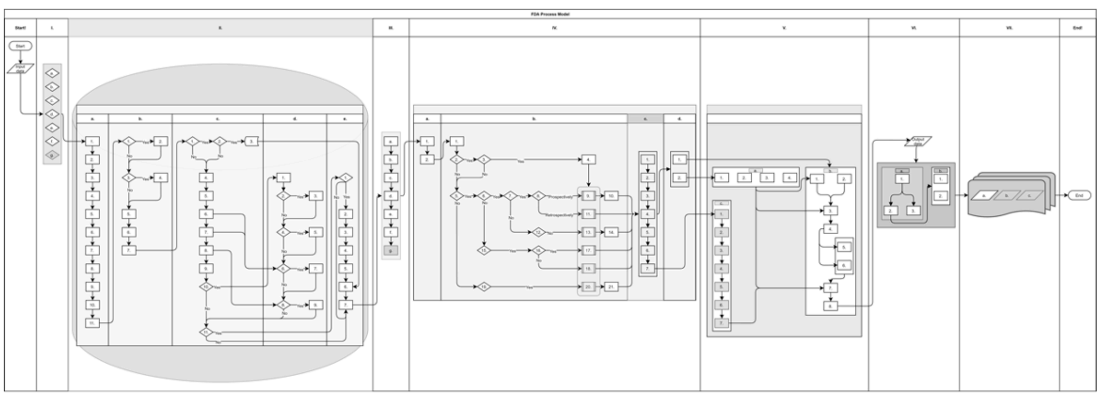

Figure 3: Detailed version of the FDA process model

Receive documents (I.)
The purpose of this step, which largely follows existing practice, is to source information required for the analysis. Its sub steps (a-f) are existing activities: a. contract documents, b. progress records, c. resource records, d. cost records, e. correspondence and administration records, and f. key programmes. The availability of these documents has an impact on the selection of the delay analysis method. In addition to these current activities, a new sub-step, checking the availability of *g.* BIM data is proposed. Despite the recognition, in SCL (2017), of the growing use of BIM and its acceptance as evidence, there is no guidance on how to utilise it and integrate it into the FDA process. This will be covered in the proposed process model.

Organise database (II.)
In this completely new main step, the previously received documents are split into five sub steps (a-e) requiring the entry of: a. 'general' project information, b. 'Delay-specific' project information, c. electronic document management system (EDMS) information and project records, d. programme information, and e. 'other' project information. Each sub step is further broken down to include different types of questions. For example, a. Enter 'general' project information contains eleven questions as sub-sub steps (1-11): 1. What is the project description?, 2. What is the original contract value of the project?, 3. What is the date of instruction to proceed with early work?, 4. What is the date of contract award/ letter of appointment?, 5. What is the date of access to site?, 6. What is the original completion date of the project?, 7. What is the expected date for completion of the project?, 8. What is the project type?, 9. What is the role of the client in the project?, 10. What is the legal role in the tribunal?, and 11. What is the form of contract used for the project and which version?. In sub step b. (Enter 'delay-specific' project information) seven delay-specific questions are introduced as sub-sub steps (1-7): 1. Does the contract specify/mandate a specific delay analysis method?, 2. What is the delay analysis method?, 3. Does the contract language constrain the selection of delay analysis method?, 4. What is the relevant provision in the conditions of contract?, 5. What is the size of the dispute?, 6. What is the budget for the FDA?, and 7. What is the time for the FDA? In sub step c (Enter EDMS information and project records) the aim is to check the availability of an EDMS in the project to expedite the factual data linking process of project records or to do it through categorising questions. Eleven sub-sub steps are introduced (1-11): 1. Does the project have an EDMS?, 2. Does the client share EDMS?, 3. Data stored in EDMS are linked to the database, 4. Which of the resource records are available?, 5. Which of the cost records are available?, 6. Which of the minutes of meetings are available?, 7. Which of the progress reports are available?, 8. Which of the technical records are available?, 9. Which of the other correspondence and administration records are available?, 10. Are the programmes available?, and 11. Does the project have BIM scope? One of the key factors which affects the selection of FDA method is the availability and quality of project programmes. In sub step d (Enter programme information) nine sub-sub steps aim to question these key factors (1-9): 1. What is the scheduling software used in the project?, 2. Is the baseline programme available?, 3. What is the nature of baseline programme?, 4. Is/are the updated programme/s available?, 5. What is the nature of updated programme?, 6. Are the site records available?, 7. What are the types of site records?, 8. Are the as-built data available?, and 9. What are the types of records? In sub step e (Enter 'other' project information) the intention is to collect the BIM

information of the project to link it with the data collected in the previous sub steps. Seven sub-sub steps are introduced (1-7): 1. Are there any BIM models available? 2. For what purposes are these models produced? 3. What are the file formats of BIM models? 4. What is the BIM authoring software of the project? 5. How many people have read/write permissions on BIM models? 6. Link all collected and organised project data with BIM models (if any) to start preparing of Forensic Information Model (FIM). If not, move to the next step, and 7. Database is organised, move to the next step 'review'.

Review site records (III)

The data collected and organised in the previous steps are ready to be reviewed. This step examines these collected data. There are seven sub steps (a-g): a. Review delay-relevant conditions of contract, b. Review progress records, c. Review resource records, d. Review cost records, e. Review correspondence and administration records, f. Review key programmes, and g. Review BIM models. With the greater availability of appropriate digital information collected so far, the learning, inference, and predictive powerful capabilities of AI (such as analysing voluminous, complex, and interdependent data sets of varying structure for deriving useful insights) can be applied to this step to enhance the efficiency of the resulting FDA process.

Develop a pre-analysis plan (IV.)

Both AACE (2011) and SCL (2017) consider the factors which affect the selection of the most appropriate delay analysis method, the main factor being the availability and quality of project information. This main step consists of four sub steps (a-d): a. Identify key issues, b. Select a suitable delay analysis method, c. Prepare BIM models to link with programmes and factual data, and d. Prepare a suitable work plan for analysis.

a. Identify key issues: Different types of sources and factors of delay which are found as outcomes of the literature review studies are split into two sub-sub steps (1-2): 1. Who/ what are the sources of delay? and 2. What are the factors of delays?

b. Select a suitable delay analysis method: All the data which are collected, organised, and reviewed in the previous steps/sub steps compose technical, legal and practical considerations which affect the selection of delay analysis method. Following these considerations, analysts can identify the most appropriate method and justify their decisions by solid reasons. The decision points and actions in this sub step are represented with twenty-one sub-sub steps (1-21): 1. Check the conditions for selection of delay analysis method, 2. Does the reviewed database suggest/ mandate a delay analysis method? (e.g., contractual requirement, etc.), 3. Can the selection of delay analysis method be proved by these constraints?, 4. Choose the identified delay analysis method, 5. Baseline programme available?, 6. Logic-linked baseline programme available?, 7. Updated programmes or progress information with which to update the baseline programme available?, 8. Delay impact is determined?, 9. Select "Time Impact" Analysis, 10. Model a selection of delay events, 11. Select "Time Slice Windows" Analysis, 12. As-built data available?, 13. Select "Impacted As-Planned" Analysis, 14. Model a selection of delay events, 15. As-built data available?, 16. As-built programme available?, 17. Select "Retrospective Longest Path" Analysis, 18. Select "As-Planned vs As-Built" Windows Analysis, 19. Logic-linked as-built programme available?, 20. Select "Collapsed As-Built" Analysis, and 21. Model a selection of delay events.

c. Prepare BIM models to link with programmes and factual data: Following the selection of suitable delay analysis method, to prepare the forensic information model (FIM, i.e., a forensic visual database), previously reviewed BIM models are linked with relevant programmes and factual data in seven sub-sub steps (1-7): 1. Identify required BIM files, 2. Check the file formats and compatibility of the BIM files, 3. Import BIM models into 4D simulation software, 4. Import key programmes into 4D simulation software, 5. Link 4D models with programmes and key issues, 6. Check whether there is work breakdown discrepancy between models and programmes, and 7. Modify models in the authoring software and re-import into 4D simulation software if necessary.

d. Prepare a suitable work plan for analysis: The sub step consists of two sub-sub steps (1-2): 1. Quantitative process (WHEN and WHERE a delay occurred), 2. Qualitative process (WHY the delay occurred).

Analyse programmes and factual data (V.)
The existing analysis process consists of two sub steps (a-b): a. Analyse factual data (qualitatively), b. Analyse programmes (quantitatively). Additionally, the support of FIM is proposed as a new sub step: *c.* Support analysis using Forensic Information Model (FIM). a. Analyse factual data (qualitatively): The qualitative process of factual data analysis includes four sub-sub steps (1-4): 1. Design analysis, 2. Procurement analysis, 3. Construction analysis, and 4. Commissioning analysis. b. Analyse programmes (quantitatively): The quantitative process of programme analysis includes eight sub-sub steps (1-8): 1. As-Built Progress Data, 2. Contemporaneous Programmes, 3. Validate inputs, 4. Construct set of programmes for the delay analysis, 5. Identify and quantify critical delays by period and milestone, 6. Identify the origin of critical delays by period and milestone, 7. Causation Analysis, 8. Conclusions and Opinion. c. Support analysis using FIM: The previously created FIM supports analysis with seven sub-sub steps (1-7): 1. Generate storyboards based on delay-specific scenarios, 2. Create simulations for what-if scenarios, 3. Convert animated model into .fbx file format, 4. Verify the correctness of geometric and non-geometric data in the game engine, 5. Return 4D simulation software, modify data and re-export if necessary, 6. Integrate with 3D mapping APIs to visualise the environment of the project (to observe/ highlight potential effects), and 7. Analyse what-if scenarios visually.

Communicate findings (VI.)
The analysis output is communicated through two sub steps (a-b): a. Generate preparatory files, and b. Generate expert reports. The former is proposed as a new sub step and consists of three sub-sub steps (1-3): 1. Design user interface (UI) of the final output (for media files or interactive application), 2. Export as a media file (e.g., image, video), 3. Export as an interactive application. The latter is an existing substep and it consists of two sub-sub steps (1-2): 1. Prepare presentations, 2. Prepare expert reports.

Present Findings (VII.)
In the existing process the findings are mostly presented as a. Presentations. As addition to this traditional sub step, b. Simulations (e.g., videos, images, etc.) and c. Interactive applications (e.g., smart applications) are proposed as potential presentation methods.

The work presented here involved three stages. In the first, a descriptive ('as-is') model of the FDA process was created based upon current literature and observation of existing practice. Stage II sought to incorporate the guidance from the SCL (2017) and AACE (2011) documents and offer a systematic decision model for selection between the different delay analysis methods contained in these documents. In the final stage, a normative model was produced that combined the necessary elements of the FDA process, with systematic FDA method selection and opportunities for greater effectiveness and efficiency offered by BIM and AI technologies. The proposed process model can assist FDA in the detection of causes of delays, the retrieval of evidence, and the better presentation of that evidence to support or reject FDA claims. It is suggested that the new process model can reduce time-consuming and costly information retrieval tasks through the implementation of BIM (and more broadly, digitisation of information) and AI.

Furthermore, the systematic approach proposed within the model can reduce confusing multiplicity of delay analysis methods. Finally, the presentational benefits of BIM can assist in presenting complex evidence. It is recommended that those professionals undertaking FDA should use the process model to achieve a better understanding of their workflow and provide a more systematic rationale for presenting their arguments. The implications of the normative model are significant in at least two major respects: (a) in terms of the potential for enhanced analytical capability, and (b) its presentational benefits in support of the existing FDA process. The resulting model can contribute to generating a more systematic approach for FDA methodologies and reducing the subjectivity of analysts: thereby increasing confidence in their arguments.

CONCLUSIONS

The present study describes part of a wider research project which explores the impact of an integrated approach of advances (such as BIM and AI) within FDA and proposes an improved FDA process model by incorporating these advances to minimize the challenges of the existing process. In line with this purpose, previous studies (including relevant publications in the literature, protocols and recommended practices from the international associations, case studies from construction law specific journals, etc.) in the subject areas of FDA, BIM, and AI (relating to construction) were thoroughly reviewed.

The review has identified that the existing methodologies lack a complete process model (integrated with the emerging advances) which aims to guide subject experts (e.g., delay analysts, etc.); therefore, the subjective approach analysis currently applied to the FDA process remains a problem. To address the issue regarding an incomplete process model, using a three-stage methodological approach, a descriptive model was generated, then, it was transformed into initially a prescriptive, eventually a normative model. As an output of the effort, an improved FDA process model, which can assist in the detection of causes of delays, finding and presenting evidence to support claims is proposed. It is proposed that the new process model can further support the idea of generating a systematic approach for FDA methodologies and reduce the subjectivity of the analysis process by underpinning the reasons of the selection of the methodologies.

The previous literature review study from an earlier stage in this project and the present study lay the groundwork for future stages of the research to explore and experiment with the integration of the advances in the FDA process to enhance its efficiency and effectiveness of its outputs and reduce its subjectivity. The initial findings show encouraging prospects for the improved FDA process model by incorporating the advances. Further work is needed to establish the viability of the improvements on real-world project workflows and to collect expert feedback to assess their effectiveness in presenting evidence in claims and disputes.

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WALKING A FINE LINE: EXAMINING THE POSITION OF THE CONSTRUCTION QUALITY AUDITOR THROUGH THE LENS OF FINANCIAL AUDIT LITERATURE

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Internal and external quality auditors must perform a complex balancing act requiring good judgement, interpretation, emotional intelligence, and empathy to achieve several, often conflicting, objectives. The position of the auditor in the financial sector has been examined in the literature in detail; however, in the construction sector this area has been largely unexplored, a gap in knowledge that this paper aims to help fill. This review considers Power's theory of 'The Audit Society' and the rich financial auditing literature to examine the position and actions of internal and external construction quality auditors. The findings show that the audit is a complex construction of performance and judgement and that the 'facticity' of the audit should not be taken for granted. Auditor independence and competence can be difficult to achieve within the current construction quality regulatory system. Construction quality auditing takes place behind closed doors - greater exposure is needed of auditing practice.

Keywords: auditing; quality management; financial regulation; ISO 9001

INTRODUCTION

Internal and external auditors play a pivotal role in the transparency and credibility of regulation, certifying the accuracy of systems compliance. Internal auditors must manage complex and often conflicting objectives (Guénin-Paracini *et al.,* 2015). They should thoroughly correct identified failings prior to external audits. They must foster trust and a good working relationship with the colleagues that they are auditing to induce their cooperation (Van Peursem 2005). The work of an internal organisation's auditors could be described as 'marking their own homework', whereas the continuing appointment of an external auditor is dependent on the favour of the directors whose company they audit. The same broad principles apply, whether to a financial audit or a construction quality audit. ISO 19011 defines an audit as the "systematic, independent and documented process for obtaining audit evidence and evaluating it objectively to determine the extent to which the audit criteria are fulfilled" (2012, p. 1). It lists the 6 guiding principles which auditors should follow as: integrity, fair presentation, due professional care, confidentiality, independence, And an evidence-

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based approach. These principles apply to both financial audits and construction quality audits, although these audits examine different distinct sectors.

Power (1997) suggested that we live in an 'audit society' where organisations are increasingly compelled to externally assess and report their performance against an expanding number of factors - financial and quality management, as examined in this paper - but others including health and safety, environmental performance, diversity, information management and data quality. Audits are inferential, in that they use a sample of documents, interviews and site visits to draw conclusions as to the performance of a company (power, 2000). Audits are intended to ensure legitimacy and accountability (power, 2021), to help a company demonstrate that customer needs and regulatory and statutory requirements are being met (benner and tushman, 2003).

Audit reliability has been widely addressed in accountancy literature (Including Guénin-Paracini *et al.,* 2015, Chu *et al.,* 2011, FRC,2020.) Despite this spotlight on the mechanics and quality of financial auditing, a recent study by the International Forum of Independent Audit Regulators (FRC,2020) Found that audits by the world's largest 6 auditing firms (KPMG, EY, PWC, Deloitte, Grant Thornton, BDO, and Mazars) were 'persistently riddled with flaws.' KPMG are under investigation by the UK financial reporting council for failing to uncover and report misstatements in Carillion's company accounts before its collapse (Prior, 2022); and PWC have been fined for audit failure with Kier and Galliford Try Accounts (Cruise, 2022).

This raises the question - if financial audits, which are under a research spotlight and stringent regulatory scrutiny, can be unreliable, manipulated or misstated, how dependable are the audits which are carried out in the much less visible world of construction quality management? Recent construction quality control scandals such as the Edinburgh Schools PFI problems (Cole, 2017) and the Grenfell Tower fire (Hackitt, 2018) point to systemic failings in construction quality audits which need further examination.

Numerous studies examine the independence and authority of auditors in the financial sphere (Including Selim, *et al.,* 2009; Heras-Saisarbitoria and Boiral 2013; Tepalagul and Lin, 2015) and several in other industries regarding ISO 9001 (Ahlawat and Lowe, 2004; Abbott, *et al.,* 2016), But few recent studies have examined the position of quality management auditors in the construction sector. This paper therefore aims to compare research on the position and independence of the auditor in the financial sector (which is plentiful) with that of the position of the auditor in construction quality auditing, using Power's theory of the 'Audit Society' as a lens. The first objective is to explore Power's theory of the 'Audit Society.' The second is to examine internal and external auditor independence, authority, access to information and competence in the financial sector. The final objective is to use this information to raise questions regarding quality management audit practice in construction to provide a road map as a basis for further research into the quality auditor in construction.

Method

Papers were systematically selected from peer reviewed sources in two distinct exercises. For the first, Scopus, Google Scholar and the authors' institution online library were searched using the terms 'Financial Audit' 'and 'Audit Regulation'. 83 abstracts were then reviewed to determine which papers met the inclusion and exclusion criteria. Inclusion criteria include papers that examine financial audit performance, practice, and regulation. Exclusion criteria comprise non-peer reviewed work, studies with a high degree of cross pollination and repetition, and ultimately conference paper constraints. A rich seam of research was mined in this exercise. 33 papers were selected for review, including those on the concept of 'the Audit Society'. The second selection process used same databases with the search terms 'Construction ISO 9001 Auditing' and 'Construction Quality Auditing'. 51 abstracts were reviewed for alignment with inclusion criteria which comprise studies that examine construction quality audit performance and practice. The exclusion criteria above were supplemented with papers that refer to 'financial construction', for example 'the construction of auditing expertise'. Fewer papers were identified in this second search; 13 papers were selected, many are 20+ years old.

The identified literature was critically reviewed, and initial codes generated by hand, to reflect the themes identified by Power and his theory of the audit society. Coding followed the principles of Braun and Clarke (2006), generating themes that are linked to the data, that are distinctive, consistent and are internally coherent. A second stage of coding was then undertaken to refine the hand generated themes using NVivo software under the parent headings of ‘Financial’ and ‘Construction.’ Sub-codes were then generated against the headings of external financial auditor independence and competence; internal auditor independence and competence; access to information; and communication. The analysis considers the concept of the audit society and the financial audit literature to identify themes that may be relevant to construction.

The Audit Society and the Auditor

Power (1997) coined the term ‘the audit society’ to describe the self-generating increase in audit activity over the past decades. He avoids a clear definition of ‘auditing’ suggesting that ‘official’ definitions merely project hope and idealise the process. When working on the theory of the audit society within the social sector Kastberg and Österberg (2017) found that audit can be undertaken as a ritual. Auditing happens when an organisation is compelled by institutional pressure to account for a particular aspect of its performance (Bromley and Powell, 2012). Power (2021) contends that the audit has 3 main aspects - it is material (in terms of the documents, records and artefacts that are examined); ideational (in that it expresses the concept that transparency means that it is traceable) and it is processual (in terms of the production and abstraction of information for the audit, and of the process of the audit itself). He suggests that the audit requires complex information to be simplified and standardised. Although ‘the audit’ is presented as rational, procedural, and value-neutral, it is influenced by the prevailing social pressures at the time and has been characterised by Power (2021) as reductive and unrepresentative, challenging its legitimacy.

Auditors play a mediating and adjudicating role, but they are often portrayed as agents whose choices are replicable, calculable, and comparable (Miller and Power, 2013). This role is “far more complex than might be currently conceived” and is a “complex interweaving of collegiality and friendships, guides and impositions, qualifications and status” according to Van Peursem (2005). During an audit, “the acute compromises that the auditor is forced to make as an individual are rendered invisible” (Power, 2003 p382). Despite this, auditing maintains the appearance of ‘facticity’ (Friedland, 2017) - a 'taken for granted' objectivity. This ‘facticity’ is given weight by the documents involved, by cultural and organisational expectation, and by the performance of those involved in the audit. The practices of the audit are legitimised and are made possible through a system of negotiation (Power, 1996). The auditor's position is socially constructed, and the audit report simplifies, decontextualises and supresses conflict (Miller and Power, 2013). The records produced during an audit "can be used to beat the system, control others, protect oneself, save time, avoid scrutiny, as well as document that work has been done" (Power, 2003 p386).

Although the audit is presented as a structured, 'technical' exercise, much rests on the auditor's judgement (Power, 2003). The understanding of Auditor independence, professionalism and faith in the audit practice have been generated by consensus and reproduction (Power, 2003). Power examines the gap between the official version of the audit and what happens in practice. He suggests that "the roles and operations of auditing are never fixed and self-evident" (2003, 388), and that the audit is a social exercise that focuses on 'community, rules and authority.' The literature examining the complexity, negotiation, and selective presentation of information during an audit and the position of the auditor within this system in the financial sector, is reviewed in the next section.

Financial Accounting and Auditing Literature

Auditor independence is required for an effective audit (Abbott *et al.,* 2016). Power (1997) suggested that in the absence of independence, an audit has no value. Bazerman *et al.,* (1997) examined the psychological barriers to maintaining auditor independence, claiming that even honest auditors cannot fail to be influenced by the factors mitigating impartiality, primarily conscious or unconscious auditor bias. According to Bazerman *et al.,* this bias is induced by auditor self-interest, itself generated by desire for continued business through the client's ongoing appointment of the auditor. He claimed that "people tend to confuse what is personally beneficial with what is fair or moral." As a result, auditors tend to rationalise the exploitation of ambiguous standards to the benefit of their clients and, by extension, themselves. Guénin-Paracini *et al.,* (2015) examine the real-world relationship between the auditor and auditee. In their observations, the auditors are reliant on maintaining an ongoing positive relationship, leading to a relationship as a 'kind of therapist' and only using sanctions as a last resort. This type of close working bond may compromise the auditors' willingness to uncover and report errors.

Conflict of interest is a common theme across accounting scandals (Moore *et al.,* 2006). In the financial sector, an auditor serves both the directors of the organisation who appoint him; the organisation's shareholders and investors (Guénin-Paracini *et al.,* 2015); and assumes a public responsibility which should override the client relationship. Moore *et al.,* (2006) describe the post rationalisation of questionable decisions by auditors through their 'moral seduction' theory. They state that, if the conflicts of interest are not acknowledged and dealt with, auditors can fall down a 'slippery slope' of lax standards and letting minor deviations go. Auditor independence is gradually eroded through a process of unconscious bias - which they claim is more prevalent than outright cheating and fraud. This process happens gradually, imperceptibly, through the willingness of the auditor to 'go along' with biased proposals made by the auditees, or to internalise the client organisation's way of thinking (Guénin-Paracini *et al.,* 2015). This unconscious bias may be motivated and aided by personal, firm and client interests, or through ignorance (Peytcheva and Warren 2011). Auditor rigour depends to some degree on whether they perceive that their actions will be uncovered by their professional bodies and by the auditor's firm

(Peytcheva and Warren 2011), and on the likelihood of litigation (Tepalagul and Lin 2015).

Internal auditor function and effectiveness can be opaque (Power 1997) and is an 'enigmatic phenomenon' (Lenz, *et al.,* 2018). Arena and Azzone (2009) found that internal auditor effectiveness was influenced by the characteristics of the internal audit team, in terms of their competence and resources, and that auditors must be sufficiently resourced and have enough capacity and knowledge of the subject under audit to have legitimacy at manager level. Lenz *et al.,* (2018) link legitimacy with effectiveness thus: "legitimacy is needed in order to survive and providing evidence of added value and effectiveness is one way to be perceived as legitimate in the eyes of major stakeholders."

The internal auditor can play a key role in enhancing the quality of financial reporting (Abbot *et al.,* 2016). Internal auditing is "an independent objective assurance and consulting activity designed to add value and improve an organisation's operations" (Selim *et al.,* 2009). Internal auditors must be both dependent and independent of management (Glascock 2002). Ahlawat and Lowe (2004) found that it is difficult for internal auditors to remain truly independent, providing objective feedback, when this conflicts with their role to provide best value solutions to issues identified on behalf of their company; auditors are heavily influenced by their desire to advocate for, and present the 'best face' of, their company. Sarens and de Beelde (2006) suggest that internal auditors should cultivate an 'open and friendly attitude' and act as 'conduits for whistleblowing.' Internal auditors' associations with management can be 'close'; however, on occasion, internal auditors are required to report their direct managers' non-compliance to higher management, and make their voice heard to senior management. This can create conflict (Van Peursem 2005). Organisational stress factors including role conflict, when an individual is expected to manage competing, conflicting demands, are a source of stress for internal auditors (Larson 2004). The Institute of Internal Auditors Research Foundation stated that "IA [Internal Audit] is, by its very nature, a schizophrenic management function. On one hand, it needs to be completely integrated and knowledgeable. But it also needs a measure of independence required of all auditors. Therefore, IA has a built in cognitive disconnect" ((IIARF,2011, 14).

Abbot *et al.,* (2016) include competence as a measure of auditor independence - that is, the auditor must be able to recognise when what they are seeing is contrary to regulations, to uncover anomalies, report and prevent their recurrence. Power (1999, 132) linked competence to the "ability [of auditors] to detect material misstatements." Guénin-Paracini *et al.,* (2015, 224) interview an auditor who describes the "skill you need to acquire: figure out when you're being told fibs, read the body language." Van Peursem (2005) found that managers did not find internal auditors to be credible when they did not rate their knowledge of the subject under audit; if this was the case the managers would ignore the auditor's advice. Financial auditors tend to be qualified accountants, although even they may not sufficiently understand complex technical areas of accountancy (Nehme 2017).

The concept of 'materiality' is important to the financial audit - that is, how wide is the scope of the audit, and what documents and processes are deemed to be relevant to the audit. It refers to the 'sampling' process and is a complex matter of professional judgement (Canning *et al.,* 2019). Canning *et al.,* (2019) find that when data is ambiguous, this materiality becomes more difficult to judge and yet is central to the quality of an audit; and that auditors need to deploy intuition, expertise, and flexibility to address this issue. The audit is a classic example of information asymmetry - where those under audit may understand the information in far greater depth than those examining it. Auditors must rely on documents and information provided by those they are auditing, which gives an opportunity for selective disclosure or manipulation (Abbot, *et al.,* 2016).

Financial regulation requires full access to accounting information for financial auditors. Given the regulation requiring cooperation with auditors, those being audited have in their arsenal an array of techniques for delaying and otherwise undermining the audit whilst still complying with the letter, if not the spirit, of regulation. The timescale of the audit - typically a day or two to examine a year's worth of reports or accounts - ensures that any delay in the provision of information to the auditor can reduce the scope and depth of their investigation. Delaying techniques include putting the auditors in a room far from the information they need, not giving them contact details for those they need to speak to, or those under audit making themselves scarce to the auditors (Guénin-Paracini *et al.,* 2015). The opposite approach can also be used to deny information. This entails appearing to give the auditor everything they need in a single room and discouraging them from leaving the room to speak to others and probe beyond what they are given, leading to 'in-chamber audits' where the information given to the auditor is controlled and the auditor only sees what the organisation under audit wants them to (Guénin-Paracini *et al.,* 2015).

Communication style is an important skill that auditors, both internal and external, employ to manage and navigate the conflicting demands placed upon them (Selim *et al.,* 2014). Their tools include listening, gentle persuasion and consensus building to get a message through to people that 'just don't want to hear' (Van Peursem 2005). Successful auditors must constantly moderate their communication in response to those being audited, undertaking a constant negotiation of the audit process, and acting differently according to the context in which they are operating (Guénin-Paracini *et al.,* 2015). However, due to the requirements of the audit and the time constraints involved, the best auditors know when to stop cajoling and 'draw the line' (Van Peursem 2005). Giving audit feedback requires sensitive communication and use of language, as the feedback usually involves pointing out where individuals have made mistakes. Guénin-Paracini *et al. (*2015, p219) quote an interviewee who says, "you have to be very careful in handling the professional ego of your client." Techniques for 'sweetening the pill' described in this study include use of euphemism, anonymisation, de-dramatisation, downplaying, self-deprecation, and humour.

FINDINGS

Only a handful of studies look at quality management audits in construction (including Calder, 1997; Cheetham, 1997; Goh *et al.,* 1996; Gunning, 1995 and Gunning, 2004); excluding those which look at Total Quality Management the authors can find no studies which have been published within the last 10 years. Recent research has looked at construction quality management (including Brooks, et al.; 2021 Khalfan *et al.,* 2020; and Neyestani, 2016), but none has focussed on the audit process itself, or the position of the auditors within the system. This lack of recent investigation, Power's work on the Audit Society and the financial literature critically examining the audit, indicate that more research on the construction audit is needed.

Both financial and quality management audits are designed to increase public trust in an organisation and increase its legitimacy as described by Power (2003), although quality management audits are voluntary and financial audits are a statutory requirement (Kouakou, *et al.,* 2013). In construction, ISO Quality Management audits, crucial to maintain certification, are based on the verification of documents that are provided by the company under audit. Manipulation of the information presented may be used to 'beat the system' (Power, 2003), which necessitates the reduction and simplification of information (Power, 2021). The auditor may be tempted to 'go along' with what is being presented (Guénin-Paracini *et al.,* 2016). More construction specific research is needed to investigate these concepts in greater detail.

Some construction literature accepts the rationality of the quality management system and its 'facticity' at face value (Bubshait and Al-Atiq, 1999) and focus purely on the benefits of ISO 9001 implementation (Cachadinha, 2009; Ali and Rahmat, 2010). Goh *et al.,* (1996) look at the 'effectiveness' of the audit in construction from a technocratic point of view and do not consider the factors raised by Power's 'audit society' (1997, 2021) that can make an audit reductive and unrepresentative. The mediating role of the construction auditor and the judgement that they use is under researched. Gunning (2004) suggests that auditors often act with either 'extreme leniency' or pedantic adherence to detail. Cheetham (1997, p280) suggested that procedures were circumvented by some auditors "when production needs dominate." More critical research, which examines the compromises that auditors must make (Power, 2003), the social pressures that they are operating under (Power, 2021) and does not accept the 'facticity' of the construction audit as a given, is needed.

Regarding auditor competence, financial auditors tend to be qualified accountants; although even they may not sufficiently understand complex technical areas of accountancy (Nehme, 2017). The training and expertise of ISO auditors is not as consistent or as well developed as that in financial auditing, according to Boiral and Gendron (2011), with less codified requirements for audit, leading to what Kouakou *et al. (*2013, p1284) describe as "less demanding norms of professional practice." This means that some auditors must rely on the technical expertise of those they are auditing, which compounds the information asymmetry already inherent in the audit situation. Gunning and McCallion (2007) reported a conversation with a construction quality manager who claimed that he could fool an auditor into granting ISO 9001 certification to any company, regardless of its worthiness. Gunning (2004, p. 1092) suggests that construction quality audits would benefit from more sector specific auditors who would fully understand "the technical complexities of construction processes."

CONCLUSION

To 'build back wiser' we must learn how to improve practice from other sectors. Construction quality auditors and researchers have much to learn from the breadth of research undertaken in the financial auditing sphere; this paper contributes to knowledge through use of Power's concept of 'the Audit Society' and the abundant literature on financial auditing to derive concepts that may equally apply to construction quality auditing, to propose areas for future research. Construction auditors need to be more reflexive, considering their own motivations and actions. They must be made aware of the context in which they are acting - and should be sceptical about the taken for granted 'facticity' of the audit. Research should focus on the independence, competence, judgment, and mediating role of construction auditors.

The importance of transparency in financial auditing is unarguable, given its statutory status and the reliance placed by investors on independent financial audit reports. The financial services industry was forced to take action to improve accounting audits in the wake of several high-profile scandals, including regulation in response to the collapse of Worldcom and Enron. Oswald, *et al.,* (2021) argue that in the wake of the Grenfell disaster, more work is needed to examine the construction industry's systemic failures, borrowing concepts from other disciplines. The authors of this study agree and assert that research which examines the process of the construction quality audit and addresses the conflicts of interest that are inherent in the position of internal and external construction auditors is overdue.

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THE DECISION-MAKING BEHAVIOUR OF PUBLIC PROCUREMENT OFFICERS: AN INTERPLAY BETWEEN PROCEDURAL RATIONALITY AND GROUPTHINK BIAS

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Malaysian public procurement has always been regulated by comprehensive procedures to enhance rationality in decision-making. Nevertheless, the public procurement is still plagued with recurring irregularities. This research investigates the opposing factors at play in between the individual decision-making process and the group decision-making environment. A research model was built on the notions of procedural rationality and groupthink to examine the outcome of individual procedural rationality under the influence of groupthink behaviour. The Partial Least Square-Structural Equation Modelling technique was employed to analyse 289 datasets from the Malaysian public procurement officers. The result showed that while procedural rationality is correlated strongly with groupthink, it had insignificant influence on the outcomes of groupthink - defective decision-making processes at the group level. Apparently, it fails to stop the defective decision-making process once the elements of groupthink have permeated the group. Recommendations are made for improving the composition of public procurement committees.

Keywords: groupthink; procedural rationality; procurement; structural equation

INTRODUCTION

The most distinctive property of decision-making is the notion of contemplating between choices of action or inaction. It involves cognitive processes of weighing, narrowing, and justifying choices that eventually transforms into decisions. This information processing behaviour can be performed individually as well as by a group of individuals.

Individuals often prefer a fast-track course to resolve problems due to time and resource constraints. These rough estimates are adequate if not perfect, for reaching a decision, simply because individuals are often satisficing rather than optimising (Tversky and Kahneman 1974). While satisficing enables individuals make prompt judgements, it may induce erroneous decisions (Kaufmann, Carter and Buhrmann 2010, 2012).

On the other hand, decisions jointly made by a group of individuals may produce positive as well as negative effects. While decision-making in a group setting would

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invite extensive deliberation (Eisenhardt and Bourgeois 1988), it may also produce negative effects when conformity seeking behaviour appears among the members (Janis 1982).

This situation warrants investigation especially within the public procurement environment, involving individual procurement professionals making decisions in group settings. In Malaysian public procurement, tender evaluation and awarding have never relied on individuals, but on groups or committees (MOF 2007, 2008). The Treasury Circular in 2004 for infrastructure maintenance projects required the participation of a broader group of officials at the open tender stage (MOF 2004).

The effectiveness of group deliberation as well as individual decision-making bears a significant impact on the quality of public works, goods, and services. This research investigated the opposing factors at play between individual and group decision-making, which ultimately affect the quality of deliberation.

For that, a research model was built on the notions of procedural rationality and groupthink to examine the outcome of individual procedural rationality under the influence of groupthink behaviour. The following section discusses the fundamental concepts of related constructs and their hypothetical relationships

Theoretical Background and Hypotheses

Bounded rationality
Isenberg (1984) found that senior managers oftentimes depend on intuition rather than normative ways of decision-making since information acquisition is costly and painstaking. Oftentimes, individuals with limited mental capacity are unable to collect and process all information and determine if a decision is truly rational. This constraint is conceptualised as bounded rationality (Simon 1990).

Procedural rationality in individual decision-making
To overcome this limitation, a sensible individual will therefore devise an adaptive procedure for decision-making (Simon 1976). Such a procedure is believed to enhance an individual's rationality as a problem solver for finding the most optimal solution - procedural rationality. This strategy is not about producing and analysing enormous data. Instead, experience and wisdom are employed to produce a few good enough alternatives for further investigation and analysis (Simon 1976). Procedural rationality is defined by Dean and Sharfman (1993) as 'the extent to which the decision process involves the collection of information relevant to the decision and the reliance upon analysis of this information in making the choice'. Alessandri (2008) stated that a higher level of procedural rationality demands more judgement-related information and exhaustive assessment, whereas a lower level of procedural rationality requires less mental effort in information collection and assessment.

Procedural rationality in group decision-making
The group setting is believed to be conducive for the adoption of procedural rationality. Group decisions are largely derived from comprehensive procedures (Dean and Sharfman 1996; Papadakis and Barwise 2002). These procedures allow members with different backgrounds, values and viewpoints to be challenged and debated by the others, while reconciling with their own thinking on how key issues should be construed (Bettenhausen 1991).

Simons, Pelled and Smith (1999) discovered that active deliberation was correlated positively with decision comprehensiveness, ensuring that group decisions have considered broader choices. Groups that employed procedural rationality produced less faulty decisions and were more successful in meeting their decision objectives (Dean and Sharfman 1996). H1: Procedural rationality (PRA) is negatively related to defective decision-making (DDM) processes.

Klein and Yadav (1989) found that greater procedural rationality generates improved decision outcomes while lower procedural rationality produces poor decision outcomes and tends to bring procurement irregularities. H2: Procedural rationality (PRC) is negatively correlated with procurement irregularities (IRR).

Antecedents of procedural rationality
This research adopted three antecedents of procedural rationality identified by Kan and Khalid (2021), i.e., accountability, prior knowledge and experience. High accountability of the decision environment exerts pressure to be correct (Rausch and Brauneis 2014), thereby significantly minimising decision error (Tetlock, Skitka and Boettger 1989). Decision-makers who are responsible for their decision outcomes employ sophisticated decision-making approaches or greater procedural rationality (Kaufmann, Michel and Carter, 2009). H3: Accountability (ACC) is positively correlated with procedural rationality (PRC).

A person with prior knowledge of a product would require less time in making a decision (Bettman and Park 1980). New information can be processed with lesser thinking effort, leaving additional resources for using more sophisticated decision strategies (Johnson and Russo 1984). Riedl, Kaufmann, Zimmermann and Perols (2012) found a positive correlation between prior knowledge and procedural rationality. H4: Prior knowledge (PKW) is positively correlated with procedural rationality (PRC).

Jacoby, Chestnut and Fisher (1978) found that more experienced individuals assess more information sources, make more conservative decisions (Perkins and Rao 1990), are more discerning of information relevancy and apprehend information more comprehensively (Sanbonmatsu, Kardes and Herr, 1992). Thus, experienced decision-makers would likely employ more complex decision-making strategies or higher procedural rationality. H5: Work experience (WEX) is positively correlated with procedural rationality (PRC).

Groupthink

In the public sector, the tender assessment and awarding process is administered in committee settings. This setting however may attract a groupthink bias which was defined by Janis (1982) as '…a deterioration of mental efficiency, reality testing, and moral judgment that results from in-group pressures'. Under this circumstance, the committee may overestimate its power and morality, prompting closed mindedness to members' views, imposing pressures towards concurrence-seeking and ultimately undermining the importance of deliberation.

Nevertheless, the awarding committee would decide based on the assessment made by the tender evaluation committee. The assessment process of the tender evaluation committee is conducted with high procedural rationality since it includes deliberative procedures, alternative assessment procedures and information search procedures, allowing individual members to air their dissimilar views and constructive criticism. Solomon (2006) found that aggregation of individual views and decisions, rather than deliberation to a consensus, would generate better decisions than group deliberation. H6: Procedural rationality (PRC) is negatively related to groupthink (GTK).

Antecedents of groupthinks
Groupthinks are largely preceded by group cohesiveness and group insulation (Janis 1982). When a group is highly cohesive, its members will 'express solidarity, mutual liking, and positive feelings about attending meetings and carrying out the routine tasks of the group'. H7: Group cohesiveness (COH) is positively related to groupthink (GTK).

Sundstrom, Meuse and Futrell (1990) found that groupthink is more prevalent in self-regulated groups where the group decisions are produced with minimum external input. As an insulated group, it relies largely on the shared views from its group members where this blended mental model unfortunately would offer a very low analytical power (Fischhoff and Johnson 1997). H8: Group insulation (INS) is positively related to groupthink (GTK).

Defective decision-making processes
Under the influence of groupthink, the members would be more concerned regarding whether a decision is made consensually rather than on how the decision is concluded (Solomon 2006). The members are unlikely to challenge their counterparts, lest such action would have contradicted their group's view. Herek, Janis and Huth (1987) operationalised this defective decision-making process as an incomplete survey of alternative and objective, failure to re-examine the originally preferred choice and initially discarded alternatives, poor information search, selective bias in processing information and failure to develop contingency plans for probable decision failures. H9: Groupthink (GTK) is positively related to defective decision-making (DDM) processes.

Procurement irregularities
Within a procurement committee, the groupthink effect is completely unintended from the standpoint of group members (Janis 1982). It is a product of the integration of the people, the cohesive sentiments and the situation, undermining the members' capabilities as competent decision-makers (Tetlock 1979), thereby causing irregularities in procurement. Procurement irregularities indicate that the outcomes of procurement decisions deviate from their objectives, which generally include cost overruns, project delays, shoddy workmanship, work abandonment, etc. (National Audit Department Malaysia 2018, 2019). H10: Groupthink (GTK) is positively related to procurement irregularities (IRR).

The public procurement system assumes that the officers have full access to market information. In fact, they depend on a little information in reaching decisions (Csáki 2006), having limited time to participate in comprehensive deliberation, willing to accept reasonably good choices (Kuchina-Musina, Morris and Steinfeld, 2020). The National Audit Department Malaysia (2017) found that the compliance in procurement procedures is relatively low in the public sector, i.e., 28%. This low compliance in procurement procedures is akin to defective decision-making processes, which inevitably contribute to procurement irregularities. H11: A defective decision-making (DDM) process is positively related to procurement irregularities (IRR).

METHOD

This research employed a quantitative approach. A research model was built on the notions of procedural rationality and groupthink and tested using partial least square-structural equation modelling (PLS-SEM) technique. The measurement items were adapted from Riedl *et al.,* (2012) for accountability (4 items) and prior knowledge (3 items) constructs. Procedural rationality (7 items) was adapted from Kaufmann *et al.,* (2012). Furthermore, insulation (3 items), cohesiveness (3 items) and groupthink (27 items) were adapted from Park (1989). In addition, defective decision-making processes (14 items) and procurement irregularities (8 items) were adapted from Moorhead and Montanari (1986) and Kan (2016), respectively. The model was validated by five experts in public procurement via semi-structured interview.

Non-probability sampling was employed as it is convenient. The secretaries of selected Malaysian local authorities were duly briefed about the purpose of research and verbal consent was solicited prior to the survey. The respondents were the officers involved in procurement decision-making in the past 12 months. In total, 1,035 self-administered questionnaires were hand-delivered and followed up with emails, of which 322 were returned. There were 289 valid responses, equivalent to a 27.9% response rate. Of these, 80.3% of respondents possessed tertiary education and thus, could comprehend the questionnaires.

FINDINGS

Assessment of the measurement model

The convergent validity and discriminant validity were determined using confirmatory factor analysis to assess the construct validity. Items with a loading value lower than the cut-off value of 0.5 were discarded (Hair, Hult, Ringle and Sarstedt, 2017). All Cronbach's alpha values exceeded the ideal value of 0.7, affirming that the model constructs were sufficiently convergent. Furthermore, the Average Variance Extracted (AVE) values had exceeded the threshold level of 0.50, indicating that these latent variables could explain more than half of the variance of the indicators. Thus, this research model demonstrated good convergent validity.

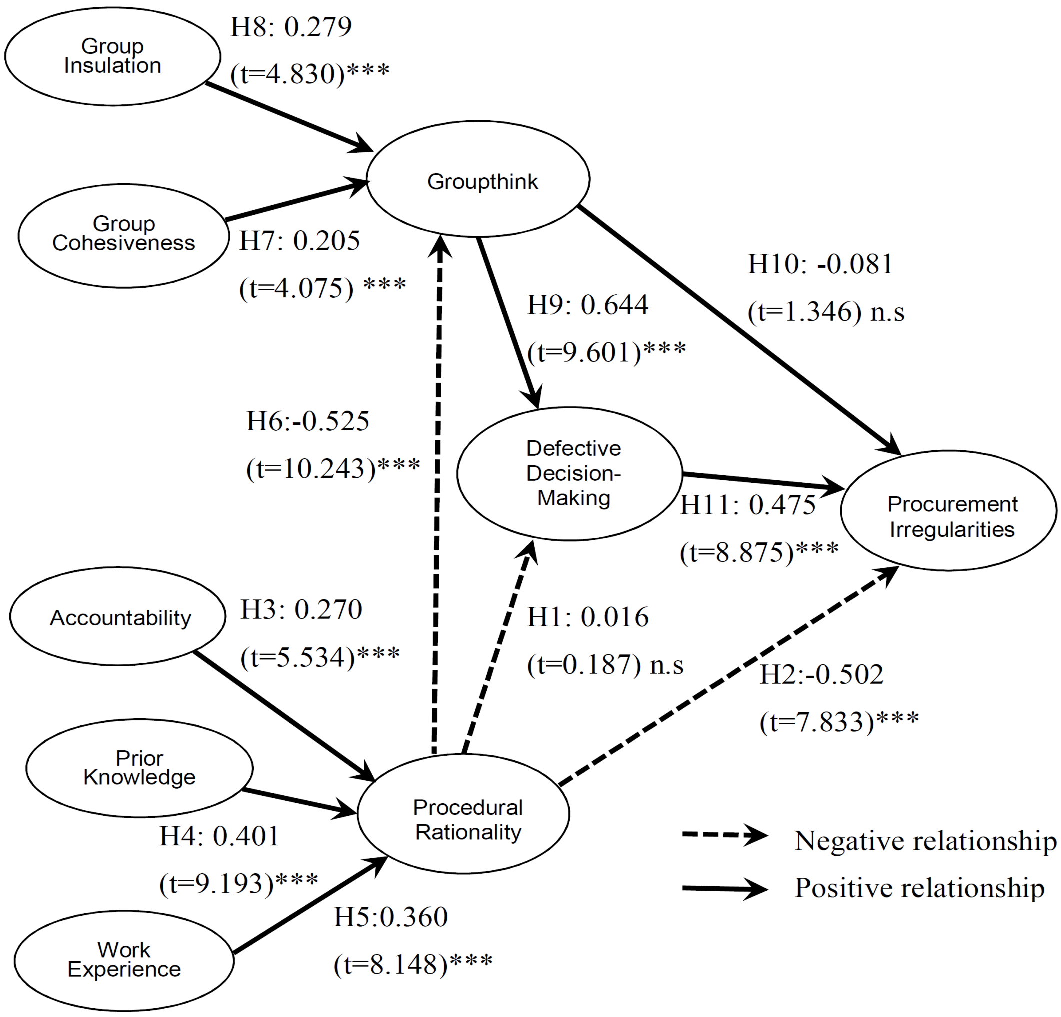
The discriminant validity was assessed via the Fornell-Larcker criterion, where the square root of the AVE in each construct should exceed the highest correlation value with any other construct (Fornell and Larcker 1981). The results show that the inter-correlation of each construct with its counterparts was less than the square root of the average variance extracted with its associated indicators. Hence, the underlying constructs were unlikely to be overlapped with other constructs (Hair *et al.,* 2017). Conclusively, the measurement model was acceptable in terms of composite reliability, convergent validity, and discriminant validity.

Assessment of the structural model

Figure 1 shows the path coefficient (β) and t-statistics (t-value) of each hypothesis. They were determined by a bootstrapping approach using 5,000 samples with 289 cases per sample. All the path relationships, except H1 and H10, recorded t-values of more than 3.090 and hence, these relationships were significant at a level of 0.1%. The overall fit of the path model was tested via PLS path analysis modelling - global fit measure (GoF).

This is the geometric mean of average communality and average R square. The baseline values for assessing the PLS model were GoFsmall = 0.10, GoFmedium = 0.25 and GoFlarge = 0.36 (Wetzels, Odekerken-Schröder and van Oppen, 2009). In this research, the GoF value was 0.500 (R square = 0.250, average AVE = 0.674) and was more than the largest cut-off value of 0.36. Hence, this model was confirmed as possessing a high explanatory power.

Figure 1: Results of path analysis



Procedural rationality was negatively correlated with groupthink (H6), showing that extensive deliberation at individual level would not only reduce individual decision bias but alleviate the irrationality behaviour at group level. The result affirmed the works of Janis (1982) that groupthink would induce defective decision-making processes in procurement committees (H9), which eventually leads to procurement irregularities (H11).

Surprisingly, while procedural rationality was strongly correlated with groupthink (H6), it had an insignificant influence on the outcomes of groupthink - defective decision-making processes at the group level (H1). Apparently, even though individual procedural rationality can prevent the symptoms of groupthink, it fails to stop the defective decision-making processes once the elements of groupthink have permeated the group. In other words, even if the individual procurement officers can maintain high procedural rationality at tender evaluation stage, they have minimal resistance to the general norm and culture of group decision-making at tender awarding stage.

Furthermore, although groupthink was positively correlated to defective decision-making processes (H9) and thereafter defective decision-making processes were also positively correlated to procurement irregularities (H11); the result surprisingly does not reveal any direct correlation between groupthink and procurement irregularities (H10).

Apparently, the existence of the groupthink phenomenon may not always contribute to procurement irregularities. On the other hand, groupthink could manifest in some unique situations (i.e., at a later stage of a decision process), producing positive effects on decision outcomes. According to Longley and Pruitt (1980), when a mature consensus is reached at the end of diligent deliberation, a dominant leader may bolster the solution in a highly biased manner. This behaviour affirms the group's decision, enabling the solution to be executed in a more committed manner despite its possible drawbacks (Janis and Mann 1977).

CONCLUSIONS

Malaysian public procurement has been built on conservative and comprehensive procedural control. It largely does not consider the influence of cognitive limitations and group decision behaviour. Individual procurement officers, however, may adopt a satisfying approach in decision-making, which inherently deviates from the axiom of rationality. On the other hand, the decision-making in group settings is also susceptible to irrational behaviours under the influence of groupthink.

This situation is worsened by the confidential nature of procurement decision-making, particularly at the tender awarding stage where the deliberation process is completely insulated from outsiders, and it may be dominated by an authoritative leader. It is important to note that once groupthink occurs, group censorship would block the recognition of the fact that groupthink is present. The members may oppose any efforts to change toward multiple advocacies.

The governing bodies of public procurement are urged to 'build back wiser', rectifying the drawback of committee composition from the cognitive and behavioural perspectives. To avoid consensus seeking, the tender awarding committee should be composed of an independent assessor. Furthermore, repetitious membership should be prohibited since this may create a veiled bonding among the committee members, where critical deliberation within the committee would be difficult.

In addition, the element of accountability should be introduced to the awarding committee. Frequently, procurement irregularities are found only at the post-contract or post-completion stage. To ensure value for money in procurement decisions, an internal audit and control system should be established at the pre-contract stage, aiming not only to prevent procurement irregularities but holding the decision-makers accountable for their decisions.

Limitations

This study focused on the decision-making processes and settings of public procurement committees. It ignored completely the influence of external factors, such as trade lobbying, political interference, and corruption, which very often, would lead to public procurement irregularities.

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A MAPPING OF SWEDISH LEAN CONSTRUCTION VARIANTS IN PRACTICE: REVIEW AND SURVEY

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Swedish Lean Construction (LC) practices focus mainly on improving technical process parameters – however, issues claimed to have been solved by LC (e.g., high production costs), are still apparent. This study reports on a survey about Swedish companies' LC practices. A literature review on Swedish LC variants served as the background. The questionnaire survey itself was answered by around 490 construction-related companies across all Swedish regions. Survey results indicate a cross-sectoral discrepancy of LC knowledge and practices, with almost 65% of respondents claiming not to know about LC – while those doing so, are applying it in variants (e.g., integrated with location-based planning). Such an implementation can either pertain to project portfolios or be required by clients – and is more visible in large contractors and some SMEs claiming to be LC-competent. A stronger cross-industry collaboration may be needed for facilitating LC knowledge in Sweden, as well as underpinning LC practice variants befitting each company's specific business model.

Keywords: lean construction; practical variants; Sweden

INTRODUCTION

Lean construction (LC) was initially suggested for implementation in Sweden close to 15 years ago, where innovations in construction processes were sought in lessons-learned from the automobile industry - especially regarding contractual, supplier, and customer relations. In academia, this has evolved into a growing research interest featured in more than 350 Swedish publications over 2007-2022. Moreover, elements of a practical LC implementation by some contractors commenced in 2007. However, only a fraction of the academic studies tried to go beyond LC theorisations by empirically investigating such LC practices. Kifokeris and Koch (2020) and Kifokeris (2021) sought to map those empirical studies, which resulted in the identification of six academically conceptualized (but also possibly practically implemented) LC variants in Sweden (see "Literature review"). Such variants can reflect the dedicated use of specific LC elements (e.g., the Last Planner system (LPS) (Ballard 2020a)), and/or the integration of LC with other frameworks, tools, and methodologies, (e.g., Building Information Modelling (BIM) (Dave and Sacks 2020)) (Kifokeris 2021).

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Identifying such LC practice variants can clarify the state-of-art, inform LC adoption, and initiate a practical benchmarking of LC in Sweden (Kifokeris 2021).

On this background, and going beyond the literature, our research question would be: How can Swedish LC practices be empirically documented, in order to grasp the current state-of-art, identify contemporary practical shortcomings, and start considering what a Swedish requirements-driven adoption of LC could be? This study's objective is to tackle such a research question by adopting an operations management approach and reporting a mapping of the Swedish companies' LC practices, as investigated in large-scale questionnaire survey (including basic LC concepts to more advanced themes, e.g., integrating LC with IT) conducted in the end of 2021. It targeted 1,200 companies of all sizes across all three construction-related industry groups and all geographical regions in Sweden. Close to 490 companies provided valid answers. Among others, preliminary survey results indicate a large discrepancy of LC-related knowledge and practices across the Swedish sector.

Following this introduction, the paper's literature review and research method will be described. Afterwards, the analysis of the survey's preliminary results will comprise the empirical focus of the study, followed by critical discussion points. The current study then concludes with its final remarks and recommendations for future work.

LITERATURE REVIEW

LC can be described as a bundle of interconnected themes and concepts (Koskela 2020). Central among those are eliminating waste (i.e., non-value-creating activities) (Koskela 2020), streamlining and internally improving production processes and quality with the Toyota system (Gao and Low 2014), and just-in-time construction production flow (Liker 2004). Complementarily, LC aims at efficiently using resources, optimising workflow, delivering information and material on-time, building relations and cooperation, continuous improvement, minimising cost, and maximising customer value (Tzortzopoulos *et al.,* 2020). Moreover, on-site logistics and supply chains can be optimised by using prefabrication (Vrijhoef 2020). Green and May (2005) have identified three levels of LC implementation maturity: (1) technical and operational waste elimination, (2) cooperation and teamwork enhancement, and (3) fundamental change in project delivery. Finally, London (2008) identified five LC foci (possibly understood as precursors of LC variants): lean project management, lean supply, lean design, lean partnering, and cooperative supply chain management.

Practical LC variants themselves can point to dedicatedly implementing specific LC concepts, processes, and tools - e.g., the LPS (Ballard 2020a), target value delivery (Ballard 2020b), and prefabrication (Yuan *et al.,* 2022). Moreover, they can reflect an integration of LC and other tools, frameworks, and methods - like, indicatively, location-based planning (Kenley and Seppänen 2010), virtual design and construction (VDC) (Kunz and Fischer 2012), visual management (Tjell 2016), six sigma (Plenert and Plenert 2018), integrated project delivery (Alves and Lichtig 2020), BIM (Dave and Sacks 2020), and robotic systems (Brissi *et al.,* 2021).

For LC variants within the Swedish context, Kifokeris and Koch (2020) and Kifokeris (2021) reviewed the relevant publications featuring empirical content, leading to the identification of six LC variants in Swedish practice, as communicated in research:

1. The industrialized construction variant: Prefabrication, modularisation, standardisation, just-in-time, product platforming, mass customisation (optionally), and usually integrated with CAD and BIM

2. The production processes variant: Prefabrication (but not on a fully industrialized level like in the previous variant), vertical integration, pull systems, just-in-time, LPS, stakeholder cooperation, broadening of partnering teams, and usually integrated with CAD, BIM, and VDC
3. The production strategy variant: production strategy optimisation, product platforming, bottom-up feedback, stakeholder cooperation, broadening of partnering teams, and even appointing specialised LC managers
4. The design variant: constructability, product platform development, early supplier, and client involvement in design, and usually integrated with 4D CAD, BIM, VDC, and visual management
5. The planning variant: process mapping, location-based planning, stakeholder collocation, LPS, just-in-time, usually integrated with BIM, VDC, and visual management, and sometimes combined with the design variant
6. The logistics and supply chain variant: process mapping, value-driven purchasing, location-based planning, just-in-time, LPS, and early supplier involvement in the material and economic flows

While these variants appear precise and hint to an advanced LC implementation in Swedish practice, Kifokeris (2021) points out that this may not actually be the case in the 2021-2022 state-of-art. Specifically, Kifokeris (2021) notes that most reviewed studies had a disproportionately large focus on industrialized construction - while the relevant market segment, although well-defined, is small compared to the rest of a sector dominated by more conventional construction practices (Steinhardt *et al.,* 2020). Moreover, Kifokeris (2021) shows that the reviewed studies mostly focused on the LC practices of few specific case companies - leading to well-contextualized, but not easily generalisable results. Furthermore, Koch *et al.,* (2020) empirically showed that practical LC implementation in Sweden focused mainly on improving technical process parameters, and issues claimed to have been solved by LC (such as impaired productivity and high production costs), were still apparent.

METHOD

To identify the literature for the background of this study, a concept-centric systematic review augmented by units of analysis was conducted in iterations - so that the review could be gauged to conclude when no new relevant concepts could be found (Webster and Watson 2002). The main concepts were “Swedish LC practices” and “LC variants”. The emerged units of analysis included, indicatively, “production platforms”, and “prefabrication”. This framework was supported by the “snowballing” and references-of-references techniques (Greenhalgh and Peacock 2005).

The empirical part of the study tackled the research question stated in the Introduction, through the conduct of a questionnaire survey addressing a wide sample in a well-structured manner with standardized questions (Boynton and Greenhalgh 2004). An operations management approach (Slack and Brandon-Jones 2019) was used in conjunction to our LC knowledge to inform the survey’s design - as we investigated lenses of designing and controlling production processes and business operations for efficiently and effectively meeting the client’s requirements. This resulted in a total of 23 questions categorized thus: information about the respondent’s role and company affiliation (two questions), knowledge and understanding of basic LC concepts (two questions), LC elements (incl. overarching philosophies, waste elimination, pull planning and kanban, LPS, and lean supply chain and logistics) implemented by the company currently (five questions) and in the past (five questions), other applied approaches to facilitate LC (incl. e.g., BIM 360, VDC, and six sigma) (one question), factors of LC implementation (incl. e.g., competence development and training, communication, rate of implementation, and effects) (seven questions), and an optional contact confirmation for requesting to receive the project report when the survey is completed (one question). Each question had one of the following forms: multiple choice inquiry, free-from textbox, tick box list, Likert scale, or a combination thereof. The survey was designed and went live using the online tool Survey Monkey.

The respondents were not sampled, but rather, an industry-wide response pool was sought. As such, a nationwide database of all companies active in the Swedish construction sector was created - including around 1,200 firms across all geographical regions in Sweden and all entries in the construction-related industry groups 41 (development of buildings and construction of residential and non-residential projects), 42 (infrastructure), and 43 (facilities and crafts). The database fields covered the companies' names, website, place of main activity, postcode, registration year, organisation number, 2019-2020 turnover and net profit, number of employees, contact person (name, e-mail, cell phone number), and business activities. The questionnaire was then sent via e-mail (through Survey Monkey) to all database entries. This process was iterated thrice; in between each iteration, the targeted respondents were also called on the phone, to ensure the highest possible response rate. The survey was live between 23/08/2021 and 31/10/2021 (with a few stray responses until 31/01/2022), and around 490 companies offered valid (i.e., not blank, or partial) responses - resulting in a ca. 41% response rate. Companies in groups 41, 42 and 43 provided ca. 43%, 12% and 45% of the responses respectively.

The synthesis of the literature review and survey results followed the abductive reasoning of qualitative research (Bell *et al.,* 2019), where observations and explanations were developed by working iteratively between theory and data.

Empirical Part - Survey, Results, and Analysis

The survey results will be presented and analysed here in more detail. Table 1 offers an overview of the respondents' profiles and contribution to the overall response rate.

Table 1: Survey respondents' profiles and overall contribution to the response rate

Role in company	% of responses
Top managers: CEOs, department managers, business unit managers	55
Middle and lower managers: project, site, and production managers	31
Officers and clerks	7
Technical personnel: engineers and craft/site workers	1
Other, e.g., environment and HR managers	6

This strong representation of top management may indicate that most respondents are possibly responsible for important initiatives and even top-down strategic decisions. This strikes however as particularly alarming, as when the respondents were asked in the following question about whether they knew what LC was and for what it could be used, close to 65% answered that they did not. A far lower percentage (ca. 34%) declared that they knew about it, and very few noted that they knew about LC, but implemented it under a different definition (without, however, offering a further explanation about what such a definition could be). This response already supports the problematisations in Kifokeris and Koch (2020) and Kifokeris (2021), as it shows a rather different picture than the one described by the reviewed academic studies in the Swedish context. Figure 1 offers a graph depicting the aforementioned responses.

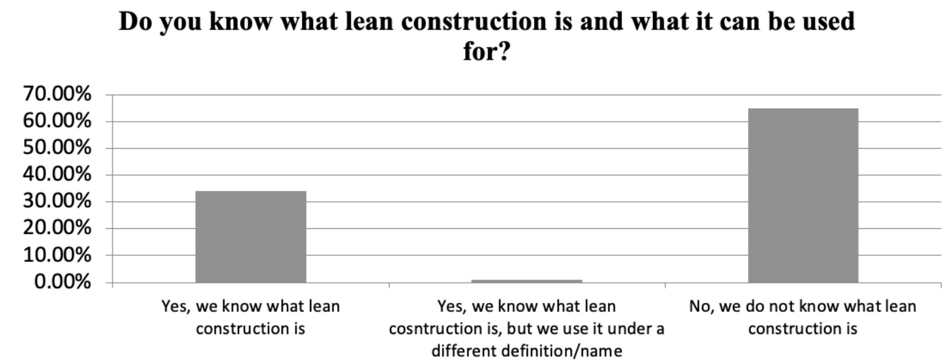

Figure 1: Survey responses regarding the state of knowledge about what lean construction is

Then, a basic definition of LC was offered to aid the respondents, as it was anticipated that some would not know about LC - although, not to such a large percentage. That definition was a simplified combination of concepts by Koskela (2020), Gao and Low (2014), and Liker (2004): "Although there are many concepts of lean construction, it is generally considered that it aims to eliminate waste and increase value for the client". The survey then continued under the premise that equipped with this definition, even less knowledgeable respondents could follow through.

The respondents were then asked about how strongly they agree with specific LC-related statements (see Figure 2). They could choose multiple answers on a 5-step Likert scale: 1 - Not at all, 2 - Weakly, 3 - Relatively weakly, 4 - Relatively strongly, and 5 - Strongly, while also having the opportunity to choose Don't know / N/A.

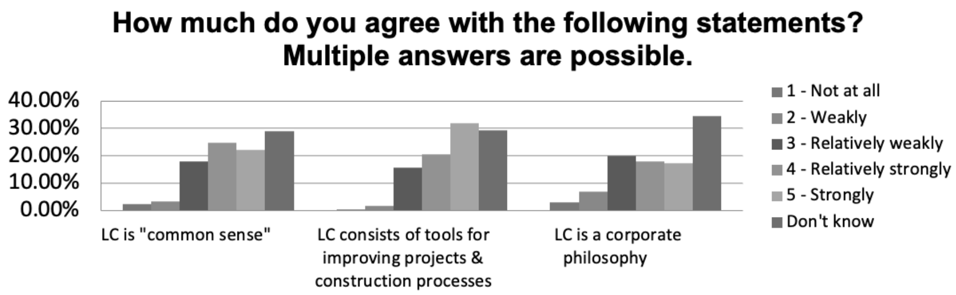

Figure 2: Degree of agreement with specific lean construction-related statements

Due to space limitations not permitting the inclusion of all survey graphs, below we will textually describe the rest of the survey's Likert-like questions and responses, while focusing on the most prevalent degree of agreement for each statement.

Succeeding the previous question, the respondents faced a series of inquiries regarding the degree with which LC factors or elements have been applied in their companies' contexts. In the inquiry about overarching LC philosophies, waste elimination and customer value increase applied relatively strongly, the transformation-flow-value (TFV) framework applied relatively weakly, and the Toyota production system was N/A. Waste elimination was then shown to be relatively strongly associated with errors, non-utilisation of human resources, inefficient resource management, reworks, delays, transportation, and value-creating activities; and relatively weakly associated with overproduction and the inventory. Finally, three following inquiries about specific tools showed that there was a relatively strong application of pull planning, a relatively strong and similar application of the different LPS elements (master plan, percent of completed plan, and preparing the seven healthy flows regarding completed documents, prepared workplace, machines and tool on site, ready crew, building materials, completed related work, and external conditions like the weather), and a relatively weak application of lean supply chain and logistics.

The following set of inquiries was like the previous one but concerned the companies' application of LC tools and elements in the past. Regarding overarching LC philosophies, waste elimination and customer value increase applied strongly, the transformation-flow-value (TFV) framework applied relatively strongly, and the Toyota production system applied relatively weakly. Waste elimination was relatively strongly associated with errors, reworks, delays, non-utilisation of human resources, transportation, inefficient resource management, and value-creating activities, and relatively weakly associated with overproduction and the inventory. Finally, there was a relatively strong application of pull planning, a relatively weak and similar application of the different elements of LPS, and a relatively strong application of lean supply chain and logistics. It seems that while not fully aligned, past and current applications of LC elements by the Swedish companies are similar.

When asked about other approaches that have been applied by their companies to specifically facilitate LC, the respondents answered that there was a relatively strong application of initiatives connected to communication, leadership and work organisation, a relatively weak application of BIM, production process analysis, and value flow analysis, and a weak application of BIM 360, 4D CAD, 5D CAD, VDC, virtual reality (VR), integrated project delivery (IPD), and six sigma.

The last group of questions considered the efforts that had been made by the responding companies to apply LC. First, the companies were asked whether they've been involved in competence development and training activities (incl. workshops, academic or industrial courses, etc.) of the respondent roles stated in the beginning of the survey (multiple roles could be selected). Close to 46% focused on project and site managers, ca 40% on top management, and the percentages pertaining to engineers, officers and site workers were far lower. Interestingly, close to 34% elaborated on other training and development activities, the most notable of which being a relevant "unofficial" training by working with clients having strict requirements. Secondly, when asked about which of the respondent roles were aimed at by most of the relevant communication activities (incl. meetings, information flows, etc.), the trend was like the previous inquiry, just with relatively different percentages: 50% at project and site managers, ca 40% on top management, and less at engineers, officers, and site workers. Around 28% elaborated on other communication activities, including meetings with logistics specialists.

Considering other implementation activities, around 30% responded that they have used educational games (e.g., SIM Lean), ca 24% that they sought long-term relationships with the supplier, 20% that they implemented simulation activities (e.g., through lessons-learned from other projects), and close to 26% that they implemented something else - a notable case being what was claimed as a special production system developed in-house. The two final inquiries in this set concern the degree of LC implementation within the company activities (see Figure 3), and the results of such an implementation (see Figure 4). In both cases, the prevailing percentage reflected answers documenting no implementation and no effect, respectively. However, among the rest of the answers, LC was claimed to prevalently be implemented in all company's projects (28%), and the main result of such an implementation to be an increase of efficiency and productivity (39%), respectively.

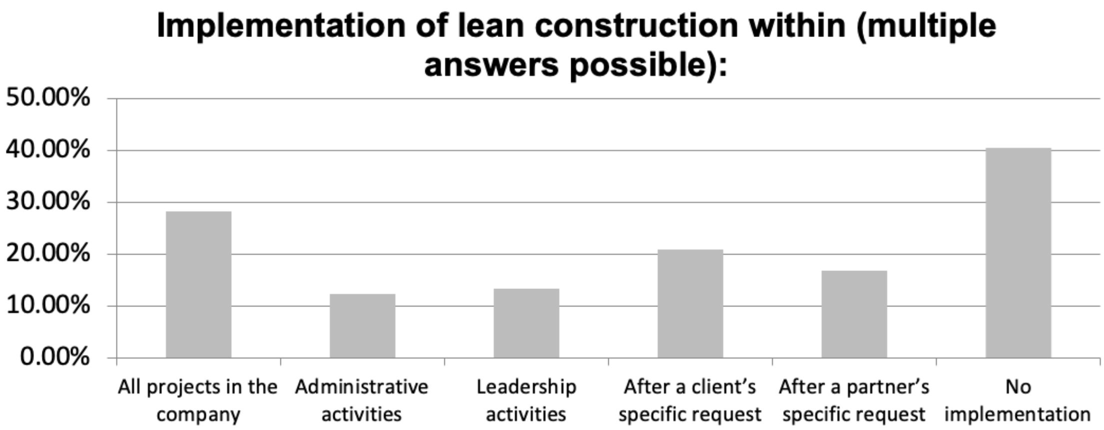

Figure 3: Degree of implementation of lean construction within companies

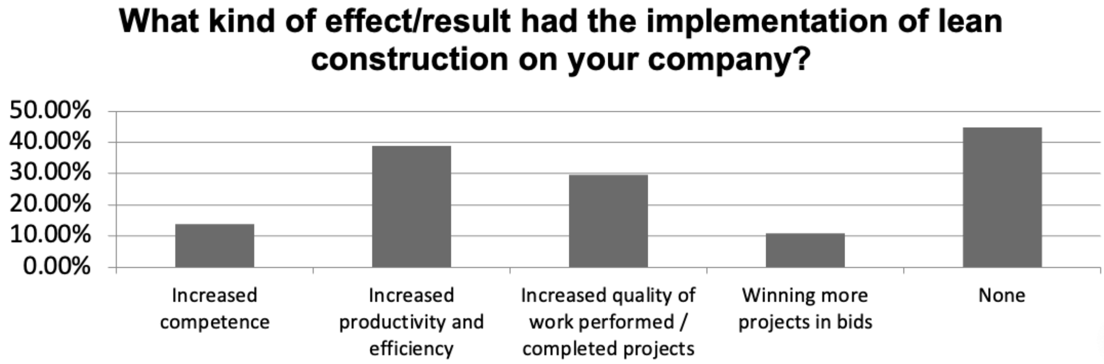

Figure 4: Effect of lean construction implementation within companies

The statistical analysis of the results discretized per geographical region and industry groups is still ongoing. However, it has preliminarily been shown that most LC-competent companies are found in the larger Swedish urban centres (Stockholm, Gothenburg, and Malmö), and that LC implementation appears to be more visible in companies within groups 41 and 42, rather than 43; within group 43, elements of LC are mostly found in HVAC companies.

FINDINGS

The overall survey results show that there is a large discrepancy of LC knowledge and practices across the industry, with almost 2/3 of the companies not being aware of LC. However, subsequent inquiries also showed that even among those respondents, some might have still implemented or are implementing elements of LC unwittingly.

While a detailed interpretation of the survey results is still ongoing, the relevant analysis can so far show that there are four discernible LC variants implemented in practice by those respondents working with LC:

1. A design variant integrated with IT systems (e.g., BIM, VDC).
2. A planning variant integrated with location-based planning and partly to LPS.
3. A management variant integrated with management systems.
4. A production variant integrated with production platforms.

These variants were deduced by drawing correlations among the survey results, as well as between each company and its responses. This correlation also shows that LC implementation appears to positively relate to the company's size and volume of projects - the larger, the better. However, there are also LC-competent SMEs, which might mean that LC is part of their strategy in practice for rising above the competition.

When comparing to the relevant literature, the disproportionately large research focus on industrialized construction evidently does not reflect the reality of the rest of the sector - which, as shown by the survey, is dominated by more conventional construction practices and other LC variants. This “skewed” interest in the literature might reflect the researchers’ particular interests in arguing in favor of a more industrialized sector in Sweden. However, it indicates that LC research, training, information, and dissemination, need to be redirected to also meet the demands of the rest of the industry. Moreover, most reviewed studies focus on the LC practices of a few specific Swedish case companies, which paint a far more advanced picture than what is shown in the current, industry-wide survey.

This mapping implies that a stronger cross-industry collaboration may be needed for establishing a common ground in LC knowledge in the Swedish context. In that vein, an improved facilitation of LC in Swedish companies should maybe pervade all organisational levels - possibly even a combination of top-down and bottom-up strategizing about practical LC implementation (Kifokeris and Löwstedt 2021). Furthermore, LC variants should be underpinned to fit each company’s specific needs and business model - LC should not be approached as a dogma, but as a flexible bundle of concepts, tools, processes, and methodologies. The current empirical results confirm Kifokeris’ and Koch’s (2020) assumption that practical LC adoption in Sweden probably follows patterns of other management concepts - i.e., picking parts and shaping them to local needs (i.e., the LC variants), thus vesting the adoption with different scopes within construction processes and firms (Kamp *et al.,* 2005).

CONCLUSIONS

This study aimed to empirically document lean construction (LC) practices in Sweden, to grasp the current Swedish state-of-art, identify contemporary practical shortcomings, and facilitate a requirements-driven adoption of LC. A large-scale questionnaire survey was conducted at the end of 2021 to map Swedish companies’ LC practices. Close to 490 construction sector companies of all sizes and across Sweden, provided valid answers. Survey results indicate a large discrepancy of LC-related knowledge and practices across the Swedish sector. Close to 2/3 of the respondents claimed to not know what LC is, and among those who did, they mainly implemented it in variants: a design-based variant integrated with IT systems (e.g., BIM, VDC), a planning-based variant integrated with location-based planning, a management-based variant integrated with management systems, and a production-based variant integrated with production platforms.

Given the above, this study’s main contribution to the body of knowledge is the clarification of the Swedish state-of-art in practical LC implementation, informed by an industry-wide survey covering multiple concepts, themes, understandings, methodologies, activities, tools, and techniques associated with LC. The structure of this study may be used for the design of other relevant studies in different contexts.

However, generalising the content and results of the present study beyond Sweden can be debated. Construction sectors in different national contexts can vary significantly, possibly impeding attempts of generalisation. However, acknowledging such variations can be considered as a methodological strength, since research delimitations are more specifically defined and unfounded claims of universality are avoided. As such, while this study's results may not be easily generalisable, the reasoning behind the mapping of LC practices and variants, as well as the envisioned benefits from it, have indeed been noted in international studies (e.g., Tzortzopoulos *et al.,* 2020).

Recommendations of future work include the further analysis of the survey's results, the possible discerning of other practical LC variants, and the communication of such results across the Swedish industry, through workshops and education activities - which can even include LC fundamentals, to help companies not recognising what LC is in understanding whether they could benefit from it in the first place.

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CONSTRUCTION LABOUR PRODUCTIVITY IN SOUTH AFRICA: CHALLENGES AND POSSIBLE REMEDIES

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Low labour productivity in the construction industry has become a concern for many professionals, not only in South Africa but also in most other developing countries. Earlier studies reveal that South Africa's labour productivity is one of the lowest in the developing world. This has several ways of negatively impacting the nation's economy. Consequently, this paper investigates the critical challenges affecting labour productivity in the South African construction industry, and the possible ways to overcome the identified challenges. Secondary data obtained from the literature review generated 33 challenges which were examined and analysed using the RII to rank the significance level. The 33 identified productivity challenges factors were systematically grouped into 6 clusters revealing five critical labour productivity challenges namely: Quality of site management, ineffective communication, disruption from the local forum group, equipment problems and delay in material delivery. Possible remedies to the identified challenges were highlighted and further discussed.

Keywords: challenges; labour productivity; KZN Province, South Africa

INTRODUCTION

The construction sector plays a vital role in any country's economy. Its various activities across the building and infrastructure lifecycle are the key drivers to achieving socio-economic development goals which can uplift any nation's economy. Nevertheless, in the South African economy Statistics, the construction sector contributes 3.4% to the Gross Domestic Product (GDP). However, KwaZulu Natal (KZN) province contributes 4.2% of GDP to the construction industry. The percentage of the GDP contribution indicates a significant poor performance in this sector. This poor performance in construction projects could be linked to project complexity, inefficiency in the construction process, cost and time overrun, skills shortage, delay in delivery, poor project planning, risk, late delivery of construction materials, fragmentation, and low labour productivity (Bitamba and An, 2020). In the meantime, Hamza *et al.* (2019) reported that low labour productivity in any country could be tailored to the challenges faced by the construction workers, which disrupt the smooth running of day-to-day activities. Construction labour refers to the site workers saddled with one or more responsibilities in producing the construction-related project(s) works on-site. The construction labour can be generally categorized

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into two: Skilled and Unskilled. The measure of those labour productivity is of high importance.

This measure allows the client/contractor to know if the value of money spent and the quality/quantity of work done is at the optimal expected level. Dozi and AbouRizk (1993) described productivity in the construction industry as the unit person-hour (p-h) rate, the ratio of input-output, i.e., the ratio of the input of an associated resource (usually, but not necessarily, expressed in p-hs) to actual output (in creating economic value), performance factor and production rate. To further reiterate the definition for use in the construction industry: Labour productivity is the physical progress achieved per p-h, e.g., p-hs per linear meter of conduit laid or p-hs per cubic meter of concrete poured. Czumanski and Lodding (2012) suggested that assessment and productivity improvement are vital for labour-intensive processes. In the built environment, this has been a source of worry. Construction firms are under pressure to improve their performance based on the quality of work, delivery time, the scope of operation, and more, due to the significantly low contribution to economic growth and increased competition. Malisiovas (2010); Siriwardana and Ruwanpura (2012) agreed that the ratio of finished work to labour hours is known as construction labour productivity (CLP).

However, poor CLP contributes significantly to the frequent delays that affect many projects, resulting in substantial cost overruns and abandoned projects. However, Labour performance over decades has not attained its optimal expected productivity in the construction industry. This is due to some alarming challenges facing labour output on construction sites (Soekiman *et al.,* 2011). This has created a great deal of debate among researchers and construction stakeholders to find lasting solutions to those challenges. There is no doubt that KZN province of South Africa is faced with some challenges which give room for the low contribution of KZN construction industry to the GDP. Therefore, this study seeks to investigate those challenges facing the KZN province construction industry and suggests possible remedies that could avert those challenges.

LITERATURE REVIEW

One of the crucial stages of conducting good scientific research is conducting a literature review on existing knowledge in the study context (Toyin and Mewomo 2023). It is necessary to conduct an overview of the persisting challenges affecting construction labour productivity in the construction industry. This will assist in identifying the challenges that have been evolving over the years and are still prominent in the construction industry. The study conducted in Kuwait by Jarkas and Bitar (2012) identified forty-five challenging factors affecting CLP on construction sites and ranked them according to their level of importance. These challenges were classified into four primary clusters/groups: Technological, management, external, and human/labour.

In the same vein, Robles *et al. (*2014) also identified; shortage or late supply of materials, clarity of the drawings and project documents, clear and daily task assignment, tools or equipment shortages, and level of skill and experience of labourers, as the top five ranked challenges affecting CLP. In addition, Hamza *et al. (*2019) conducted an extensive review on CLP. The authors thoroughly made justice to over 80 articles covering 25 countries, revealing that none of the studies was conducted in the South African construction industry. Also, all the reviewed articles only focused on identifying and ranking the challenges, noting that limited research has been carried out in South Africa. Therefore, this study is crucial as it may serve as one of the pioneer studies in the context of CLP that suggested possible remedies by seeking South African construction professionals' opinions. Table 1 shows the challenges affecting CLP as identified in various literature reviewed.

Table 1: Challenges facing construction

Code	Challenges facing labour productivity in the construction sites.	Reference
CLPC1	Quality of site management and project management personnel	(Dozi and AbouRizk 1993; Kazaz, Manisali and Ulubeyli 2008)
CLPC2	Ineffective communications	(Sarihi, Shahhosseini and Banki 2021)
CLPC3	Restrictive union rules on its labour member	(Kazaz, Manisali and Ulubeyli 2008)
CLPC4	Weather variability	(Kazaz, Manisali and Ulubeyli 2008)
CLPC5	Non-availability of Materials, Tools, and Equipment.	(Dozi and AbouRizk 1993; Dai, Goodrum and Maloney 2007)
CLPC6	Disruption of power/water	(Muhammada *et al.,* 2015)
CLPC7	Lack of personnel training for supervision and project management.	(Dozi and AbouRizk 1993; Kazaz, Manisali and Ulubeyli 2008)
CLPC8	Rework/change orders	(Dai, Goodrum and Maloney 2007)
CLPC9	Firm reputation	(Kazaz, Manisali and Ulubeyli 2008)
CLP1C0	Crew size and efficiency	(Muhammada *et al.,* 2015)
CLPC11	Delay in material delivery to site and management	(Sarihi, Shahhosseini and Banki 2021)
CLPC12	Foreman changes/Foreman's incompetence	(Dai, Goodrum and Maloney 2007)
CLPC13	Slow approvals and issue of permits	(Dozi and AbouRizk 1993)
CLPC14	Amount of pay per assigned task.	(Kazaz, Manisali and Ulubeyli 2008)
CLPC15	Inadequate planning and scheduling of workflow.	(Kazaz, Manisali and Ulubeyli 2008; Sarihi, Shahhosseini and Banki 2021)
CLPC16	Site congestion	(Dai, Goodrum and Maloney 2007)
CLPC17	Lack of skilful labour with a specific scope of work	(Muhammada *et al.,* 2015; Sarihi, Shahhosseini and Banki 2021)
CLPC18	Bad road access to the site.	(Muhammada *et al.,* 2015)
CLPC19	Absenteeism at work site/ lack of Commitment.	(Sarihi, Shahhosseini and Banki 2021)
CLPC20	Inspection delays.	(Dai, Goodrum and Maloney 2007)
CLPC21	Lack of incentive payments and financial rewards	(Kazaz, Manisali and Ulubeyli 2008)
CLPC22	Design complexity	(Sarihi, Shahhosseini and Banki 2021)
CLPC23	Health and safety conditions	(Aluko, Idoro and Mewomo 2020)
CLPC24	Cultural differences	(Czumanski and Lodding 2012)
CLPC25	Site distance from population centres	(Soekiman *et al.,* 2011; Robles *et al.,* 2014)
CLPC26	Disruptions from the local forum group	(Muhammada *et al.,* 2015; Hamza *et al.,* 2019)
CLPC27	Civil unrest in the vicinity of the project	(Moswane, Aigbavboa and Mewomo 2018)
CLPC28	Site conditions after inclement weather (rain/snow)	(Aluko, Idoro and Mewomo 2020; Moyo, Crafford and Emuze 2021)
CLPC29	Breakdown of plant	(Hamza *et al.,* 2019)
CLPC30	Availability of skilled labour in the vicinity of the project	(Moswane, Aigbavboa and Mewomo 2018; Hamza *et al.,* 2019)
CLPC31	Level of education of labour	(Aluko, Idoro and Mewomo 2020)
CLPC32	Lack of incentive program	(Robles *et al.,* 2014; Hamza *et al.,* 2019)
CLPC33	Working hours.	(Muhammada *et al.,* 2015)

Recently, there has been an increase in the initiatives to improve CLP (Sarihi, Shahhosseini and Banki 2021). The authors reported that many modelling techniques have been presented, "including the expectancy models, action response models, statistical and regression models, artificial neural networks (ANNs), and expert systems. Those models could function well if the challenges are well identified and have clues on the possible solution from a real-life field survey.

Suggested Possible Remedies (SPR) to Mitigate the Challenges

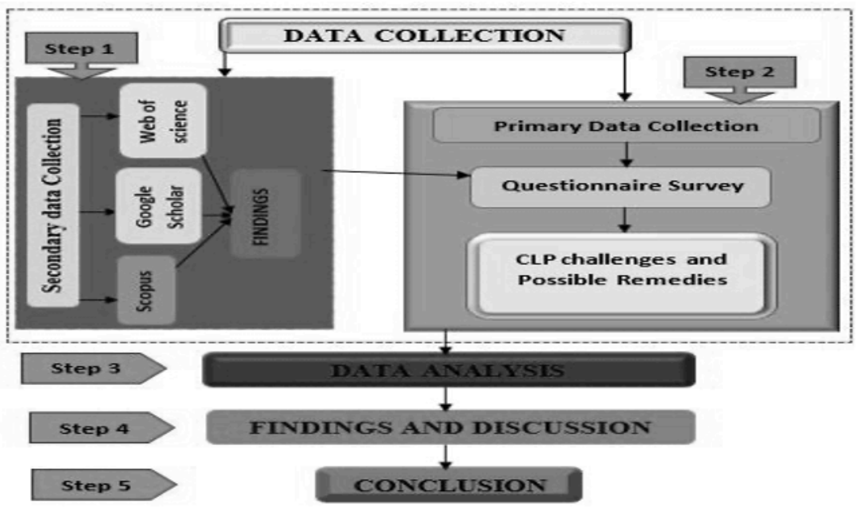
The section presented a review of suggested possible remedies that can be used in mitigating the challenges of CLP. Remedy means the strategies or measures put in place to eradicate challenges, which enhance the efficiency and output of humans or machines. Several measures have been noted in the literature. Hamza *et al. (*2019) mentioned that the construction industry and the government should take proactive measures to train and encourage local people to join the construction industry. The level of supervision and level of skills of craftsmen particularly must be improved. CLP can also be improved by increasing the benefit, satisfaction, and team-building program (Shashank *et al.,* 2014, Ohueri *et al.,* 2018).

Financial incentives have a positive correlation with worker motivation and is an important way to satisfy the basic need of the labourers (Afolabi *et al.,* 2018; Palikhe *et al.,* 2019). Planning software should be used in the project to have proper planning of the work to reduce the frequency of working overtime. Also, material delay and material arrangement, tool and equipment management should be improved by adopting a proper material management system (Ghoddousi and Hosseini, 2012; Afolabi *et al.,* 2018). It is also significant to promote the function of effective management of labour and human resources as this could lead to successful management of construction projects and initiatives (Alaghbari *et al.,* 2019). By avoiding interruptions during the construction phase, project teams can reduce the probability of disputes and costly litigations and claims while instead maintaining healthy business relationships through successful and timely project delivery (Griego and Leite, 2017).

METHOD

This study adopted a quantitative research method as shown in Figure 1. The quantitative research method was used because it focuses on gathering numerical data and generalising it across groups of people.

Figure 1: Research method framework



Also, quantitative studies are undertaken to yield statistical evidence of relationships and their strength, as statistics are very useful in determining directions of relationships when combined with theory and literature. Thus, this research is divided into five (5) processes namely, literature review, questionnaire design, distribution, collection, data analysis, findings and discussion, and conclusion of the study. A similar approach was adopted by Toyin and Mewomo (2021) "review", Moswane *et al. (*2018) and Aluko and Mewomo (2021) who mentioned that quantitative research is a research strategy that indicates the relationship between theory and research and usually emphasizes how theories were generated.

Data collection

The target population for this survey are construction professionals working in KZN province of South Africa. The identified challenges and remedies from the reviewed articles were used to formulate the questionnaire for this study. The targeted respondents were asked to rate the significance of identified challenges on a 5-point Likert scale (1: Not significant; 2: Less significant; 3: Neutral; 4: Significant and 5: Very significant) and "remedies" importance level from 'Not important to very important. The questionnaire was administered and received via Google forms. Out of the 98 questionnaires distributed, 55 were received which represents 56% of the overall received questionnaires. 15.3% of the respondents were females, while 84.7% were males. Although, the sample size received was small, the return rate for this study was considered adequate for analysis (Chan *et al.,* 2018). The structured questionnaire was preferred because of the relative ease of providing standard data suitable for the research economically and quickly (Aluko *et al.,* 2020).

Data analysis

In this study, Cronbach's alpha was used to determine the internal reliability and the internal consistency among factors in the survey questionnaire. Cronbach's alpha test greater than or equal to 0.5 means the scale has relatively good internal reliability (Aluko and Mewomo 2021). Using the SPSS statistical software version 27.0, the computed alpha value was 0.870, indicating that using the five-point Likert scale was reliable at a 5% significance level for the data. The alpha value of 0.870 justifies that the data can proceed for further analysis (Aluko, Idoro and Mewomo 2020). The mean and standard deviation of each variable, according to Faridi and El-Sayegh (2006) and Robles *et al. (*2014), are not adequate measures to analyse global rankings since they do not represent any link between them. Thus, descriptive analysis conducted on the survey data is "relative important index (RII), which involved the computation of representative rating point or a weighted average for the collective ratings made for each variable in the subgroup. Thus, this tool is employed to check the significance level and rank each explored data using SPSS 27.0. Thereafter, the 33 challenge variables were systematically grouped into 6 clusters for easy understanding. A similar method was adapted from Toyin and Mewomo (2023); Toyin and mewomo (2021) and Alaghbari *et al.,* (2019).

FINDINGS

Background Information of Respondents

From the survey result, the 55 respondents entail the following characteristics: Gender [Male 45; Female 15]; Categories of organisation [Large organisation: 20; Medium organisation: 24; Small organisation: 11], CIDB grading [Grade 1-3: 13; Grade 4-6: 17; Grade 7-9: 25]; Sector: [Public: 28; Private: 27], Year of experience[0-5 years 5:11 years: ; 6-10 years: 14 ; 11-15 years: 13 ; more than 15 years: 17].

Analysis of construction Labour Productivityy challenges (CLP)
Table 2, presents the value of the descriptive analysis: Relative (CLPC1, CLPC2, CLPC26 CLPC5, and CLPC11: 0.81, 0.81, 0.81, 0.8, and 0.8, respectively, are ranked as the most crucial challenges facing construction labour productivity in KZN province of South Africa from the respondent's perspective.

Table 2: Analysis of results of Construction Labour Productivity

Code	Challenges facing labour productivity in the construction sites.	Reference
CLPC1	Quality of site management and project management personnel	(Dozi and AbouRizk 1993; Kazaz, Manisali and Ulubeyli 2008)
CLPC2	Ineffective communications	(Sarihi, Shahhosseini and Banki 2021)
CLPC3	Restrictive union rules on its labour member	(Kazaz, Manisali and Ulubeyli 2008)
CLPC4	Weather variability	(Kazaz, Manisali and Ulubeyli 2008)
CLPC5	Non-availability of Materials, Tools, and Equipment.	(Dozi and AbouRizk 1993; Dai, Goodrum and Maloney 2007)
CLPC6	Disruption of power/water	(Muhammada *et al.,* 2015)
CLPC7	Lack of personnel training for supervision and project management.	(Dozi and AbouRizk 1993; Kazaz, Manisali and Ulubeyli 2008)
CLPC8	Rework/change orders	(Dai, Goodrum and Maloney 2007)
CLPC9	Firm reputation	(Kazaz, Manisali and Ulubeyli 2008)
CLP1C0	Crew size and efficiency	(Muhammada *et al.,* 2015)
CLPC11	Delay in material delivery to site and management	(Sarihi, Shahhosseini and Banki 2021)
CLPC12	Foreman changes/Foreman's incompetence	(Dai, Goodrum and Maloney 2007)
CLPC13	Slow approvals and issue of permits	(Dozi and AbouRizk 1993)
CLPC14	Amount of pay per assigned task.	(Kazaz, Manisali and Ulubeyli 2008)
CLPC15	Inadequate planning and scheduling of workflow.	(Kazaz, Manisali and Ulubeyli 2008; Sarihi, Shahhosseini and Banki 2021)
CLPC16	Site congestion	(Dai, Goodrum and Maloney 2007)
CLPC17	Lack of skilful labour with a specific scope of work	(Muhammada *et al.,* 2015; Sarihi, Shahhosseini and Banki 2021)
CLPC18	Bad road access to the site.	(Muhammada *et al.,* 2015)
CLPC19	Absenteeism at work site/ lack of Commitment.	(Sarihi, Shahhosseini and Banki 2021)
CLPC20	Inspection delays.	(Dai, Goodrum and Maloney 2007)
CLPC21	Lack of incentive payments and financial rewards	(Kazaz, Manisali and Ulubeyli 2008)
CLPC22	Design complexity	(Sarihi, Shahhosseini and Banki 2021)
CLPC23	Health and safety conditions	(Aluko, Idoro and Mewomo 2020)
CLPC24	Cultural differences	(Czumanski and Lodding 2012)
CLPC25	Site distance from population centres	(Soekiman *et al.,* 2011; Robles *et al.,* 2014)
CLPC26	Disruptions from the local forum group	(Muhammada *et al.,* 2015; Hamza *et al.,* 2019)
CLPC27	Civil unrest in the vicinity of the project	(Moswane, Aigbavboa and Mewomo 2018)
CLPC28	Site conditions after inclement weather (rain/snow)	(Aluko, Idoro and Mewomo 2020; Moyo, Crafford and Emuze 2021)
CLPC29	Breakdown of plant	(Hamza *et al.,* 2019)
CLPC30	Availability of skilled labour in the vicinity of the project	(Moswane, Aigbavboa and Mewomo 2018; Hamza *et al.,* 2019)
CLPC31	Level of education of labour	(Aluko, Idoro and Mewomo 2020)
CLPC32	Lack of incentive program	(Robles *et al.,* 2014; Hamza *et al.,* 2019)
CLPC33	Working hours.	(Muhammada *et al.,* 2015)

The systematic grouping of the variable result is presented in Table 3.

Table 3: Variables group naming

Group naming	Coding	Variables
Management Related Challenges	MRC (1 - 6)	CLPC1; CLPC7; CLPC9; CLPC13; CLPC15; CLPC33.
Site Organisation Challenges	SOC (1 - 5)	CLPC2; CLPC16; CLPC18; CLPC20; CLPC25.
Labour Related Challenges	LRC (1 - 5)	CLPC3; CLPC10; CLPC19; CLPC26; CLPC31.
Weather and Safety Related Challenges	WSRC (1 - 5)	CLPC4; CLPC23; CLPC24; CLPC27; CLPC28.
Work Disruption Related Challenges	WDRC (1 - 6)	CLPC5; CLPC6; CLPC8; CLPC11; CLPC22; CLPC29;
Incentives and Labour Scarcity Related Challenges	ILSRC (1 - 6)	CLPC12; CLPC4; CLPC17; CLPC21; CLPC30; CLPC32.

Management Related Challenges: These challenges are centred on the company readiness and the on-site construction manager's capabilities to manage and effectively coordinate the construction activities.

Site Organisation Challenges: In any construction project, the knowledge of site organisation, coordination, and communication is vital for the construction managers. The lack of a proper program (construction schedule) could lead to overcrowded labour and machines during the construction process, and these should be avoided.

Labour Related Challenges: The Labour force cannot be neglected in the construction industry, the challenges identified under this cluster are related to the labour guiding policy and their act toward their assigned task.

Weather and Safety-Related Challenges: Proper organisation and adherence to health and safety on-site is crucial to achieving project success. H&S would help to mitigate life lost due to accidents or hazardous occurrences.

Work Disruption-Related Challenges: The challenges linked to this cluster are related to the shortage of materials and availability of tools and equipment, wasteful effort due to rework or complex design understanding issues.

Incentives and Labour Scarcity-Related Challenges: These challenges are motivational or reward-based expectations for the labour which are not readily in place and the unavailability of labour. These factors could affect the commitment of labour towards the task assigned to them.

From the survey, 'inconsistencies in monitoring and evaluation projects tools; delayed payments; non-recognition of the labour group; poor PPE; skill transfer difficulties and poor-quality control compliance' were identified as additional productivity challenges in KZN.

Possible Remedies: The suggested possible remedies were administered to the respondents to rank their level of importance on a 5-point Likert scale. The result indicated that all the identified 16 remedies were crucial, with RII values ranging from 0.80 to 0.86 and a mean item score of 4.00 to 4.36, as shown in Table 4.

CONCLUSIONS

This study investigated the challenges affecting construction labour productivity in KZN province of South Africa. Thirty-three challenges were identified from the existing literature which were grouped into six clusters namely: Management Related Challenges; Site Organisation Challenges; Labour Related Challenges; Weather and

Safety-Related Challenges; Work Disruption Related Challenges; Incentives and Labour Scarcity Related Challenges; on which both the descriptive and inferential statistics were conducted.

Table 4: Suggested possible remedies

Code/Suggested Remedies	Mean	Std. D	RII
SPR1: Availability of adequate H&S provision on site	4.22	.917	0.84
SPR2: Building up employee confidence	4.24	.881	0.85
SPR3: Good working condition	4.25	.821	0.85
SPR4: Adequate provision of PPE	4.18	.841	0.84
SPR5: Good use of employees working standard time	4.00	.903	0.8
SPR6: Good welfare facilities	4.07	.790	0.81
SPR7: Good and effective management practices	4.25	.799	0.85
SPR8: Stimulating workers commitment	4.11	.809	0.82
SPR9: Teamwork approach	4.27	.827	0.85
SPR10: Use of incentives	4.05	1.061	0.81
SPR11: Upholding employees right	4.02	.972	0.8
SPR12: Good management accessibility approach	4.11	.956	0.82
SPR13: Training of workers for new skills	4.31	.858	0.86
SPR14: Improved construction methods	4.11	.875	0.82
SPR15: Good coordination of construction activities	4.11	.936	0.82
SPR16: Good site organisation	4.36	.677	0.87

The result of the descriptive analysis (RII) reveals 5 critical labour productivity challenges namely quality of site management, ineffective communication, disruption from the local forum group, equipment problems and delay in material delivery. In addition, this study identified sixteen possible remedial/preventive measures to the identified productivity challenges which if utilised will not only promote CLP but will create an appreciable positive effect on the SA economy and the socio-economic welfare of its citizens.

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ACCELERATING CONSTRUCTION PROJECT DELIVERY USING AGILE'S INTEGRATED SYSTEM OF PRINCIPLES AND METHODS

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Agile's roots in lean thinking describes an adaptive mindset approach to project management. While Agile's application in certain sectors is well established there is a paucity of construction related research. This study evaluates the novel application of agile principles to improve well documented problems with traditional construction project delivery. The mixed methods approach evaluates the implementation of Agile principles and the Scrum framework over a 12-week design period of a pharmaceutical facility utilising data collected from a literature review, digital planner board analysis, facilitated review and retrospective sessions, and semi-structured interviews. The outcome of the principles and framework intervention was considerable improvement in the number of tasks completed and blockers removed. Agile offers flexibility in the change management process and brings stability and reliability to design while highlighting focus areas to continuously improve processes. Agile should be considered complementary to traditional methodologies and not be viewed as a competing paradigm.

Keywords: Agile; lean; lean construction; scrum; value

INTRODUCTION

The construction industry is continuously seeking improvement opportunities, to increase competitiveness, and generate greater profits while offering enhanced customer value (Wandahl *et al.,* 2021). Traditional delivery methodologies (Design Bid Build, Design and Build, Construction Manager at Risk, and Engineering, Procurement, Construction Management EPCM) are commonly used globally (Mesa *et al.,* 2016); however, most struggle to achieve project goals primarily due to lack of collaboration, inflexibility to accommodate change, or inability to integrate stakeholders needs throughout the project lifecycle (Daniel *et al.,* 2020; Ballard *et al.,* 2020). The current state of planning in construction has been criticised for its inadequacies, principally accruing from a lack of collaboration between those involved in developing the plan (Hamzeh *et al.,* 2016; Daniel *et al.,* 2020). The Last Planner System (LPS), a key tool of lean construction, is proposed as a means of coordinating project interactions and achieving more reliable production outcomes by encouraging collaborative planning between project participants (Ballard *et al.,* 2020). Others (Tommelein and Ballard, 2016; Daniel *et al.,* 2020; Ballard, 2020) have

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suggested looking outside construction to other sectors, for example the software and IT sectors, for inspiration towards improving construction's value offering.

Agile focuses on early and repeated delivery of value and continuous improvement of the processes used to deliver the product while consistently adapting to customer needs (Layton *et al.,* 2020). It emerged from the software industry in the early 1990's as a response to the need to modernise project management and has dominated the software and IT sector since publication of the Agile Manifesto (Sutherland, 2014; Layton *et al.,* 2020). Scrum is the most widely used Agile framework and is a flexible, adaptable, empirical, productive, and iterative method that uses the ideas of industrial process control theory for the development of software systems (Sanchez and Nagi, 2001).

The Scrum Guide (Schwaber and Schwaber, 2020) describes Scrum as: '…a lightweight framework that helps people, teams, and organisations generate value through adaptive solutions for complex problems.' Its theory is founded on empiricism and lean thinking (Sutherland, 2014, Engineer-Manriquez, 2021) and is built on three pillars of transparency, inspection, and adaptation. As construction faces numerous challenges while it recovers from the global pandemic it is important all paradigms that can contribute to improved project delivery are considered. This study evaluates the application of Agile Project Management (APM) practices and the Scrum framework at design stage to assist construction planning, collaboration, and accelerate construction project delivery.

LITERATURE REVIEW

Agile, according to Sanchez and Nagi (2001) is a response to complexity brought about by constant change. Putnik and Putnik (2012, p.252) summarise the two signature features of Agile as: '…speed, in change, organisational change, mind change, action, and pro-activity, in changing.' Unlike the traditional methodologies, Agile methods deal with unpredictability by relying on people and their creativity rather than on processes (Layton *et al.,* 2020); APM emphasises a generative approach where only the processes, tools, procedures, and documentation that is required on a project is utilised (Fernandez and Fernandez, 2008).

The prevailing approach in traditional construction project management is limited to the 'transformation view theory' as exhibited in Critical Path and Waterfall methods (Daniel *et al.,* 2020). According to Koskela (2020), transformation in construction is viewed as the conversion of inputs to outputs, and where production consists of tasks fully planned out before any work commences. Critically, APM's theoretical foundation understands variability will always exist and therefore prioritises accommodation of change as opposed to the traditional approach of its reduction or removal (Layton *et al.,* 2020) or the lean construction approach of early customer engagement to agree scope and desired value outcomes thus minimising change (Tommelein and Ballard, 2016; Koskela, 2020).

The successful adoption of responsive and collaborative methods in other sectors illustrates that construction could transition from its current overly rigid and technical approach to a more socio-collaborative model that encourages collaboration and responsiveness (Daniel *et al.,* 2020). APM was identified as a comprehensive management method that skipped over conventional project management doctrine; Sutherland (2014) and Layton *et al.,* (2020) suggest the success of Scrum theory offers substantial improvement on the traditional theory of project management as espoused in PMBOK. However, these well-rehearsed and desirable benefits must be nuanced with the realisation that every production system requires a core structure (Koskela, 2020) and construction must be cautious in moving too far to the extreme of reliance on decentralised management and on tacit knowledge (Owen *et al.,* 2006).

In construction, an agile project is designed to be nimbler and more dynamic; team-defined clear deliverables and work packages are incrementally and iteratively progressed by small development teams while being consistently reviewed for quality and customer-need requirements, ensuring seamless transition through each phase and stage-gate (Hamilton *et al.,* 2019; Pound *et al.,* 2021). The application of APM to construction was examined by Owen *et al.,* (2006) and noted significant cultural restructuring would be required to allow workers contribute to organisational learning on the scale required for self-performing teams with sufficient tacit knowledge to sustain speed and flexibility in their work execution.

APM demands greater commitment and dedication from team members and can lead to burnout and frustration from blindly following agile's constant quest for speed (Bryar and Carr, 2021). Notwithstanding the possibilities offered by APM in the design stage there are also challenges identified to its applicability to construction, particularly relating to the fractured and temporal nature of construction being an impediment to extending APM from design through to construction and support (Owen *et al.,* 2006; Fernandez and Fernandez, 2008). Caution is also proffered by Wysocki (2010) when proposing APM carries more risk than traditional management practices. While traditional projects are clearly defined with well documented features, functions, and requirements, in contrast, agile projects only discover the complete requirements by undertaking the project in iterations (Layton *et al.,* 2020). Traditional project managers manage cost, scope, and schedule against pre-agreed baselines. The agile project manager primarily focuses on deliverables and business value with less adherence to process (Fernandez and Fernandez, 2008). Resultingly, construction has been reluctant to adopt APM arising from the fear of compromising safety, technical quality, and the management of risk (Hamilton *et al.,* 2019).

In the context of design and construction, Scrum is a framework applicable to project work planning through to deliverable completion. The deliverable could be a calculation, a design, a drawing, an element of a physical task, or a component of a structure. A key characteristic of Scrum is the autonomous team which is empowered to make relevant decisions to achieve its goals. Work is carried out in time-boxed ‘sprints’ that empower teams to examine progress and adjust if required, thus minimising risk of miscommunication or over-processing tasks (Sutherland, 2014; Layton *et al.,* 2020; Engineer-Manriquez, 2021).

METHOD

A mixed methods approach is adopted utilising case study design and data collected from a literature review, facilitated review sessions, planner workspaces analysis, and semi-structured purposeful interviews. The mixed-methods approach helped to minimise bias as both the quantitative and qualitative models have individual weaknesses which can be compensated by the comparative strengths of the other methods (Creswell, 2013). The research utilised case study design at a single project. Yin (1993) states that when a researcher is investigating into the 'how and why' of a set of events, a case study offers distinct advantages not found in more quantitative research tools. Principles of action research and learning were also applied allowing numerous interventions and augmentations to be implemented. This pharma sector case project was selected for the study as it is based in the Netherlands and has design and support services inputs from local offices and regional offices in Ireland thus requiring extra coordination across different countries and cultures. The overall project value exceeds €300 million, and the Engineering, Procurement, Construction Management, and Validation (EPCMV) company's scope consists of Concept Development, Basis of Design, Detailed Design, Procurement, Construction Management, and Commissioning and Validation.

Five purposefully selected interviewees had over 130 years combined project and construction management experience, all possessed Agile certifications, all were part of the project team, some as department managers and some as Agile coaches. Five interviewees were considered sufficient to achieve saturation on this small study. A semi-structured interview format was chosen as it reveals interviewee's subjective assessment of situations, thereby broadening the researcher's knowledge on the subject (McIntosh and Morse, 2015).

The participants were informed of the nature and purpose of the research, and what the collected data will be used for in advance of the interviews. The data is password protected, confidential information is not disclosed, and the identities of those involved remain anonymous. Interviews were conducted online lasting between 40 to 60 minutes in duration, were transcribed, then analysed using a thematic analysis approach and were organised into different themes in accordance with Braun and Clarke (2006). Inferences drawn from the emerging themes were checked by triangulation against the literature review findings and against the planner workspaces to check their reliability and integrity. Daily workspaces consisting of 15 individual virtual Scrum boards were monitored and examined as part of the data analysis. Interventions were proposed by the agile coaches after sprint review sessions aimed at improving the planning, communication, and escalation process. Limitations exist due to the research being conducted within a single organisation and over a short duration. Bias was mitigated by two researchers being distanced from the projects and unconnected with the case company.

FINDINGS

Improvement opportunities identified

Concept Development and Basis of Design were completed, and Detailed Design had commenced at the time of this study. A facilitated After-Action Lessons Review conducted after the initial phases identified improvement opportunities and demanded improvements be implemented for subsequent phases. Table 1 outlines these improvements and the changes required when transitioning between phases, incorporating countermeasures identified and utilising virtual workspaces that the EPCMV company had successfully implemented on smaller projects.

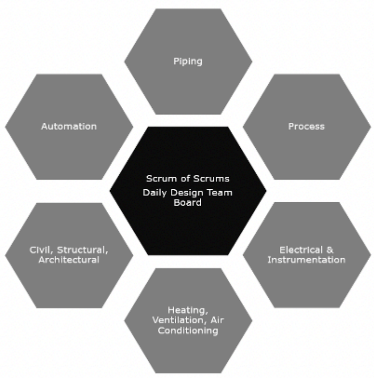
Implementing the Scrum framework

Design teams were organised as 'self-performing' Scrum teams utilising the Scrum of Scrums framework to progress their work packages. Scrum of Scrums is a scaled agile technique that offers a way to connect multiple teams who need to work together to deliver complex solutions. It helps teams develop and deliver through transparency, inspection, and adaptation, at scale (Layton *et al.,* 2020; Juan *et al.,* 2022). Process, Piping, Electrical and Instrumentation, Automation, Heating and Ventilation and Air Conditioning, Civil and Structural and Architectural, and the onsite construction team had their own individual Scrum workspaces and specifically worked on predefined and sized batches of work ensuring frequent release of deliverables.

Table 1: Improvement opportunities from Concept Development and Basis of Design phases

Improvement opportunities identified	Proposed countermeasure
Remote working hampered levels of engagement, interaction, communication, and collaboration that would have been expected with co-location.	Creation of Agile self-organising and self-performing teams supported and mentored by two Agile coaches.
As new client team members joined from a recently completed project, new features were being requested, introducing more change.	Change requests would undergo early screening and impact assessment via a dedicated escalation board.
Scope creep was identified as a threat prior to entering Detailed Design.	Early impact of change requests and extra scope accommodation would be assessed via Scrum workspace
Siloed disciplines working on mis-aligned packages.	Daily huddles and weekly sprint planning ensured all teams were working on priority deliverables and handoffs and aligned towards common goals.
Slow communication channels ("I sent you an email on that topic")	Virtual workspaces would allow live team member and inter-team communications with immediate blocker escalation opportunities.

This ensured early inspection and alignment with the next-customer's requirements for satisfaction.



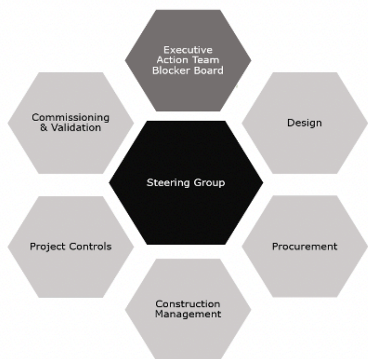


Figure 1: Scrum of Scrums with 6 teams Figure 2: Steering Group and Executive Action Team

Figure 1 illustrates how the Agile process was developed and implemented on the case project, showing the design discipline workspaces feeding into the Scrum of Scrums daily design team board. This is a support touchpoint for each Scrum Master or Product Owner to escalate a blocker and receive rapid feedback. A blocker is also known as an impediment in Scrum - anything that will slow down the progress of the team should be removed in advance. The Scrum Master directly oversees the team and is responsible for keeping the process as efficient as possible. They facilitate the daily huddles, help plan the sprint with the team, run the sprint review and retrospective meetings, and communicate with the Product Owner. The Product Owner serves as the key person who owns the project and is responsible for the timeliness and quality of the handoff to the next or final customer. The Product Owner has the authority to make decisions. Similar workspaces existed for Procurement, Construction Management, Project Controls, and Commissioning and Validation. The discipline Scrum teams are self-organising and self-performing and over 95 per cent of interactions occur at the Scrum team level. Figure 2 illustrates how the workspaces escalated blockers to the EPCMV Steering Group (Project

Sponsor, Project Director, plus Design, Construction, Project Controls, and Commissioning and Validation Directors). The Steering Group and Executive Action Team (EPCMV Sponsor, Director and Client representatives) workspace touchpoints are fixed weekly calendar events and primarily deal with blockers that could not be resolved at Scrum of Scrum or Steering Group levels.

Any blockers to work release at Team level were immediately escalated to the Scrum of Scrums workspace. Its key functions are to agree deliverable milestone alignment across disciplines and to resolve blockers to progress, ensuring the team could focus on value-adding work rather than wasting effort tracking others to resolve blockers. Any issue not immediately resolvable at Scrum of Scrums level was rapidly escalated to the Steering Group workspace. Major issues, unresolvable heretofore, could be brought to the Executive Action Team workspace for senior management for action.

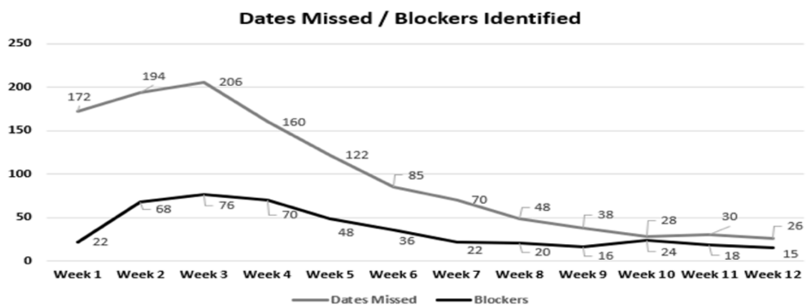
The Agile coaches conducted sprint reviews and retrospective sessions after the first two sprints with each team. All team members inputted to the improvements and the coaches ensured that best practices were shared across all workspaces. Table 2 presents the improvements implemented.

Table 2: Improvements implemented

Improvement Opportunity	Intervention Applied
Inconsistency of implementation	More training, facilitated coaching & mentoring, Guideline & Implementation Health Check issued.
Key persons not attending huddle	Emphasis on the 'Team' as opposed to 'individuals'.
Command & control behaviours	Product Owners & Scrum Masters retrained on facilitation & ideal team behaviours.
Dilution of ownership	Roles of Product Owner, Scrum Master & Team clarified.
Sprint Planning too broad	Refocus on highest priority deliverables. Limited work in progress & context switching.
Product backlog prioritisation & refinement	Some Product Owners offered better service to the team as Subject Matter Experts as their tacit knowledge & experience clarified priority tasks.
Milestone's focus required	Focus on incremental releases & handoffs to achieve the milestone. Breaking bigger chunks of work into smaller batches increases flow & efficiency.
Disengagement and value-loss associated with working from home and remote from office	Small wins & progress was celebrated. Workvivo shout-outs within the organisation, virtual coffee events, and chocolate gifts sent to those working remotely helped inclusivity, engagement & fostered a project-team ethic.

On commencement of the implementation, data became available from the virtual workspaces. The initial three weeks of the study shows an average of 190 planned dates were missed weekly and an average of 55 blockers were raised weekly (Figure 3).

Figure 3: Dates missed, and blockers identified trend



Cumulative stacking of weekly issues resulted in everything becoming urgent rather than identifying and focusing on what was the critical priority. As part of the intervention, blockers to the highest priority tasks were identified and escalated for resolution. Teams became familiar with the process and with increased clarity and visibility could focus totally on their own deliverables and the number of missed dates began to fall to a weekly average of 28, an 85% improvement.

Weekly blockers raised fell to an average of 19, a 66% improvement. As teams and Scrum Masters recognised 'patterns' of repetitive blockers arising, improvements were made by the input providers to ensure recurring blockers were permanently resolved. In parallel, as teams began to anticipate a pattern around recurring blockers and as sprint review and retrospective derived continuous improvements were implemented, the number of blockers raised also began to decline and stabilise. Team speed and velocity increased as they developed better knowledge of agile concepts and the Scrum framework.

Figure 4 illustrates the number of tasks undertaken by the teams expanded from 220 on week 1 to 355 in week 12, an increase of 62%. With task prioritisation, external blocker removal, and minimal distractions, teams were able to increase their velocity and output and take on more tasks without adding stress or discomfort. A burndown chart measures daily and weekly progress in a sprint and is typically illustrated as a percentage of completed tasks versus planned tasks. As well as measuring progress a burndown also shows the total work remaining and over time is used to predict the team's likelihood of completing their work in the time available. Figure 4 presents total sprint tasks and burndown %.

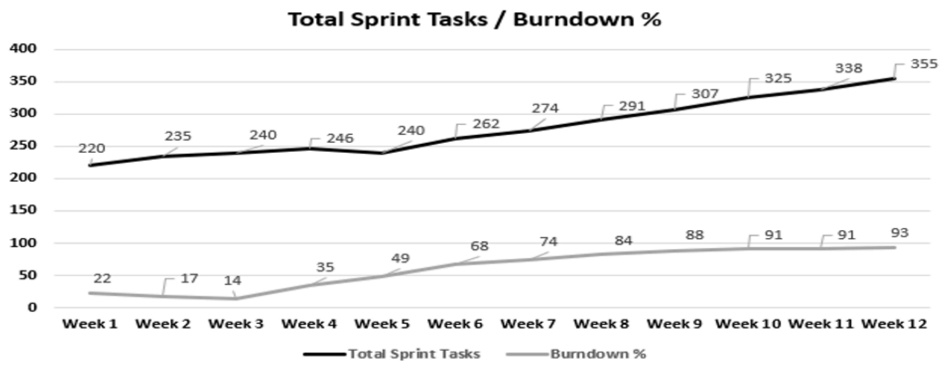


Figure 4: Total sprint tasks and Burndown %

The burndown shows 22% task completion on week 1, dropping to 14% on week 3 and improving and maintaining at over 91% for weeks 10 to 12. This represents a 71% improvement in task completion from week 1 to 12. The initial fall in task completion from weeks 1 to 3 was attributed to 'slowing down to speed up' while teams were settling into the new format of working and communicating with one another.

Interviewees considered traditional methodologies constrained flexibility and struggled to accommodate change when introduced or imposed on projects. When change occurred in the case project, it was accommodated more easily within the smaller self-organised team environment. Decisions emanating from change were promptly escalated with responses returning to the team quicker.

Challenges and mitigating actions

The Pandemic further complicated the implementation, as some team members faced challenges adapting to working from home, including home schooling, caring for vulnerable family members, and isolation. Every opportunity to foster team inclusivity, cohesiveness, and to improve individual's wellbeing was explored. A new routine and cadence of daily huddles, weekly sprint planning, and weekly sprint reviews ensured open interaction and involvement of all team members.

Teams initially expressed apprehension that a proposed reduction in review cycle time duration from twelve to four days would result in extra workload. However, concerns were mitigated once demands were prioritised, and the workload balanced.

In some teams the client representative initially resisted the move from the traditional meeting structure to the Scrum framework implementation. However, focused senior management support acted as a catalyst for positive engagement and outcomes.

Some commented on the increased 'pressure' to achieve deadlines within the Scrum teams. This was recognised by management and was mitigated by coaching and mentoring the team members and ensuring that the pursuit of speed and velocity didn’t become overwhelming.

DISCUSSION AND CONCLUSION

When compared with traditional methodologies utilised during the Concept Development and Basis of Design phases, the findings demonstrate substantial improvement in schedule alignment, work package clarity, inter-discipline communication, and openness and adaptability to incorporation of change. Horizontal communication lines and aligned interdependencies offered greater understanding, clarity, and information radiation. This was evidenced by the 85% reduction in weekly dates missed.

The depth and breadth of tacit and technical knowledge required to deliver a project can only be accumulated over a substantial period. Maintaining Agile teams moving at a steady rhythm relies on tacit knowledge and oversight. In smaller Agile teams the onus rests on the more experienced members to develop a learning environment that ensures those with less experience can contribute while advancing their competency. Tables 1 and 2 illustrate how consistent discovery of improvement opportunities through a regular review cycle can refine and streamline the process. Additionally, management, dissemination, and accessibility of new knowledge requires focus when applying APM.

Consistent identification and immediate escalation of blockers allowed the team focus on value-adding work while others outside the team resolved the issues. Rapid removal of blockers enabled path-clearing and unimpeded workflow. However, caution must be exercised as pressure to make quick decisions without having all the necessary information, and not allowing time for reflection on the decision, can have adverse consequences compromising overall value. Agile's pillar of 'Adaptation' offers flexibility towards accommodation of changing requirements and The Agile Manifesto (principle 2) states 'welcome changing requirements, even late in development'. This can be difficult to translate and justify in construction as cost increases exponentially as the project moves into later phases. Therefore, APM's flexibility should be complimented with selected tools of lean construction like Target Value Design to assist earlier Client satisfaction requirements.

The Project Sponsor and Client acknowledged improved visibility of progress and issues. Agile principles and the Scrum framework introduced discipline into new ways of working. Prioritisation of deliverables, focusing on one task at a time, external resolution of blockers, availability of team knowledge, time-boxed events, and capacity planning all reduced stress. Availability to the Scrum Master and Product Owner provided extra support. Visual representation of Sprint tasks planned, burndown rate, blockers raised and closed, offered real-time visibility of both project and team health. However, as the team is heavily reliant on the efforts of each member, an obvious decline occurs if an individual is absent through vacation or illness.

Such productivity fall-off might not be so obvious in traditional methods where larger teams can accommodate an absent member. Involvement of onsite and offsite construction and procurement in the Scrum framework and Scrum of Scrums assisted phased and incremental handover from design to construction. Directly transferring the process to construction requires realignment from traditional thinking and delivery methodologies. An Agile mindset, and particularly the Scrum framework, has a distinct role in supporting the LPS constraints management function, procurement support interactions, and design discipline ongoing support requirements. While the metrics associated with LPS and Takt planning may be more applicable to the nature of construction, the opportunities offered by APM and an Agile mindset to stabilise necessary inputs should be considered.

Agility brings stability and reliability to design which leads to improvement in procurement, construction management, and cost control, while offering flexibility to the change management process. Stabilising these key support functions and inputs to the construction execution process contributes to more controlled project delivery. However, construction may be slower to adopt Agile concepts, as major cultural change relating to organisational learning is required. Additionally, traditional governance and oversight of quality and safety compliance would require diligent examination if Agile were to replace existing methodologies. Nevertheless, this study has affirmed that Agile, in conjunction with facilitation and coaching, brings speed and adaptability to many aspects of project management while highlighting focus areas to continuously improve processes. This study confirms that an Agile construction project delivery paradigm can complement existing project management and lean construction methodologies.

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RESEARCH AND EDUCATION

IDENTIFYING COMMUNICATION KNOWLEDGE AND SKILLS FOR CONSTRUCTION MANAGEMENT GRADUATES USING CONTENT ANALYSIS OF ENTRY LEVEL JOB DESCRIPTIONS FROM THE SOUTHEAST UNITED STATES

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An analysis of 53 entry level job postings from companies recruiting from a large construction management program in the southeast United States was conducted to identify the communication knowledge and skills required of graduates. Content analysis was used to determine not only the frequency of certain words, but also the context in which words were used. Results identified the most frequently used words related to communication tools were meetings, drawings, submittals, documents, contracts, and reports. Selected results for the type of "meeting" identified "project" and "weekly" as the most frequent types of meeting, with "minutes" being mentioned after meeting in a third of the observations. "Attending" or "participating" in meetings were the most frequently observed action verbs. Additional results of the keyword-in-context analysis of the remaining communication phenomenon provide useful information for identifying the knowledge and skills construction management graduates need as they transition into industry.

Keywords: communication; recruitment; education; graduate attributes; HRM

INTRODUCTION

Construction education programs around the world are guided by various accreditation agencies and professional organisations in developing their academic curriculum. In the United Kingdom the Quality Assurance Agency for Higher Education (QAAHE) in its Frameworks for Higher Education Qualifications (FHEQ) of UK Degree-Awarding Bodies (2014) establishes descriptors that define the generic characteristics of learning outcomes for a higher education qualification at bachelor's degree (level 6 on the FHEQ). Among several other descriptors there is a requirement for graduates with a bachelor's degree to "communicate information, ideas, problems and solutions to both specialist and non-specialist audiences".

At the professional level in the United Kingdom the Chartered Institute of Building (CIOB) (2018) has an established Educational Framework with core standards for construction education for those institutions seeking to become an approved centre of

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Burt, R, Redden, L and Yantis, A (2022) Identifying Communication Knowledge and Skills for Construction Management Graduates Using Content Analysis of Entry Level Job Descriptions from the Southeast United States *In:* Tutesigensi, A and Neilson, C J (Eds) *Proceedings of the 38th Annual ARCOM Conference,* 5-7 September 2022, Glasgow, UK, Association of Researchers in Construction Management, 492-501.

learning for the CIOB. In the United States the American Council for Construction Education (ACCE) (2022) establishes and maintains standards for construction education. In both the CIOB Educational Framework for Undergraduate Programmes and ACCE Document 104 - Standards and Criteria, learning outcomes are used to guide institutions in the development of their curriculum. Learning outcomes are defined by the ACCE (2021) as "the set of knowledge, skills, and abilities to be attained by students upon completion of an event." Effective communication is identified by both the CIOB and the ACCE as an important outcome of undergraduate construction education. The location and specific outcomes related to communication are set out in Table 1.

Table 1: Communication related learning outcomes in accreditation standards

Location	Outcome
CIOB Education Framework - Section 2.8 Work-Based Learning	Present information effectively to audiences Demonstrate effective meeting skills
Developing Transferable and Management Skills Communication	Demonstrate effective interpersonal skills and informal communication
ACCE Document 104 - Standards and Criteria Section 3. Curriculum for the Bachelor's Degree Section 3.5 Student Learning Outcomes	Create written communications appropriate to the construction discipline. Create oral presentations appropriate to the construction discipline.

Although both the CIOB and ACCE set learning outcomes for students to achieve by graduation, they do not specify the curriculum or topical content. Institutions are empowered to develop their own curriculum to meet the standards. Previous work in construction education related to curriculum development, presented below, shows several different approaches to obtaining stakeholder input. Surveys are a popular method for obtaining information to aid curriculum development. Studies have focused on identifying not only general and comprehensive skills and knowledge construction graduates should acquire, but also more specific skills or subject matter knowledge.

The Aim of the research is to identify those activities related to communications skills that graduates need upon entering the construction industry, to inform decisions regarding curriculum content and assessment. The specific objectives will focus on identifying communication tools such as meetings, drawings, submittals, documents, contracts, reports etc. and the action verbs used in the context of these tools.

Following a revision of Bloom's defining work on categorizing educational objectives, four general types of knowledge were identified: Factual, Conceptual, Procedural and Metacognitive. Although construction communication involves elements of all four types of knowledge it is primarily concerned with procedural knowledge which is how to do something, including methods of inquiry, as well as criteria for using skills, techniques, and methods (Anderson and Krathwohl, 2014). Biggs and Tang (2011) define "intended learning outcomes" as statements that define what a student should know at the end of an instruction period. The kind of knowledge and the level of student understanding are key points to consider in crafting these outcomes. Key to defining the intended level of expected student performance is to identify the appropriate outcome action verb. Moon (2002) suggests well written learning outcomes contain three components; a verb that indicates what the learner is expected to be able to do, words that indicate on what or with what the learner is acting and word or words that indicate the nature of the performance required as evidence that the learning was achieved.

The most important skills the construction industry requires from graduating construction management students was the focus of a study using a structured survey administered to construction professionals. Respondents were requested to evaluate 93 skills across seven attribute/skill areas deemed significant for graduating construction management students (Ahmed, Yaris, Farooqui, and Saqib, 2014). Several studies focus on specific skills and knowledge. A questionnaire-based survey was used to gather information from general and electrical contractors in the United States regarding the desired skills of construction management students upon graduation in the area of electrical systems (Tatum and Conradi, 2019). In another study, a list of Heating, Ventilating and Cooling (HVAC) curriculum topics grouped into six subject areas was developed and the importance of each topic evaluated using a 5-point Likert scale by construction industry professionals (Burgett, Perrenoud and Smith, 2018).

Another approach used in construction education to obtain stakeholder input on curriculum development is the use of consultation with individuals or groups of individuals. To identify construction superintendent competencies and develop curricula to support superintendent education and training, Gunderson (2008) held interviews to identify and rank the skill sets required by project superintendents. Tatum (2013) used interviews with general contractors, construction mangers and electrical contractors, together with literature reviews to develop a survey to gain feedback regarding electrical curriculum content.

As part of a comprehensive review at Purdue University, faculty used industry input to establish undergraduate educational competencies and revise the curriculum within guidelines. An industry panel was used to develop and rank competencies that students should acquire prior to graduation (Benhart and Shaurette, 2014). As part of an Australian government sponsored national endeavour, a series of 14 workshops and follow-up questionnaires was convened to examine the preferences of a building discipline group to develop "Threshold Learning Outcomes." Many of the workshops were for academic staff of construction programs, while others were for industry practitioners and employers, current students, and recent graduates (Newton and Goldsmith, 2011).

In a study to identify the competencies that construction companies expect from construction graduates (Attallah, Mahfouz and Jones, 2019) used semantic analysis to analyse job descriptions and identify the most significant competencies expected for certain jobs. In similar studies outside the field of construction education, Hartmann and Jahren (2015) analysed seven years of job posting data from engineering companies to first understand the frequency and use of the word “leadership” in job descriptions. A content analytic approach was used to examine active job postings for entry-level business analytics positions to offer insights for those seeking to develop academic programs in this area (Cegielski and Jones-Farmer, 2016).

METHOD

An analysis of 53 entry level job postings obtained from companies recruiting from a large, established construction management program in the southeast United States was conducted. In general, entry level job descriptions contain the following elements: position name or title; a general description of the position; detailed job duties or requirements and qualifications. The job descriptions were analysed to obtain specific information on the position name or title and the job duties or requirements. MAXQDA (https://www.maxqda.com/) qualitive analysis software was used for content analysis of the position name or title and the job duties or requirements. Content analysis was used to determine not only the frequency of certain words, but also the context in which that word was used. Content analysis is a long-established research method for making replicable and valid inferences from written texts such as job postings to the contexts of their use (Krippendorff, 1980).

To provide some context of the position names or titles, these were analysed to identify the frequency of nouns, pronouns and adjectives and the context certain pronouns and adjectives were used in relation to nouns. The detailed job duties or responsibilities were analysed to identify those words that had a relationship to the communication process. For example, "meetings" was included because this is an activity that involves a communication process and "minutes" was included because this a communication tool. The frequency and overall ranking of each type of communication were recorded and for those words with the highest frequency, a context analysis was conducted to identify additional words that provide greater information on the context in which the word was used. For example, when analysing the communication tool drawings, there is interest in knowing the type of drawing and what graduates are expected to do with the drawings. The context analysis identified certain words of interest up to 15 words before or after certain keywords located in the same sentence. For example, in the sentence "Write meetings agendas and meetings minutes", if the keyword "meetings" was analysed, the word "write" would be identified as an action verb providing information on what a graduate is to do in relation to meetings. The words "agenda" and "minutes" would also be identified as communication tools.

FINDINGS

A total of 53 entry level job position name or titles were analysed. Table 2 shows the frequencies of the nouns, pronouns and adjectives used in job position titles. "Engineer" is the most used noun with "Project" being the most common pronoun. The adjective "Assistant" is used in 15 of the position titles, but interestingly not in any of the positions using the noun "Engineer". The most common title was "Project Engineer", followed by "Field Engineer". Other positions not mentioned in the table below include "Virtual Design and Construction (VDC) Engineer".

Table 2: Frequency of words used in job position names or titles

Adjective - Freq		Pronoun - Freq.		Pronoun - Freq.		Pronoun - Freq.		Noun - Freq.	
		Preconstruction	3	Field	9	Project	20	Engineer	36
Assistant	8			Field	2	Project	9	Manager	11
Assistant	5			Field	2			Superintendent	5
Assistant	2							Estimator	5

The results in table 2. Show there is significant diversity in job titles of the sample group, indicating graduates are filling multiple roles.

Communication Content in Job Duties or Responsibilities

The analysis of the 53 separate job duties or responsibilities identified the frequency of specific individual words related to communication activities. A total of 910 paragraphs each containing a individual job duty or responsibility were analysed for a total of 8157 words. The highest ranked individual word was predictably "Project" with 348 individual mentions. The frequency and overall rank of top 15 ranked communication related words are set out in Table 3. The results in table 3 show most of the words relate to "communication" products such as drawings and documents.

However, the most highly ranked communication word is "meetings", which is an activity involving participation, from which communication products are generated. This high ranking would confirm the need for inclusion of "effective meeting skills" in the CIOB accreditation requirements. The requirement to create written communications and oral presentations as a requirement of ACCE accreditation also has significant application to meetings.

Table 3: Frequency and overall ranking of "communication" words used in job duties or responsibilities

Word	F	R	Word	F	R	Word	F	R
Meetings	88	6th	Reports	42	23rd	Request-for- Information	38	31st
Drawings	81	8th	Scope	41	24th	Logs	31	42nd
Submittals	63	11th	Bid	39	28th	Schedules	30	43rd
Documents	60	12th	Specifications	39	28th	Requirements	27	47th
Contract	56	13th	Change-Orders	38	31st	Estimate	26	49th

A keyword-in-context analysis was conducted to further identify types of communication tools, and the most frequently used words used in context providing additional useful information on the critical skills and knowledge for a construction graduate.

Meetings

Context analysis was conducted to identify the type of meeting, any action verb that described what a graduate was to do regarding meetings and any word that indicated a communication product connected with meetings. Table 4 shows the results of the analysis of the 88 instances the words "meeting" or "meetings" are used. The types of meeting, action verbs and communication products are all documented.

Table 4: Frequency and overall ranking of words used in context related to meetings

Type of Meeting			Action Verb			Communication Product		
Word	F	R	Word	F	R	Word	F	R
Project	39	1st	Attend	23	2nd	Minutes	18	5th
Weekly	14	6th	Participate	20	4th	Agenda	7	12th
Coordination	13	8th	Assist	12	7th	Notes	4	20th
Subcontractors	13	8th	Review	7	12th			
Team	11	10th	Distribute	6	15th			
Safety	10	11th	Maintain	4	22nd			

Further analysis of the 18 instances where "minutes" was mentioned identified that in 12 cases, it was implied a responsibility of the job is to create, prepare or develop meeting minutes. Examples of text included in the descriptions of job duties and/or responsibilities that illustrate the type of meeting, action verb and communication product are set out in Table 5.

Table 5: Examples of text included in job duties and/or responsibilities that illustrate the type of meeting, action verb and communication product

Job Duty and/or Responsibility
Attends and takes notes for project team meetings, including weekly Owner/Architect meetings and subcontractors' coordination meetings.
Assist weekly site OAC (and all other onsite meetings), take clear and concise notes, and maintain meetings minutes.
Prepare all project meetings agendas and associated attachments as directed by the PM

The results in table 4 shows graduates are involved in a variety of meetings. This would indicate the need for graduates to communicate with diverse audiences. This was a requirement for graduates set out in the FHEQ descriptors to communicate to both specialist and non-specialist audiences. The results also suggest multiple activities connected to meetings, not only attendance and participation. There are also three specific products produced in relation to meetings.

The high ranking of meetings set out in table 2. and the alignment with accreditation requirements mentioned earlier has implications for construction educators. In defining what Biggs and Tang (2011) define as course-level "intended learning outcomes", educators would need to create outcomes to cover not only the factual, conceptual, and procedural knowledge related to meetings and communication products but also the skills needed to actively participate in meetings. Group projects that include structured periodic meetings with meeting agenda, notes and minutes, may be an effective form of assessment for this type of outcome.

Drawings

Context analysis was conducted to identify the type of drawing and any action verb that described what a graduate was to do regarding drawings. Table 6 shows the results of the analysis of the 81 instances the word drawings is used. The types of drawing and action verbs are all documented.

Table 6: Frequency and overall ranking of words used in context related to drawings

Type of Drawings	F	R	Action Verb	F	R
Shop	30	1st	Review(s)	25	2nd
Contract	11	3rd	Maintain(s)	11	3rd
Project	11	3rd	Assist	6	7th
As Built	6	7th	Record	6	7th
Design	6	7th			

Examples of text included in the descriptions of job duties and/or responsibilities that illustrate the type of drawing and action verb are set out in Table 7.

Table 7: Examples of text included in job duties and/or responsibilities that illustrate the type of drawings and action verb used

Job Duty and/or Responsibility
Effectively review and expedite shop drawings and coordinates, and exercises functional authority for project correspondence on shop drawings
Maintains as-built drawings
Review contract drawings, specifications, and shop drawings to ensure proper coordination and installation

In creating curriculum content and assessment strategies, construction educators should design course learning outcomes that not only address the different types of drawing including shop drawings, but also the skills involved to conduct reviews for specific tasks such as dimensional control or quality assurance.

Submittals

Context analysis was conducted to identify any action verb that described what a graduate was to do regarding submittals. Table 8 shows the results of the analysis of the 63 instances the word submittals is used.

Table 8: Frequency and overall ranking of action verbs used in context related to submittals

Action Verb	F	R
Review(s)(ing)	17	1st
Manage(s)(ing)	6	6th
Assist	4	8th
Create	3	12th
Update	3	12th

Examples of text included in the descriptions of job duties and/or responsibilities that illustrate the type of action verb used in relation to submittals are set out in table 9. The most common words used to describe the type of submittals are project and subcontractors. The most mentioned communication tool related to the submittal process is "log(s)" as can be seen in two of the examples below.

Table 9: Examples of text included in job duties and/or responsibilities that illustrate the action verb used in relation to submittals

Job Duty and/or Responsibility
Assist with the development a project submittals log and obtain approvals in a timely fashion
Review shop drawings and submittals for conformance with project specifications
Create, update and maintain project submittals logs and all other project specific QAQC reports

In creating curriculum content and assessment strategies, construction educators should design course learning outcomes that not only address the factual and procedural knowledge related to submittals, but also the skills involved to conduct reviews and even create submittal logs for specific tasks. There may be options to combine both the review of submittals and drawings into a combined assessment package.

CONCLUSIONS

Professional accreditation agencies such as CIOB in the UK and ACCE in the US set academic standards requiring graduates from construction programs to demonstrate they have developed communication skills to succeed in the industry. Analysis of entry level job postings are a proven method used to identify the skills and knowledge a graduate will need, when developing academic curriculum. An analysis of 53 entry level job postings identified significant variety in the job title or position name. The most common titles or names were "Project and Field Engineer" followed by "Assistant Project Manager" and "Field or Assistant Superintendent". The term "Assistant" was only applied to non-Engineer positions indicating those positions are supporting a more senior-level person. It is interesting to note the significant variety in job titles and names indicating graduates are pursuing multiple career tracks within the construction industry. However, it may be companies are using different titles to describe what is essentially the same position with similar job duties and responsibilities and further research is recommended in this area.

The aim of the research was to identify those activities related to communications skills that graduates need upon entering the construction industry. The results suggest the most important activities are related to meetings, drawings, and submittals.

The highest ranked communication phenomenon was "meeting". There is some variation in the names or types of meeting. There is a possibility the words used to describe the meetings might be different ways for describing what is essentially the same meeting. However, the results provide us with some indication of the purpose of these meeting. A more focused approach such as using individual interviews or focus groups would provide valuable information about these meetings. It is clear from the action verbs used in context with meetings that graduates are expected to attend and participate in meetings.

There is strong alignment here with CIOB's Education Framework where graduates need to demonstrate effective meeting skills and effective interpersonal skills and informal communication. The research objectives sought to identify communication tools and the action verbs used in the context of these tools. The results show that meetings require three primary tools: agendas, meeting notes and meeting minutes. Analysis of the context of the use of "minutes" indicated in some instances it was a responsibility of the job to create, prepare or develop meeting minutes. In defining the expected procedural knowledge expected, the results suggest graduates need the skills to actively participate in meetings through actively listening and communicating. There may also be a need to acquire specific techniques for taking notes during a meeting and creating minutes from notes. The conceptual knowledge of how agenda and minutes relate to one another is also very important.

The second highest ranked communication tool is "drawings". The most common types of drawing were shop, contract, or project, as built and design. The most common action verbs indicate the main function is either to review or maintain drawings. Drawings are not specifically mentioned in the CIOB and ACCE accreditation standards. However, ACCE (2022) does have a student learning outcome requiring graduates to "analyse construction documents for planning and management of construction processes." Commentary on this standard identifies drawings as a contract document. The results suggest a need to acquire the factual and conceptual knowledge to review drawings. This would include knowledge of the various types of drawings and the related terminology and graphic symbols used. Students would also need to develop the techniques and methods to review different types of drawings for specific functions.

The next ranked communication tool is "submittals". In building construction, submittals are the documents provided by a contractor to an architect for approval of use of certain materials, components, or equipment. The action verbs identified in the context analysis indicate that the review of submittals is the main function followed by management of the submittal process via tools such as a submittal log or register. Therefore, it is important to have knowledge of the procedural processes regarding submittals and the specific elements involved in this process.

Ultimately decisions regarding curriculum content and assessment are made by academic faculty. However, informed decisions cannot be made in ignorance of national accreditation standards and stakeholders needs. There is a thin line between where academic education ends, and where specific industry training begins. There is a strong case to be made for developing curriculum and assessment measures to best prepare graduates to be successful communicators in the construction industry. This study has identified some of the factual, conceptual, and procedural knowledge that needs to be addressed in the curriculum. This study has used professional accreditation standards from both the UK and USA to justify the need for inclusion of communication content in a construction curriculum. However, one of the limitations of this study is that the data for this study came exclusively from the USA and future research should include and analysis of entry level positions in the UK. Additional research will use certain strategies addressed in the introduction, such as the use of industry focus groups to centre on delineating where the teaching and learning in academic environment ends and where industry training begins. The aim of this ongoing research seeks to identify suitable assessment strategies for measuring student learning.

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SUSTAINABLE DEVELOPMENT GOALS IN CONSTRUCTION ENGINEERING EDUCATION: COMPARISON OF CURRENT CURRICULA IN DENMARK, FINLAND, AND BELGIUM

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The construction industry plays an essential role in achieving the Sustainable Development Goals (SDGs) targeted in the 2030 Agenda. However, limited research exists on how sustainability is implemented in higher education in construction programs. This study aims to map and compare the SDGs and their targets in the curricula of three construction engineering programs at bachelor level in Denmark, Belgium, and Finland. This was done by sorting the learning objectives of the curricula according to their contribution to the SDGs and targets. The learning objectives in the three curricula were then discussed concerning their contribution to the SDGs. The results show that the SDGs were addressed in all three curricula. Furthermore, all three sustainability dimensions were identified in the curricula. The results provide insights into the sustainable knowledge, skills, and competencies that higher education students are expected to obtain to tackle the sustainability challenges of the Northern European construction industry.

Keywords: education; sustainability dimension; Northern Europe; SDG; development

INTRODUCTION

The construction industry accounts for around 40% of the world's energy usage and 33% of the world's CO2 emissions (Gade and Opoku 2020). This underpins the urgency of addressing the environmental challenges while not comprising the social and economic dimensions of sustainable development (SD). In 2015, the 17 Sustainable Development Goals (SDGs) were agreed upon by 193 member countries of The United Nations as an ambitious, universal framework for SD towards 2030 (United Nations 2015). The SDGs consist of 169 targets and 231 indicators, equally encompassing environmental, economic, and social dimensions of sustainability

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(United Nations 2015). For the construction industry, the 2030 Agenda provides a common ground for SD and a global and stable definition of sustainability (Goubran and Cucuzzella 2019).

The educational institutions are critical stakeholders for SD and can be changemakers when their institutional capacities align with worldwide efforts to achieve the SDGs (Wright *et al.,* 2021). Therefore, it is also necessary for the educational sector to evolve, adapt and reflect present and future needs. With the SDGs, institutions equip future professionals with capabilities to manage and respond to complex challenges in sustainability in their careers (Sandri *et al.,* 2016; Bangay 2016). For construction engineering educational programs, the SDGs equip future graduates with increased knowledge, skills, and awareness to tackle the sustainability challenges met by the construction industry (Opoku and Guthrie 2018).

LITERATURE REVIEW

In recent years the global context of education has focused on policies and practices to incorporate SD. Research has shown an increased interest in assessing higher educational institutions' role in SD (Becker *et al.,* 2017; Chandran 2017). Investigations into universities and their policies reveal the importance of reflections on sustainability being part of all aspects of education (Almeida *et al.,* 2018). However, studies of higher educational programs' content uncover a low presence of sustainability in curricula addressing primarily sub-topic issues (Etse and Ingley 2015). Another investigation of postgraduates' sustainability skills compared workplace expectations to graduates' learning outcomes and curricula development (Sandri *et al.,* 2018).

The study concluded a gap between the learning outcomes regarding SD and the need for sustainable professionals due to a lack of skills in sustainability. El-Adaway *et al.,* (2015) examined engineering education learning by focusing on enhancing engineering undergraduates' skill sets in designing, constructing, and operating infrastructure systems using problem-based learning. The study revealed that students' performance increased despite of more complex SD activities the students solved. As shown above, only limited research concerning the implementation of SD in higher education exists, even though researchers have pointed out that institutions and programs play an essential role in SD. (Wright *et al.,* 2021). Scholars also argue that curricula and their links to SDGs and SD need to be studied as it gives students a new vision to adopt responsibility for creating a sustainable future (Braun Wanke 2017; Wamsler 2020; Etse and Ingley 2015).

This study aims to compare how the SDGs are considered in the curricula of three construction engineering programs at bachelor level higher education (EQF level 6) in Denmark, Belgium, and Finland. The results provide valuable insights into which sustainable skills, knowledge and competences are understood to be central in construction engineering programs from a Northern European perspective and serve as a first step to research this topic further, e.g., on a broader geographical scale. Furthermore, the results provide educational institutions and educators with a baseline for SDG implementation in the construction industry.

METHOD

This study focuses on mapping the SDGs and targets in three construction engineering programs across Northern Europe at a bachelor level (EQF level 6). The research question is how the curricula in the three higher education institutes differ from each other the SDGs addressed. The selected programs were Architectural Technology and Construction Management at University College of Northern Denmark (UCN 2021), Construction and Municipal Engineering at Satakunta University of Applied Sciences in Finland (SAMK 2022), and Bachelor of Construction at PXL University of Applied Sciences and Arts in Belgium (PXL 2022). These programs were selected to provide a Northern European perspective on how construction programs currently include the SDGs and targets in their curricula. All three institutions emphasize a practical perspective with solid links to the respective countries' national and regional construction branches.

Researchers from the respective institutions mapped the links between learning goals and SDGs. They all had a thorough knowledge of the study programs, curricula, learning objectives, and actual teaching activities, including the SDGs and related targets. The curricula were written in local languages and had different structures; thus, local researchers did the initial mapping of which learning goals contributed to which SDGs and targets. If clarifications were needed, feedback was requested from the relevant teachers. This was especially important as the links to the SDGs and targets were not explicit but had to be interpreted by the researchers. After this, the curricula were translated and aligned with the mapping results from the other two institutions.

The primary limitation of the study is that only curricula from three educational institutes were analysed. Therefore, the results are not providing the complete picture across Northern Europe. However, the study forms a foundation for further studies, where more programs from other countries could be studied to get a more accurate picture of the current state of SDGs in the European construction programs.

FINDINGS

This section presents the results of the mapping of the Danish, Finnish, and Belgian construction engineering curricula. Results focus on the dimensions of social, environmental, and economic sustainability, and implicit incorporation of the SDGs and targets into the topics and learning goals of courses in the curricula.

The authors define the division into the social, environmental, and economic sustainability dimensions inspired by a model created by Albareda-Tiana (2018). In relation to the SDGs, the social dimension focuses on two overall topics: human wellbeing (SDGs 1, 2, 3, 4, 5, 8, 16, and 17), and infrastructure that supports human health and the ability to live a dignified life (SDGs 6 and 7) (Agenda 2030; Hildebrandt 2016). The first social topic is essential for economic SDGs too, while the second social topic is essential for the environmental dimension (Agenda 2030; Hildebrandt 2016).

The economic dimension (SDGs 8, 9, and 17) focuses on minimizing tensions between material welfare and environmental values (Hildebrandt 2016). It includes economic growth, resilient infrastructure, decent work for all, promoting inclusive, sustainable industrialisation, and fostering innovation (United Nations 2015; Hildebrandt 2016). SDG 17 differs from the others by only being a central instrument for the other SDGs, and its main purpose is to encourage collaboration between countries. The environmental dimension is defined by SDGs 7, 9, 11, 12, 13, 14, and 15, focusing on stopping the ecosystem's overload and creating sustainable societies (Agenda 2030; Hildebrandt 2016).

The rate of inclusion of SDGs and their targets into curricula was determined by addressing each topic and calculating the percentage of the respective SDG(s) covered. For example, if 3 out of 12 targets related to one SDG are included, the SDG is 25% covered. Table 1 shows which SDGs have been identified in the three curricula for each sustainable dimension, based on the division by Albareda-Tiana (2018).

Table 1: SDGs in the Danish, Finnish, and Belgian curricula, along with the related sustainability dimensions

	Social dimension SDGs	Economic dimension SDGs	Environmental dimension SDGs
Danish curriculum	SDGs 4, 7, 8, 16, 17	SDGs 8, 9, 17	SDGs 7, 9, 11, 12, 13
Finnish curriculum	SDGs 4, 6, 7, 8, 17	SDGs 8, 9	SDGs 7, 9, 11, 12, 13
Belgian curriculum	SDGs 3, 4, 6, 7, 8, 17	SDGs 8, 9, 17	SDGs 7, 9, 12, 13

SDGs and Targets in the Danish Curriculum

To realize the social, economic, and environmental sustainability goals, several SDGs from each dimension are incorporated into the Danish curriculum, consisting of a national and institutional curriculum. The overall topics include single-family house construction, constructing buildings up to 2 ½ floors, profession, and prefabrication, multi-story building over three floors, building renovation, elective elements, digital design, internship, and study trips. The overall goal is to broaden students' knowledge, skills, and competences in sustainability to be applied in practice.

The targets 4.4 - 4.7 of SDG 4 are useful in moving education toward sustainability and focusing the students' understanding of sustainable principles, theories, methods, and skills. 25% of SDG 8 is included, incorporating targets 8.3; 8.4; 8.5. SDG 8 is a part of the social and economic sustainability dimensions and used to address humans' wellbeing. Furthermore, SDG 8 is used in the educational elements' theories and practices, focusing on social aspects for the practitioners, such as laws, contract management, equal salaries, and rights, and promoting development-oriented policies.

It supports productive, innovative activities and resource efficiencies (Agenda 2030). The goal also addresses sustainable construction principles, design, production, technical installations, and entrepreneurship. SDG 7, as part of the social and environmental dimension, is the only goal that is 100 % covered in the curriculum. It is used in the learning goals focusing on clean energy in relation to the learning of energy and infrastructure, optimizing concepts in theory, materials, and practices. SDGs 16 and 17, which are 31,6% included in the curriculum, focus on international cooperation across different cultures, using various partnerships to enhance sharing of science, technologies, and innovations (Agenda 2030).

SDG 9 targets 9.3 and 9.4 are part of the environmental and economic dimensions. Together with SDGs 8 and 11, it addresses the curriculum's elements focusing on sustainable upgrading and construction using efficient and clean resources, environmentally sound technologies, and industrial processes - including digital tools to minimize resource waste and experiment with innovative solutions - and economic practices and value chains. It is also used to reflect on knowledge development and energy optimizing renovation concepts and current building renovation practices.

The curriculum incorporates the environmental dimension through SDGs 11, 12, and 13. Besides SDGs 7 and 9, that are also used for the social and economic dimension. SDG 11 and 12 - 63,6% included in the curriculum - address practices and materials through sustainable urbanisation, focusing on building design planning and management, including digital design. Additionally, focusing on construction principles, solutions, materials, production processes, and recycling of natural resources. SDG 13 target 13.3 is addressed by improving awareness of climate changes for housing construction, maths, and building principles to make them more environmentally friendly.

SDGs and Targets in the Finnish Curriculum

In the curriculum, SDGs from the social, economic, and environmental dimensions are incorporated into the following elements of the program: Basic Studies, Common Studies of Construction and HVAC - Engineering, Common Studies of Construction Engineering, Professional Building Production Studies, Studies of HVAC-Engineering, Studies of Mathematics and Natural Science, Basic Studies of Construction and Municipal Engineering, Practical Training. They shall ensure students achieve sustainability knowledge relevant to professional construction engineers, infrastructures, and industrialisation besides sustainable practices.

For the social dimension, SDGs 4, 6, 7, and 8 are included between 15-30% in the curriculum. SDG 4 targets 4.3, 4.4, and 4.7 are used as a frame for the curriculum for students to achieve sustainable education and education in sustainability. Together with SDG 8 targets 8.3 and 8.8, they are included in curricula elements to learn about safe and secure conduction and environment at a site. Additionally, they are used to understand professional engineers' labour rights, treatment, contracts, and salary. Other elements are used to understand sustainable economic growth, productive activities, and innovation.

The other part of the social dimension focusing on a dignified life is also covered by using SDGs 6 and 7 to address sanitation and clean, modern energy in the curriculum elements for infrastructure. Following topics from the curricula: water systems (designs, materials, and process, fluid technologies), heat systems and production, renovation, air conditioning and ventilation. Thus, supporting the human right to a dignified life (Agenda 2030). This indicates SDGs cover social and economic perspectives.

The economic dimension in the curriculum utilizes SDGs 8 and 9 to focus on construction engineering, entrepreneurship, project and contract management, and practical training. SDG 9 target 9.4 focuses on sustainable infrastructure and the use of clean and environmentally sound technologies in the curriculum's elements: upgrading/renovating infrastructure, building materials to be used, geotechnical engineering, foundation structures, building residential houses and their infrastructure (including fire protection) and heating systems (including production and transfer) and heat pumps (Agenda 2030).

The environmental dimensions, i.e., SDG 7, 9, 11, and 13, are tackled in the curriculum. SDGs 7 and 9 are targeted and cover the social, economic, and environmental dimensions focusing on sustainable infrastructure and industrialisation (Agenda 2030). SDG 11 target 11.3 is included in the curriculum to address climate awareness and limit and reduce its impacts on infrastructure and construction engineering such as materials, technologies, and practices (Agenda 2030). SDG 12 target 12.4 is part of the curriculum focusing on environmentally sound management of waste, including chemicals, throughout their life cycle (Agenda 2030), by addressing the following elements: a sustainable perspective of technical parts, materials, and practices for indoor climate, energy-efficient building materials, technical maintenance and renovation of buildings, heat and air conditioning, ventilation, contract management and tasks onsite (Agenda 2030). SDG 13 target 13.1 is used to address HVAC engineering and building materials to be more resilient against climate hazards.

SDGs in the Belgian *C*urriculum

The curriculum includes SDGs from all three dimensions to focus on students' competencies. It covers competencies that make the students capable of organizing a building project, understanding the materials, managing, and supervising the building project, and understanding the building project in a bigger context. This ensures that students possess sustainable, technical competencies, including analysis of sustainable and innovative solutions and practices (Agenda 2030).

For the social dimension, the curriculum uses SDG 3, 4, 6, 7, 8, and 17. This curriculum is the only one addressing SDG 3, which is incorporated 15,3%. It includes targets 3.6 and 3.9, focusing on traffic infrastructure and handling and analysing materials; contaminated one and hazardous chemicals and air, water, and soil pollution (Agenda 2030). SDG 4 targets 4.4 and 4.7 ensure that all learners will acquire sustainable knowledge, vocational skills, and technical and analytical competencies.

Students are educated in sustainable development and lifestyle, including cultural diversities, promoting sustainable development (Agenda 2030). SDGs 8's and 17's target 8.8 and 17.17 are included in the curriculum to focus on economic growth, secure working environments, rights, and cooperation, considering multicultural differences in international teams. SDGs 6 and 7 are 40% part of the curriculum focusing on technical aspects of a building project, an analysis of construction and innovative solutions to address improvement of water quality, to reuse water and reduce untreated wastewater next to increasing the share of renewable energy (globally) and improving the efficiency (Agenda 2030).

The curriculum's economic dimension incorporates SDGs 8, 9, and 17. SDG 9 targets 9.4 and 9.5 are used to address sustainable infrastructure upgrading, enhancing scientific research, and upgrading technological capabilities of industrial sectors through the curriculum elements. This is done by analysing building projects and development, focusing on innovative materials, techniques, and practices - and learning innovative solutions (Agenda 2030).

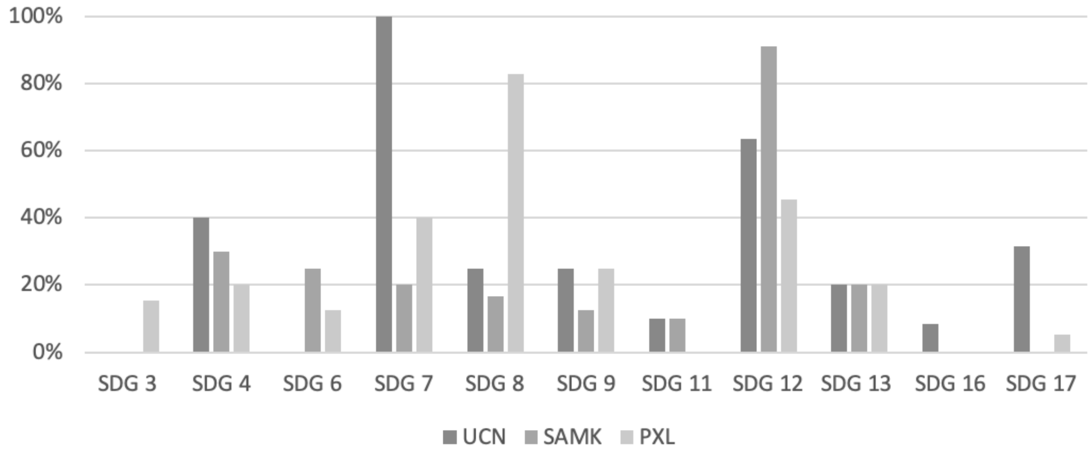
The environmental dimension includes SDGs 7, 9, 12, and 13. SDGs 7 and 9 are both part of the social, economic, and environmental dimensions, focusing on the curriculum covering energy efficiency, sustainable infrastructure, and industrialisation (Agenda 2030). SDGs 7, 9, and 12 are the SDGs incorporated most into the curriculum. SDG 12 uses the targets 12.2, 12.4, 12.5, 12.6, and 12.8 to address material recycling, to analyse innovative materials and development, optimize practical problem(s) and create a responsible professional building engineer. Therefore, they are used for sustainable sound management and efficient use of natural resources and waste products, including polluting chemicals. SDG 13.1, like the Finnish curriculum, focuses on improving climate awareness in the most current sustainable practices and developments.

Education of SD is a concept evolving with emerging sustainability issues, and it is a necessity for construction engineering programs to be considered. Furthermore, SDGs can be used to identify priorities and dimensions relevant to educational programs

(Albareda-Tiana 2018; Goubran 2019). This paper reports, how the three compared engineering programs utilize the SDGs and targets to ensure that students achieve SD knowledge, skills, and competencies. Despite the differences in the design and elements of the curricula, the results show that all three curricula support students in achieving sustainable knowledge, skills, and competencies related to several SDGs. These SDGs focus primarily on sustainable and efficient practices, materials, and design. The topics and approaches of the programs to SD are similar, differing slightly in which SDGs and targets are addressed in the three curricula.

Previous research has highlighted SDGs that directly and indirectly contribute to the built environment (Goubran 2019). Opoku and Guthrie (2018) argue that SDGs 7, 9, 11, 13, and 15 are the most relevant to be applied in the built environment. Other scholars state that the SDGs 6, 7, 12, 13, and 15 are the ones that the construction sector can directly contribute to (Gade *et al.,* 2021; Goubran 2019). The results of this study indicate similarities and differences in all three curricula. Figure 1 shows the level of implementation of each SDG in the three curricula from the point of view of social, environmental, and economic sustainability. The X-axis shows which SDGs are covered in the curricula, while the Y-axis shows the SDGs' level of implementation.

Figure 1: Diagram of the level of SDGs in the three curricula



The Danish curriculum includes five, the Finnish four and the Belgian six of the SDGs related to the social dimension, consisting of ten SDGs. The economic dimension consists of SDGs 8, 9, and 17, and both the Danish and Belgian curriculum address all three of these while the Finnish curriculum includes 8 and 9. For the environmental dimension of sustainability that consists of SDGs 7, 9, 11, 12, 13, 14, and 15, the Danish and Finnish curricula use SDGs 7, 9, 11, 12, and 13, while the Belgian utilizes SDGs 7, 9, 12 and 13.

All the three curricula use SDGs 4, 7, and 8 from the social dimension, differing in how many targets are being used. Only one or two curricula use SDGs 3, 6, 16, and 17. As shown in Figure 1, SDGs 8 and 9 from the economic dimension are used, while SDG 17 is part of both the Danish and Belgian curriculum. For the environmental dimension, SDGs 7, 9, 12, and 13 are part of all three curricula, SDG 7 being included 100% in the Danish curriculum, and the Danish and Finnish include 10% of SDG 11. SDG 14 and 15, on the other hand, are excluded from all three programs. However, only the Danish curriculum uses one SDG 100%, and SDG 15 is not used. Only two programs address SDG 11 (target 11.3). Of the commonly used

SDGs 7, 12, and 13 for building projects (Gade *et al.,* 2021), SDG 12 is used more than 60% in two curricula, and SDG 13 is used 20%. SDGs 6, 7, and 15 are directly dependent on construction activities (Gade *et al.,* 2021). Results reveal that SDG 6 is used in two curricula and incorporate over 20% of it.

CONCLUSIONS

This study compared the state and use of SDGs in the curricula of three construction engineering programs at bachelor level (EQF level 6) in Denmark, Belgium, and Finland. The paper also provides information on which knowledge, skills, and competencies students are expected to achieve across Northern Europe. A comparative analysis was conducted for the three curricula. Although the programs were not directly comparable due to the differences in professions and programs, the results reveal that the SDGs and targets utilized for the professions in the national building sectors are similar for all three curricula, with minor alterations. The results show that all three curricula implicitly and explicitly address sustainable construction, providing graduates with sustainable knowledge, skills, and competencies.

The SDGs 4 (quality education), 7 (affordable and clean energy), 8 (decent work and economic growth), 9 (industry, innovation, and infrastructure), 12 (responsible consumption and production), and 13 (climate action) were implicitly addressed in all three curricula. In addition to this, all three curricula use the social, economic, and environmental dimensions to address sustainability and include similar SDGs and targets. Only SDG 7 (Affordable and clean energy) has all its targets addressed, though only in the Danish curriculum. Previous research has shown that the SDGs 6 (clean water and sanitation), 7 (affordable and clean energy), 9 (industry, innovation, and infrastructure), 11 (sustainable cities and communities), 12 (responsible consumption and production), 13 (climate action), and 15 (life on land) are directly connected to the construction sector.

These SDGs were used in the three curricula, except SDG 15 (Life on Land). The number of included SDGs differs slightly in the three educational programs, indicating different focus and approaches to sustainable construction. Furthermore, some of the SDGs were included in more than one curriculum but used different targets. These minor exceptions highlight differences in sustainable practices, methods, and techniques across the three countries.

The results contribute to understanding the current situation with regard to SD and SDGs in higher education, in construction engineering programs in three European countries as a foundation for assessing graduates' sustainability knowledge, skills, and competencies. The results show despite all three curricula being different they still use similar SDGs for SD.

The paper fills a gap in the current research by mapping the links between the learning goals and the SDGs, in the context of the social, environmental, and economic sustainability dimensions. The authors propose future research to include a broader investigation of the links between construction engineering curricula, SD and the SDGS in Europa and worldwide, along with assessment of the actual learning outcomes of the students.

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MAINSTREAMING PREVENTION THROUGH DESIGN IN ENGINEERING EDUCATION

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The integration of Prevention through Design (PtD) concept into the engineering education has evolved progressively in response to accreditation requirements. Despite the previous studies focusing on the integration of PtD principles into the curriculum, practical knowledge integration through effective teaching and learning mechanism remains elusive. The objective of this paper is to discuss the core elements of teaching and learning approach, as well as best practices in integrating the PtD concept into curricula. A systematic literature review was conducted based on 27 identified studies focusing on PtD education. The findings indicated that the current PtD educational approach incorporates five constructivist learning principles: content learning, outcomes learning environments, learning domains and pedagogical approaches. This study extends the PtD literature in the educational context, by providing insights into designing an effective curriculum for mainstreaming the PtD in engineering education.

Keywords: education; curriculum design; prevention design; constructivist learning

INTRODUCTION

Prevention through Design (PtD) in construction has been acknowledged by scholars and practitioners as one of the preventive efforts throughout the design phase to mitigate work related to risks and hazards, hence balancing occupational safety and health over the lifecycle of a project. The PtD concept has attracted growing research interest and practice in wide-ranging domains, including practicality and resources (Toole, 2017), technological advancements (e.g., (Din and Gibson, 2019)), sustainability (Stacey and Simpson, 2009), education (Behm *et al.,* 2014; Toole, 2017) and financial implications (ASCC, 2006).

Despite widespread adoption of PtD practice, practical implementation can be challenging. One of the notable challenges documented in the literature was the lack of knowledge and abilities among duty holders, notably designers, in addressing the OSH implications of their design in relation to the project lifecycle. One of the possible causes of concern was a lack of early PtD education in tertiary and continuing education. Research suggests that charting the curricula development toward PtD is

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an essential first step in enhancing graduates' competency towards safety and health (Hinze, 2000; Toole, 2017).

LITERATURE REVIEW

The PtD educational issues were initially highlighted in the early 2000s, with a focus on creating a commitment to preventative culture to ensure graduate designers had a solid foundation of the safe design prior to real-world work experience (e.g., Hinze, 2000; Mann, 2008).

Several studies (e.g. (Hinze, 2000; Popov *et al.,* 2013; Toole, 2017) have highlighted that one of the major barriers to incorporating the PtD into the curricula was the crowded curriculum among engineering programmes. Mann (2008) discovered that a lack of awareness on the occupational safety health (OSH) has contributed to designers' failure to create safer construction methodologies. Gambatese (2003) has emphasised that limited knowledge of OSH is one of the factors impeding the diffusion of PtD in the United States. Several other studies in different countries, for instance in Malaysia (Che Ibrahim *et al.,* 2021); in the UK (Stacey and Simpson, 2009); in Australia (ASCC, 2006) have acknowledged that the designers must improve their OSH knowledge and skills for PtD to be realised in their designs. It's worth highlighting that the possible reason for designers' lack of safety understanding is due to the lack of early safety education in tertiary education (Toole, 2017). Furthermore, it is thought that PtD practise among designers is conceived through training or courses are taken throughout their professional experience, rather than during their undergraduate education (Cortés et. al., 2012).

Although there have been examples of the current state of PtD education (e.g., Spain (Lopez *et al.,* 2015), the United States (Din and Gibson, 2019), and Malaysia (Che Ibrahim *et al.,* 2021)), as well as proposed educational approaches (e.g., Popov *et al.,* 2013; Wilbanks, 2015; Toole, 2017); little initiatives to investigate the integration of teaching and learning mechanisms into PtD practice. Thus, to fill the identified gap in the PtD education, this study explores the relation between PtD principles and teaching and learning approach based on the constructivist learning principles. This study is part of a wider study to understand the extent of PtD education in engineering accredited programmes. Gaining an insight on how PtD could be integrated into curricula could facilitate the academic transform of the present engineering curriculum into a practical transformational change in bridging the safety and health education gaps for engineering graduates.

METHOD

The overall review workflow was based on a systematic literature review, and it included three major phases: identification of articles, selection of targeted articles, and examination of the target articles. The scope of the review aimed to cover PtD related education literature in the construction domain, this study used a combination of diverse PtD terminologies and educational context. The search was based on 19 different key terms that were shown in either the title,

TITLE-ABS-KEY ("Prevention through Design" OR "Design for Safety" OR "Safety in Design" 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 "OSHCIM" OR "DfCWS" OR "DfCS" OR

"CHPtD" AND (“Construction") AND ("Education*" OR "curriculum" OR "teaching" OR "institution" OR "Pedagogy"))

The review exercise covered articles published from 2000 until the year 2021. The initial search found 46 related articles, including articles published in both journal articles and conference proceedings. Next, further screening was conducted to exclude 11 articles that were not related to construction (e.g., power plant, crime prevention) context, incomplete details, and duplication of conference articles (similar and greater depth of content was published as journal articles). The initial screening returned 35 articles from 17 different publications outlets.

The following inclusion criteria were used to select the articles to assess their relevance to the subject: (1) the article should focus (majority of the content) specifically related to PtD education context in the EAC domain; and (2) the article should emphasise at least on the perspectives, educational concepts, and approaches of PtD. Articles focusing on PtD but not on educational context were excluded from the sample, resulting in only nine relevant articles out of 35. To ensure that no significant publications on PtD education are overlooked, a snowballing technique was conducted. Finally, 27 relevant articles were finalised, with most of the articles (48%) coming from conferences, followed by journal and report articles (41% and 11%, respectively). In terms of geographical location, most of the authors (56 percent) were from the United States, followed by Australia and Malaysia with 11 percent each, and the remaining 33 percent were mostly from European countries (e.g., UK and Spain).

A qualitative thematic analysis was adopted to identify and synthesis the trend of PtD educational elements highlighted in the 27 articles. The inclusion of datasets from different sources over the past decades enabled the triangulation of elements for increased validity. Several initiatives have been proposed (ranging from academic capability, syllabus, innovative pedagogical approach, technology integration, etc) to instil safe design thinking and skills in graduates (Toole, 2017; Behm *et al.,* 2014).

FINDINGS

The Constructivist Learning Principles

The PtD educational elements were identified from the literature and were framed based on the five constructivist learning theory principles suggested by Terhart (2003) i.e., content, learning outcomes, learning environments, domain learning and pedagogical approaches. The consideration of the constructivist learning is appropriate due to the need of making sense of the knowledge, skills and experience related to PtD landscape during the learning process (Behm *et al.,* 2014; Toole, 2017). In framing the PtD engineering education, the constructivist didactics (CD) theory has offered must-have educational elements in integrating the PtD concepts and its principles into the curriculum structure.

The construction of CD in engineering education is mainly governed by two (2) main principles: (1) principle of learning which aims to create own learning of knowledge and experience and (2) principle of instructors which designs the strategies of learning of the learners based on the metacognitive of learning skills. These governing principles have constructed the curriculum into a practical pedagogy approach to achieving the intended learning outcomes. Another component that mechanises the learning is the didactics. Didactics is the approach of instruction from the instructor to the learners which stimulates and controls the learning through selected content, obligates a response from the learners, evaluates students' responses and provides reinforcement of correct responses or feedback for the learner based on the learning environments and facilities (Terhart, 2003).

Popov *et al. (*2013) further research how to integrate the PtD concept with constructivist learning principles by mapping the requirements set by accreditation bodies [e.g., Accreditation Board for Engineering and Technology (ABET); Engineering Accreditation Council (EAC) Joint Board Moderators (JBM);] (Che Ibrahim *et al.,* 2021; JBM, 2021). The requirements of mapping will align the PtD concept easily when the curriculum is compliant with the outcomes-based approach. The outcomes-based approach provides classical guidance on mapping the engineering content (e.g., health and safety risk management) within engineering teaching and learning approaches and demonstration of students' attributes to become competent safe thinking design engineers. The students' attributes for the curriculum will be designed based on the transferable skills (e.g., knowledge profiles; engineering analysis; engineering activities; engineering practice) based on the intended learning outcomes within the wide range of real scenarios in PtD practices.

The PtD Educational Elements

Many efforts have progressively grown in engaging the PtD practices in teaching and learning. Table 1 presents the summary of best practices of previous studies on PtD educational elements. It is worth noting, that there is a multifaceted relationship between the five (5) key elements of the constructivist didactics approach (content, learning outcome, learning environment, learning domain, and pedagogical approaches), the need to consider them dependently is crucial because each of these represents a key element to develop student's knowledge, attitude, and competency towards PtD practice when they work in the industry.

Content

The content is one of the significant mediums of didactics to craft the learning of the students (e.g., authentic materials; lesson plan consisting of learning activity and the learning outcomes). The literature indicated the dominant concept of PtD was incorporated into the existing course of design (i.e., steel design, concrete design, timber design) (Batson, 2013), safety and risk hazard management and risk assessment were mostly the chosen content to be small sub-topic incorporated in the course (Ghosh and Bhattacharjee, 2016; Maraqa, 2015; Popov *et al.,* 2013; Toole, 2017).

Occupational safety and health (OSHA) was introduced as a short course with a minimum of 10 hours of lectures inclusive of a day with visiting professional speaker sharing the notes and experience of safety practices at the site (López *et al.,* 2015; Mann, 2008). Several scholars (e.g., Behm *et al.,* 2014; Foley *et al.,* 2016; Lew and Lentz, 2009) have highlighted the exposure to construction techniques, legislation, regulation, policies, and ethics, are added as new topics in different existing subjects and new subject into the curriculum due to limited credit hours as strictly guided by the accreditation. However, many civil engineering programs are integrating sustainability into their curricula but focusing on environmental sustainability and economic sustainability (such as life cycle costing) but missing the third pillar of sustainability, which is social sustainability which is the core to the PtD principles (Toole, 2017).

Learning Outcomes

In terms of learning outcomes, most of the literature indicated that the intended skills acquired to perform in PtD practices are translated on how effective the learning environment will be created. The complex relationship between learning outcomes and the learning environment needs to be carefully designed for the students' exploration to attain knowledge is achieved through the capability of the course in guiding the students to develop knowledge and skills from their prior knowledge to more advanced learning. In particular, 'to address and to understand' the fundamental intended learning outcome of PtD practice is designed based on the sequential consideration of safety by designers in the phases of design, analysis, and safety consideration during the identification of hazards for workers and end-user (Bhattacharjee and Ghosh, 2011; Che Ibrahim *et al.,* 2020). Mostly the authors (Batson, 2013; Maraqa *et al.,* 2015), highlighted the chosen taxonomy used in developing the learning outcome is based on the development of lower order, intermediate and higher order of the taxonomy. It signifies the level of development of a student's cognitive domain (i.e., knowledge, comprehension, application, analysis, synthesis, and evaluation).

Learning Environments

Exposure of experiential learning space for PtD that creates student-cantered learning activities in meaningful learning experience related to the complexity of real-world PtD practices. PtD can serve as an engaging platform through classroom, workshop, and collaborative networking (Popov *et al.,* 2013; Toole, 2017). Bringing the real-world PtD practices into the classroom is favourable to the instructor so the students can get a real feel of commitment towards safety. Some of the engineering programmes invite speakers from the industry to share their knowledge and experiences with the students (Jia and Gilbert, 2017; Wilbanks, 2015). In terms of contextual design process evolves from the concept of contextual enquiry, where decisions are based on how users interact with the work environment, site visit exposure was introduced by Bhattacharjee and Ghosh, (2011); Toole (2017) and Che Ibrahim *et al. (*2021). An interactive environment of learning has been driven by the technology of digital transformation. The widespread technologies (i.e., building information modelling, big data, virtual reality, game-based, design simulation modelling) has been used to visualisation of OSH in the construction site environment (Che Ibrahim *et al.,* 2021; Din and Gibson, 2019).

Learning Domains

Expected competencies of knowledge, skills, and attitude to be acquired by learners in relation to PtD practices have been well addressed by (Che Ibrahim *et al.,* 2020) based on tacit, explicit, and implicit knowledge distributions based on the PtD practices. Many researchers (Batson, 2013; Behm *et al.,* 2014; Toole, 2017), are concerned about how the students instil the safety commitment when making a crucial decision that leads to providing facilities, and methods of construction to offer during the commencement of the project, the process that is relevant and economically viable to the client and user in managing the risk and hazard throughout the lifecycle of the project. As this is the most challenging effort, the students need to understand and be aware of the importance of having safe design thinking and commitment toward the workers and users. Furthermore, the central essence of skills is leadership skills as it will need to ensure the safety premises are kept and follow orders as per stipulated in the law and regulations. Furthermore his/her command is important as it will ensure the success of the project/construction in fulfilling and satisfying the need of PtD requirements.

Table 1: The best practices of PtD educational elements based on constructivist learning principles

Exemplary of Best Practices in Constructivist Didactics Learning Principles

Content	Learning Outcomes	Learning Environments	Learning Domains	Pedagogical Approaches	Relevant authors (Examples)
Construction techniques; construction site safety; planning and operation	To address the construction technique in the safest practice	Classroom	Systematic thinking	Lectures; Training	Hinze, (2000); Gambatese, (2003); Lew and Lentz, (2009); Cortés *et al.* (2012)
Safety in design; safe design in lifecycle concepts; identifying hazards; PtD concept and its constructability	To understand the designing for safety issues and design decision making based on PtD concept and principles	Classroom; Workshop; Collaborative networking; interactive software; internship	creative thinking; communicate effectively; decision making; leadership	Lectures; Modules; Training	ASCC, (2006); Batson, (2013); Popov *et al.* (2013); Maraqa, (2015); Ghosh and Bhattacharjee, (2016); Toole, (2017)
Ethical role of the engineer	To understand the roles and responsibilities of duty holders within the framework of PtD	Classroom	Instilling commitment	Lectures; Training	Batson, (2013); Behm *et al.* (2014); Toole, (2017)
Construction techniques; identifying hazard	To understand the safety hazards recognition and designing solutions by substitution of tools and systems.	Classroom; computer/ paper-based game; internship; research project; site visit; workshop	Critical thinking	Lectures; Research; Training	Popov *et al.* (2013); Ghosh and Bhattacharjee, (2016); Din and Gibson, (2019)
Safety framework, legal and regulatory; public policy; legal duties	To understand the available laws and regulations based on the lifecycle of the project	classroom; workshop	critical thinking; forward thinking; leadership	Lectures; Training	Stacey and Simpson, (2009); Foley *et al.* (2016); Che Ibrahim, *et al.* (2021)
Concept of PtD; safety and risk hazard management; risk hazard assessment; lab safety	To understand the safety management and responsibility in managing risk	Classroom; internship; laboratory; multimedia; MOOC; site visit; seminar; websites	Critical thinking; leadership; systematic thinking;	Lectures; tutorials; visiting speaker	Wilbanks, (2015); Jia and Gilbert, (2017); Che Ibrahim *et al.* (2021);
Occupational Safety and Health (OSHA)	To understand the safety concept of hazard assessment at the site	Animated software; Classroom; competition; seminar; site visit	Competencies in risk prevention	Lectures; modules; visiting speaker	Mann, (2008); Popov *et al.* (2013); Lopez *et al.* (2015); Toole, (2017);

Pedagogical Approaches

Effective and innovative teaching delivery strategies are the key to drive experiential learning and crafting the mind of the learners through effective learning is notable.

The best practices have yet need to be improved as the instructor needs to be up to date with the current concept of PtD and some still use the traditional lecture-based educational modules that cover wider PtD dimensions.

The pedagogical approach that can be used in PtD teaching and learning proposed that using case studies as part of a risk prevention exercise could influence students' design thinking in terms of accident causality, prevention, and hierarchy of controls (Che Ibrahim *et al.,* 2022).

To nurture the low to high levels of skill attainment among the student, Popov *et al.* *(*2013) proposed three techniques (i.e., What if/Checklists, Failure Mode Effects Analysis and Preliminary Hazard Analysis and Risk Assessment) that could be embedded in the curriculum that aligned with outcomes-based learning. In contrast, suggested that technology-driven approaches such as computer-based and serious game is more effective to instil in the students' interest in acquiring the safe design thinking and instil the safety commitment during their lessons throughout their exposure to PtD practices in their programme.

CONCLUSIONS

The study adopted a systematic literature review approach to investigate the trend of how the PtD integrates into engineering education based on the constructivist didactics theory's learning guiding principles. In general, the current PtD educational approach is mainly focusing the identification and analysis of risk and hazard. The integration of wider fundamental and practical knowledge is needed to equip future engineering graduates with cognitive, practical, and affective attributes in the safety and health domain.

The finding generates insights into the five (5) key elements of PtD educational approach based on constructivist learning principles; (1) content, (2) learning outcome, (3) learning environment, (4) learning domain and (5) pedagogical approach. The first element, content is related to the exposures of breadth and the depth of PtD concept covers identification of risk and hazard, ethics, construction techniques and others through its curriculum to craft the meaningful learning of learners. The next element, the learning outcome is focused more on the aim of intended skills to acquire for each learning domain in terms of knowledge, skills, and experience to perform the PtD practices. The learning environment is described as exposure to an experiential learning space for PtD that creates learner centred-learning activities in meaningful learning experiences related to the complexity of real-world PtD practices. The fourth element, the learning domain covers the expected competencies of knowledge, skills, and attitude to be acquired by learners in relation to PtD practices. The last principle, the pedagogical approach deals with effective and innovative teaching delivery strategies of the instructor to deliver the PtD contents to the learners.

It is believed that these elements could drive the experiential learning PtD and creates the interest in the student's appreciation towards PtD practice. Furthermore, including these elements in existing curricula has the potential to increase the safety and health outcomes required by associated engineering professional bodies. Nevertheless, in acknowledging that the key elements are conceptual embedded, further research through quantitative and qualitative methodologies in different geographical contexts could be conducted to capture the PtD or safety and health best practices in the educational landscape to further improve the learning experience of future graduates in the tertiary education.

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FACTORS INFLUENCING BUILT ENVIRONMENT APPRENTICESHIP COMPLETION RATES: A SYSTEMATIC LITERATURE REVIEW

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There has been a surge in public interest in apprenticeships in Ireland, because of increased awareness, political support, increased state funding and a new 2021 Apprenticeship Action Plan. In Ireland, there are 62 apprenticeships available, involving over 8,000 employers and 24,000 apprentices. However, non-completion can be costly for both employers and program administrators, as well as proving difficult for the apprentice. The aim of this research is to undertake a systematic literature review to identify 1) Where is apprenticeship completion research taking place? and 2) What factors influence the completion of apprenticeship programmes? The research method investigates findings from twenty-four articles published between January 2000 and December 2021. The investigation concludes that the reasons for completion fall into three main categories: apprentice related issues, curriculum and programme quality and employer issues. Overall, the findings will help to contextualise why apprentices do not complete their apprenticeship and determine if this might be applicable to Ireland. While only two papers were found during the systematic literature review pertaining to Ireland, the key contribution of this research is to apply the international findings with the intention of increasing built environment apprenticeship completion in this country.

Keywords: apprentice; systematic review; vocational; education; training

INTRODUCTION

An apprenticeship is a programme of structured education and experiential training, which formally combines learning and training in the workplace and an educational setting (Department of Education and Skills, 2013). It emphasises learning by doing, while meeting the needs of the economy, and preparing the apprentice for a specific occupation. Apprenticeships involve being employed under a contract of employment, where there is a minimum of 50% workplace-based training (Generation Apprenticeship, 2020). Of the 62 apprenticeships in Ireland, there are currently 8 Built Environment Apprenticeships.

These are brick and stone laying, electrical, plastering, stonecutting and masonry, wood manufacturing, painting, and decorating, carpentry and joinery and plumbing. These follow a seven phase, on the job and off the job standards-based model (O'Connor, 2006). Apprenticeship training programmes are an attractive way to

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retain employees, as they provide a structured framework within which employers can build loyalty and broaden the range of entrants to their company (Department of Further and Higher Education, 2021). There is however, apprehension about a skills shortage within the Irish construction industry and policy makers agree that apprenticeship should be encouraged, to ensure that there will be enough trades people to continue to build Ireland into the future (Department of Further and Higher Education, 2021). There are increased demands for skilled workers as Ireland enjoys a growing economy.

The Climate Action Plan 2021 offers opportunities for growing business and employment in offshore windfarms, retrofitting and renewable resources technology. This will result in increased demand for skilled built environment workers and apprentices. Expert Group on Future Skills estimates and increase in employment in this sector from 5000 in 2020 to 27,000 in 2030 (Ireland, 2021). There are reviews scheduled to the curriculum content of existing craft apprenticeships to support the move to zero carbon economy as well as new green apprenticeships. The Action Plan for Apprenticeships 2021-2025 sets out the need to increase the number of apprentice registrations to 10,000 annually by 2025 and this gives ample opportunity to train the built environment construction workers of the future to green technology, retrofitting and the use of renewable and recycled resources. However high retention and completion rates are as important as increased registrations to address skills shortages.

Apprenticeships are an integral part of Further and Education Training sector, have the support of employers, educators, Government, and unions (O’Connor, 2006). It is in the best interests of employers and policy makers to identify factors that affect completion, as the loss of human capital, may prove expensive for both companies and apprentices alike. Apprenticeship non-completion may be an indication of the programme’s weaknesses, the capacity of the employers, and the individual characteristics of the apprentices (Gambin and Hogarth, 2016). Despite evaluations of training and educational programmes, gaps remain in knowledge of the effectiveness of apprenticeship in Ireland.

For example, how the characteristics of the training programme and the apprentice themselves can affect their success. O'Connor (2006) begins by outlining that over 66% of registered apprentices complete their apprenticeship in Ireland. In 2019, an Oireachtas report declared completion rates of 65% in Carpentry, 73% in Electrical and 69% in Plumbing. In 2019, The 2019 Review of Participation and Costs of Apprenticeship reported that the government costs to the of an Irish apprenticeship was €7159 to 9877 annually. Identifying the factors that contribute to the loss of apprentices is critical in assisting government agencies, training providers, and other organisations, in determining whether and when to implement specific measures to, prevent early termination of apprenticeships. In 2018, 6.4% of the those employed in Ireland were in the construction industry. The successful delivery of Project Ireland 2040 depends on sustained and diversified construction employment and fulfilled careers.

The motivation for undertaking this research is that there exists evidence on the factors of apprenticeship non-completion in other countries, including United Kingdom (UK) (Daniel *et al.,* 2020), Australia (Harris and Simons, 2005), Canada (Laporte and Mueller, 2013), England (Gambin and Hogarth, 2016) and Germany (Bessey and Backes-Gellner, 2015), Scotland (Greig, 2019), but there is no comparable study in Ireland. Low levels of completions along with an aging population within the Irish construction industry could result in skilled built environment workers scarcity in the future. It will present an opportunity to develop while providing a foundation for future studies on relevant research in apprenticeship completion in Ireland. This approach will aid development of more efficient apprenticeship programs, by attempting to fill the gaps in present knowledge of the various determinants and factors of success or failure. By using extant research from other geographical regions, a systematic literature review will be used, as a guide for future study into the efficacy of various methods to increase apprenticeship completion in Ireland. Such studies may give invaluable insight to policy makers working to build effective and stable apprenticeship training programs.

Subsequently, two research questions emerge and are as follows.

- RQ1 - Where is apprenticeship completion research taking place?
- RQ2 - What factors influence the completion of apprenticeship programmes?

METHOD

The aim of this research was to uncover the gaps and trends in current information about built environment apprentices in the building industry. The current study employed a systematic literature review, to combine existing information and give a greater comprehension of the topic area. Because of the replicability and rigor of its conclusions, a systematic review was the preferable method, as it draws work from other researchers together, using a scientific and systematic approach, allowing the data to be synthesised. The search needed to be specific in the search terms so that only relevant papers were captured, whilst also including vital papers (Beecham *et al.,* 2008).

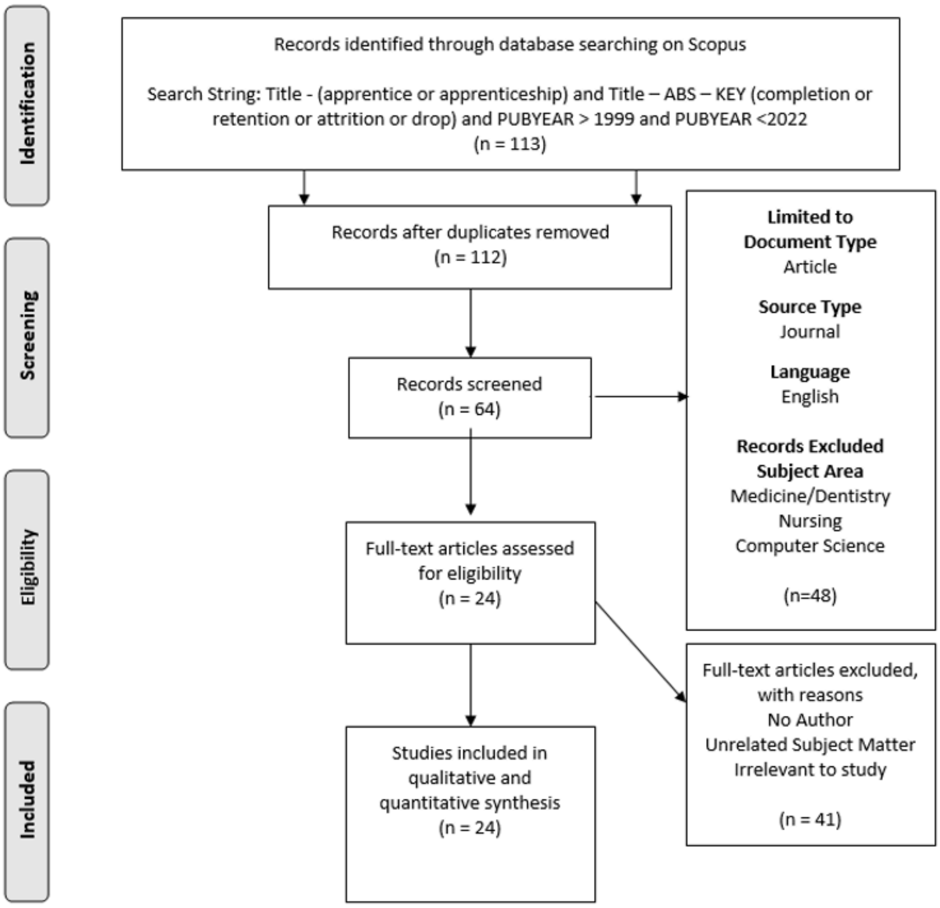
This systematic review was carried out in three stages, each of which were interconnected. A database search was carried out first, where then selection, inclusion, and exclusion criteria were applied. Finally, to provide answers to the research questions, a content analysis of selected publications was undertaken. Figure 1 depicts these steps in a graphical format, outlining the four stages adopted: identification, screening, eligibility, and inclusion in the study.

The sample consists solely of publications published in academic journals in Scopus in the University of Limerick Glucksman Library. This article research yielded one hundred and thirteen articles, which were further limited to those relevant according to the specific inclusion and exclusion criteria. The inclusion criteria included all papers pertaining to apprenticeship completion with the exclusion of those pertaining to non-construction apprenticeships. Other papers excluded include those with no author or unrelated subject matter. Finally, a total of twenty-four articles were included in the meta-analysis. Three papers were further eliminated, as they had no significance to this study, including the impact of regional climate on apprenticeship (Zoellner *et al.,* 2017), a study regarding homelessness (Cebulla and Goodwin-Smith, 2015) and school-based apprenticeships (Hill and Dalley-Trim, 2008).

LITERATURE REVIEW

In addressing the first research question, that is, where is apprentice completion research taking place, the systematic literature review identified a total of twenty-four papers, located as follows: Ireland (1), Germany (3), UK (5), Australia (6), Canada (2), USA (6), and Ghana (1). Table 1 documents the twenty-four journals, their respective author/year and associated country.

Figure 1: Flow Diagram of the process of selection of articles



The second research question delved further into the topic by asking "what factors influence the completion of apprenticeship programmes?". The literature offered insight into factors that may have an impact on the process of apprenticeship completion. According to the research, these can be broadly classified into three categories; employer considerations, apprentice attributes, and curricula factors, and are discussed as follows.

Employer Considerations

Relationship with employer

The relationship between an apprentice and an employer is an important factor of apprenticeship completion. Many apprentices identify challenging working conditions and inadequate training as major factors in their decision to leave (Smyth and Zimba, 2019; Greig, 2019; Gow *et al.,* 2008). Larger employers are often associated with a higher completion rate (Neuber-Pohl, 2021), because they can offer well-developed apprenticeship programme, along with high wages and better career prospects.

Larger companies frequently hire full-time trainers to give job-specific and more general support to apprentices (Greilinger and Sandner, 2021) while apprentices in smaller companies are given more personalised instruction, usually by the company owner. Their research shows that, the employer may let an apprentice go if they perform poorly on the job or in training centre whereas the apprentice will initiate the termination if it is because of the quality of training by the employer. Studies by

Harris and Simons (2005) in Australia concur and they identify various contributing training factors to this including: a deficit of qualified trainer or training.

Table 1: Publication title, author(s)/year, and country of origin

Publication Title	Author and Year	Country
Apprenticeship non-completion in Germany: a money matter	Neuber-Pohl, (2021)	Germany
How fast do apprenticeships come to a premature end Insights into the factors that determine the speed of the process	Greilinger and Sandner, (2021)	Germany
Strategies for improving construction craftspeople apprenticeship training programme: Evidence from the UK	Daniel *et al.,* (2020)	UK
An Investigation into apprenticeship completion and retention in Northern Ireland: A social exchange programme	Smyth and Zimba (2019)	UK
Factors affecting Modern Apprenticeship completion	Greig (2019)	UK
Unemployment, The Great Recession, and apprenticeship attrition in the US	Bilginsoy (2018)	USA
Regional disparities in apprenticeship attrition rates: heat and quarter four's significance in northern Australia	Zoellner *et al.,* (2017)	Australia
Factors affecting completion of apprenticeship training in England	Gambin and Hogarth (2016)	UK
Staying within or leaving the apprenticeship system? Revisions of educational choices in apprenticeship training	Bessey and Backes-Gellner (2015)	Germany
Apprenticeships in homelessness: A quantitative study	Cebulla and Goodwin-Smith (2015)	Australia
When working hard is not enough for female and racial/ethnic minority apprentices in the highway trades	Kelly *et al.,* (2015)	USA
Apprenticeship programme requirements and apprenticeship completion rates in Canada	Coe (2013)	Canada
The completion behaviours of registered apprentices in Canada: who continues, who quits, and who completes the programs?	Laporte and Mueller (2013)	Canada
Reasons for non-completion among apprentices: The case of automotive trades of the informal sector in Ghana	Donkor (2012)	Ghana
Retention and intentions to quit among Australian male apprentices	Gow *et al.,* (2008)	Australia
Hanging in there: What makes a difference in the first year of an apprenticeship	Hill and Dalley-Trim (2008)	Australia
Surviving apprenticeship training: A duration analysis of apprenticeship contracts in Australia	Mangan and Trendle (2008)	Australia
Delivering Skills: Apprenticeship program sponsorship and transition from training	Bilginsoy (2007)	USA
Meeting the skill needs of a buoyant economy: Apprenticeship - the Irish experience	O'Connor (2006)	Ireland
Exploring the notion of retention in apprenticeship	Harris and Simons (2005)	Australia
Registered apprenticeship training in the US construction industry	Glover and Bilginsoy (2005)	USA
General training by firms, apprentice contracts, and public policy	Malcomson *et al.,* (2003)	UK
The hazards of training: Attrition and Retention in construction industry apprenticeship programs	Bilginsoy (2003)	USA
Do unions help or hinder women in training? Apprenticeship Programs in the United States	Berik and Bilginsoy (2000)	USA

Much research has been carried out in the United States on the effect of union involvement. Apprenticeship training in the United States is sponsored under three different schemes: jointly by a union and the employer (JP), by Non-Joint Multi Employer Programmes (NJMP), or unilaterally by Non-Joint Single Employer Programme (NJSP) (Glover and Bilginsoy, 2005). The sponsor determines the basic parameters of training including apprenticeship duration, mentor to apprentice ratio, wages, work practices and instruction. Bilginsoy (2007) found that the highest apprenticeship completion rate was found in JPs (56.8%) and the lowest were in NJMPs (47.3%). In his 2018 study, findings state that between 2001 to 2014, apprentices were able to maintain their apprenticeships for longer whilst with JP programmes, even when jobs became scarce. Similar results were reported by Glover and Bilginsoy (2005), Bilginsoy (2003), and Berik and Bilginsoy (2000).

Human Capital Theory

Human capital includes employees' skills, training, education, and knowledge viewed in terms of their value or cost to a company (Becker, 1962). Companies invest in human capital to enable higher levels of production and quality. Apprenticeship is an investment in skills and the cost of training can be viewed as an investment in future earning capacity. Non-completion of apprenticeships leads to a loss of human capital which in turn harms companies, which train to secure their skills supply. Apprenticeships must have a pecuniary benefit to both apprentice and the training establishment as well as the other partners in the apprenticeship. The apprenticeship will end when the benefits fall short of its costs (Neuber-Pohl, 2021).

Wages

In Northern Ireland, Smith and Zimba (2019) found that where apprentices were paid higher than the recommended rate, this positively impacted on their intentions to stay with their apprenticeship. Similarly, in Germany, apprentices paid 5% more than the mean apprenticeship wages, had a slightly higher completion rate (Neuber-Pohl, 2021). In addition, those apprenticeships which led to a skilled profession and who were paid 5% more, had a 3.1% higher completion rate, signifying the influence of future payoffs. Malcomson, *et al. (*2003) also say that companies who commit to paying increased wages on successful completion, will be better positioned to retain more capable staff. In Australia, Mangan and Trendle (2008) found that wages only had an impact on completion, in the early stages of an apprenticeship, and had no effect in the latter stages. Bessey and Backes-Gellner (2015) found that financial distress led to choices towards an unskilled employment route rather than apprenticeship, due to the higher initial income on offer. Donker (2012) found 55% of non-completers from the motor trade in Ghana, citing financial distress, compared to 40% who cited workplace issues. 60% of interviewees suggested that increased financial support would have improved their chances of completing.

Guidance Counselling

Daniel *et al. (*2020) discusses how poor career guidance and an underestimation of what the apprenticeship entails, can result in apprenticeship non-completion. Donker (2012) found that the early termination of 25% of automotive trade non-completers interviewed in Ghana, was because of wrong career choice, or loss of interest in the trade. Inadequate career guidance may represent misunderstanding or difficulties in locating apprenticeship information, resulting in career predicaments (Powers and Watt, 2021). Gambin *et al. (*2016) argues that if better recruitment procedures are carried out, then a better match can be created between company and apprentice. Additionally, they argue that apprentices only discover elements of the craft that they dislike while ‘on the job’, leading them to reconsider wages acceptability and apprenticeship completion.

Apprentice Attributes

Gender and Age

In the context of gender, there is evidence to suggest that women are more likely to complete apprenticeships (Kelly *et al.,* 2015; Laporte and Mueller, 2013; Berik and Bilginsoy, 2000). Berik and Bilginsoy (2000) however found that men on average, had higher retention than women, except in joint sponsorship programmes in the United States. On the other hand, Gambin and Hogarth (2015) found that when gender was interacted with company sector in male dominated apprenticeships, women were 5% less likely to compete.

Prasil (Prasil *et al.,* 2005) followed the training of apprentices registered in 1992 for a 10-year period. Age on commencement was a factor with fewer older apprentices finishing and she suggested influences relative to age might be a factor like educational attainment, literacy levels etc

Disability

Gambin and Hogwarth (2016) indicated that those with learning difficulty or a disability, are found to have lower probability of completing their apprenticeship. In contrast, Greig (2019) did not report a difference in the probability of apprentices with disabilities completing. Some apprentices may need more support than others including those with learning difficulties.

Mental health

Powers and Watt (2021) looked at apprentice experience at 6 monthly intervals and examined factors influencing non-completion including anxiety and workplace interest. They found that even if the apprentices do not drop out, that their experience may be poor and that they may seriously consider quitting, therefore their study looked at drop out consideration. Their study supported the hypotheses that drop out considerations were predicted by apprentices’ level of interest and anxiety on commencement of training (Powers and Watt, 2021).

The COVID 19 health crisis has had significant impacts to apprentices, most notably training disruptions, lockdowns, pandemic payments and redundancies as well as future career opportunities. Irish research would be welcome in this area to examine the impact of the pandemic, restrictions and ultimate reopening of the country on apprentice's mental health.

Apprentices characterises and entry levels

Entry levels are attributable to apprenticeship success. Laporte and Mueller (2013) found that the level of completion increased, if the participant had competed their high school diploma. Neuber-Pohl (2021) also discusses that non-completion is more prevalent from those who enter the apprenticeship from the lowest track of secondary school. Some students, on successfully leaving college, purposefully follow an apprenticeship, as a combination of further and academic education, which can be associated with higher earnings (Neuber-Pohl, 2021). Gambin and Hogarth (2015) summarised those entering Level 2 apprenticeships, having a Level 2 or Level 3 education previously, was associated with higher completion rates, and similarly at Level 3 apprenticeship.

Curriculum and Programme

The quality of teaching and relationship with instructors has been found to be a factor affecting apprenticeship completion (Greig, 2019; Gambin and Hogarth, 2016). The structure of the apprenticeship programme in Canada was not related to apprenticeship completion (Coe, 2013). Coe (2013) found that longer apprenticeships did not result in lower completion rates or that block release training delivery were barriers to completion. In Germany, on passing a final exam, the qualified apprentice receives a nationally recognised Diploma. (Neuber-Pohl, 2021). Neuber-Pohl (2021) goes on to explain that where some trades, like electrical, are licensed, requiring apprentices to get a trade certificate before practicing, whereas others, like carpentry, are unlicensed, making it less competitive to begin and attracting lower salaries upon completion; thus, resulting in diffing completion rates between trades. Coe (2013) also found that where certification was mandatory, completion rates were 10% higher. Communication and collaboration between the company and the vocational training centre are vital to connect long term learning processes and teaching units (Neuber-Pohl, 2021). In a vocational school, the activities that apprentices must do are simpler at first, and progressively grow more difficult, so a lack of competence may not become apparent until later (Greilinger and Sandner, 2021).. In Ireland, the theory learned in the training centre, including the science and mathematics modules, are crucial to the education portion, but it is the application of these competencies in real life situations 'on the job'. (O'Connor, 2006).

CONCLUSION

As the built environment continues to struggle to fulfil the void in skilled trades people, there is a need to mitigate against the non-completion levels within Irish apprentices. The Climate Action Plan 2021 and the Action Plan for Apprenticeships 2021-2025 outline, the construction industry in Ireland needs to change and there will be a need for not only more apprentices but apprentices in environmental practices. When properly trained, these qualified apprentices will become the key construction and built environment workers of the future. Therefore, this paper asks the question; what factors influence built environment apprentice's completion rates?

To address this, factors influencing apprenticeship completion rates were investigated via a systematic literature review. The factors influencing completion were found to include fundamental apprentice attributes, features of the apprenticeship programme and employer considerations. Improvements in policies are vital strategies for improving completion rates, to attract, train and retain apprentices to meet the industries future needs and stabilise the apprenticeship system.

This paper contributes to the current body of knowledge, by providing an understanding of the challenges faced by apprenticeship in built environment training, identifying the need for further research and subsequent change in practice and procedures, with possible policy changes required in the future. Further research into the issues of prevention and early warning, as well as the wider issue of prematurely ended apprenticeships in the Irish apprenticeship system, will proceed this study. Future investigations would be justified by the gaps highlighted in present understanding about apprenticeship training.

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SUSTAINABILITY IN THE BUILT ENVIRONMENT

MOBILISING THEORY AND PRACTICE FOR THE ENHANCEMENT OF BUILDING INFORMATION MODELLING BASED BUILDING SUSTAINABILITY ASSESSMENT: AN EXPLORATORY STUDY AND A CONCEPTUAL FRAMEWORK

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The adoption of Building Sustainability Assessment (BSA) systems is becoming a growing trend, but it has been criticised for being inconsistent and resource-consuming. Recent development of Building Information Modelling (BIM) could help facilitate the BSA process. There has been useful research conducted in this area but there has been limited focus on the practitioner's perspective. This paper fills that gap by exploring the practitioners outlook on the subject. The main aim is to develop a conceptual framework that compiles the wisdom of both theory and practice. Two-step method was adopted; a survey targeting different practitioners, followed by semi-structured interviews with selected experts. Lack of knowledge and data exchange limitations were ranked highest among the survey respondents, while the level of information (LOI) and BIM libraries attracted more attention by the experts. Additionally, new challenges were introduced and new research areas to promote the development of BIM-based BSA were uncovered.

Keywords: BIM; building sustainability assessment; practitioner

INTRODUCTION

Climate change has become the most pressing challenge we face today. This was clearly signified in the unprecedented extreme weather events that took place during the last decade. The building sector is a major contributor to that climate change and according to the International Energy Agency Global Status Report in 2018, buildings generated nearly 40% of global carbon emissions, and consumed almost 50% of all extracted materials. Recognising the urgency of these challenges, the demand for green buildings is steadily increasing, and the role of Building Sustainability Assessment (BSA) systems is becoming more significant to building professionals.

A BSA scheme is a systematic portfolio of guidelines, with defined categories and benchmarks, that aims to evaluate the sustainability performance of buildings.

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Examples include BREEAM in UK, LEED in US, and Green-Star in Australia. However, BSA is still criticized of being inaccurate, inconsistent, and resource-consuming process (Carvalho *et al.,* 2021). On the other hand, Building Information Modelling (BIM), a data-rich digital representation of geometrical and functional characteristics of a building, is proposed as an optimum solution to overcome BSA challenges (Ayman *et al.,* 2018). Recent development of BIM might be capable of supporting BSA process through facilitating the collection and documentation of real-time information needed for the assessments (Gandhi and Jupp, 2014).

Due to various reasons, the synergy of BIM and BSA is still immature, unwelcomed by project teams, and far away from being widely adopted (Lu *et al.,* 2017). Alsehrawy *et al.,* (2020) attempted to explore the reasons behind this lag through examining peer-reviewed literature, published within the last decade, and has successfully outlined 10 major challenges facing BIM-based BSA (Table 1). However, most of the reviewed papers were theoretically oriented, tended to overlook real project environment, and since this topic is a rapidly evolving area that is highly impacted by technology development and market conditions, it was insufficient to rely on literature findings, and there was a strong need to incorporate the input from industry practitioners.

Based on the above conviction, this paper explores the practice community outlook on the subject, aiming to develop a framework that bridges the gap between existing theory and practice. The framework defines the main areas of concern to achieve an effective enhancement of BIM-based BSA. This aim is achieved through a two-rounds of data collection; a practitioner's survey and experts' interviews, and the results were analysed using a hybrid approach of inductive and deductive thematic coding.

The objective of the survey is to explore the attitude of an adequate sample of respondents, who represent different areas of the industry, about the previous literature findings, through asking them to assess the BIM-based BSA ten-challenges (Table 1). While the interviews seek to collect more in-depth insights on selected professionals' thoughts and ideas (Kendall, 2008), utilising their wide experience and knowledge, to evaluate the research findings and uncover new areas of interest.

The two methods were carefully selected to help satisfying the paper's aim by adding two layers of practitioner input, where upon completing both steps, an updated list of BIM-based BSA challenges shall be concluded, with new challenges added, and existing ones rearranged based on the practitioner's feedback. Also, and according to Harris and Brown (2010), the simultaneous use of both methods helps generate confirmatory results (Harris and Brown, 2010).

Questionnaire Survey

A questionnaire to investigate the subject was developed using Microsoft Forms web-application due to its reliability, simplicity and ease to export tabulated results. It was then shared online with more than 200 industry members, based in the Middle East, and belong to different building disciplines. Since a wide respondent's coverage was targeted, the selection of respondents was not limited to a specific criterion (Age, Gender, etc.). Online communication in sending and receiving responses was adopted for its time and cost-effectiveness, allowing wider access to higher diversity of respondents, and eliminating influence that might take place during face-to-face contact. The response percentage was 25% (50 out of 200).

Table 1: Ten Major Challenges facing BIM-based BSA (Alsehrawy et al., 2020)

#	Challenge	Challenge Description	Category
01	Technology	Deficiency of the available BIM tools and software in supporting sustainability assessment process.	BIM-related
02	Data Exchange	Lack of interoperability between different BIM software and inability to manage exchange information in consistent way.	BIM-related
03	Level of Information	Lack of LOI standard and ignorance of LOI concept when conducting BSA processes using BIM.	BIM-related
04	BIM Library	Current BIM databases lack the sufficient building components with sustainability-data needed for BSA.	BIM-related
05	Standards	The absence of well-defined workflow, standards or professional codes to manage the BIM-based BSA process.	BIM-related
06	BSA Complexity	The complicated nature of BSA schemes that requires that only qualified professionals can deal with.	BSA-related
07	BSA Diversity	The availability of many BSA manuals worldwide makes it difficult to integrate BIM consistently.	BSA-related
08	Knowledge	Lack of Knowledge and Awareness about the benefits and applications of BIM and BSA.	Organisation-related
09	Resources	Financial limitations and economic constraints.	Organisation-related
10	Culture	The resistance to change and the unwilling to embrace the BIM and BSA being relatively new concepts.	Organisation-related

The questionnaire was divided into two sections. The first comprises ten-questions, each question aims to evaluate a challenge based on a 5-points Likert Scale (1- A Major Challenge, 2- An Average Challenge, 3- A Minor Challenge, 4- Not a Challenge and 5- Not Sure).

Table 2: Distribution of Respondents

BIM Proficiency	Respondents	Perc.
Expert and internationally certified BIM professional	8	16%
Get involved into BIM processes occasionally	26	52%
Never got involved in a BIM process, but got some knowledge about BIM	14	28%
Never got involved into a BIM process and do not know what BIM is	2	4%
BSA Proficiency	Respondents	Perc.
Expert and Internationally certified BSA professional	3	6%
Get involved into BSA processes occasionally	17	34%
Never got involved in a BSA process, but got some knowledge about BSA	27	54%
Never got involved into a BSA process and do not know what BSA is	3	6%
Industry Field	Respondents	Perc.
Building (Design Area)	27	54%
Building (Construction Area)	17	34%
Building (Other Areas)	6	12%
Non-Building	0	0%
Experience	Respondents	Perc.
Under 10 years	13	26%
10-20 years	30	60%
20-30 years	6	12%
Above 30 years	1	2%

The definition of each choice was indicated at the section preamble, to limit disparities in respondent's interpretation to the meaning of each choice. The second section seeks to collect personal information about the respondent and his/her knowledge. This section comes later to allow respondents to evaluate the challenges at the first section, before they might lose interest and engagement. Table 2 shows the respondents distribution in terms of BIM proficiency, BSA proficiency, Industry field and Experience. Most of the respondents have an experience of 10-20 years, belong to the design area, and have an acceptable level of awareness and knowledge about BIM and BSA.

The objective of the questionnaire is to rank the ten-challenges according to their significance, by giving a score to each challenge. Theses scores are calculated using the responses received through the following steps:

1. Convert the textual choices to numbers that can be used for further statistical quantitative analysis, in a similar approach to what has been proposed by Srnka and Koeszegi (2007). As shown in Table 3, the highest value (1.5) was assigned to 'a major challenge' choice, and the value decreases as we go down, while 'not sure' was given zero, and 'not a challenge' was given a negative value. On the other hand, corresponding numbers were also assigned to the levels of BIM and BSA knowledge and expertise. The highest value (3) was assigned to 'Expert and Internationally certified' and the value decreases as we go down. The rationale behind assigning these values, is to award more credit to responses provided by experts and those who have wider knowledge in the field, while give lower credit to responses made by those who have less or no knowledge nor experience.
2. The response score for each challenge is calculated through multiplying the corresponding numerical values of each response (Response Assessment Value * Respondent BIM Knowledge Value * Respondent BSA Knowledge Value).

Table 3: Conversion of Questionnaire Textual values to Numerical Values

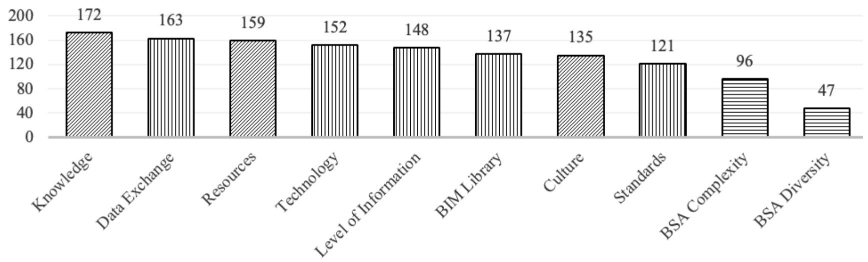
Assessment Textual Value	Corresponding Numerical Value
A Major Challenge	1.5
An Average Challenge	1.0
A Minor Challenge	0.5
Not a Challenge	-1.0
Not Sure	0
BIM Knowledge Textual Value	Corresponding Numerical Value
Expert and internationally certified BIM professional	3
Get involved into BIM processes occasionally	2
Never got involved in a BIM process, but got some knowledge about BIM	1
Never got involved into a BIM process and do not know what BIM is	0.25
BSA Knowledge Textual Value	Corresponding Numerical Value
Expert and Internationally certified BSA professional	3
Get involved into BSA processes occasionally	2
Never got involved in a BSA process, but got some knowledge about BSA	1
Never got involved into a BSA process and do not know what BSA is	0.25

Figure 1 presents the final total scores of all challenges after counting all the received responses. As indicated, 'Lack of Knowledge' ranks first with a total score of 172.375, while 'BSA Diversity' ranks last with a total score of 47.2. Table 4 shows the calculation of Challenge-9 'lack of knowledge' as a demonstration example. Figure 2 indicates the total score of the three groups of challenges; BIM-related (denoted in vertical stripes), BSA-related (denoted in horizontal stripe) and Organisation-related (denoted in diagonal stripes). Findings reveal that BIM-related challenges are considered by participants more influential than BSA-related. This opposes the theoretical belief that BSA-related challenges, such as the diversity and multiplicity of BSA methods are major hurdle to BIM-based BSA (Carvalho *et al.,* 2020), such a variance confirms the gap between theory and practice. Another unexpected outcome is the relatively high score gained by the Level of Information (LOI). LOI was one of the topics that has not received appropriate attention within literature. Only few studies have attempted to investigate its impact on the BIM-based BSA (Ramaji *et al.,* 2017). However, survey results conveyed interest of practitioners in the topic.

Table 4: Demonstration example of Score calculation: Challenge (9)

Respondent	#1	#2	3-48	#49	#50	Challenge (9) Total Score
BIM Proficiency	3	2	--	3	2	-
BSA Proficiency	3	1	--	3	1	-
Challenge (9): Knowledge	1	0.5	--	1	1	-
Calculated Score of Challenge (9)	9	1	--	9	2	172.375

Figure 1: Challenges facing the integration of BIM and BSA / Score



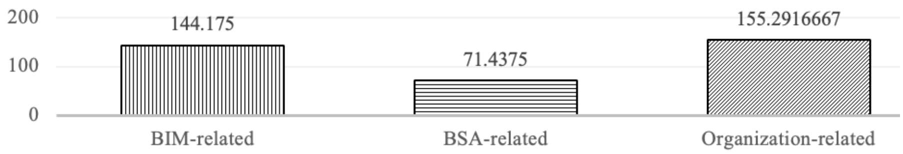


Figure 2: Categories of Challenges / Average Score

In part-two of the questionnaire, respondents were asked about the benefits of BIM, with 4 choices. Since the question was investigating a BIM-subject, BIM knowledge corresponding values (Table 3) were again used to calculate the total answers. As shown in Figure 3, 'coordination purposes' were seen as the top benefit with a total score of 66, followed by 'productivity, 'visualisation' and 'sustainability' respectively. These findings indicate how BIM is still not recognised by practitioners as a tool to optimise sustainability applications, including sustainability assessment (BSA).

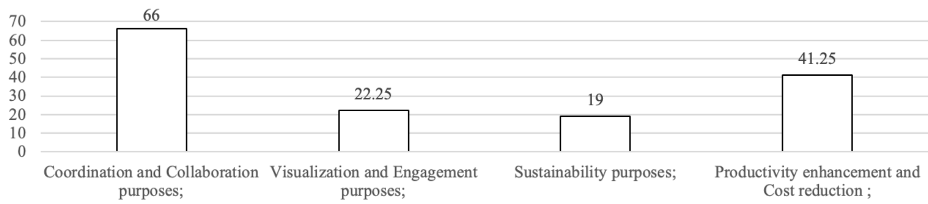


Figure 3: Top benefits of BIM / Score

Interviews

Following the Survey, six interviews were conducted with six experts who have broad experience and knowledge in the areas of BIM and BSA. The main objective is to validate the survey findings, explore the subject deeper, elicit qualitative experience-based insights into the topic and draw out genuine conclusions. Compared to questionnaires, interviews provide the opportunity to ask longer and more complex questions, while allow participants the time and flexibility to engage in sharing more details about their views in their own terms (Harrell and Bradley, 2009). Interviews were administered online to save time, expand the access to wider circles of experts and make it easier to record and transcribe the dialogues.

They were also conducted with individual experts, one at a time, to avoid the cross influence they may have on each other in case interviewed in groups. Interviewees were carefully selected out of tens of potential candidates if they had at least 10 years of experience and deemed to have the adequate expertise in the fields of BIM or BSA or both.

Additionally, variation was considered, by having interviewees with different backgrounds, working at different areas of the industry as shown in Table 5. Interviews were divided into two parts; the first comprises general pre-structured questions about the topic, allowing a qualitative open discussion, that is centralised around these questions. The second part is based on the survey questions, where interviewed experts are asked to give their input on the survey questions and received responses. This order and structure encourage more objective interviews, through avoiding any biases that might be caused by introducing the survey questions and findings at the beginning.

Table 5: Interviewees Background

Interviewee	Position	Company	Area of Industry	Years of Experience	Area of Expertise
#1	Projects Director	Financial Institution	Operation	25	BSA
#2	Site Manager	Contractor	Construction	24	BSA
#3	Principle Architect	Consultancy	Planning	18	BSA and BIM
#4	BIM Technologist	Consultancy	Sustainability	21	BSA and BIM
#5	BIM Manager	Consultancy	Design	20	BIM
#6	Architect Lead	Consultancy	Design	11	BIM and BSA

Part-One: Pre-Structured Questions

Initially, interviewees were asked about the most used BSA scheme and BIM software. There was a consensus over US LEED as the most common BSA system. #3 attributed that to the geographical diversity of the US, and that US LEED was developed to satisfy the requirements of both hot and cold regions. However, #1 believed that no single BSA system can be applied at two different locations, due to the unique needs of each. He recalled when his team once faced difficulties applying US LEED in a Middle Eastern project, due to inapplicability of some of its requirements, such as providing bicycle facilities “Bicycles are not commonly used here as the temperature exceeds 40°C most of the year”.

On the other hand, Autodesk Revit was selected by all participants as the most prevailing BIM software. However, as per #5 “when it comes to green design and assessment, there are other BIM software, that are more specialized than Revit”. Interviewees were then asked about how BIM is currently used to facilitate the BSA process by practitioners. There was a general agreement on the absence of any accepted approach that utilises BIM to facilitate BSA. #4 a BIM developer at an international consultancy stated that “this might be a market gap, only individual attempts and few basic plug-ins for BREEAM and LEED exist, but nothing specific is out there, practice will be welcoming any work in that direction”. #3 also confirmed that practitioners are still far away from utilising the full potentials of BIM “we are using less than 10% of what BIM is capable to do”. Lastly, interviewees were asked about the reasons behind the weak integration of BIM and BSA in practice based on their own experience.

Part-Two: Survey Questions

The second and the last part of the interview involved taking each interviewee through the ten challenges and the survey findings, asking for their assessment and feedback.

Surprisingly, interviewees disagreed with the survey findings which ranked technology and data exchange limitation at the top. Although, they confirmed that these may represent current challenges, however, they gave little weight to them. #4 claimed that "today, we have a variety of software that support green design, they might not be enough, but they are improving quickly, while we have GBXML and IFC4 which facilitate green BIM data exchange, and again they are developing fast".

Interestingly, 5 out of the 6 interviewees found level of information (LOI) to be a major challenge. #6 believed that "utilising BIM for sustainability assessment will stay infeasible as long as the BIM models are not accommodating all the information needed for the assessments". He also pointed out a new International Standard which will be released soon and can support addressing this area. "ISO 7817 will establish a methodology for specifying the level of information need in a consistent way, this can be helpful to define the LOI needed for sustainability assessments". In the same context, #3 confirmed that this area "needs to be explored".

BIM libraries limitation was another challenge that attracted interviewees' attention. Although #3 believed that "the number of manufacturers and suppliers who develop their products into BIM models is growing", #4 highlighted that we still don't have standards for BIM library elements, "Most of the BIM families used by design teams are generic and inconsistent, with no sufficient data".

When asked about the standards, interviewees listed a wide range of related standard documents as (PAS1192, ISO19650 and NBS toolkit), however, #5 affirmed that we still have no official standard that regulates the integration of BIM and BSA, "It might not be much needed 5 years ago, but today, in 2022, we definitely need a one".

Like the survey findings, interviewees have not put much focus on BSA-related challenges as BSA complexity and diversity. #1 believed that there is no diversity of BSA systems, on the contrary "We need more BSA schemes, for example, Middle East unique environmental priorities are not well addressed by the top rating systems, as LEED and BREEAM".

Regarding organisation-related challenges as lack of knowledge, lack of resources and resistive culture, interviewees gave mixed feedback. For example, #3 argued that "Practitioners do not know how to use BIM data, and only small percentage of BIM data is currently utilised in practice", but #4 believed that practitioners are gaining knowledge fast, "Today is not the same as 5 years back, and it is a matter of time till practitioners get mature dealing with BIM and its different applications".

Conceptual Framework

Thematic Coding (TC) is a research analytical method for systematically identifying insights into patterns of themes across a set of qualitative data as interview transcripts (Clarke *et al.,* 2015). It was proven to be convenient for investigating people's views and opinions (Kvale and Brinkmann, 2009). There are different approaches to TC, one of them is the distinction between inductive and deductive, where an inductive allows the data to determine the themes, while a deductive approach investigates the data with a group of predetermined themes (Fereday and Muir-Cochrane, 2006). This study adopts a hybrid approach of inductive and deductive. The study was initially based on 10 themes of challenges (Table 1), concluded from existing literature, in addition to exploring new themes. All 6 interviews were recorded and transcribed for an accurate study and easier TC. Transcripts were read carefully, to label all phrases addressing ideas relevant to the aim of the study. Labelled phrases were categorised under the existing 10 themes, while unclassified new themes are presented in (Table 6).

Table 6: New Themes identified across Experts Interviews

Int#	Highlighted Phrase	Codes	New Themes	Category
#1	"Unlike theory, in practice, the integration and coordination between different design teams, which is crucial for both BIM and BSA, is a serious hurdle"	Integration	Lack of integration	Project-related
#2	"In practice, there is a lack of clear purpose for using BIM and BSA, they are mostly used for attracting clients rather than actually supporting sustainability"	Purpose	Lack of purpose.	Project-related
#3	"BSA rating score is perceived by practitioners as the endpoint, however it should be the starting point of the building life cycle, where BIM and BSA shall play their major role"	Operation Phase	Project Phases Application	Project-related
#4	"When using BIM for sustainability purposes, new trends as Digital Twins, Collecting Sensors and Internet of Things (IoT) shall be considered, the adoption of these technologies allows an efficient utilisation of BIM for sustainability"	Operation Phase, Digital Twin, Big Data, IoT	Project Phases Application	Project-related
#5	"Use of BIM and BSA has to be driven by governments via mandates and incentives, which are not available today in the Middle East"	Government Incentives	Lack of Driver	Regulatory Driver

The third column shows the keywords (Codes) identified within each highlighted phrase, while the fourth shows the new theme name proposed by authors, and the fifth shows the proposed category. In addition to BIM, BSA and Organisation challenges, two new categories are introduced: Project-related and Regulatory Drivers.

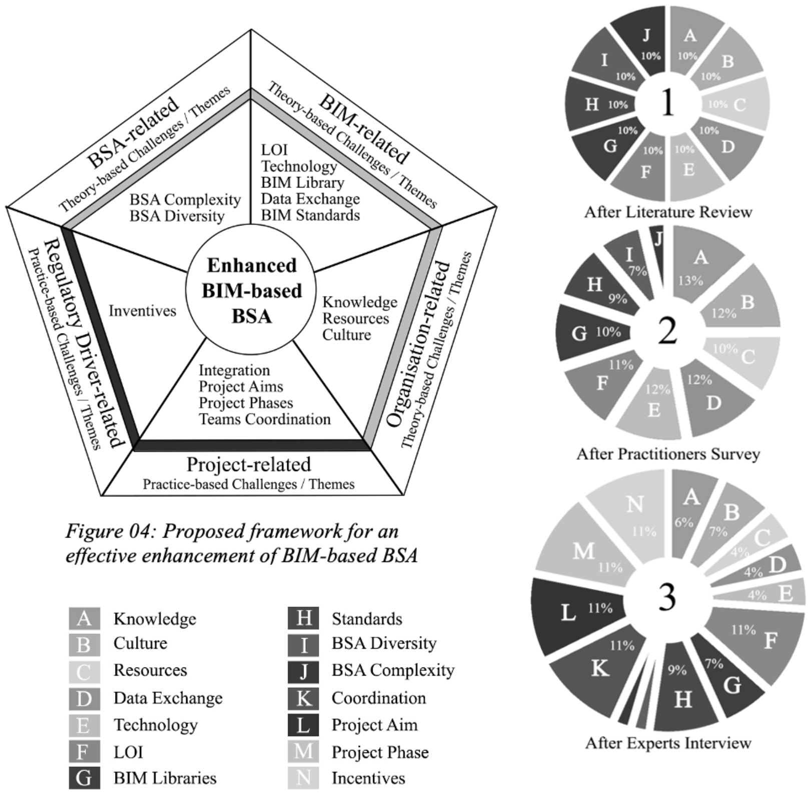
Like the triangle proposed by Lu *et al.,* (2017), Figure 4 presents a conceptual framework in a Pentagon shape, compiling the wisdom of both theory and practice into five major areas. Three are Theory-based, elicited from literature, and validated by experts (denoted in Grey), and two are Practice-based added by the investigations and findings within this paper (denoted in Black). According to the findings of this paper, addressing those five areas signified the satisfaction of both theoretical and practical reported challenges. On the other hand, the precedence of addressing some challenges over others can be also guided by Figure 5, which presents the development flow of the weight and significance of each challenge theme over the different research stages.

CONCLUSION

This paper aims to build upon previous research work investigating the integration of BIM and BSA, by incorporating the practical factor, attempting to provide a collective wisdom of theory and practice. A survey targeting 200 of industry practitioners, in addition to interviews with 6 professional experts in the field were conducted and analysed. A slight deviation between the results of the survey and interviews, can be construed as an impact of the difference in experience and knowledge between the participants in each method. The study was based on 3 main themes of challenges facing BIM-based BSA: 1) BIM-related, 2) BSA-related and 3) Organisational-related. The ten challenges were ranked based on the survey findings. Lack of knowledge and resources, in addition to technology and data exchange limitations, were ranked the highest of all challenges.

However, interviewed experts showed more interest in the Level of information (LOI) and BIM libraries. Coordination and collaboration were seen as the top BIM benefits by practitioners, while sustainability came last. Few qualitative insights were uncovered through the conducted interviews, such as 1) the application of Digital Twins and IoT within the building operation phase as potential areas for enhancing the integration of BIM and BSA; and 2) the use of ISO 7817 as a guide for establishing a level of information need for sustainability assessments.

Figure 5: Priority of Challenges Themes



Finally, a framework is introduced, demonstrating five major areas for future research and development to achieve an effective enhancement of BIM-based BSA. Study limitations include geographical restriction, where all participants are based in the Middle East; Size constraints, where the number of interviewees (6) and survey respondents (50) might be arguably small; and finally, the subjectivity of the thematic coding, which quite relies on the authors judgement. Future work might address these limitations through extending the research to other areas of the world, expanding the number of study participants, and using different research methods.

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LITTLE BIG TRANSITIONS: ELECTRICAL CONSTRUCTION MACHINES ON SMALL SITES

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Apart from grand projects (e.g., bridges) with large material and diesel-related emissions, civil engineering mostly comprises small and medium-sized projects (e.g., roundabouts, parks), where climate impact must also be mitigated. Because equipment manufacturers have been slow in providing electric machines (e.g., +/-2,5 tonnes electric excavators, wheel-loaders, etc.), which supports the transition to emission-free sites, the following enquiry appeared: which are the relevant barriers, enablers, benefits, and perspectives. This paper adopts an interdisciplinary operation management framework for a Swedish urban park project, where an electric wheel-loader was used (study includes interviews, observations, energy measurements and assessment electric vs. diesel equivalent machines). Main findings show operators being modest in their expectations, electric machines performing as diesel-driven ones, and the difference in emissions being relatively significant. The considerable idle time indicated that a meta-level project portfolio planning would have huge potential - e.g., through involving machine rental companies in a sharing economy setup.

Keywords: heavy-duty; engineering; electrical; sustainable transition; Scandinavia

INTRODUCTION

In the areas of greater Oslo around 100 electrical construction machines over 10 ton are by winter 2022 in operation. Documented emission-free building sites in the Oslo area with electrical supply above 50% of the energy consumption both internally on site, and for mass transport to the site, now amounts to 6 and sites with more than 50% electrical power supply have reached 10 (Wiik *et al.,* 2022). This can be compared to one site in Oslo during 2019-2020 (Wiik *et al.,* 2021).

Internationally it was established in 2020 that small electrical machines up to 2,5 tonnes were available all over Europe (BBI 2021). And by 2022 37 machine types above 2,5 tonnes are available, from suppliers such as Hitachi/Nasta, CAT/Pon, Huyndai, Kubota, Komatsu, JCB, XCMG, Volvo, Valla Manitex, Takeuchi, Suncar HK , Snorkel, Sany, Liebherr, Futuricum, CIFA and Ahlmann (Bellona 2022), albeit in very limited numbers.

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On the other hand, in Sweden, some 14200 new diesel driven machines were sold in 2018-2020, which is record high figures. They are probably all at a high environmental standard (EU step 5), but still diesel driven. Others, some 20000 diesel machines from 2011-2018, are at a somewhat lower standard (Maskinleverantörerna 2022).

These figures are meant to demonstrate a slow sustainable transition. Sustainable transition theory (Köhler *et al.,* 2019) points to the incumbent regime which tends to prevent sustainable transition and in the case of civil engineering, the large public clients, the contractors, the machine renters, and the manufacturers of construction machines all have their share.

There are thus signs of sustainable transition, but still a reluctancy, the adoption is slow, and it is therefore relevant to ask

-which are the barriers, enablers, benefits, and perspectives for the adoption of electric construction machines?

This paper addresses this research question by analysing a case study of ground works in an urban park project in Sweden, which involved the use of two electric machines, wheel loader and an excavator, where the focus here is mostly on the wheel loader. We thus adopt a micro perspective on a macro issue, the needed global sustainable transition.

We do this appreciating that civil engineering activities in contemporary western societies are mostly constituted by a large amount of small and medium-sized projects such as playgrounds, roundabouts, and bicycle lanes, carried out for mostly public clients such as municipalities, regions, and the state.

The machines in the test were 4,9 tonnes battery wheel loader, with charging time between 2h and 12h depending on charger and an estimated operation time at 8h. And a small excavator at 2.5t, battery driven. With an estimated operation time at 8 hour and a charging time at 1-6h, depending on charger.

The paper adopts an interdisciplinary operational management approach, that combine operations management with activity study, work environment and technology studies. Methodologically, document analysis, interviews, site observations and power/fuel measurement were conducted, where the energy consumptions of the vehicles were measured. A systematic comparison between the use of diesel-driven and electric machines was done. Note that the material behind comes from an ongoing project and the concepts methods and results are all preliminary.

Framework of Understanding

The framework juxtaposes and (partly) integrate four different strands of concepts and theories that underpin a micro approach to sustainable transition: Operations management, activity study, work environment and technology studies. The framework is thus under elaboration, being at present multidisciplinary, but striving for an interdisciplinary framework (Strathern 2007).

Operation Management in Construction

Operation management offer a distinct micro perspective on how to carry out processes that transform material into products (Slack and Brandon-Jones 2019). When adopting an operation management perspective (Slack and Brandon-Jones 2019) there is a need to conceptualise construction operation specifics. Construction is a project-based production, which is (although its often claimed) not producing one of a kind, but where the element of repetition is considerable. Design and execution is normally separated economically, organisationally and geographically. It involves moving components, workforce, and equipment to the sites to carry out execution operations, whereas the assembled partial products remain fixed. (In contrast to manufacturing where the partial products are transported, whereas workforce and equipment remains fixed).

The attempts to understand, model and control operational processes and management in construction, be it building or civil engineering, have quite often ended up in to marked different poles. One widespread understanding draws on operational analysis and systems theory, relying on the classical transformations model input-transformation- output, picturing operations as pearls on a string (Koskela 2000). Another understanding describes construction processes as chaos. For Bertelsen (2002, 2003), “chaos-in-the-large” means a situation where the progress of the whole project cannot be predicted. Bertelsen and Koskela (2003) argues on the other hand that “chaos-in-the-small” may be managed. However, the “small” may very fast turn into the “large” if it is not observed, understood, and kept under control.

In other words, Berthelsen's preoccupation is to bring construction operations “back into” the controllable world of operation management based on systems theory. To do so the operation managers must balance dynamics and stress, such as budgetary limits and scheduling with the decision power of the operation manager team. Bertelsen and Koskela (2003) predicts/views this as working at the edge of chaos. Duc (2002) along with Carassus (2002) finds double variability to be central for the understanding of building processes. Double variability is the combination of external variability, which is due to heterogeneity of products and markets, and the internal variability which refers to handling live work with its flux in space and time. The external variability creates complexity through unclear and emergent demands from the client and the characteristic fragmentation amongst companies in the industry, between architects, technical consultants, and contractors and more.

The internal variability can be seen as occurring because of quantitative complexity, the products and process consist of a very large number of components and subsystems that need to be produced and assembled. Moreover, designs of details are usually occurring overlapping in time with the execution period. This in total creates multiple and parallel processes. Parallel operations are at the same time to some extent interdependent and can therefore be expected to interrupt and disturb each other. Building processes can be conceptualized as encompassing requisite parallelism and fragmentation due to their predominantly quantitative complexity. Construction processes therefore occur fragmented, interwoven, and with strong, but also less strong, interdependencies.

The operations share physical space, share abstract space (site operation management, negotiation, and coordination) and the conditions are dynamically transformed over time. Interruptions are planned and unplanned. The characteristics are shared with other complex product industries such as aerospace, shipyards, and capital goods, in having a limited repetitive element as the basis for operations management.

Activity Study

To better understand, order and distinguish the activities on site we adopt a combination of work sociology and works standards The work standards "Allmän Material- och Arbetsbeskrivning" (AMA) or "General material and workmanship specifications" encompass one standard for civil engineering, which is recurrently in use in Sweden (AMA-Anläggning Svensk byggtjänst 2019, just called AMA here). AMA suggests classifying civil engineering in main functions and side functions. AMA suggest that main functions in civil engineering should be ordered in 13 main categories and 187 subcategories. For example, main categories encompass preparation work, terracing, group topping, on site concrete moulding, brick walls. Side functions would then for example be: internal transport, idle engine, charging and tanking.

We suggest to precise the activity categories so they can be fitted to urban parks and playgrounds with the following main functions: Remediation, removal, disassembling and demolition, tree felling, removal of stumps and roots, excavation of earth, removal of cliffs, stone drilling, ground topping, mounting of asphalt layer, sand zones, ground topping for plant zones, erecting plant zones, seeding and planting, support and protection of plants, edge support, gutter valleys and surface water gutters and renovation of pipes (Svensk Byggtjänst 2019).

Work Environment

Work Environment is here conceptualised according to the Scandinavian traditions of working life studies that largely build in work sociology (Hvid and Falkum 2019). This implies among other thing adopting concepts of work as bases for understanding the environmental factors that impact on people active at the work. Here work environment is understood as the total set of factors that impact on the working persons wellbeing (Lindberg and Vingård 2012). The factors then include ergonomics, physical work strain, noise, chemical emissions, light etc.

Technology Studies

Science, Technology and Society (STS) studies offer a series of strong concepts to understand the interaction between broadly speaking people and technology. In this context we need to map expectations, experiences, and proposals of improvement of the technology, that is the electric construction equipment. Technology acceptance studies (Davis 1989) offer simple models to understand the related issue of employees having to accept technology implemented by their employer. If this is combined with a soft version of social shaping of technology (Williams and Edge 2004), it can be appreciated that users of technology through their interaction and experience, can contribute to shaping it and bringing it further in a healthier and user-friendly direction and therefore also contribute in cocreating them as improved tools for the enterprise.

Summarizing, by combining elements from operations management, work sociology (activity study, work environment), and technology studies a multidisciplinary operational management framework of understanding is established, that support the research interest of understanding micro sustainable transition. Moreover, the direction for future development is to strive for integration into a more comprehensively interdisciplinary framework.

METHOD

To support our research interest in micro contributions to sustainable transition, we adopt an interpretive critical sociological approach to operations management (Christensen 2002), which combine elements from operation management, work sociology (activity study, work environment), and technology studies, in a multidisciplinary operational management approach (Slack and Brandon-Jones 2019, Strathern 2007).

To understand the activities carried out, we have taken inspiration from a Swedish standard of civil engineering works AMA anlägg (Svensk Byggtjänst 2017).

For this paper we have selected the material and results from one site. As the project is ongoing, we still have limited empirical material, and the choice of this site is therefore done by quite pragmatic criteria and as a matter of convenience. It is our best described case so far.

We have collected empirical material from documents, interviews, site observations, and power consumption measurements.

Eight interviews were conducted, four before the test and four after. The foreman and two machine operators and one craftsman were interviewed before the test. After it was the foreman and two machine operators interviewed alone and the site manager and planning engineer together.

The site observations consisted of one work week for the diesel engine and one work week for the electrical machine. One work week would be 40 hours from Monday to Friday roughly from 7 o'clock in the morning until 4 o'clock in the afternoon (including breaks). During observations the power consumption, the engines activities, the operators' activities, and their work environment was observed and measured, and extensive field notes taken. The power consumption measurements were done with an ad hoc set up. The diesel fuel measured by using the machines indicator for the test week and the electricity was measured at the charging station for the test week.

A limitation worth noting is that our present framework of understanding does not directly address whether and how our micro understanding connects to and possibly even change the understanding of sustainability and how the contribution to sustainable transition is more precisely, than assuming that a substitution of diesel engines with electrical ones is indeed a sustainable transition.

Empirical Material

The site studied was a park and playground project with the city as client. The site has a rectangular shape roughly measuring 400 m times 600 m. A precursor project had taken care of industrial pollution at the site and the works consisted of excavating draining, installing piping and cloaks, reshaping the inclination of the overall site, erecting small hills (for children's sledging) preparing for and planting trees, seeding lawn, ground preparing of foot paths in a foot path system going north to south and east to west. Storage of masses of material, 23 different types of earth and stones, was established at the north-west end of the site.

The observations made it very clear how fragmented the activities were. The wheel loader served as mover of masses in a lot of situations, which is close to coordination function, making it possible to do groundwork at specific places on the site. Therefore, the wheel loader was used whenever there was a need for moving masses from A to B on the site. As table 1 shows below the duration of these operations are mostly rather short and they are interchanging with the machine standing still. This work pattern was largely identical for the electrical and diesel driven wheel loader.

Table 1: Excerpt of site observation electrical wheel loader

Time	Activity	Location	Duration
08.00	OP drives WL to new place	Point 9	1min
08.02	WL is in idle state		12
08.05	WL loads and transports earth from point 9 and unloaded to point 10	Point 9 -10	26 min 18 sec
08.30	WL is parked and shut down	Site hut	9 min
08.39	OP takes WL and drives it to point 10	Point 10	4 min
08.43	Unloading gravel at the point 11	Point 11	14 min
09.00	Break	Site hut	15 min
	WL shot down not charging		
	WL shot down	Site hut	1 hour, 32 min
09.15	Not charging		
10.47	OP drives WL to point 9	Point 9	1 min

Label explanation: WL= wheel loader, OP = Operator. Point 9 = footpath north, Point 10 = grass lawn at foot path east, point 11 = large grass lawn centre. Distance point 9-10 = 10 meters, points 9/10 to 11 = 150 meters

Technology Expectancy and Experience

Expectations

The operators and site managers had consented to participate in the test when asked.

There was a diverse set of experience from previously operating electrical machines but most of them had limited experience and had relatively enthusiastically approved to be part of the test. The expectation of performance was expressed to be “as good as diesel”.

There were expressed worries as to how the charging function would work - would it be a hassle, and would the machine run flat? Some had tried electrical vehicles before, where this was an issue.

Experiences

There was expressed overall satisfaction with the performance of the machine from operators and site management. The workers' crew had been asking for a wheel loader for some time, to support the activities, both for moving masses on site (from the corner depot to a particular place on the site for example) for receiving incoming masses, or for supporting the two other diesel excavator machines on site. This was forwarded as explanation for the good experiences. The machine fitted in the constellation of equipment which the site had and was needed for this reason.

The electrical machine was designed with a dual electrical system, one primary for the drive unit and one secondary for the remaining electrical function (i.e., lights, instruments etc). Charging these two systems at the same time in a few instances during the test meant discharging the secondary system, which made it impossible to start the machine. This was a particular predicament on Monday morning, where the secondary battery would be flat. This led to the decision not to charge the machine over the weekend, but only during the night between workdays. The manufacturer subsequently modified the engine to tackle this issue.

The machine did not have air conditioning in its cabin. It was quite sunny and hot during test operations and the machine operators preferred closed windows because of the dust generated when operating the machines. However, the fact that the machine did have a closed cabin became a large advantage, once heavy autumn rain set in.

The activities carried out in the studied project and in the two test weeks clearly illustrated that works in making public parks and playground are but a very small part of the activities in civil engineering.

The moving of masses was the main task for both the wheel loader and the excavators but smoothing out of earth ground and moving of smaller machines were also occurring as tasks for the wheel loader.

The activities carried out were very fragmented and mostly the machine was active less than half an hour at a time. The machines stood still for long periods of times. The electrical machine ran 17 hours during the 40 test week hours, whereas then diesel ran 11 hours. This is a very low activity level, compared to the sector's rule of thumb that a machine needs to be active more than 70% to be profitable.

The work environment for the operators and workers at the electrical machine was roughly like that of the diesel. The manufacturer has chosen to design the electrical machine with an identical body, cabin, wheels, add on equipment (buckets, forks, shovel etc), which are in sum largely determining the work environment for operators working with the machine, electrical or diesel. The differences in work environment were in the sounds the machine was making, and/or not making. Instead of a speeding engine, the operator would hear wining hydraulics, this could be understood as alarming sounds. For most operators and workers, the silence of the machine was experienced as an improvement. It was felt however that the silent operation of the machine did not improve the communication amongst workers as they already operated mobile radios installed in their hearing protection and continued to use this.

When the expectation of performance was expressed as "as good as diesel" it could be seen as a moderate expectation as the operators and site managers are used to being introduced to new diesel engines with improved performance compared to previous ones. As noted in the introduction the investments in new civil engineering machines in Sweden has been at a historically high level. Adding to this, it has become common that public clients demand new machines as the EU regulation implies reduced levels of CO_2, NO_x, soot, and unburned fuel for new machines (a regulation profile like a downwards going staircase with the years). The machine manufacturers and their reseller network do extensive marketing, demonstration, and training to convince operators and company investors that their next generation/version of machine are superior to the previous. On this background the expectancy and experience that the electrical machines would be and was "as good as diesel" is a modest evaluation.

It was expected with a feeling of insecurity that the charging might lead to difficulties. In general, the machine had electrical power to be taken in use immediately and used to solve a given task. However, the battery did run flat three times after the weekends, and the operators did not systematically manage to use pauses in use of the machine or personnel breaks to do charging (i.e., breakfast and lunch breaks).

FINDINGS

This paper asks: Which are the barriers, enablers, benefits, and perspectives for the adoption of electric construction machines? We answer this from a micro perspective and study how an electrical machine performs compared to a diesel in a contribution to sustainable transition.

The main barriers for providing a strong case for electrical operation are multiple. The fragmented activity patterns could be understood because of Laissez faire planning: Operational management activities were held to a minimum using only coordination meetings with workers, operators, self-employed and subcontractors. This operations management practice could be interpreted as explaining the large amount of idle time and consequently the large unused machine capacity on the site. However, the advantage of planning with over capacity of engines is to assure more optimal use of work force and optimising on the work force costs, rather than machine costs.

The trouble with charging procedures can be seen as a “children's” disease, that has been amended by the manufacturer after the test.

There was a slight tendency that the electrical machine had a reduced capability for certain operations (such as lifting masses), a finding like that of Wiik *et al. (*2021).

There was also a slight tendency among site personnel to question whether electrical engines with their batteries are really performing superiorly in term of sustainability.

In a future perspective, when sites become emission free and fully electrical it has been predicted that the electrical consumption would need meticulous planning and expansion by municipal operators. SINTEF (2021) is considering civil works in connection with house building, investigating whether the new building's future electricity system would suffice supporting the civil works in the early phase, thus providing a possible local source of electricity. They carry out simulations using civil works at a kindergarten building as example. They find that peak electrical consumption derived from several electrical machines running intensively in short periods would generate more electricity consumption than the electricity system for the future building, leading to a need for either more precise planning, taking limited resources into concern, or planning for other sources of electricity than that of the future building.

In the larger perspective, public clients/ cities have an opportunity to accelerate the transition by posing well-grounded demands for machines that are available on the European market. Some cities like Bergen and Oslo have ambitious goals for the climate. Oslo thus wants to reduce CO2 emission by 95% before 2030. And such demands would trigger and increased focus on electrical machines.

The enablers for electrification and realising emission free sites are the following:

The park and playground represent small sites where there are limited distances from one end to the other. This enables use of electrical machines because distances to charging facilities are limited. There is even increased possibility for using cabled vehicles. The electrical machines are designed as a copy of diesel engines - this makes it easy for operators to swiftly adopt competences for manoeuvring but might possibly involve other weaknesses compared to a more fundamental redesign of the electrical engines. The urban context means even shorter distances to other sites, which means possibilities for sharing resources.

CONCLUSIONS

This paper has analysed a case of a little big transition, namely adoption of electrical construction machines on small sites. We wanted to know which are the barriers, enablers, benefits, and perspectives for the adoption of electric construction machines? The main findings were that operators were right in being modest in their expectations, as electric machines performed just as well as contemporary diesel-driven machines. There was expressed overall satisfaction with the performance of the machine from operators and site management. Nevertheless, the considerable idle time involved during operations, indicated that a meta-level project portfolio planning, i.e. improved operation management of the use of the small machines would have huge potential - for example, through involving machine rental companies in a sharing economy setup between several sites. The difference in emissions is relatively significant when comparing diesel and electric vehicles, but absolute figures appear modest, risking users to neglect or downplay the positive effect on the climate and environment.

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CIRCULAR ECONOMY OR CIRCULAR CONSTRUCTION? HOW CIRCULARITY IS UNDERSTOOD BY CONSTRUCTION PRACTITIONERS

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The increasing popularity of the Circular Economy (CE) concept in construction has come with a myriad of publications and solutions that aim to contribute to the transition. However, CE is still debated and the interpretations and framings in practice seem to be equivocal. In this study we developed two models: one to map the societal challenges that are addressed by CE and one to map the solutions. Here, we take the interpretations of practitioners as a basis to define CE in the Dutch construction context by means of 20 semi-structured interviews. Results revealed that there is a wide variety of societal challenges addressed by CE. Circular solutions in the current construction industry turn out to be highly asset and material specific. However, there seems to be a shared understanding of the solution strategies that contribute to becoming circular. Nevertheless, this collection of solution strategies does only partly address the main challenges mentioned. The results imply that a better alignment between problems and solutions is necessary to address CE. Therefore, we urge for context-specific considerations of CE and for distinguishing between CE and circular construction.

Keywords: circular economy; sustainability; transition; system change

INTRODUCTION

Circular Economy (CE) has in construction become one of the main themes to address the many societal challenges the sector is facing (Thomson *et al.,* 2021). In the transition towards a circular economy (CE), the construction industry is an important sector, due to its large share in emissions, resource consumption, and generation of waste (Benachio *et al.,* 2020). The body of literature on CE in construction has grown exponentially in the past half decade (Mhatre *et al.,* 2021), resulting in a myriad of conceptualisations and solutions for a circular construction industry (Hossain *et al.,* 2020). Also in practice, CE has received much attention. Both in theory and practice, it is generally linked to closing resource loops to minimize resource depletion, waste creation and wider environmental impact while sustaining a healthy economy.

To cover the various conceptualisations and interpretations (Goyal *et al.,* 2021), it has been presented as an umbrella concept (Blomsma and Brennan 2017). This means

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Coenen, T, Visscher, K and Volker, L (2022) Circular Economy or Circular Construction? How Circularity is Understood by Construction Practitioners *In:* Tutesigensi, A and Neilson, C J (Eds) *Proceedings of the 38th Annual ARCOM Conference,* 5-7 September 2022, Glasgow, UK, Association of Researchers in Construction Management, 552-561.

that its value lies in connecting the various ideas that come under it. Corvellec *et al.,* (2021) take it even a step further and state that CE as a concept lacks substance of its own. Despite these critiques, CE objectives have been implemented in national and supranational policies. In the European construction domain, CE has been strongly embedded in waste and sustainability policy, albeit fragmentedly (Giorgi *et al.,* 2022). To make these strategies operational, a comprehensive substantiation of the concept is needed, for which a clear and shared meaning amongst actors is important. However, such substantiations turn out to be context-specific in practice, varying between, e.g., geographical areas, actors and sectors (Salmenperä *et al.,* 2021).

Although various definitions and conceptualisations of CE have been discussed in literature - also regarding construction - still little is known about conceptualisations in practice (Klein *et al.,* 2021). How do practitioners perceive and frame circularity in specific contexts? Which problems do they relate to when talking about CE? And which solutions do they see as contributing to CE? In this paper, we will look at the interpretations of CE throughout the Dutch construction industry. Using a design science research (DSR) approach, we develop two models: one to map the problems that CE aims to address and one to map the solutions that aim to solve these.

We apply these models to study the CE conceptualisation in the specific Dutch construction context. The scientific contribution of this study is hence twofold. First, it provides a systemic approach to map the problems and solutions related to CE in construction. Second, by a case application, it shows the problem-solution space of CE as perceived by practitioners in the Dutch construction industry. This enables us to synthesize the many interpretations and to suggest directions for action in construction in order to 'build back wiser' in reaction to the many challenges that face construction. As such, this research supports practice by providing a synthesis of the variety of interpretations and it gives substance to the CE concept in the construction industry.

Principles of Circularity in Construction

Given the framing as an umbrella concept and the fact that such umbrella notions contribute to change, both from a science and from a governance perspective (Rip and Voß 2013), it is little useful to list comprehensive scholarly definitions of CE to understand its meaning for the Dutch construction context. After all, to eventually foster change in a specific societally desirable direction, the understandings of the challenges and solutions within a particular context need to converge (Elzen *et al.,* 2011). Nevertheless, there are several conceptual underpinnings of the concept that are useful to understand the fundaments of CE in construction.

Although most CE in construction literature departs from general CE definitions, Pomponi and Moncaster (2017) acknowledged the specific challenges of the construction context in terms of project-based structure, long asset lifespans and discrepancies with the manufacturing logic that add to the complexity of the sector. According to them, this implies that the major CE challenges draw upon the role of people and institutions rather than technology. In a similar vein, Giorgi *et al.,* (2022) see the lack of alignment of current legislation, policies and decision-making processes with CE principles as a central challenge for the sector to become circular. Here, a major reason is the equivocality of the CE concept. However, this does not prevent most studies in construction from leaving out an explication of CE (e.g., Charef and Lu 2021; Çimen 2021).

To parse the CE concept into its various aspects, the problem space can be separated from the solution space (Wanzenböck *et al.,* 2020). Here, the problem space contains the societal challenges that CE aims to address, whereas the solution space contains the changes and innovations that aim to tackle the problems. Given that the societal problems are wicked by nature (Head and Alford 2015), they cannot be inherently solved, yet can be positioned in a hierarchical order leading to a complex problem space. The solution space, on the contrary, can, next to the various levels of aggregation, be seen on various levels of abstraction. These include innovations, solutions strategies and structural conditions in order to facilitate these strategies. However, amplified by the fragmented nature of the construction industry (Dulaimi *et al.,* 2002), specific solutions depend on the specific asset types and lifecycle stages. Therefore, rather than focussing on specific circular changes or innovations, the solution space in construction should be described in terms of abstract solution strategies. The waste hierarchy (i.e., R-ladder) is one of the most dominant ways of positioning types of solution strategies (Joensuu *et al.,* 2020; Potting *et al.,* 2017).

METHOD

Because listing definitions will not provide the actual understanding of the problems and solutions of circularity in the construction context, we used the Design Science Research (DSR) approach to generate and synthesize perspectives from practice. By applying the models to practice, a synthesis of the problem space and solution space can be deduced from the various perspectives. Below, the DSR methodology is explained, followed by our approach towards data acquisition and analysis.

Design Science Research Method

Not only does design result in output, the design process itself also contributes to generating knowledge (Cross 2001). As such, DSR is considered suitable to develop and synthesize a plurality of ideas iteratively. We applied DSR methodology as presented by Coenen *et al.,* (2020, Figure 1), who used it to develop a conceptual framework in the construction context. It starts by defining the problem and defining the objectives of the model. Next, the solution principles with respect to CE are developed, of which the results are shown in the previous section. Following an iterative process that is guided by theoretical knowledge, practical insights and creativity, the models are designed. This is followed by an application to a practical context, which is in our case the Dutch construction industry. This application to practice was in our case primarily informed by interviews. Finally, the overall design is evaluated by peers, which offers input for design alterations. In this paper, only the final design results are presented. Where the solution principles are primarily led by scientific literature, are the design, development and application informed by Dutch construction practice. These empirical steps are explained below.

Design Steps and Application of the Models

Using the concepts of problem hierarchy and R-ladder explained in the 'Principles of circularity in construction' section, a conceptual way to map the problem-solution space in two models was formulated. To apply the models in order to study interpretations of CE in the Dutch construction practice, we investigated the framings by practitioners using in-depth interviews. We used a purposive sampling strategy to select interviewees such that both the various subsectors and the actor types were covered (Campbell *et al.,* 2020). To reach such variety, we covered the actor categories presented in Kuhlmann and Arnold (2001).

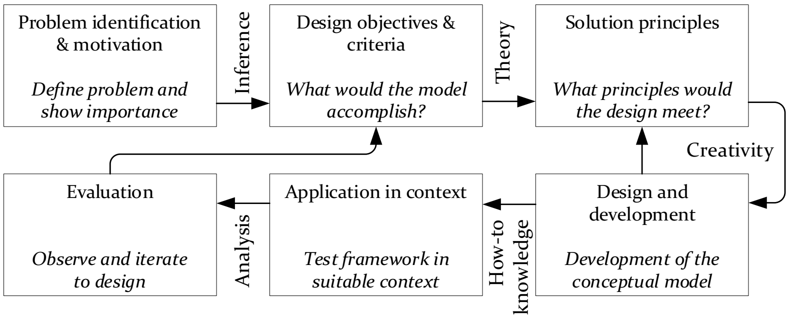

Figure 1: Design Science Research methodology (amended from Coenen et al., 2020)

After interviewing 20 individuals, saturation was reached on the various perspectives on the problems and solutions regarding CE in our context. This list included individuals with varying levels of experience with CE that offered a diverse representation of the sector. However, all individuals had in-practice experience with CE, such as cross-organisational working groups, pilot projects or sectoral networks. The list of interviewees consisted of four senior public construction clients, three public policymakers specialized in CE, four consultancies/engineering firms that were considered frontrunners in the sector, two contractor firms, two CE researchers, two network managers, a legal expert, a standardisation expert and an economic expert. All interviewees were asked for their informed consent before the start of the interviews and the data were treated in accordance with the Dutch General Data Protection Regulation.

In the interviews, we used the problem-solution space concept by Wanzenböck *et al.,* (2020) to distinguish the societal challenges CE aims to address (problems) from the changes and innovations that can be seen as circular (solutions) to substantiate the two models. The interviews led to a wide variety of answers and framings of those problems and solutions. The interview transcripts were coded using the problem-solution distinction and particularly aimed for revealing societal challenges and solution strategies in line with the 9 Rs (Potting *et al.,* 2017). The resulting coded quotations enabled us to link the problems and solutions to the models, to identify the number of interviewees that mentioned specific problems and solutions, and to see the applicability of the models. This enabled us to adjust them accordingly. This final step provided explanations for the problems and solutions found.

Design Application

The final versions of the two designs and their application to the Dutch construction context is presented and discussed in the next two subsections.

Problem space: challenges for CE to tackle in construction
The principles of the model aim to allow for collecting and listing all problems and challenges as well as to connect these in a hierarchical overview with respect to CE in a predefined context. The challenges addressed do not only aim at specific causes, but also address problems on various hierarchical levels in terms of causalities and aggregation. The wicked nature of such challenges makes it impossible to find final causes or solutions (Head and Alford 2015), so all challenges mentioned stem from something else and cause other challenges. Using the principle of causal hierarchy, we created a simplified scheme of the interrelations between the challenges that CE aims to address mentioned by the interviewees to illustrate the hierarchical positioning of and causal relations between the various challenges (Figure 1).

CE in the construction context was generally positioned by the interviewees within the environmental sustainability domain. Nevertheless, the underlying challenges mentioned appeared wider and more diverse. The most abstract categories that CE in the Dutch construction context seems to address are: (1) climate change; (2) depletion of the earth; (3) loss of biodiversity; and (4) welfare under pressure. All four trace back to wider concerns about a declining state of the living environment. Next to the problems that are plenty discussed in literature, such as resource depletion and carbon emissions, the application of the model revealed challenges that are barely addressed, such as loss of biodiversity, nitrogen pollution and increasing asset maintenance costs. Some causal relations were unexpected too, such as the relation between nitrogen emissions and increasing infrastructure costs. Drawing upon the interview transcripts, the most striking challenges and their relations are discussed below.

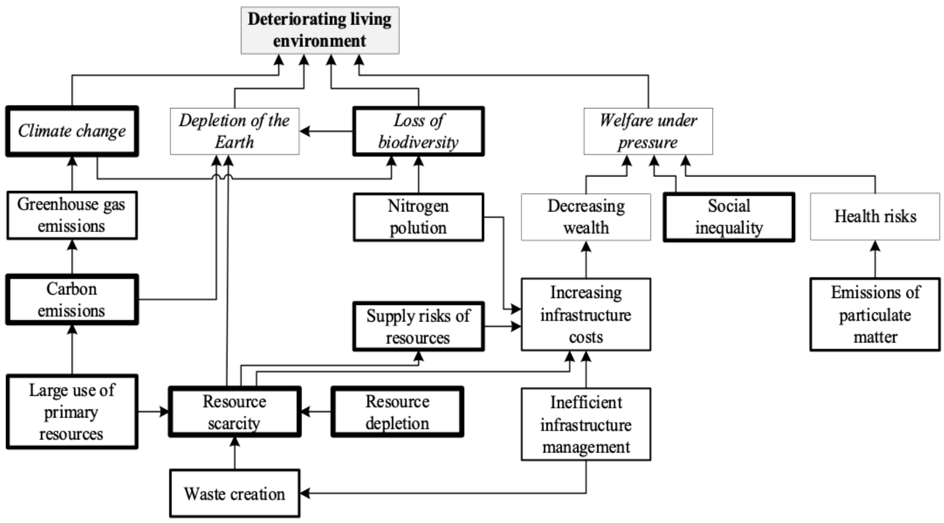

Figure 2: Problem-oriented model: hierarchy of challenges mentioned by interviewees for the Dutch construction context. Line width indicates the frequency mentioned.

A remarkably large number of interviewees mentioned social inequality and impact on labour division as challenges that are both affected by a transition towards circular construction and should be addressed by a future circular system. Furthermore, loss of biodiversity is often mentioned, particularly because of the impact of buildings and infrastructure on the public space. As such, interviewees argued, CE should contribute to preventing loss of biodiversity throughout the construction value chain and asset lifecycles, particularly when compared to the current linear way of working. Moreover, nitrogen pollution is mentioned by many interviewees to be tackled by circularity. This problem stands seemingly far from the scholarly CE definitions but becomes clear when considering the Dutch context. Here, the consequences of nitrogen emissions on construction continuity are, due to court ruling, large and can be reduced by decreasing the production of novel assets and the way of producing these. These nitrogen emissions (most notably ammonia and nitrogen oxides) affect the surrounding flora, which, in turn, affects the surrounding natural ecosystems.

Solution directions towards a circular construction sector

The second model aims at connecting the various solution strategies to become circular in the Dutch construction context. Following the section 'Principles of circularity in construction', these solution strategies are connected by asset lifecycle stage and the R-ladder. This resulted in a two-dimensional framework (Figure 3). After several iterations, we found that neither all strategies could be linked to single R strategies, nor to specific lifecycle stages. This led to the inclusion of the categories of 'full/multi asset lifecycle' and 'non/all/undefined R' in the model.

Interviews revealed ways in which the CE in the Dutch construction context was addressed in terms of change, innovations, processes and strategies. However, a respondent argued that throughout the sector there is consensus about the solution directions and strategies that can contribute to circular construction yet neither on their prioritisations nor their potential of becoming dominant in the transition. Therefore, the solution space is illustrated in terms of abstract solution strategies that contain many specific solutions. For example, the material recycling strategy contains, amongst others, concrete crushing, asphalt recycling and melting down steel. Figure 3 shows the case of circular construction in the Netherlands in terms of those strategies.

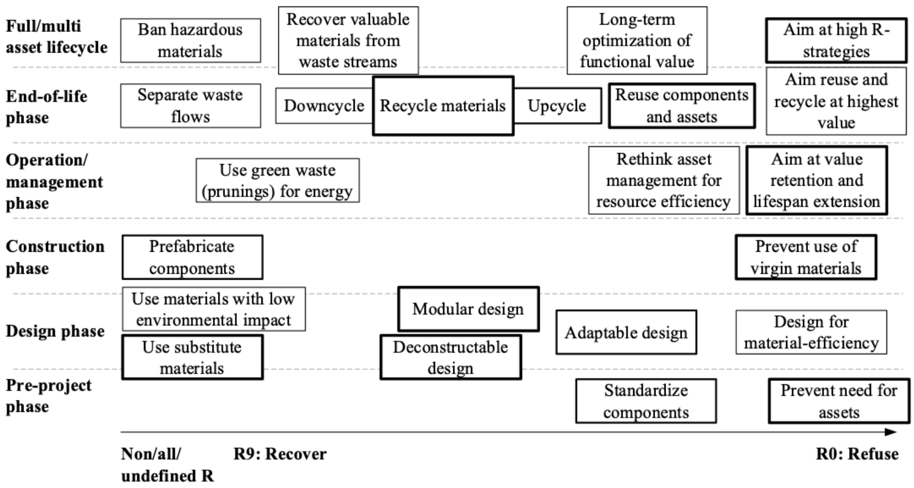

Figure 3: Solution-oriented model: strategies to make construction assets more circular. Line thickness indicates frequency of mentions

The most frequently mentioned strategies are 'recycling materials', 'reusing components', 'modular design', 'deconstructable designs' and 'substitute materials', such as bio-based materials. In terms of strategies, most aim at the highest Rs, being reducing, rethinking and refusing resource use. However, interviewees acknowledged that, although being most impactful, these strategies are the hardest to implement due to their large implications for practice. For example, preventing the need for assets requires ultimately a decrease of functional demand. This can only be achieved by fundamentally revising institutional and organisational processes. On the contrary, recycling strategies, for instance, can often be implemented without major changes in the institutions, supply chains, demolition processes and production processes.

There were several surprising strategies mentioned that are highly specific to the built environment. First, interviewees argued to revise the management of the vegetation, including mowing policy to stimulate biodiversity and using prunings for biomass energy. Second, industrialisation of the production process was mentioned, including the prefabrication of components to reduce waste and increase efficiency, and standardisation to ease maintenance and replacement of construction components. Third, there appeared to be a clear distinction by the interviewees between avoiding primary materials, including reuse, recycling and substitute materials on the one hand, and using any material at all on the other. Despite the seemingly small difference, its implications for strategies to use are enormous. Particularly the latter requires fundamental revisions on asset management and end-of-life practices.

In addition to these strategies, solutions were mentioned by interviewees that generate the conditions for those strategies rather than producing circular outcomes themselves. These are positioned particularly on institutional and organisational levels and include novel business models, shifts in attitude (or culture) towards reused components and revised maintenance practices. Also, policy interventions and changing legislation are mentioned on this level. However, since these merely stimulate or facilitate circular strategies and solutions, we did not include those in Figure 3 as circular solutions.

FINDINGS

Design Evaluation

The problem-oriented model has fulfilled its purpose of synthesizing the diverse set of challenges that are in construction practice thought to be addressed by circularity. Earlier versions of the model did not include an all-encompassing challenge that united all underlying challenges. However, by doing so in this final design, the model enables researchers and policymakers to link the CE concept to other concepts, such as sustainability or the energy transition. As such, it contributes to integrating the multiple societal challenges in a particular context. Moreover, it allows for comparison between understandings of concepts within contexts. Not only does this raise awareness for differences between those contexts, but it also enables researchers and policymakers to direct circular actions in line with a specific context.

The solution-oriented model allowed for generating insights into the various strategies and to link those to the more generic waste hierarchy and construction asset lifecycle stages. Its explanatory value lies in the ability to couple the strategies to various levels of circularity and to show which strategies are relevant when. Regarding the construction domain, this is particularly interesting because of the long lifespan of construction assets and differing lifespans of individual construction components (Joensuu *et al.,* 2020). Moreover, it indicates gaps in strategies. For example, in the case application, the emphasis by interviewees was on the design phase and end-of-life phase, while major circular improvements can be made during the asset life in terms of lifespan extension. As such, the model has the potential to compare and explain the solutions towards a CE between particular contexts and to direct policy.

The validity of the models can be increased in several ways. On the one hand, by extending it to other sectoral and geographic contexts and, on the other hand, by a quantitative approach to validate the results for the current context. Regarding the former, a similar sample can be used from another context, while, regarding the latter, a larger sample could help in increasing the validity of the case results. This can be done in the shape of large-scale surveys, but also using consensus methods such as the Delphi method or Q-methodology. In both ways, the categories of Kuhlmann and Arnold (2001) used in this study can be points of departure for selecting participants.

Understanding Circularity in Construction

By iteratively developing and applying two literature- and case-based conceptual models, the interpretations of the CE in the Dutch construction context were studied and synthesized. As such, this study on practitioners' interpretations of the circularity concept in the specific context has resulted in a comprehensive account of the challenges CE aims to address and the solutions that are aimed at becoming circular. Here, it seems that the challenges that are addressed by CE in Dutch construction practice go beyond both the challenges addressed in the formal policies (IenW and

EZK 2016) and what is in construction literature generally understood by CE (e.g., Çimen 2021; Joensuu *et al.,* 2020).

Considering the four top-level challenges found (climate change, depletion of the Earth, loss of biodiversity and welfare under pressure), particularly the link with biodiversity loss is barely mentioned in construction-related CE literature. Nevertheless, CE's implications for biodiversity should not be underestimated, considering both its potential impact and its limitations (Buchmann-Duck and Beazley 2020). Moreover, several challenges were mentioned that are rather construction specific. Examples are the nitrogen deposition that limits construction activities at specific locations and leads to delays and increasing costs and more general inefficiencies in the construction process and construction value chains.

The solutions indicate strategies that do largely match the solutions mentioned in literature (Benachio *et al.,* 2020; Gerding *et al.,* 2021). Several existing solution directions, such as recycling and reusing construction materials, components and assets are increasingly implemented in practice. However, the higher-R strategies (Reduce, Rethink, Refuse) are strongly advocated, but do not yet occur on a large scale in practice, particularly due to the large implications for construction practices. Solutions for circular construction appear to be, just as regarding the challenges, partly construction specific. Examples are the large focus on the long lifespan, which includes the optimisation of functional value of construction assets and their components as well was the asset management practices.

When considering the problem-solution space in which the various challenges and solution pathways need to converge and align for an effective transition (Wanzenböck *et al.,* 2020), there is a remarkable mismatch between problems and solutions. While the problem space covers this wide range of societal challenges, do solutions primarily address challenges regarding resource scarcity and waste creation. Despite the secondary effects that are beneficial for, e.g., reduction of greenhouse gas emissions, solution strategies that clearly contribute to, e.g., social inequality or nitrogen pollution are generally missing. Alignment is needed to effectively address challenges.

CONCLUSIONS

Our findings contribute to the large stream of CE research in the construction context by adding nuance to the often taken-for-granted definitions of circularity and by offering two models to study these in specific contexts. In addition, results indicate that the interpretations of CE were highly context-specific, aiming partly at construction-specific problems and proposing several construction-specific solution strategies. Therefore, we propose to take the contextual dimensions of CE more seriously when studying and implementing CE, considering both the spatial and sectoral dimensions. As such, it could be beneficial for conceptual integrity and policy directionality to explicitly distinguish circular construction from CE in order to reduce the equivocality. Moreover, the variety of problems and solutions do not have a direct fit, which calls for convergence to support the CE transition that is currently pushed by governments. The models developed in this paper could provide a starting point for mapping the problem-solution space and the context-specific elements.

The study has been conducted in a single context. Further research into the interpretations of CE in other sectoral or geographical contexts is needed to validate the models and to reveal the contextual differences of CE. Moreover, the study was based on 20 interviews. By extending the data sources, a more complete and further validated overview could be compiled on the problems and solutions that are linked to CE in the construction context. This would add nuance to the various problems and solutions covered under the CE umbrella throughout the sector and could reveal opportunities to align and converge the circular solutions. Nonetheless, we think that the current results show an appropriate overview of the most pressing problems and solution directions for the transition towards a circular Dutch construction context.

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EVALUATING THE PERFORMANCE OF A HIGH THERMAL MASS DWELLING: COMPARING PREDICTIONS AND IN-SITU MEASUREMENTS

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Improved building fabric performance is essential for the decarbonisation of buildings. Evaluating fabric performance is often predicted; but inaccuracies are present within commonly used prediction methodologies. Accurate measurement of building fabric is therefore advantageous when identifying the improvement made through retrofit. The QUB/e method is a practical and effective method of measuring the whole building performance in low-to-medium thermal mass properties. In this paper, a property of high thermal mass was studied for the first time with the QUB/e method. The results identify challenges in undertaking QUB/e measurements in the application of high thermal mass including the impact of stored solar heat contributions resulting in a wider dispersion of measurements. In the case presented; a significant prediction gap is identified when comparing the predicted and measured results. The implications of the prediction gap observed include a change in the regulatory EPC band of the property. Additionally, using performance measurements would avoid overestimations of the reported decarbonisation and annual cost saving benefits of future retrofit works to improve the property at 2.3 Tonnes of equivalent CO2 emissions and £570 respectively.

Keywords: building performance; building regulation; energy; measurement

INTRODUCTION

Building Performance Evaluation

Energy use from buildings accounts for 19% of the UK's greenhouse gas emissions (HM Government, 2020). The performance of building fabric will play a crucial role in decarbonising this sector through energy efficient retrofits and high performance in new constructions reducing heating demand. This will in turn contribute to tackling fuel poverty; an issue that is exacerbated by increasing energy costs.

The current regulatory method for evaluating building fabric performance uses predicted values of fabric performance based on the age and construction of the building. These values are used to compute the HTC (Heat Transfer Coefficient) of the building and its annual energy use. The HTC characterises whole house heat loss

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through both transmission and infiltration and details the power required to achieve a given internal / external temperature difference in units of W/K (BSI, 2017). This process is used to determine the EPC (Energy Performance Certificate) banding of the building's energy performance.

It has been identified that assumptions in such calculation methodologies may not always be accurate, manifesting in a "prediction gap" a difference between actual and predicted energy performance (Fitton, 2021; Marshall *et al.,* 2017).

Awareness of the prediction gap has highlighted the benefits of measuring building performance, particularly the HTC (Deb *et al.,* 2021). Building performance measurement used in legislation could potentially be introduced soon, although it is acknowledged that the lack of a thoroughly validated method could inhibit this (Fitton, 2021).

Measuring the performance of existing building stock enables the construction sector to "Build Back Wiser" in respect of conducting more meaningful building performance evaluation compared to that completed through predictions. Accurate performance evaluations are of high importance when completing energy efficient retrofit to determine what improvement (if any) has been achieved (BSI, 2022). The work presented aims to further understanding of the QUB/e measurement technique for wider application.

QUB/e Method

The QUB/e method is an in-situ measurement technique, developed by Saint-Gobain capable of measuring the as built HTC and U-values of an unoccupied property within a single night. As such it has potential to be a cheaper and quicker technique than conventional alternatives (Alzetto, Farmer, *et al.,* 2018). The procedure consists of a constant heat input and a free cooling phase of equal length, taking place at night to limit the impact of solar radiation. The thermal response of the building takes the form of a first order differential equation, and the associated algebra can be used to compute the HTC of the building and its elemental U-Values (Meulemans *et al.,* 2017).

Development of the method has identified the optimal power input for the heat input stage can be determined through the dimensionless parameter α (Alpha). α characterises the power input against starting internal/external temperature difference and HTC_{ref}, a reference HTC. Studies have identified that an α value of between 0.4 - 0.7 results in the most accurate results with tests of shorter lengths (<10 hours) being more influenced by this variable (Alzetto, Meulemans, *et al.,* 2018; Meulemans *et al.,* 2017). To date, little work has been done on exploring the most appropriate method of determining HTC_{ref} for this purpose.

The duration of the QUB/e test makes it attractive to those wanting to measure building fabric performance. The single night duration is advantageous over HTC measurement through the established coheating test (2+ weeks) (Johnston *et al.,* 2013) and standardised U-Value measurement through the heat flow meter (HFM) method (ISO 9869) which requires 3 Days (BSI, 2014).

In addition to theoretical justification (Ahmad *et al.,* 2020; Alzetto, Meulemans, *et al.,* 2018), several studies have been conducted that validate the precision and/or accuracy of the procedure through completing field testing. These include:

- 150+ comparative QUB/e, coheating and HTC measurements on a 1900's property located in a climate chamber for various retrofit configurations (Alzetto, Farmer, *et al.,* 2018; Meulemans *et al.,* 2017).
- 150+ QUB/e tests completed on a detached 1950's uninsulated masonry property for two air permeability configurations (Sougkakis *et al.,* 2021).
- Comparative QUB/e, coheating and HFM measurements on a modern low energy house (Sougkakis *et al.,* 2021, 2017)
- Further international validation studies have been completed (Alzetto, Meulemans, *et al.,* 2018; Sougkakis *et al.,* 2018) and QUB/e has formed part of government funded building performance evaluation projects TIWI (Meulemans *et al.,* 2020) and SMETER (HM Government, 2022).

These studies validate QUB/e across property characteristics of age, insulation levels and air permeability. The impact of thermal mass has not been explicitly explored.

Thermal Mass

The thermal mass of a building is its ability to absorb, store and release heat and can be a beneficial feature in building design (Wallin, 2010). Measurement of high thermal mass (e.g., stone) buildings is valuable as common methods of predicting fabric performance for these constructions are not accurate (Baker, 2011). However, measurement of such buildings can be challenging. When conducting a co-heating test several days may be required for the building to reach heat saturation required for the test to commence (Johnston *et al.,* 2013). It has also been suggested that longer data-aggregation intervals are required to smooth the effects of stored heat within the building fabric, further elongating the required duration (Stamp *et al.,* 2013). Furthermore, when undertaking U-Value measurement of high thermal mass, stone constructions, a minimum test duration of two weeks is suggested to take account of "the thermal inertia of the wall" (Baker, 2011).

Traditional building performance evaluation methods clearly experience challenges with high thermal mass dwellings. Given that QUB/e is relatively new, further understanding of how the QUB/e results are impacted by thermal mass and its relationship with solar radiation is also required.

METHOD

Research Design

This study aims to answer the following research question: "What are the benefits and disadvantages of measuring the performance of a high thermal mass dwelling through the QUB/e method, when compared to predicting performance?". A quantitative case study method will be used. Case studies are beneficial in exploring relationships that are not well defined (Gray, 2018). The QUB/e method has been the subject of many validation studies, though none on a high thermal mass building. This research presents the first QUB/e case study of a high thermal mass building.

Description of the Property

A series of QUB/e tests were completed on a farmhouse located in North Yorkshire, England originally constructed in the 1800's, pictured in Figure 1. The external walls of the house are approximately 500mm thick sandstone.

Assuming a thermal capacitance of 0.78$KJkg^{-1}K^{-1}$ (Waples and Waples, 2004) gives the property a characteristic thermal mass parameter of 1,110$KJm^{-2}K^{-1}$ positioning it comfortably above the indicative value used in SAP (Standard Assessment Procedure) for high thermal mass dwellings of 450KJm^{-2}K^{-1} (BRE, 2014). The testing was completed on the property in its uninsulated state prior to a fabric orientated retrofit.

Figure 1: External View of Farmhouse

Table 1 details the characteristics of the farmhouse building fabric along with predicted U-Values calculated by the BRE U-Value calculator software and /or SAP (Appendix S). Since its original construction there have been multiple additions to the property including a ground floor extension and conservatory. The property is also adjoined to a converted former barn introducing an effective solid party wall to the property, for the purposes of this study the conservatory and the former barn area are excluded from the thermal perimeter of the property. The air permeability was measured at 19.8m^{3}m^{-2}hr^{-1}@50Pa post study. The maximum allowable air permeability for new build homes is 10m^{3}m^{-2}hr^{-1}@50Pa indicating the building is leaky by modern standards.

Table 1: Farmhouse Building Fabric Characteristics

Fabric Element	Construction	U-Value BRE Calculator / SAP (Wm-2K-1)
External Walls	500 mm Sandstone	2.44 / 2.00
Ceiling (Main House)	Pitched Roof insulated at ceiling level.	0.42/ 0.40
	12.5 mm plaster + 100 mm mineral wool insulation	
Ceiling (Ground floor extension)	Pitched roof no insulation. 12.5 mm plaster	2.50 / 2.30
Floor	50 mm screed + 100mm rock straight on ground	0.60 / 0.64
Windows (7 No.)	Single glazed windows with wooden frames	- / 4.80
Windows (4 No.)	1980's double glazed units with wooden frames	- / 2.80
Windows (5 No.)	Modern style double glazed units	- / 2.00
Doors	Single glazed glass with wooden partitions (assumed same performance as single glazed windows)	-/ 4.80

Reference HTC and Predicted Performance

The predicated U-Values listed in Table 1 will allow for comparisons against measured values. These were used to predict the property performance and calculate HTC$_{ref}$ to determine the ideal heat input and starting temperature for the QUB/e tests.

HTC_{ref} was computed using the BRE domestic energy model that mirrors the calculation basis for SAP, used in production of EPC's. Comparing this predicted performance to measurements will identify any prediction gap that would occur if this was the sole method of evaluating pre-retrofit performance.

The U-values used to compute HTC_{ref} were those listed in Table 1 using BRE calculated values for opaque elements and SAP values for glazing. In the absence of thermal bridging details, a global Y value of 0.15 $Wm^{-2}K^{-1}$ was used as an estimate of thermal bridging losses throughout the property. The infiltration rate was based on 0.83 air changes/hour, an estimate considering the property construction and low quality of seals around openings. The measured air permeability was not used as this was unknown when the study was undertaken. This calculates HTC_{ref} = 548 W/K that would be used to set up the QUB/e tests.

Testing and Analysis Procedure

Testing was conducted at the property over a ten-night period in January 2022. The optimal heat input and internal temperature was calculated referring to HTC_{ref} and the forecast external temperature. A power input of 7.5 kW was sized though a combination of 2 kW and 500 W heaters giving an optimal initial temperature difference ~6 K to achieve an α value in the recommended range. A larger power input would have been preferable as it would allow for greater range of temperature difference whilst still resulting in a compliant α value. However, this needed to be balanced against the limits of the electrical supply of the property.

The following monitoring equipment was deployed. The power draw of heaters was monitored through a kWh pulse counter, a second set of thermostatically and timer-controlled heaters were used to maintain the optimal starting temperature. Temperature sensors were placed on a tripod in each room to ensure a central representative temperature. Two external temperature sensors were shielded and placed outside to monitor the external temperature along with a south facing pyranometer to measure solar radiation. Huskeflux heat flux plates (HFP) were affixed to external walls, glazed elements for U-value measurement along with the ground floor and elements facing the conservatory and barn areas that were excluded from the thermal perimeter.

20 QUB/e tests were performed at 10-, 6-, 4- and 2-hour duration. A 10-hour test duration represents a minimum, ideal, test duration. Shorter durations have been demonstrated as being accurate in several properties although more influenced by the α value (Alzetto, Meulemans, *et al.,* 2018) and problematic on U-Value measurement on elements of higher thermal mass (Sougkakis *et al.,* 2022). The inclusion of the shorter durations aims to identify whether they can be effective in QUB/e HTC measurement in this instance of extreme thermal mass. Shorter durations could be advantageous in locations with shorter nights and position QUB/e as an evening measurement activity rather than overnight if required by project time constraints.

Over the testing period measurement of U-values was also undertaken in line with ISO 9869, which could then be compared to the QUB/e measurements. The HTC and U-Values were determined using established QUB/e algebra (Alzetto, Meulemans, *et al.,* 2018; Meulemans *et al.,* 2017). The QUB/e measurement uncertainty was calculated through Taylor's series of uncertainty propagation (Ghiaus and Alzetto, 2019). By evaluating the spread of results and comparing measurements to predictions the suitability of QUB/e on high thermal mass buildings and the impact of solar can be determined.

FINDINGS

QUB/e U-Value Measurements

The accuracy and precision of the QUB/e U-Value measurements are evaluated in Table 2. Statistical measures of RMSE (Root Mean Square Error) and MBE (Mean Bias Error) are presented to describe the dispersion of the QUB/e measurements against the ISO 9869 method. The average QUB/e results are also compared against their corresponding predicted performance used to compute HTC_{ref}.

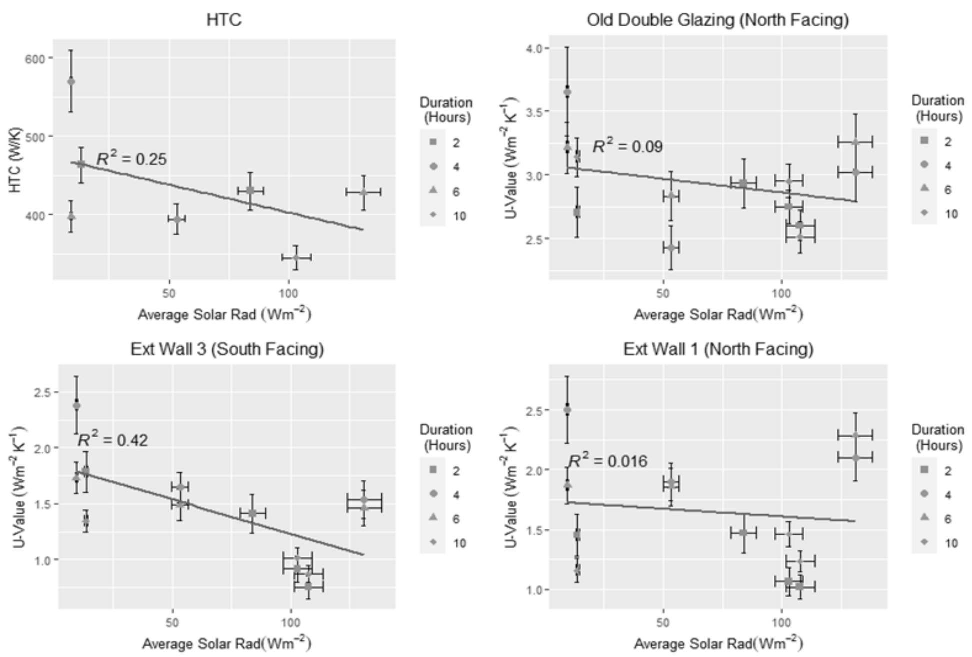
Table 2: Summary of QUB/e and HFM U-Value Measurements

U-Value (Wm-2K-1)

HFP (Orientation)	Average QUB/e Result	ISO 9869 Result	RMSE	MBE	+/-% QUB/e Against Prediction
Ext Wall 1* (North)	1.48±0.37	1.45±0.12	0.47 (32%)	0.21 (14%)	-38.38%
Ext Wall 2* (South)	0.55±0.34	0.51±0.14	0.46 (90%)	0.22 (44%)	-76.90%
Ext Wall 3 (South)	1.22±0.43	1.30±0.33	0.48 (37%)	0.13 (10%)	-49.28%
Ext Wall 4 (East)	1.20±0.23	1.19±0.07	0.27 (23%)	-0.02 (2%)	-49.96%
Ext Wall 5 (North)	1.54±0.38	1.98±0.14	0.49 (25%)	-0.12 (6%)	-35.77%
Modern Double Glazing (South)	1.31±0.15	1.37±0.03	0.18 (13%)	-0.05 (4%)	-34.63%
Old Double Glazing (North)	2.76±0.26	2.45±0.08	0.49 (20%)	0.38 (15%)	-1.49%
Single Glazing 1 (South)	4.63±0.50	4.93±0.07	0.62 (13%)	-0.15 (3%)	-3.54%
Single Glazing 2 (North)	4.56±0.61	4.53±0.18	0.93 (21%)	0.35 (8%)	-5.08%

* HFP did not reach the 5% convergence criteria of ISO 9869

Figure 2: QUB/e U-Value and HTC Measurements against Solar Radiation



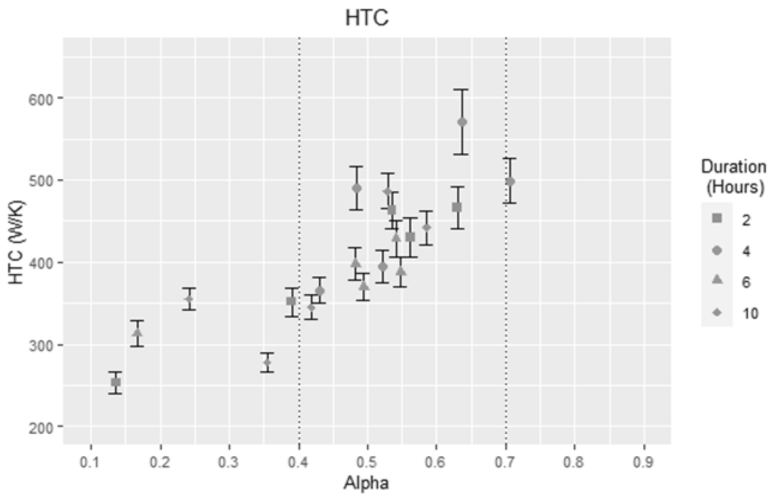
For all measurement points the average QUB/e measurements are comparable to those undertaken via ISO 9869, albeit with larger associated uncertainty. The uncertainty associated with the external wall measurements is more significant than those reported in studies for uninsulated walls of lesser thermal mass (Sougkakis *et al.,* 2022). Higher RMSE values are also observed for the external walls than glazed elements indicating that the overnight duration of QUB/e is better suited to lower thermal mass elements. This variation can be impacted through stored solar contributions that are significant in the external walls. The relationship between the measured U-values and average solar radiation recorded prior to the QUB/e test is illustrated in Figure 2. This shows a clear correlation for South facing measurements and little to no correlation for North Facing measurement evidenced by the low R squared value.

Considering this impact of solar, placing HFP on elevations that are not exposed to direct solar radiation would limit this impact and still allow the performance to be measured. This approach would not be possible for HTC measurements. Furthermore, a larger temperature difference would promote monodirectional heat transfer and lessen the proportional impact of any stored solar, this would in turn require a larger initial power input.

QUB/e HTC Measurements

The HTC measurements shown in Figure 3 are more stable between the recommended α limits of 0.4 and 0.7 although appear tightly clustered around centre of this range, indicating a heightened sensitivity to the parameter. Tests of 10-hour duration still follow this pattern indicating that, in the application of a high thermal mass dwelling, a duration of 10 hours is still impacted by the α value, and a longer duration may be necessary to limit this impact. During the testing, obstacles in achieving a compliant alpha value were identified. These include differences between the observed and forecast external temperature and the recorded power input differing from the installed rated power, possibly due to voltage fluctuations at the property. If only a single night was allocated for testing, these could result in an invalid test.

Figure 3: HTC measurements Against Alpha Value with Recommended α limits (dotted lines)



The mean result for the HTC measurements is 408.73 ± 10.46 W/K respectively with a range of 55% relative to the mean. This range of results is higher than those observed in previous works (Sougkakis *et al.,* 2021, 2022). Contributing to this dispersion of results is the impact of stored solar contributions. This creates an additional heat input to the property not accounted for in the analysis resulting in a lower HTC measurement, as shown in Figure 2. It is also likely that the high air permeability the of the property is contributing to the dispersion of results. The HTC consists of transmission and infiltration losses, the latter of which is significant due to the high air permeability. Infiltration losses are liable to vary with wind conditions and internal / external temperature difference. The effectiveness of QUB/e on buildings with such high air permeability characteristics has not been researched and cannot be isolated in the tests performed; this is an area that should be investigated further.

Comparing Measurements and Predictions

A prediction gap is evident when comparing the values of measured and predicted performance. The mean HTC measurement is -25% its predicted performance. This phenomenon is likely to be particularly pertinent to dwellings such as the farmhouse under evaluation. This is because such dwellings are often not homogenous with varying composition, cavity presence and mortar fraction (Baker, 2011). This is evidenced by varying external wall U-values in Table 2 being on average -50% that of the predicted value. 'Ext Wall 2' had a much lower U-Value than all other measurement points. This area was in an extension area of the house, possibly having a different construction than the main property despite appearing similar. This shows the advantage of performance measurements over predictions in evaluating building fabric that is heterogeneous.

The prediction gap identified impacts on the perceived energy performance of the property. Using the predicted performance equates to an EPC band F property, but substituting the mean measured HTC for HTC_{ref} would lower the banding to E. This is significant as the EPC grading is often the only interpretation of energy performance the public (including potential house buyers) will review. Moreover, had only the predicted performance been used, this would have resulted in an overestimation of the cost saving and decarbonisation benefits achieved through future retrofit. Assuming heating through a gas boiler, a fuel cost of 5p / kWh and current carbon factors, this would result in an additional £ 570 of annual heating cost and 2.3 Tonnes of CO2 equivalent emissions being assumed in the pre-retrofit baseline. The risk of such discrepancies should be considered by policy makers on retrofit, failing to conduct meaningful performance evaluation will discredit building decarbonisation plans. An analysis of EPC data shows there are at least 409,000 properties of sandstone construction in England and Wales. If the prediction gap from this case study were extrapolated to all these dwellings, 900,000 Tonnes of annual CO2 equivalent emissions retrofit savings would be overestimated in Sandstone properties alone, jeopardising national decarbonisation targets.

Whilst the benefits of performance measurement have been discussed it should be noted that completing measurements is more disruptive and potentially costly than predictions. Whilst the duration of the QUB/e test is preferable to other measurement techniques (Alzetto, Farmer, *et al.,* 2018) it would be required that residents or the construction team vacate the property to enable set up, completion and take down of the test. Comparatively, predicted HTCs could potentially be completed as a desk top exercise with minimal or no disruption.

CONCLUSIONS

The work presented shows that conducting QUB/e measurements on a high thermal mass property is possible. However, as with other measurement techniques the nature of the construction and its interaction with solar radiation introduce challenges into conducting measurements. As such a larger dispersion of results is observed compared to lower thermal mass properties.

Whilst measurement of high thermal mass properties is challenging, doing so can enable the construction sector to "Build Back Wiser" as commonly used methods of predicting performance for such dwellings are not accurate. The resulting prediction gap has impacts on the EPC banding of the property as well as the reported decarbonisation and cost saving benefits of retrofit works. To further the validation of QUB/e and answering of the research question, follow up measurements should be conducted on the property in its post-retrofit insulated state.

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EU TAXONOMY FOR SUSTAINABLE ACTIVITIES: A SOURCE OF DECOUPLING OR A PATHWAY FOR GREENING THE CONSTRUCTION INDUSTRY?

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The European Action Plan on financing sustainable growth sets new legislative demands to meet the Paris agreement obligations and fulfil the ambition to make Europe CO_2 neutral by 2050. An important element in this respect is the EU taxonomy. In this paper, we ask the question how a construction organisation implements strategies in relation to the EU taxonomy and analyse the strategic responses throughout the organisation. The study builds on qualitative data from a large Danish construction company. Through an institutional theory perspective, we explore how and with what effects the regulation is received and implemented at different levels of the organisation. The preliminary results show that the taxonomy is a source of decoupling and that different levels of the organisation respond differently to the regulation with focus shifting from ensuring compliance at a strategic level to a more practice-orientated approach on the project level. In conclusion, it is argued that the taxonomy as a policy tool to greening the construction industry is still underdeveloped and immature as displayed by the observed decoupling between policy instrument and project practice.

Keywords: EU; taxonomy; institutional theory; organisational response; sustainability

INTRODUCTION

The climate is in rapid degradation and according to Intergovernmental Panel on Climate Change (IPCC, 2022) global warming is causing irreversible threats to ecosystems, biodiversity, and human systems. This calls for radical measures and UN (2015) and the European Commission (2019, 2021) have accordingly agreed on several policy initiatives to counter the climate changes and create political pressure in the aim of e.g., minimising CO2 emission globally. As the construction industry is responsible for a large part of the global pollution and use of finite resources, much attention is placed on developing solutions to the environmental problems it causes. Despite an increased focus on sustainability, the Danish construction industry has not contributed to a significant CO2 reduction (Danish Climate Council, 2021). This could be a result of the various ways organisations respond to policy and regulatory pressure (Weigelt and Shittu 2016) or highlight a potential conflict in the relationship

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between political influence and organisational behaviour, as recent strategies have only led to corporate greenwashing (European Commission, 2018). To unfold these mechanisms, we focus on the attempts of a construction organisation to implement the EU taxonomy regulation and analyse the strategic responses at different levels of the organisation.

In the quest for ensuring economic growth without compromising environmental concerns, the European Commission (2018) has published an action plan for financing sustainable growth. The action plan aims at creating a more sustainable path for the European economy and suggests a series of actions that collectively should guide governments in Europe and inspire sustainable investments around the world. The actions is furthermore, answering three main development categories: (1) reorienting capital flows towards sustainable investment in order to achieve sustainable and inclusive growth, (2) managing financial risks stemming from climate change, resource depletion, environmental degradation and social issues and (3) fostering transparency and long-termism in financial and economic activity (European Commission, 2018).

The first action within the first category entails the establishment of an EU classification system for sustainable activities also referred to as the taxonomy regulation (European Parliament and the Council, 2020). Companies subject to the Non-Financial Reporting Directive (NFRD) are required to disclose information on taxonomy-eligible and taxonomy-aligned activities, defined as the proportion of a company's revenue, capital expenditures and operational expenditures. This information is intended to provide investors with insights into companies' sustainable activities, increase transparency, limit the risk of greenwashing, and provide a comparison tool for stakeholders.

Extant research has, however, demonstrated that organisations differ much in complying with regulation. A central factor is that regulation often is general in nature and developed without considering, which opportunities different companies must meet the requirements (Hillary, 2017). Moreover, it has also been documented that enforcement action often involves uncertainty, which can lead to resistance or other forms of non-compliance (Desai, 2016) that may inhibit the diffusion of regulation into practice. On this basis, we explore how an organisation integrates the legislation and discuss whether the taxonomy regulation has the intended effect on improving sustainable initiatives or constitutes a source of decoupling or resistance.

Organisational Responses to Regulation

The theoretical approach to the study builds on an institutional understanding of organisational responses to regulation. Institutional theory is well-suited for this purpose due to its focus on how social, political, and cultural (i.e., institutional) factors influence the performance and operation of organisations.

Institutional theory posits that organisations conform to prescriptions of legitimate behaviour that stem from the institutional environment in which they are embedded. Early institutional literature emphasised processes of isomorphism, and the factors leading to organisations becoming increasingly uniform. Meyer and Rowan (1977) e.g., argued that formal organisational structures arise as reflections of rationalised rules in society. DiMaggio and Powell (1983) moreover described the apparent paradox that actors make their organisations increasingly similar as they try to change them in response to externally induced uncertainty and constraints. In particular, state influence, stemming from transactions with public agencies and regulation in the form of legislation or standard setting, was considered to drive this process.

While early institutional theory assumed a somewhat causal relationship between such institutional influences and organisational responses, more recent contributions have proposed that a more heterogeneous relationship is at play. Greenwood *et al.,* (2010) have e.g., demonstrated that organisations respond differently though patterned ways to the complex institutional contexts they face. In this perspective, organisational responses are influenced by a host of specific organisational attributes, such as the organisation's position in the field, structure, identity, etc. (Greenwood *et al.,* 2011).

Such findings have highlighted that the relationship between an organisation and its institutional environment is complex, and that there exists anything but a causal link between changes at the level of the field and the organisation's operation. This is also the case when it comes to legislative and regulatory influences. Extant literature on how organisations respond to regulation has shown that organisations deploy different strategies when complying with regulatory mandates. Policy and regulatory compliance often involve uncertainty (Weigelt and Shittu, 2016), which may lead to resistance, decoupling, co-optation, symbolic action, or other forms of non-compliance (Desai, 2016). Pedersen *et al.,* (2013) moreover illustrate that non-conformance with regulatory requirements is not solely about conscious resistance, but that lack of awareness, misinterpretations and resource limitations may influence this result.

Other strands of research on organisational responses to regulation acknowledge the heterogenous relationship between regulation and organisational impact, yet focus on the possible tensions that may arise, as organisations respond to institutional pressure and attempt to balance between conformity and operational efficiency. Here focus is directed towards issues such as understanding: (1) how a degree of institutional fit between organisational practices and regulatory demands can be maintained (Boon *et al.,* 2009), (2) how regulation is adapted to and impacts organisational practices (Ahrens and Khalifa, 2015) or (3) the strategic behaviours that organisations may enact when responding to pressure to conform with their environment (Oliver, 1991).

As this brief exposition of the literature on organisational responses regulatory pressure illustrates, there are many possible processes and ways to approach the issue at stake in this study. We use these insights in the analysis to explain how a construction company works with the taxonomy regulation and what issues arise.

METHOD

The case concerns a large Danish construction company that is structured as a multi-divisional organisation consisting of a holding company (referred to as 'Holding') and five subsidiaries. In 2021, the company's annual turnover was a €940M making it one of the largest Danish construction companies. We focus on Holding and one of its subsidiaries that accounts for one third of the total turnover. In 2021, the subsidiary employed 700 persons with core activities within renovation and new-build projects for public, private, and social housing association clients. Besides production departments, the subsidiary also comprises departments within finances, human resources, IT, marketing, prequalification, and project development.

Holding defines strategies, financial structures, and overall targets for the entire company, while the subsidiaries are self-governed units that undertake different construction disciplines, such as renovation, new built and infrastructure projects. The company strategy has a strong focus on development, collaboration, and sustainability in accordance with the national climate law and strategy for circular economy (Danish Ministry of Climate, 2020; Ministry of the Interior and Housing, 2021).

Holding is responsible for corporate social responsibility (CSR) reporting in accordance with the NFRD (European Commission, 2014) and is thus responsible for the taxonomy reporting. In their CSR report, Holding has defined five development areas in support of environmental and social sustainability: (1) 'local and social responsibility' that aims at e.g., increasing the number of female employees, (2) 'health and learning' that aims at decreasing injury rate and prioritising internal education, (3) 'climate and environment' to reduce CO2 emissions, (4) 'circular economy' with an aim of reaching 70 percent recycling rate; and (5) 'collaboration and certifications' that aims at increasing the proportion of environmentally certified (i.e. DGNB) projects.

Data Collection

The empirical material consists of qualitative data gathered from documents, observations, and interviews. The document analysis is based on legal documents, including the EU delegated acts of the taxonomy regulation and Holding's strategy, annual financial- and CSR reports. We also draw on 20 hours of observations at strategy meetings related to the taxonomy, and 12 interviews covering organisational responses to the taxonomy in Holding, the subsidiary and at the subsidiary's project level. All interviews were conducted on basis of a semi-structured interview guide supported by open-ended questions making the respondent talk as freely as possible. The interviews were conducted with informants from Holding as well as top managers from the subsidiary's different operational areas as shown in Table 1.

Table 1: Respondents in the study

Respondents from Holding	Respondents from the subsidiary
Head of Sustainability (2 interviews)	Head of Sustainability
Technical Sustainability Manager	Contract Manager
External Consultant on Sustainability and Finance	Chief Financial Officer
External Consultant on Sustainability	Head of IT
	Chief Marketing Officer
	Business Area Director
	Production Support Manager

ANALYSIS

As is illustrated in Figure 1, the analysis is structured into three parts unfolding the organisational responses to the taxonomy regulation at different organisational levels. The aim of the analysis is to understand how the taxonomy regulation as policy instrument affects a construction organisation and if the intention of accelerating sustainability reaches the project level. Furthermore, we aim to illustrate that such organisations not necessarily constitute a unitary entity that responds uniformly to regulation. This is accomplished by analysing the strategic responses and engagement of compliance at different levels in the organisation. First, we describe the strategic response at the level of Holding as they have the overall strategic responsibility for the company and communicate the taxonomy demands to the subsidiaries. Second, we describe the strategic response at the subsidiary level and analyse how different departments conform and decouple the guidelines formulated by Holding. Finally, we describe the responses at the project level within the subsidiary as they are met with new requirements for data collection.

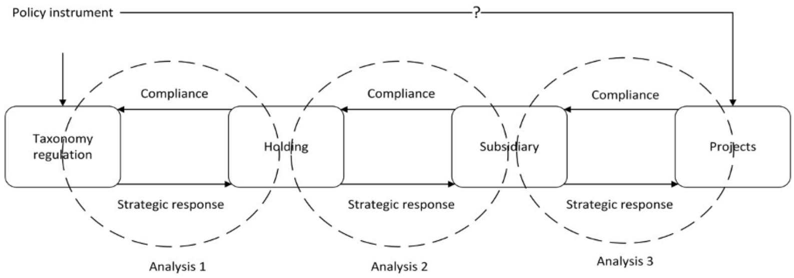

Figure 1: Levels of analysis in the study

Holding's Response to the Taxonomy Regulation

Since 2014, Holding has published CSR reports with a strong focus on environmental and social elements, presenting their proclaimed strong engagement and responsibility towards sustainability. In Holding, the team working with sustainability sees the taxonomy regulation as an opportunity to distinguish the company from its competitors and market the company with a strong sustainable profile.

Even though the taxonomy reporting is mandatory, there has been limited government involvement in disseminating taxonomy guidelines to corporations at a national level. Consequentially, Holding's Sustainability Manager who is responsible for preparing CSR reports, and hence the taxonomy reporting, has relied on internet forums and casual dialogue with industry colleagues to gather necessary information regarding the taxonomy. The information and knowledge level in Holding is thus a result of scattered inputs and the Sustainability Manager's personal desire to understand the taxonomy regulation. As the Sustainability Manager says: "after having read sporadically about the taxonomy regulations, I realised that we need to get started on this, and we need to get started right now, and I need help". The Sustainability Manager has therefore arranged internal taxonomy working groups and established external advisory guidance. This is done to understand the scope and future relevance of the taxonomy and minimise risk by balancing the company's investment level in the aim of not under- or overperform.

However, Holding is continuously working to strengthen their CSR profile and the added value from a potentially positive taxonomy score could benefit the company and is therefore not overlooked. As the Sustainably Manager has had the leading role in collecting taxonomy data from the subsidiaries, there has been a lot of dialogue with the entire organisation. Even though the investment level and strategic response have been debated, there is a common understanding in Holding of the relevance and opportunities in aligning projects with the taxonomy. This has resulted in a continuous knowledge seeking mentality in the sustainably team, however the challenges that the taxonomy regulation prompts are also evident in Holding. Reflecting on the role of the finance department in the taxonomy regulation, the Sustainability Manager e.g., comments: "It's a culture crash […] now sustainability has to be calculated in financial terms […] and they are super sceptical […] and they have complained, they have complained a lot".

The Subsidiary's Response to the Taxonomy Regulation

In the subsidiary the taxonomy responsibility is also centred around the Sustainability Manager, even though the reporting demands rest under a financial legislation. The scope of the taxonomy regulation in respect of purpose and demands has been scattered throughout the organisation and elements of information have been traveling from top management to the construction projects with mixed interpretations.

In the preliminary stages of implementing the taxonomy, there has been a tug of war between financial, marketing, and environmental concerns regarding priorities and how to comply with the regulation. At the top management level, there is an insecurity about the actual impact of the taxonomy regulation, which has resulted in an indefinite strategic response and a general 'wait-and-see' attitude - albeit with important differences in different areas of the subsidiary. The marketing department has a positive attitude towards the taxonomy, as they see it as a source of new business opportunities and has consequently assumed the strategic responsibility for driving the implementation of the taxonomy, as the department has the client contact and a strong relation to the market.

The subsidiary's Sustainability Manager is affiliated with the marketing department and is in direct contact with the Sustainability Manager in Holding. The subsidiary's Sustainability Manager has been one of the first actors to take responsibility and initiate taxonomy-related work tasks relevant to the subsidiary, with a focus on collecting data from the construction projects. In collaboration with the subsidiary's IT department, he has established a new data system. The aim of the system is to make data management easier and create a platform that provides a better internal overview of sustainability data. He strongly acknowledges the importance of data and strives to make the organisation more data driven in general to improve the handling of sustainability demands in the future. Besides an interest in documentation and data collection, the Sustainability Manager also believes that the taxonomy regulation has created an opportunity for a new sustainability awareness in the subsidiary: "It helps us create a cultural change, and a wide awareness of sustainability".

The financial department exhibit a general reluctance to implementing organisational changes. The fear of doing too much work on something that could possibly lose momentum is a risk not to be overseen, as the Chief Financial Officer argues: "it is like GDRP, when it rumbled out […] there was also a lot of things we were supposed to do […] but that throttled down again".

As sustainability-related work activities slowly influence different departments, the added workload creates barriers that potentially could dis-align the organisation's common taxonomy acceptance and further sustainability strategy. The Chief Financial Officer thus continues: "My approach is that we should deliver what we need to deliver, but not set the bar too high and not being first movers […] And then we must be ready if it gives us a competitive advantage […] So, it is a bit of a balance". The combination of uncertainty regarding future market demands and the mix of economics, legal work, data handling, production, CSR strategies and sustainability in a joint legislative framing, creates uncertainty related to both the strategic response and the character and level of compliance. This uncertainty is clearly reflected in the organisation as the different departments have different perceptions of how to respond strategically and implement taxonomy standards in the organisation.

Strategic Responses to the Taxonomy Regulation at the Project Level

At the project level, the Production Support Manager is responsible for aligning the construction projects with the subsidiary's documentation systems - and thus the taxonomy data from the construction projects. The Production Support Manager is in direct contact with the project managers and creates a link between the sustainability demands nested in the IT department's newly created system, and the construction projects. The Production Support Manager has been involved in several meetings to develop taxonomy standards for better and easier data collection, and he plays a key role when implementing new sustainability systems.

As the Production Support Manager acknowledges the need for data collection, he explains that in the future there is a need to hire employees who can support collection of data. As argued: "We need to get someone who has this perspective, […] and make sure we get the right things reported, so it is actually useful in the end". Data is thus an important element, and the Production Support Manager has worked with several DGNB projects that required extensive project data. But data collection is one thing, understanding the purpose is another: "…they [craftsmen and project managers] do not need to know that once a year a huge calculation [taxonomy reporting] takes place […] but we must obtain an understanding of why they should report data in this way".

The Production Support Manager explains that he struggles with understanding the purpose of the taxonomy regulation, and that if sustainability is important, there are several practical alternatives that could contribute more to reducing CO2 than reporting for the taxonomy regulation, e.g., turning off construction lights when they are not needed. He explains that a contractor in general has only little influence on clients' design decisions and that optimising the construction processes is more useful than buying specific products: "It is crazy that we have to count and look through invoices to see how many urinals we have bought […] we need to focus on what we can change and what makes sense".

While there is great will to promote sustainable construction at the project level, the Production Support Manager explains that the project managers should rather focus on practice-orientated elements that will create direct substantiable outcomes instead of wasting time counting toilet types: "an emission-free construction site […] that is something I can influence". The general lack of focus on practice orientated on-site sustainably triggers frustrations for the Production Support Manager. He explains that it makes no difference for a contractor if the client chooses low flow urinals because it is only related to operation and maintenance.

The Production Support Manager also elaborates on the importance of understanding the purpose of regulation. Besides the complicated language and technical difficulties of the taxonomy, the consequences of changing documentation practices create resistance, making actors struggle with justifying the added workload. To comply with the regulatory mandate and limit the resistance, a common understanding of the taxonomy regulation is essential. As the Production Support Manager explains: "We need to get the taxonomy translated into plain language, or you never get them [the employees] interested in it". This indicates a necessity for communicating taxonomy regulation demands and describing the purpose, not only to sustainability managers and marketing departments, but throughout the entire organisation.

FINDINGS

In the analysis, we have described three levels of the case organisation and how they respond and comply with the taxonomy regulation. We summarised the findings from the analysis in Table 2. On this basis we now unfold the institutional processes at play at the different levels of the organisation.

Table 2: Institutional processes in relation to the taxonomy at different levels in the company

	Holding	Subsidiary	Project level
Strategic response to institutional pressure:	Balanced response; Following the market	'Wait-and-see' attitude; Passive conformity	Decoupling from taxonomy intention
Basis of attention:	Competition; Full compliance with taxonomy regulation	Awareness; New opportunities; Counter greenwashing	Expedience; Focus on practice-oriented initiatives
Compliance responsibility:	CFO and Sustainability Manager	Sustainability Manager	Production Support Manager
Level of compliance interest:	Full compliance	Medium compliance	Low compliance
Strategic operational responsibility:	Sustainability team; CFO	Sustainability Manager	Not involved
Strategic behaviours / Practice adaptation:	Expansion of sustainability team	Implementation of new IT system	Collection of new types of data
Degree of institutional fit to regulation:	Tight regulatory-political fit	Partial social-normative fit	Low cultural-cognitive fit

In Holding, the taxonomy is seen as an additional strategic opportunity by the sustainability team to create market legitimacy for the company. This is achieved by describing a devoted taxonomy involvement in the CSR report. Furthermore, Holding closely follows the market, and the insecurity regarding the forthcoming compliance level is clearly reflected in the choice to continuously gather a high level of information. Due to uncertainties regarding the impact of the taxonomy, Holding seeks strategic support from CSR consultants and financial auditors and thus simultaneously works on understanding the scope and creating a corporate strategy that fits within the institutional environment (Boon *et al.,* 2009). This means that the corporate response transpires in an institutional political context as Holding seeks a balanced response following both market development and political obligations.

In the subsidiary, the taxonomy regulation influences processes in many operational areas. Nevertheless, taxonomy-related tasks are centred around the Sustainability Manager, who are responsible for collecting and passing on project information to Holding. As previously stated, tensions may arise when organisations try to balance conformity and operational efficiency accompanied by institutional pressure. There are various ways organisations can respond to such pressure (Oliver, 1991) and organisations are not always conforming to the expectations from the environment. In the case, we nevertheless see that there is a general understanding in the subsidiary of following the taxonomy development and creating operational systems for conforming to documentation criteria.

At the same time, the future impact of the taxonomy is indistinct and creates strategic insecurity and a 'wait-and-see' attitude. Furthermore, as Ahrens and Khalifa (2015) describe, organisational meaning-making is necessary to comply with regulation. This is substantiated in the case, as the subsidiary's Sustainability Manager seeks to legitimise the taxonomy work in the organisation as an opportunity for increased substantiality awareness and creation of cultural-cognitive changes to support nuances of the concept of sustainability.

At the project level, the organisational response to taxonomy regulation resembles a distinct type of decoupling described by Bromley and Powell (2012) as a means-ends decoupling. When data necessary for complying with the regulation is collected, internal taxonomy strategies are implemented in practice, but they also have a weak link to the organisation's practice-orientated approach to sustainability at the project level. This is highlighted in the analysis by the Production Support Manager, being responsible for aligning project-level activities with new requirements forwarded by the department heads, who argues that the taxonomy regulation is perceived as a policy tool rather than a tool that is expedient in the projects.

This perception contributes to decreasing the experienced institutional pressure as the taxonomy regulation is framed as inexpedient in projects. Employees working at the level of the project thus collect and report taxonomy regulation data demanded by the department heads, but distance themselves from the idea that the regulation should be more suitable than other instruments to promote sustainable construction. A consequence hereof is a low level of compliance at the project level and a low degree of institutional fit.

Finally, the analysis has illustrated that the aim of a taxonomy as competitive tool to distinguish companies' sustainability efforts from each other may be at risk, being undermined and instead give rise to isomorphism (DiMaggio and Powell, 1983). The current strategic response from Holding thus rests on a "balanced" insecurity between under- and overperforming. When faced with uncertainty associated with the need for new resource investments (Weigelt and Shittu, 2016) companies may thus be inclined to aim at being in the "middle of the class" to reduce financial risk while maintaining legitimacy. This in turn may compromise the intention of the taxonomy as a pathway for greening the construction industry.

CONCLUSION

The focus in the paper has been to explore how a construction company responds to new sustainable regulation. We have examined the taxonomy regulation, which represents the European Union's latest policy attempt to meet the climate obligations. We have focused on three different parts of a Danish construction organisation and analysed the strategic responses and level of compliance in relation to the taxonomy regulation. We found that the different levels of the organisation respond differently to the regulation. The basis of attention shifts from regulatory fit and high strategic response at Holding, to a more practice-orientated approach on project level, focusing on hands-on initiatives that promote operational sustainability partly regarding regulation demand as non-instrumental.

Through the analysis, we displayed some elements of isomorphic tendencies at Holding level, as the response to the taxonomy unintendingly places the company in a stream of uncertainty, which results in desires to neither under- nor overperform. We thus conclude that the taxonomy as a competitive investment tool is still underdeveloped, and immature as displayed by the observed decoupling between policy instrument and organisational practice.

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EU TAXONOMY ON SUSTAINABLE FINANCING: A NEW PARADIGM FOR THE BUILDING FIELD?

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As part of the effort at making a climate neutral economy, the EU has developed a sustainable finance taxonomy to steer capital flows towards sustainable activities, connecting financial and environmental elements of sustainability in a new way. Here we study how the taxonomy regulation, affects the field of construction. The research builds on institutional theory and empirical material from interviews and annual reports. This is done to establish a broad understanding of the field structure, and how the organisations in the field respond. The taxonomy presents new challenges and barriers. It is concluded that even though the purpose of the regulation is to motivate companies to document their sustainable activities and develop more sustainable businesses, the company responses have so far been diverse, to some extent reluctant and for some even evasive. The taxonomy will change notions of sustainability, but it is likely that it will enter a heterogeneous rather than a uniform direction.

Keywords: building industry, EU taxonomy, sustainable finance, regulation

INTRODUCTION

The transition needed to accommodate the Paris Agreement obligations in 2030 poses tantamount demands on the earth's societies and requires full mobilisation of not only public institutions but also private companies and the entire financial system (TEG, 2020). The European Commission is committed to contribute through legislative, non-legislative and financial initiatives. In particular, the regulation of the financial sector aiming at redirecting investments in a sustainable direction is remarkable. EU aims to: (1) reorient capital flows towards sustainable investment to achieve sustainable and inclusive growth, (2) manage financial risks stemming from climate change, resource depletion, environmental degradation and social issues and (3) foster transparency and long-termism in financial and economic activity (European Commission, 2018) This has led to the establishment of an EU classification system for sustainable activities, that later became regulation 2020/852, here denoted the "taxonomy" (EU, 2020) The taxonomy regulation requires companies subject to the Non-Financial Reporting Directive (NFRD) to publish information on environmentally sustainable economic activities from the company's total revenue, capital- and operational expenditures.

The reporting is gradually expanded and categorised in sustainable eligible (can) and aligned (do) activities. Through a series of technical screening criteria, provided by

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the Technical expert group on sustainable finance (TEG, 2020), it is defined which activities can be classified as environmental sustainable by contributing a substantial contribution to one of six categories, set out in article 9 of the taxonomy regulation. The six categories are: (1) Climate change mitigation, (2) Climate change adaptation, (3) Sustainable use and protection of water and marine resources, (4) Transition to a circular economy, (5) Pollution prevention and control and Protection and (6) restoration of biodiversity and ecosystems. While doing no significant harm (DNSH) to the remaining five and meeting the minimum safeguards set out in article 18.

Further initiatives for the following years involve social sustainability and governance. This legislation also partially covers the building industry, where real estate companies and contractors are clearly covered, whereas material suppliers, retailers, consulting services (architecture, engineering, and management) are less covered. By adopting an institutional theoretical lens, what we are witnessing here is not only an emerging regulation, but also an emerging issue field that out folds continually where companies, banks and other organisation alike will be socially ordered according to the taxonomy regulation and must adapt continually over the next years (Scott, 2014).

The issue field of sustainable building according to the taxonomy develops "on top of" the four subfields of real estate, contractors, material suppliers and consulting services. On this background we aim to (1) study the impact of the taxonomy on the development of sustainable initiatives in the building industry and (2) examine sources and impact of heterogeneity in the field and its implications for field change and stability. The approach taken here to study this process of institutionalisation is to select and study a few major organisations in the field according to their different institutionalised role. They are assumed to drag the development of the issue field of sustainable building. These large organisations spearheading the institutional change both in the field and in organisations. This is partly due to the scope of the EU taxonomy legislation, which from summer 2020 have targeted listed corporations with more than 500 employees. We therefore also end our paper by discussing a possible "trickle down" effect on SMEs.

Theoretical Frame

To understand the mechanisms in the impact of the EU taxonomy, the concept of "institutional field" is useful. Institutional field represents an intermediate level between organisation and society and is instrumental to processes by which socially constructed expectations and practices become disseminated and reproduced (Scott, 1994, 1995). A field is defined as a community of organisations that interact together "frequently and fatefully" (Scott, 2014) Institutional theory identifies different types of fields organised around different actors and entails different change dynamics in terms of how rising societal issues are incorporated into the existing institutions. Zietsma *et al.,* (2017) distinguish between issue and exchange fields. Common to these fields is that they focus predominantly on a single population of organisations and on governance mechanisms or institutional infrastructure at an organisational population level (Purdy and Gray, 2009). Even if the concept is related to that of "industry" it does not need to be defined by market criteria but can concern any kind of involvement in a particular issue or policy community (Scott, 2014). In essence, "field" is an alternative to market concepts (Scott, 2014).

The benefit of building on the concept of field is the possibility to incorporate field-level structures, participating organisations, and the actors working within and between these organisations (Scott, 2014). The structures include collective interest organisations, regulators, informal governance bodies, field-configuring events, status differentiators, organisational templates, categories or labels, and norms (Hinings *et al.,* 2017). These establish the boundaries of each community of organisations, defining its membership, the appropriate ways of behaving, and the appropriate relationships between organisational communities.

Faulconbridge and Muzio (2019) and Zietsma *et al.,* (2017), observe that the concept of fields remains significantly under-developed, as most of the research that has been conducted is 'in' fields rather than 'about' fields. This is particularly true for research on building industry change, which barely exhibit a few examples (e.g. ; Jensen *et al.,* 2011; Boxenbaum *et al.,* 2013; Leiringer, 2020), Outside construction, Hannigan and Cassanovas (2020) argue that field emergence poses an intriguing problem for institutional theorists, as new fields, in the form of issue fields (Zietsma *et al.,* 2017), often arise at the intersection of existing established sectors, and accordingly are fragmented and lack clear guides for action, making it unclear how they ever coalesce.

The argument according to Hoffmann (1999) is that fields form around a central issue rather than on exchange relationships. This means that an emerging field contains a diverse set of actors with distinct identities and commitments to own institutional infrastructures that may be in different established, so-called exchange, fields. In terms of field change, however, we know very little about the processes and dynamics involved when new regulation is introduced. In the context of our research question, does the transposition of European regulation follows a pattern of transnational diffusion of dominant cultural templates (Suddaby *et al.,* 2007) leading to convergence (Gilardi, 2012), or is it translated or adapted to local context (Czarniawska and Joerges, 1996) resulting in a proliferation of different recipes for sustainability and climate mitigation? Here it is important to distinguish between different types of European legislation. So-called "minimum" and "maximum" directives are explicitly followed by national adaptation and implementation and/or whereas "delegated regulation" is followed by immediate cross EU implementation, the European taxonomy on clime and sustainability is such a delegated regulation.

METHOD

The paper adopts an interpretive sociological approach using institutional theory (Scott 2014). Institutional theory is well suited to understand societal and field change as the implementation of the taxonomy regulation represents. Empirically, major organisations in the four subfields are assumed to drag the development of sustainable building. They were initially selected from a list of 100 Danish companies from the Danish Business Authority, a surveillance list for legally obligatory business reporting, announced in November 2021. By April 2022 only partial public communication was available from the companies, as some chose to publish their report later in the autumn. This "forced selection" has been allowed to impact the selection of companies. Two real estate players have been selected amongst the ten largest in the Danish real estate sector. Apart from the two selected, four others were screened. Further four have a size or legal form, that implies that they could not be studied. Two consulting services were selected among the ten largest on the Danish market. The architects and consulting engineers are outside the scope of the taxonomy regulation, but with important sustainable building impact and ambitions. Two further consulting services were screened. Finally, two contractors were selected, one multidisciplinary building contractor, the other more traditional trade focused installations contractor. Several other companies were screened and deselected. Supplementing the company reports three interviews were carried out with financial institutional players adjacent to the building and real estate sectors: two banks and one national bank association.

Scrutinising Annual Reports

Reading and analysing annual reports is a well described and mainstream method in management research (Brunton *et al.,* 2017; Frandsen and Johansen, 2011). It continues however to be controversial, as the question remains, to what degree annual reports represent a trustworthy depiction of a company's performance. Annual reports are external corporate communication vessels that also involve a marketing objective (Frandsen and Johansen, 2011). Frandsen and Johansen (2011) point out that corporate communication and marketing about sustainability is "not only about promoting environmentally friendly products and services but also purposefully and strategically advocating (even demonstrating) responsible behavior and willingness to enter into strategic partnerships to reduce or remove causes and/or abate the negative consequences of climate change" (Frandsen and Johansen, 2011:515). In a somewhat contrasted stance, we would argue that corporate communication aims at presenting the company as contemporary and modern. Finally, there is also a predominant reactive element to this communication which involves responding to external legal demands. Therefore, a central question is to what degree the annual reports can be used to describe and analyse the development of corporate practices of sustainability.

Frandsen and Johansen (2011) draw on institutional theoretical concept of "decoupling", which posits that the embedding of new concepts initially occurs in a ceremonial manner to gain legitimacy, and that this public performance occurs detached from internal working activities that continue to focus on efficiency (Frandsen and Johansen, 2011:527). However, this can be counterposed by expecting corporate communication to contribute to corporate identity, having a real impact on the self-understanding of the organisations concerned. For example, Brunton *et al.,* (2017) pointed out that external communication impacts internal stakeholders. Thus, as Frandsen and Johansen (2011: 527) states: "organisations will become over time what they say they are (now)". Nevertheless, we will remain critical toward the communication and our knowledge gathered over the covered time period as validation tool. It is a limitation to rely on annual reports. Note that some features and figures have been changed to assure anonymity. Reports and other material written in Danish has not been referenced. Moreover, the full impact of the taxonomy is still years ahead and will be a continual process.

Empirical Material

Description of the field

The institutional field of the building industry is characterised by structuralised organisations i.e., organisation with specific functional positions in the sector Clients/real estate companies, consulting companies (engineers/architects), material suppliers and building contractors. Each of them encompasses specific interests and professional associations, but also, they share many exchanges, associations and governance (regulatory) framing. Today the company types occur in a largely linear value chain, with company structures and contracts fragmenting the field. Compared to other industries, building production is carried out under highly idiosyncratic circumstances that provide the ideal grounds for fragmentation. Building is a temporary, project-based and transactional activity.

The production of buildings is carried out in an organisational setup that brings together a multitude of autonomous companies whose interdependent efforts are expected to result in a product, which is delivered to required time, cost, and quality - despite being carried out under conditions of environmental drift, resource scarcity, time constraints and recurrent changes in project scope and priorities. The different companies involved in a project were for long organised around each their institutionalised profession, where one of many integrations attempts today also involves increasing multidisciplinary companies, for example integrating architecture, a range of engineering disciplines and management.

However, this still means that each company delivers a project-specific service that is largely distinct and governed by the knowledge, methods, rules, and norms that belong to the given occupation or craft. Moreover, all stages of building production, from the initial financing decision, over procurement and design to the execution and final commissioning, are governed by regulations. And the field typically operates with procurement methods based on the lowest price criteria and transactional contracts between the project parties, which in turn contribute to short-termism, opportunism, and low degrees of trust inhibiting collaborative behaviour and adaptive organisational forms.

The sustainability field, in which the taxonomy regulation impacts, can be viewed as a stabilised issue field sedimented in the institutional exchange field of the Danish building industry. The issue of sustainability has been emerging over a long time, also heavily impacted by regulation (Lauridsen and Jensen, 2013). The social movement of building passive houses from 2008 and onwards is one example of such an emergent development (Koch and Buser, 2012). Despite the social movement and development of competencies, only about 8-15 passive houses were built annually between 2012-2018. In a similar manner, the establishment of the Danish certification for sustainable housing, Green Building Council Denmark, has experienced increasing interest and support from companies in the industry. However, in 2021, only around 125 buildings were certified in Denmark, which is not overwhelming considering that new built between 2017-2021 accounted for more than 100,000 buildings. Despite a growing interest and support among industry players, sustainability thus remains a somewhat side-lined topic to the industry (Frick, 1998).

Consulting services

Consulting services in Denmark represent the integration of engineering, architectural and managerial consultancy for the building industry. Consulting services are not encompassed by the taxonomy legislation according to the sampled companies. Consulting services company 1 (CS1) is a broad-spectrum consulting engineering, architectural and management company with its main business areas being consulting engineering and management in Denmark, infrastructure engineering in Norway and Sweden, and architecture in Scandinavia. The company also have extensive sustainability competencies. The integration of architectural competencies came recently. In 2019, CS1's management decided to aim at carbon neutrality in 2020 and to reduce CO2 emissions by more than 70% in 2030 compared to 2008. Carbon neutrality was, according to CS1, achieved in 2020 thanks to reduction efforts already made, and by acquiring CO2 credits.

However, this is not accounted for quantitatively in the company´s reporting, and the neutrality does not encompass scope 3 emissions (Re the greenhouse gas protocol, WCI and WBCSD 2004). In winter and spring 2022, a new strategy for the company attracted attention. Within a few years, CS1 announced, the company will turn its back on climate-damaging projects. The plan is, according to CS1, that they will restructure the business over the next three to five years and no longer deal with fossil energy (oil and gas) and construction projects without a sustainable approach. There are several reasons for why this strategy is not linked to the EU taxonomy. First, CS1 is not a listed company. Second, as a consulting engineering company, it is not subject to the taxonomy regulation. Nevertheless, CS1 as a large company is under the scrutiny of the Danish authorities together with 100 other large companies with seat in Denmark. Moreover, CS1 could choose to follow the taxonomy, especially in the scope 3 area, where the buildings they design would be placed. And buildings are part of the taxonomy.

Consulting services company 2 (CS2), similarly, does not feel obliged to measure itself quantitatively. CS2 has announced an ambitious new strategy including the taxonomy as a competence and a service for its clients. One of the contractors hired one of the companies' consultants for their taxonomy evaluation. In spring 2022, CS2 announced that in the future it would measure its climate impact according to the taxonomy. CS2 is (as CS1) a broad-spectrum consulting engineering, architectural and management company with its main business areas being consulting engineering and management in Scandinavia and Europe. The company also possesses extensive environmental competencies. The integration of architectural competencies came recently. As for CS1, its design of buildings generates huge material flows and scope 3 emissions. However, this is not accounted for in the company´s reporting. In winter 2022, a new strategy for the company was released. Within a few years, CS2 announced, the company will turn its back on fossil energy.

Contractors

The size of organisations among building contractors, civil engineering contractors and technical installation contractors in Denmark involves a relatively large amounts of medium-sized companies compared with e. g. Sweden and Holland. The contractual collaboration means that regulation of the large contractors almost immediately affects the smaller. Contractor 1's (CON1) corporation is highly profiled in the sustainable building field. In the spring of 2022, its annual report entered evaluation of taxonomy eligibility activity was respectably 80% for revenue, 100% for Opex and 60% for Capex. The company pointed to that the activities that were not covered were within road building (infrastructure) and service. Also, the company explains its difficulties in gathering the necessary information in detail. First, some documentation would have required the collection of data at the beginning of the building project, and other data is only possible to collect at the end of the project. Second, another company might be responsible for a particular activity, which prevents the company from collecting the data.

The company also note, however, that some building projects do not comply with the demand, e. g. on the dimension of energy consumption. Contractor 2 (CON2) exhibits a very short report section on societal responsibility (CSR), both in 2020 and 2021. Moreover, sustainability and climate have only recently entered the company's webpage. CON2 does not report according to the taxonomy, neither its eligibility nor its climate impact in terms of degree of sustainability. It is nevertheless likely that the company's eligible activities would be over 80%. The annual report merely notes that the CON2 has the ambition for 2021 to decide upon actual goals for the climate impact and to initiate further activities for reducing carbon dioxide.

Real estate
The financial market of real estate is important to the national economy and the financial system. The taxonomy impact on the latter is due to occur over the next years. Here we focus on the regulation in force by January 2022. Real Estate Company 1 (RE1) is highly profiled both in the sustainable building issue field and sustainable financing and investments. This includes new profile building projects adopting DGNB Gold and participating in the emerging circular building community. It also liaises with all the other mentioned companies in the field that have been used as cases in this study. RE1 reports in spring 2022, that 100% of its activities are eligible and that by end of 2021 around 40% of its properties were measured as sustainable according to the EU taxonomy (see table 1). Also, about 3% or approx. 800 sqm. of the company's properties were sustainability certified in 2021 (mostly DGNB). Real Estate Company 2 (RE2) has expanded aggressively on the Danish market and internationally. However, the actual status of the existing properties is not known, and the company typically does not certify its buildings. It is thus characteristic that none of the six largest new built projects that RE2 has completed in the spring of 2022 have been sustainability certified. Moreover, the company prefers to collaborate with smaller consultants and contractors. The developer reported in March 2022 that its 2021 status was that its Capex, Opex and revenue were all 100% eligible. And that it would prepare for the next step of the taxonomy over the year 2022.

Retailers and material suppliers
Retailer 1 (R1) has a high profile in the sustainable building field in Denmark. It exhibits an impressive mapping of scope 3 impact placed around 95% of the company's impact on downstream and upstream scope 3 impact. Material Supplier 1 (MS1) provides a quantitative evaluation of the environmental impact following a ESG (environmental, social, governmental) and greenhouse gas methodology (scope 1-3). In 2021, its main effort was to reduce scope 2 emissions (energy consumption at MS1). However, 0% of MS1's activities are evaluated as eligible.

FINDINGS

The impact of the taxonomy is intermingled with several other dynamics. Likewise, there is great variation between companies in their response to the legal demands. The issue field is thus still emerging and at present diverse. Some companies only provide the core of the taxonomy demand anno 2021, namely eligible activities, others claim they are not covered or simply do not relate to the taxonomy. In the sample presented here, none of the companies provide compiled figures for their expected degree of sustainability or "alignment", except for one company that presents a loose estimate of expected 40% alignment (RE1 see table 1).

But other companies outside this present sample provide figures for their degree of sustainability. In addition, the taxonomy figures given and the companies that exhibits an explicit strategy for future reduction of CO2 emission impact are not interconnected. So far, the legislative demand is a documentation demand, and further legislation is still under development. The areas of a possible circular value chain that presently “fall outside” the taxonomy are design, engineering, and infrastructure. Is the taxonomy changing the understanding of sustainability and climate impact? Yes, there are a large number of areas where the taxonomy stresses other aspects of sustainability and its precursors (quantitative: greenhouse protocol, global reporting index, energy labels, and certifications like DGNB, BREEAM, LEED; qualitative the discourse about social sustainability, climate justice, and CSR).

The most direct is the lower priority of social sustainability, which underlines an existing weakness in the DGNB community in Denmark and the lower priority of indirect effects through finished new built - i.e. The greenhouse gas scope 3 evaluation, which for one of the investigated companies was 45% of the climate impact measured in 2021. A more complicated effect relates to how the sustainability conceptualisation will change once juxtaposed with quantitative economic factors. As Michelon *et al.,* (2020) notes, economic cost thinking and sustainability might mutually impact on each other.

But the more likely effect is that a smaller set of sustainability factors is subsumed into economic thinking and separated from a more holistic sustainability concept. There seems to be central similarities yet also heterogeneous responses to the regulation. The core of the regulatory demand in the spring of 2022 is to identify the economic activities of companies and the extent to which they are covered by the taxonomy, their so-called “eligibility”. Yet the responses differ from a promise to make this calculation later in 2022 (CON2) to a full evaluation of the degree of sustainability (RE1, called "degree of alignment" by EU).

Table 1: Annual reports 2021 and the taxonomy

Companies,	Eligible 2021 (1 January 2022)			Aligned 2022 (1 January 2023)
	Revenue	Capex	Opex	
CS1	-	-	-	Qualitative strategy, not covered
CS2	-	-	-	Will comply by 2023
CON1	80	100	60	Are preparing the 2023 reporting
CON2	-	-	-	No comments made
RE1	100	100	100	40% of real estates aligned
RE2	100	100	100	Preparing 2023 reporting
R1	-	-	-	Uneven reporting period
MS1	0	0	0	Following the taxonomy

Four companies in the exchange field of the building industry claim that they are not covered (CS1, CS2, MS1 and RE1) for various reasons, and only four responds with a clear evaluation of their eligibility (CON1, RE1, RE2 and MS1). This diversity fits with our broader screening of organisational responses. Probably the largest heterogeneity is related to the embedding of the taxonomy regulation calculation amongst other sustainability accounting indicators that the organisations have adopted in parallel or earlier, such as the UN SDGs, the global reporting index, the greenhouse protocol. It is common for all eight organisations that each measure is presented separately in the reports, and none of the organisations share any analysis or overview of the overlaps between them, so it is a form of compartmentalised heterogeneity. It might be so that the regulation of the European taxonomy on climate and sustainability is a delegated regulation and as such could be assumed to involve clear and unambiguous demands to be followed. Here we see however a diverse set of responses. The taxonomy regulation thus sits together with other initiatives that develop the field of sustainability in the building industry. We see companies exercising compliance by letter and no more, but also companies that flag ambitious strategies for sustainability in the coming years. It can be noted, that despite the anticipated strong emphasis on circularity and reuse of materials in the next step of the regulation, none of the companies place a “precompliance” or anticipative effort into matching these demands. Moreover, four companies practice what can be coined an evasive approach avoiding reporting on the taxonomy although they in our evaluation clearly are within the cluster of circular building.

Taken across a possible future circular building field in Danish construction the most direct result of the analysis is that the companies that are to support circularity largely consider themselves as operating outside the taxonomy legislation. Field emergence will therefore at best be uneven. Given the heterogenous impact on the larger companies it is straightforward to imply that a trickle-down effect from listed companies to SMEs, the most common in Denmark, will be equally diverse. While the contractual collaboration would normally mean that a regulation on the large contractors almost immediately affects the smaller ones, we are witnessing here that at least one player moving the blame the lack of data further downwards (CON1). Moreover, it can be speculated that the taxonomy regulation will enter into competition with new Danish national legislation in sustainably building, at present voluntary, but due to become obligatory by 2023. This legislation operates according to size of the building project and therefore impacts much more directly on the building industry fields SMEs. There is thus a risk that the taxonomy regulation will enter a cacophony of incentives both within sustainability and within finance and investments (Koch and Buser, 2012).

CONCLUSION

The paper set out to study first the impact of the taxonomy on the development of sustainable initiatives in the building industry and second to examine sources and impact of heterogeneity in the field and its implications for field change and stability. This leads us to study how the taxonomy, as a form of regulation, affects the field of the building industry and to examine sources and impact of heterogeneity in the field and its implications for field change and stability. And finally, whether heterogeneity gives rise to specific constellations around variants of taxonomy implementation. It is concluded that even though the purpose of the regulation is to motivate companies to document their sustainable activities and develop more sustainable businesses, the company responses have so far been diverse, to some extent reluctant and for some even evasive. There are thus plural answers to the regulation. The taxonomy will change sustainability efforts and concepts of sustainability, but it is likely that the regulation will enter a heterogeneity rather than a uniform direction, which is sorely needed to swiftly contribute to the Paris accord.

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A MACHINE LEARNING-BASED LIFE CYCLE ASSESSMENT PREDICTION MODEL FOR THE ENVIRONMENTAL IMPACTS OF BUILDINGS

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With the emerging importance of achieving climate targets and net-zero levels, assessing the environmental sustainability of buildings is of paramount importance. Life Cycle Assessment (LCA) is a popular tool used for such assessment. However, performing LCA for buildings is time-consuming and challenging due to inconsistencies in the databases, software limitations, and data intensiveness, making it a complex tool for decision-making applications. Therefore, this study proposes a methodological framework to develop surrogate LCA models for buildings using modern machine learning (ML) tools such as Multiple Regression and Artificial Neural Networks (ANN). Such a framework improves the application of LCA in environmental decision-making during the planning of building projects by reducing the time, effort, and complexity associated with conducting LCA of buildings. It can be found that the mean absolute percentage error (MAPE) for the tested dataset in the regression-based model is less than 5 percent rendering it a good surrogate model.

Keywords: life cycle assessment; artificial neural networks; multiple regression

INTRODUCTION

Buildings significantly influence the environment due to large resource consumption, energy and water use, and emission and waste generation associated with construction, operation, and end of life (Francis and Thomas, 2020). Therefore, it is essential to balance out these impacts through improved decision-making and policies to achieve global targets of net-zero and sustainable development goals. Although several tools were developed for environmental assessment, Life Cycle Assessment (LCA) is the most popular and standardized tool in this domain. LCA helps quantify the effects of human activities on the environment (Barros and Ruschel, 2020). However, buildings have a very long lifespan and are subject to changes in building characteristics, particularly during their operational phase (Fouquet *et al.,* 2015). Hence, modern research is transforming its outlook from a static to a dynamic environmental assessment of buildings (Beloin-Saint-Pierre *et al.,* 2020; Francis and Thomas, 2022a; Levasseur *et al.,* 2010).

However, the dynamic and diverse behaviour of buildings and the data intensiveness associated with their scale and size creates a lot of complexity and variability in environmental assessment (D'Amico *et al.,* 2019). Further, the absence of standard

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environmental databases and non-uniformity in assessment methods makes buildings a more challenging product for evaluation as it comprises of several materials, transportation, and significant energy and water consumption (Morales *et al.,* 2020). Further, decision-making and policy analysis in the building sector involves evaluating numerous alternatives and scenarios to arrive at the best possible solutions in terms of environmental sustainability. However, the rigorous data inventory requirement, data gaps due to improper reporting of possible impacts, and the non-uniformity of methods and databases make LCA a complex tool for such elaborate decision-making applications in the building sector.

To address the challenges mentioned above associated with conducting LCA of buildings and utilising its potential in decision making, it is worth exploring the potential of modern ML tools in this domain. Such modern computational tools of simulation and ML could ease the complexities of applying environmental assessment tools. Studies have demonstrated that such tools can be utilized to develop surrogate prediction models that enable efficient, robust, and faster analysis (Sousa *et al.,* 1999; Ziyadi and Al-Qadi, 2019).

Therefore, this paper proposes a framework for developing an ML-based LCA prediction model to perform LCA for buildings. It demonstrates the application of ML tools such as multiple regression algorithms and Artificial Neural Networks (ANN) to create robust surrogate models to predict the environmental performance of buildings. Such prediction models save time and reduce the complexity of environmental analysis while enabling efficient and dynamic assessment of the built environment. Such models enable LCA application for better environmental decision-making of buildings by enhancing its flexibility and capability to evaluate numerous scenarios and alternatives while planning building projects.

LCA helps quantify the environmental impacts of a product or a system (Rebitzer *et al.,* 2004). It takes a cradle to grave approach by considering the life cycle effects of a product or activity from the procurement of raw materials to its final demolition and disposal. International Organisation of Standardisation (ISO) standards are available to perform LCA (Guinee *et al.,* 2011). The existing studies show that LCA has been popularly applied in the built environment for research and practical applications (Cabeza *et al.,* 2014; Chau *et al.,* 2015; Sharma *et al.,* 2011). However, the widespread application and use do not negate that LCA is a time-consuming method with complex computing and analysis involved (Sousa *et al.,* 1999). Notably, when buildings are the products analysed, this complexity increases with the long-life span and varying dynamic nature of building characteristics, such as changing properties of building materials, surroundings, and energy consumption. Hence, as generally done in a conventional LCA, a static assessment would underestimate the actual impacts due to buildings (Francis and Thomas 2022a). Data gaps and non-uniformity of databases are challenges in performing dynamic LCA for buildings (Hellweg *et al.,* 2014). These challenges limit the application of LCA-based decision-making during the planning of building projects.

However, with the growing necessity to achieve climate targets, sustainable development goals, and eventually net-zero targets, it becomes necessary that environmental performance is given primary importance while planning and decision making of building projects (Francis and Thomas, 2022b). This demands the application of modern ML tools to address these complexities. ML tools are used to develop substitutable prediction models which output the results that closely represent the theoretical values. Such surrogate models are then used for prediction purposes due to their application simplicity and flexibility enabled for constantly changing evaluation parameters. Developing ML-based prediction models requires collecting extensive input/initial data. This data, after pre-processing, is then trained using a machine-learning algorithm. A suitable supervised/unsupervised learning algorithm will study the pattern of this input data and develop a "training model." This model is then used for prediction based on the test inputs provided to this trained prediction model (D'Amico *et al.,* 2019).

Few studies have explored various ML models and data mining applications for environmental assessment, particularly in the building sector. For instance, Azari *et al.,* (2016) and Sharif and Hammad (2019) used a combination of neural networks and LCA for optimal design selection of building envelopes and renovation methods, respectively. Meanwhile, another study proposes the use of ANN for a green building assessment system based on LCA (Xia and Liu 2013). Galimshina *et al.,* (2019) used a probabilistic LCA using advanced statistical methods to identify renovation strategies for buildings. Although studies have employed the use of ANN and regression models for energy assessments (D'Amico *et al.,* 2019; Li *et al.,* 2019), limited research is found using surrogate/substitute models for performing a complete LCA of buildings. However, such predictive modelling to perform LCA is proposed and demonstrated in other sectors such as agriculture machinery (Ma and Kim, 2015), chemical industry (Calvo-Serrano *et al.,* 2018), and product design (Park and Seo, 2003).

Nevertheless, considering the complexity of size, scale, and long-life span of buildings, dynamically performing a whole-building LCA is often very time-consuming and challenging (Francis and Thomas, 2022c). Hence, it is evident that the building sector needs to embrace modern computational and statistical tools to improve the decision-making process while proposing environmental conscious development. A robust surrogate model used for prediction purposes is efficient if it can ensure minimal loss of information while enabling full implementation of LCA (Eddy *et al.,* 2014). Therefore, this study demonstrates the potential of multiple regression and ANN tools in creating models to serve as substitutes for performing LCA of buildings, thereby reducing the time, cost, and complexities associated with it. Such models could then help in easing the decision-making process during project planning. The following section describes the methodological framework to develop such substitute models to perform LCA of buildings.

METHOD

Figure 1 shows the generic methodology proposed in the paper to enable the development of surrogate models to perform LCA for buildings. The first step is to collect inventory data on several building projects in terms of material consumption, transport of materials, equipment use and electricity consumption during the entire life cycle of the building. Once the life cycle inventory is compiled for various buildings, it should be analysed further for environmental impacts using suitable standard impact assessment methods (for the specific geographical boundary under consideration) or by using experimental and analytical conversion/characterisation factors (Guinee *et al.,* 2011). Once the LCA impacts are generated in the form of different indicator values (global warming potential, human health, ecosystem quality, acidification potential, etc.), the data is pre-processed to eliminate duplicate, missing, or inconsistent data. The input (inventory data) and output (LCA indicators) data are then used to develop the ML model for prediction after data pre-processing. Any suitable ML algorithm can be used to develop the training model. However, the prediction accuracy among various methods can vary. So, the suitable algorithm can be chosen depending on the area of application. Once trained with a suitable ML algorithm, the model is then tested and validated for accuracy. Post validation, the model created can be used to obtain LCA indicator results for any building without performing a detailed whole building LCA.

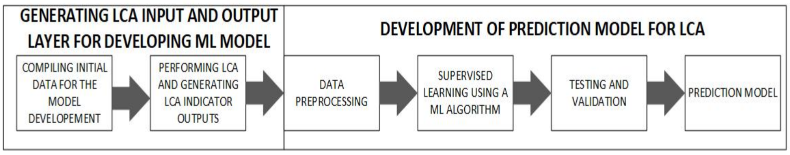

Figure 1: Research Method

The proposed methodology is demonstrated using a case dataset for Indian buildings. For this, an inventory data of 1000 buildings that contain information about five primary building materials used for building construction and their transportation to the site in ton-kilometres is collected. The five materials chosen are cement, sand, steel, bricks/AAC blocks and aggregate. The choice of five materials is made considering that these majorly affect life cycle energy and emissions according to studies in the Indian context (Reddy and Jagadish, 2003). This data is fed as inputs into the Simapro software (Version 9.1.0.8), which is software that assists in performing LCA. This data inventory is then assessed using a suitable impact assessment method. In this case, the ReCiPe end-point method (Hierachist Version) in association with the Ecoinvent database for these materials in Indian conditions is used. Post the inventory analysis using this method; results are obtained in the form of ReCiPe end-point indicators, namely Human health (Disability Adjusted Life Years (DALY)), Ecosystem Quality (Species. Year), and Resources (US Dollars) (Owsianiak *et al.,* 2014). The building inventory dataset of 1000 buildings and the three ReCiPe indicators from the impact assessment of each building becomes the training dataset for developing the ML model.

Accordingly, both multiple regression-based algorithms and an ANN-based ML model are experimented with to develop and compare prediction models based on the training dataset of 1000 buildings. A python code is used for the multiple regression model where the following relationship is derived from the model as shown in equation (1). Using these coefficients that are trained from the regression model, different LCA indicator values are predicted for a set of test data to check the robustness of the model generated.

$$Y=£_0+£_1X_1+£_2X_2+£_3X_3+£_4X_4+£_5X_5+£_6X_6+£_7X_7+£_8X_8+£_9X_9+£_{10}X_{10}+£_{11}X_{11}+€ \qquad (1)$$

Where:

Y is the predicted results of ReCiPe end-point indicators.

X_1 to X_6 is the quantity of building materials in metric tonnes.

X_6 to X_{11} is the transportation involved for these five materials in ton-kilometres.

$£_0,£_1 \ldots\ldots £_{11}$ correspond to the regression coefficients

€ is the error variable.

Similarly, an ANN-based prediction model is also developed to compare the accuracy of using substitute or surrogate models for LCA. Figure 2 shows the framework of

ANN used in this study. For this, the 1000 building inventory and impacts dataset generated earlier is pre-processed or normalized if necessary and then divided into training data (80%) and testing data (20%). The ANN structure is defined by the input layer (input parameters same as that used for the regression model), output layer (values of LCA end-point indicators) and the hidden layers in-between. The input layer in this study includes 11 different variables (materials and transportation), as shown in Figure 2 and the output layer contains the three LCA end-point indicators under the ReCiPe method. The ANN structure is developed in MATLAB (Version 2020a) (as shown in Figure 2). The hidden layers are assigned weights that help initiate the activation function. This activation function maps the non-linear relationships between the input and output layers. This non-linear analysis is what distinguishes ANN from the multiple regression model. The transformation/training of data takes place in the hidden layers of neurons based on the nature of the data trained. Bayesian Regularisation is used in training the data. The iterative process of associating weights and bias to the model continues till the number of epochs specified is achieved or when the minimizing criteria such as the root mean squared errors (RMSE) is reached.

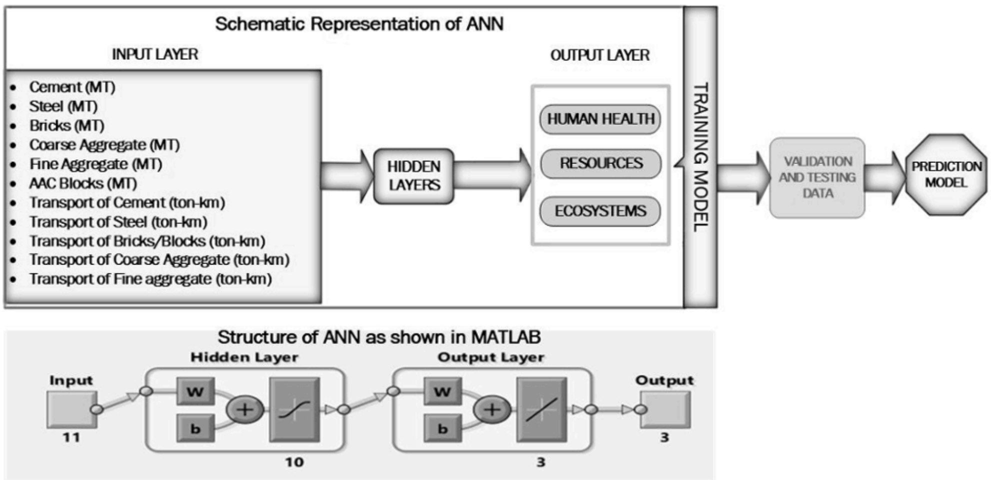

Figure 2: Framework of ANN interface

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Figure 3 shows the difference in percentage between the predicted versus actual results of ReCiPe end-point indicators for 10 test buildings for both regression and ANN. From these results, both these methods are closely representing the underlying structure of the LCA impact assessment method employed since the difference is within an acceptable range of less than 5%. Meanwhile, Figure 4 shows the results of the ANN training in MATLAB in terms of means squared error value rendering it a satisfactory prediction model. However, ANN is a more accurate prediction model when the data has a non-linear nature, as some existing studies conclude (Davis *et al.,* 2017; Ziyadi *et al.,* 2019).

Given the linear nature of the impact assessment method for LCA adopted in the case study, further extensive testing of the framework was done on the multiple regression model. The multiple regression models are tested with about 100 new building data samples. The mean absolute percentage error (MAPE) indicates the level of accuracy in terms of the difference between predicted and actual.

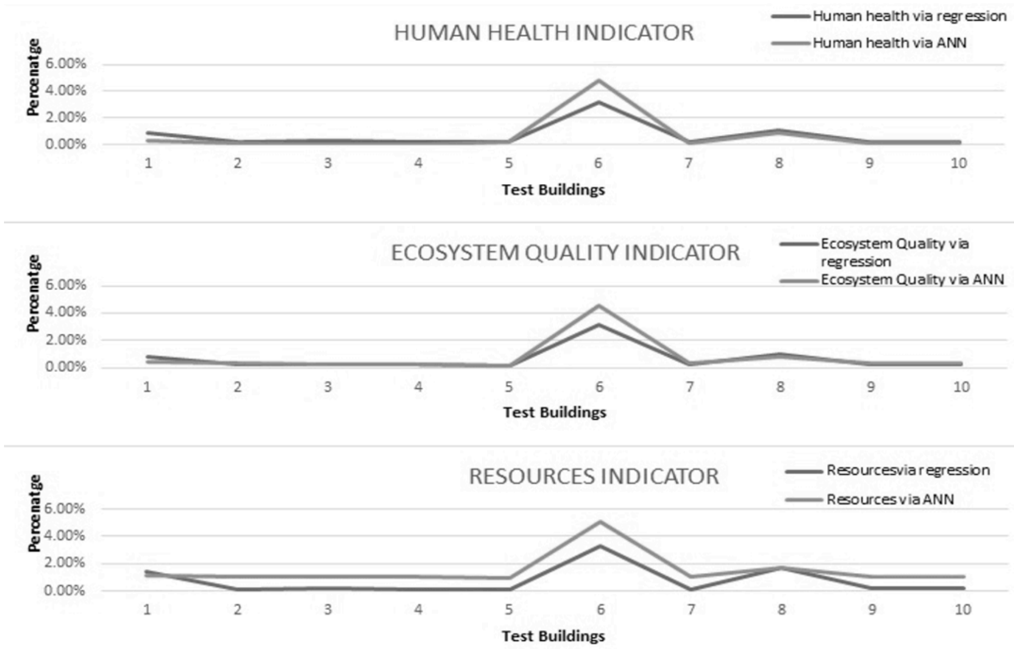

Figure 3: Regression vs ANN comparison of the percentage difference between predicted and actual

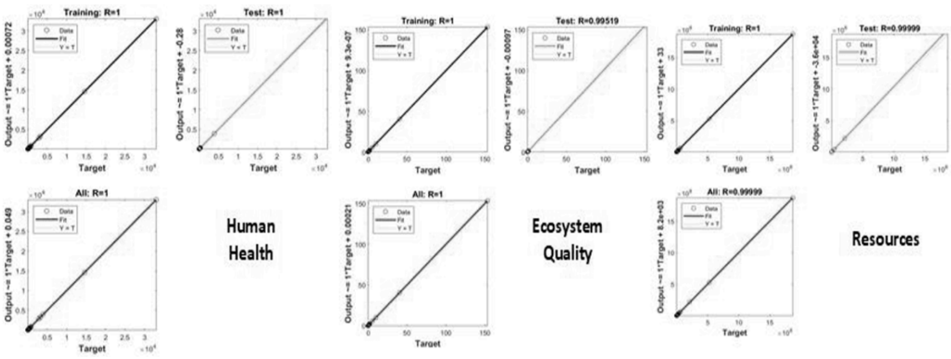

Figure 4: Results of ANN training

Therefore, for end-point indicators of human health, ecosystem quality, and resources, the MAPE for the samples tested is 4.46%, 4.52%, and 4.71%, respectively, as shown in Figure 5. It is a reasonably good model since the MAPE is below 5%. Hence, it can be used further in other decision-making frameworks for buildings which is demonstrated in the paragraphs further.

When building inputs vary (electricity consumption) constantly with time (dynamically), performing LCA becomes further tedious. Similarly, when LCA is adopted for decision-making in evaluating materials and their sourcing alternatives, it complicates the process of performing multiple scenarios with multiple datasets (Francis and Thomas, 2022b). For such dynamic applications, the use of substitute prediction models based on ML for performing LCA eases the process of decision-making even if their outputs are an approximate representation of actual cases. For instance, if there is a variation or replacement in the material content, such as cement or steel, remodelling and comparison can be quickly made using the surrogate/proxy LCA model.

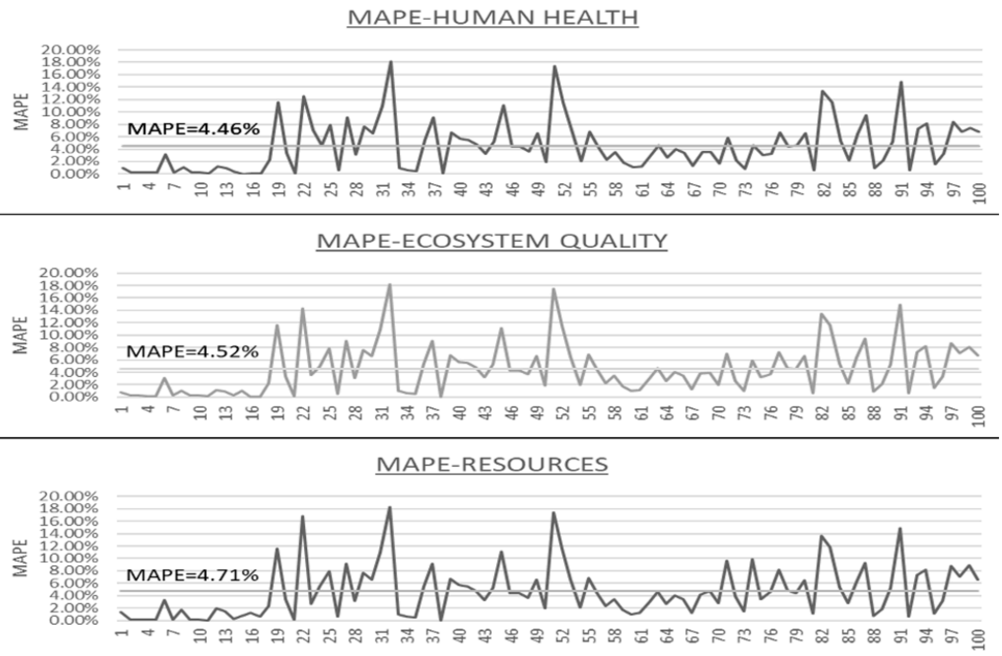

Figure 5: Mean Absolute Percentage Error for LCA indicators using regression

Figure 6 shows the average change in ReCiPe indicators with respect to the base case when material content is modified, as shown as percentage replacement from the base case. The graph shows the comparison between the actual LCA results of each scenario with the results generated from the substitute prediction LCA model as well. It shows that the trends are similar and data points are close for the 40 scenarios analysed.

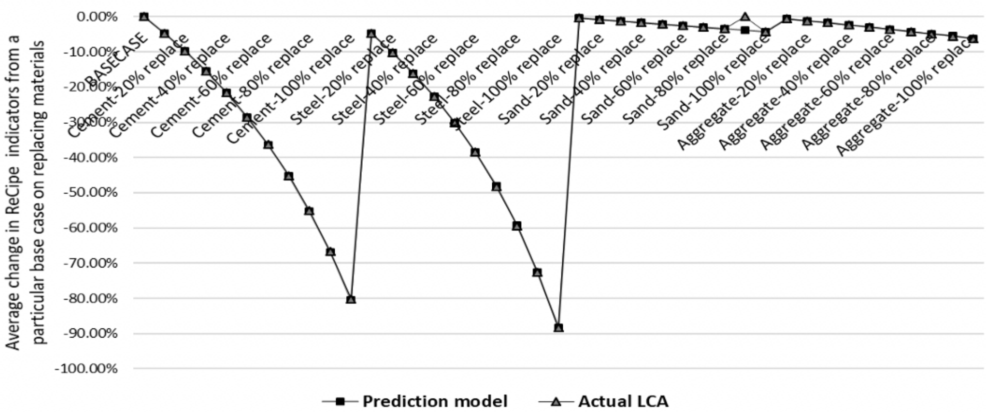

Figure 6: Average Change in LCA indicators with material variation

The advantage of using proxy LCA models is the ability to reduce complex computing when various scenario analyses are involved in enabling decision-making regarding environmental sustainability. For instance, in this specific building test dataset, the materials are replaced individually from 0 to 100 percent to evaluate the change in LCA indicators. By using the ML model, the results are obtained swiftly, and it can be observed that the cement and steel replacement significantly reduced the end-point indicators. These materials have the highest environmental impacts in terms of energy consumption among building materials, as reported by Bardhan (2011) and Jyosyula *et al.,* (2020). For this test data also, similar results are observed. Such analysis could enable the formulation of suitable policies such as local sourcing of materials to reduce trip emissions or policies regarding the use of alternative materials with lower environmental impacts. Hence, the use of substitute prediction models for LCA is recommended to enhance the decision-making process while overcoming the challenges of data gaps, data rigor, time consumption and non-uniformity in assessment methods.

CONCLUSIONS

The study introduces the application of ML algorithms to perform LCA analysis of buildings which is conventionally a time-consuming, data-intensive, and rigorous process due to the scale and size of the data involved. Further, when LCA-based decision-making is based on several scenario analyses, conducting LCA for each scenario is complex. Here, a substitute/proxy prediction model would efficiently help predict the LCA-based indicators for the buildings. Therefore, this study proposes a methodological framework to develop ML-based surrogate models to perform LCA for buildings. Testing such models on a sample building dataset shows that the MAPE between the actual and predicted is less than 5%, rendering such models suitable for prediction. However, a limitation of such ML models is the need to constantly update training data as common background LCA databases are updated periodically. Further, it would be advisable to use primary data regarding environmental impacts and characterisation factors of materials from actual sources to account for geographical influence on the data inventory and, eventually, the training dataset. The future scope should focus on testing such ML frameworks by generating larger training datasets with more materials, electricity consumption, and other entities associated with building such that a whole building LCA can be entirely done using these substitute ML-based models, enabling faster scenario analysis and its improved use as a decision-making tool.

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UNDERSTANDING THE MARKETING DEPARTMENT'S ROLE IN THE SOCIAL AND ENVIRONMENTAL VENTURES OF CONSTRUCTION COMPANIES

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Construction companies are commonly portrayed as project-based organisations that respond to client requirements and deliver standardised works and services determined by the traditional construction trades. However, modern construction companies are also partaking an increasingly important role in delivering sustainable solutions to social and environmental problems. The objective of the study is to provide insights into the efforts of a Danish construction company in delivering sustainable solutions by devising social and environmental ventures. In this regard, we have a special interest in understanding the role of the marketing department. The empirical material of the study is based on observations and conversations with employees in the marketing department gathered between 2018-2022. In the analysis, we examine two distinct ventures devised by the marketing department through an institutional work framework. On this basis, the study concludes that the marketing department plays a critical role in devising new social and environmental ventures that affect regulative, normative, and cultural-cognitive prescriptions in construction.

Keywords: institutional; social procurement; sustainability; waste management

INTRODUCTION

Building and construction sectors worldwide are increasingly confronted with demands to deliver sustainable solutions to social and environmental problems (Bal *et al.,* 2013; Buser and Carlsson, 2020; Leiringer *et al.,* 2022). These demands have been foregrounded in recent years through the gradual implementation of transnational as well as national regulation aiming to promote notions of sustainability in sectors and markets. At the transnational level, the European Union requires member states' companies with more than 500 employees to disclose information regarding their non-financial activities and report on their social and environmental impact (European Commission, 2021a). At the national level, in Denmark, the Ministry of the Interior and Housing (2021) has launched the 'Voluntary Sustainability Standard'. The

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standard has been proclaimed to support conversion and maturation of sustainability and is expected to be fully integrated in the Danish building code by 2023.

The efforts to promote sustainability in the European building and construction sectors by implementing transnational and national regulation have a dual effect on construction companies. On the one hand, the regulation stipulates specific measures and tasks that companies must endorse to ensure statutory and regulatory compliance (Brooks *et al.,* 2021; Gottlieb and Frederiksen, 2020). On the other hand, the regulation also stimulates a sense of awareness among companies implying that they must actively devise new social and environmental ventures to be at the forefront of the sustainable development (Leiringer, 2020).

Where the former primarily seeks to control the behaviour of companies (Edelman and Suchman, 1997), the latter alternatively draws attention to the agency of companies to purposefully affect and potentially change the institutional field endogenously (Dorado, 2005). The efforts of companies to devise new social and environmental ventures that diverge from otherwise institutionalised patterns of legitimate behaviour, however, are traditionally considered to be a complex and risky endeavour (Fisher, 2020; Frederiksen, 2021). This is also the case in construction, where companies are commonly portrayed as deeply ingrained in project-based organisations that respond to the requirements of the client and deliver standardised works and services determined by the construction trades (Hughes and Hughes, 2013).

The objective of the study is to provide insights into the efforts of a Danish construction company in delivering sustainable solutions by devising new social and environmental ventures. In this regard, we have a special interest in understanding the role of the marketing department. The marketing department under scrutiny has undergone a major development in recent years, which is striking as marketing research frequently reports on decreased influence of marketing departments at the level of corporate strategy (Verhoef and Leeflang, 2009). Marketing research also highlights that marketing departments often struggle to justify their relevance in the 'language of finance' that permeates most modern companies (e.g., Key *et al.,* 2020). In contrast to other departments' internal focus on production activities, the marketing department has a strong external focus on sector development and new market trends. Moreover, the marketing department is responsible for devising new ventures that bridge the company's commercial interests and emerging societal demands on sustainability in construction. Previous inquiries have demonstrated that such mediating efforts involve extensive institutional work (e.g., Rao *et al.,* 2000; Zietsma and Lawrence, 2010) by individuals or groups aiming to purposefully affect or change institutionalised patterns of legitimate behaviour in the field. We thus mobilise the concept of institutional work (Lawrence and Suddaby, 2006) as analytical framework to explain the reflexive interplay between the examined ventures and the bolstering or undermining of institutions. The empirical basis of the study consists of observations and conversations gathered in the marketing department between 2018-2022.

Institutional work

Whereas an institution represents social structures composed of regulative, normative, and cultural-cognitive elements that have attained a high degree of resilience and produces meaning and stability to social life (Scott, 2014), institutional work represents purposeful action aimed at creating, disrupting, or maintaining institutions (Lawrence and Suddaby, 2006). Institutional work thus introduces an agentic and practice-oriented approach to examine how individuals or groups become drivers of institutional change or institutional status quo by advocating for and experimenting with new ideas and practices in the field (Hwang and Colyvas, 2011; Zietsma and Lawrence, 2010). These new ideas and practices often imply relatively invisible and mundane micro-processes aiming at affecting or changing regulative, normative and/or cultural-cognitive elements of institutions in pursuit of self-interest (Lawrence *et al.,* 2011; Perkmann and Spicer, 2008). Performing institutional work moreover requires certain skills of the 'institutional innovators' (Zietsma and Lawrence, 2010) such as the ability to exert authority, set new agendas, frame arguments, and establish legitimacy (Fisher, 2020; Perkmann and Spicer, 2008). As such, studying empirical phenomena through an institutional work framework does not per se involve successful institutional change. Instead, it involves examination and understanding of the reflexive interplay between the actions of individuals or groups and the bolstering or undermining of institutions (Lawrence *et al.,* 2011).

Institutional work has experienced a growing popularity in organisation and management research since the concept was introduced more than 15 years ago (Lawrence and Suddaby, 2006). In recent years, the concept has also made its entry into construction management research along with other institutional concepts mainly to explain processes of change and innovation. For example, construction management scholars have applied institutional work to understand challenges regarding implementation of new waste management practices (Andersson *et al.,* 2019), the agency of environmental experts (Gluch and Bosch-Sijtsema, 2016) and the role of objects in change processes (Svensson and Gluch, 2022).

Scant attention has, however, been devoted to individual or groups operating in 'peripheral positions' (Zietsma and Lawrence, 2010; Rao *et al.,* 2000), such as marketing departments, despite their responsibility to translate exogeneous demands into field-level changes. In his contribution to the debate on the future trajectory of construction management theory and research, Bresnen (2017) also stresses that institutional work may enable construction management scholars to contribute to more profound organisation and management debates and thereby provide a wider impact. Mobilising the concept of institutional work thus allows us to capture and explain how the marketing department's efforts to deliver sustainable solutions involve institutional work that challenges institutionalised patterns of behaviour in context of Danish construction.

METHOD

Enemærke and Petersen is a Danish construction company founded in 1975. The company uses the slogan 'People who build for people - The construction industry’s social contractor', which reflects the company’s self-perception and declared approach to the market. The company employs more than 700 persons distributed on distinct production departments as well as cross-cutting departments such as accounting, administration, human resources and marketing. A prevailing understanding in the company is that persons affiliated the cross-cutting departments must be financed by and thereby contribute to strengthening the company's production activities. The Chief Financial Officer manifested this perception during a presentation of the company's balance sheet in 2019 where he stressed that "all salaried employees in the cross-cutting departments are resources that must be covered by our production activities".

The marketing department is led by the Chief Marketing Officer (CMO) and comprises an additional 14 persons who handle tasks and functions on branding, business development, communication, prequalification, public relations, sales support and most recently R&D. The department has undergone a major development in the past years due to ever-increasing demands from customers and governmental authorities to promote and deliver sustainable solutions in construction. For instance, the department has established a Head of Sustainability position, expanded its repertoire of activities within the social and environmental agendas and commenced industrial PhD projects to qualify the company's advancement within these areas.

The marketing department, for example, has intensified the company's involvement in waste management in the venture 'Next shed' and in social procurement in the venture 'Social employment'. In brief, Next shed introduced new practices of selective demolition in roof renovations as well as reuse and recycling of building materials that would conventionally end up as waste. Analogously, Social employment introduced principles for inclusion of unemployed residents in socially marginalised housing areas into the labour market. The two ventures are described further in the analysis.

Two researchers conducted empirical material in the marketing department between 2018-2022 through observations in the department (approx. one day a week) and conversations with the employees associated with the department. These methods were chosen as they could give us different empirical insights (Atkinson and Hammersley, 1998) at the level of the department and the individual employee, respectively. During our observations in the department, an explorative approach was mobilised to obtain an understanding of how the marketing department sought to stimulate internal awareness and coordinate its activities with the other departments when devising new social and environmental ventures.

Analogously, the conversations with employees were conducted informally (Spradley, 1979) as we mingled with employees in the department. During the conversations, we asked the employees to elaborate on the activities, developments, discussions, and challenges experienced in the department in relation to the new ventures. Our observations and the conversations with employees were not documented formally in written format but used in a reflexive manner (Klitgaard *et al.,* 2021) to reconstruct descriptions about the two examined ventures and obtain an understanding of the institutional work performed. More specifically, we analysed the empirical material by linking these to the literature on institutional work to identify how the marketing department engaged in actions aimed at disrupting, creating, or maintaining institutions.

ANALYSIS

At the global level, the building and construction sectors account for approximately 40% of the waste produced by volume (World Resources Institute, 2016) and forecasts by OECD estimate an increase towards 2060 due to the growth of the global economy (OECD, 2018). In addition, the Danish Government has in recent years published reports stressing the need to develop solutions that can contribute to waste reduction and prevention in context of Danish construction (e.g., Danish Government, 2015; Ministry of the Interior and Housing, 2021). The reports, however, largely articulate the need for construction sector companies to take a proactive role in finding and propagating solutions that redirect waste into new resources by challenging prevailing ways of planning, collaborating and communicating in construction.

With ambitions to address the waste problem in context of Danish construction, in 2018 the philanthropic association Realdania launched the competition 'Circular construction challenge - Rethink waste'. The competition invited companies from the construction sector to present new innovative proposals for recycling and upcycling of waste. As reward, the three winning proposals would be granted: (1) assistance to form the "right team", (2) expert guidance to refine the proposal and (3) up to €130,000 to develop a prototype.

Next shed was one of the winning proposals prepared by the architectural firm Krydsrum and Enemærke and Petersen's marketing department. The idea behind Next shed was to develop a construction concept for selective demolition of building materials in roof renovations that could subsequently be reused and recycled in the construction of new sheds. The proposal's stated interest in sheds was twofold. The first was that the documentation requirements in the Danish building code for secondary buildings (e.g., carports, garages, and sheds) are less strict compared to those for primary buildings (e.g., residential properties). This provides more favourable opportunities for reuse and recycling of building materials in secondary buildings. The second was that about a half million square meters of sheds are built in Denmark every year, which means that a construction concept for reuse and recycling of building materials in the construction of sheds could contribute to waste reduction.

In the Next shed venture, the architectural firm Krydsrum was responsible for preparing the architectural shed design. The design was based on the most common types of demolition waste from roof renovations such as insulation, rain gutters, roof tiles and wood. Analogously, Enemærke and Petersen's marketing department was responsible for orchestrating processes in relation to demolition, reuse, and recycling of the identified building materials, and for formulating the construction concept based on prefabrication. The building concept prescribed, among other things, how the identified building materials for reuse and recycling should be disassembled and transported to Enemærke and Petersen's construction factory for subsequent processing and assembly in prefabricated elements. Once the prefabricated elements were built, they were returned to the construction site and assembled. The process from disassembly of building materials to finished shed lasted for two weeks, of which the final assembly work took half a day.

In the venture, the marketing department introduced alternative practices in the company on selective demolition as well as reuse and recycling of building materials. This was, on the one hand, an attempt to comply with societal demands regarding waste reduction and prevention in construction and, on the other hand, an approach to stimulating awareness and promoting new practices on waste management internally in the company.

In the venture, the marketing department performed institutional work aimed at affecting or changing regulative, normative as well as cultural-cognitive prescriptions that are institutionalised in construction and thereby specify legitimate behaviour. The department engaged in actions to disrupt institutions by demonstrating that existing building code requirements on residential properties counteract reuse and recycling of building materials and thus constitutes a barrier to the wider propagation of waste management practices in construction (regulative). In addition, the department sought to create institutions by framing new practices on waste management as an approach to address societal demands on waste reduction and prevention (normative) and stimulating awareness on waste management in the company's production activities (cultural-cognitive).

A reform proposal published by the Danish Government expresses the importance to increase the workforce at large to promote a richer, greener and more talented Danish society (Regeringen, 2021). Among other things, the report presents visions for how a more inclusive labour market can contribute to increasing the workforce by creating jobs for people who are capable to work but are excluded from the labour market. An analysis prepared by the largest business and employers' organisation in Denmark, the Confederation of Danish Industry, also highlights the need of expanding the workforce in the construction sector. The analysis reveals that almost half of the companies in construction experience limited production due to labour shortage (DI Analysis, 2021). In line with this, the European Construction Sector Observatory stresses that the Danish construction sector must tackle the challenge of labour shortage to ensure economic growth in coming years (European Commission, 2021b).

According to the Danish Government (Regeringen, 2018, 2021), one way to increase the workforce is to include residents in socially marginalised housing areas in the labour market. Such an area, as per the Danish Government's definition (Regeringen, 2018), is a neighbourhood where: (1) more than half of the residents are first or second-generation migrants, (2) more than 2.7% of the residents are convicted and (3) more than 40% between the ages of 18-64 are unemployed. Hence, a more inclusive labour market has been touted as a pivotal means of addressing labour shortage and a way to increase integration of residents in socially marginalised housing areas and thereby combat parallel societies (Regeringen, 2021).

Towards 2030, major renovations of the socially marginalised housing areas in Denmark have been announced. With this in mind, a group of ten organisations (including industry associations, NGOs, social housing organisations, a pension company and a municipality) led by Enemærke and Petersen's marketing department formulated the Social employment venture. The main purpose of the venture was to develop guidelines that could inform construction companies and client organisations on how to create social value in socially marginalised housing areas by creating jobs for residents that were excluded from the labour market. As expressed by Enemærke and Petersen's Head of Sustainability during a conversation: "the socially marginalised housing areas are of particular interest because there's a shortage of labour in construction while there's a surplus of potential workforce in these areas in the sense that many of the residents are without job and education".

In the Social employment venture, Enemærke and Petersen's previous experiences from a renovation of 27 apartment blocks in a socially marginalised housing area in Aarhus, Denmark, were used as a starting point for the preparation of the guidelines. The experiences showed that a renovation project with an estimated value of €50M had the potential to create 3-5 apprenticeships, 5-10 full time jobs and 3-5 part-time jobs for residents in the local area. Examples hereof are: (1) apprenticeships in masonry and carpentry, (2) site workers who handle incidental tasks and clean up on the construction site, (3) service workers who make coffee, lunch and clean up construction trailers and (4) communications officers who, in the local language, inform the local community about the progress and purpose of the renovation project.

According to Enemærke and Petersen's CMO, inclusion of residents in the renovation of apartment blocks in socially marginalised housing areas is associated with several positive outcomes. Examples hereof are social value creation in the local community, recruitment of talented workforce, prevention of vandalism on the construction site and a strengthened corporate social responsibility profile (CSR). In addition, Green

Building Council Denmark had designated the Social employment venture as a particularly interesting case, which could potentially set a precedent for new evaluation criteria for social sustainability in the Danish version of the DGNB sustainability certification scheme.

In the venture, the marketing department developed guidelines informing construction companies and client organisation on how to create social value in socially marginalised housing areas by creating jobs for residents that are excluded from the labour market. This was, on the one hand, an attempt to comply with societal demands on increasing the workforce by promoting a more inclusive labour market and, on the other hand, an attempt to recruit talented workforce and strengthen the company's CSR-profile. The venture also involved institutional work aimed at affecting or changing regulative, normative, and cultural-cognitive prescriptions of legitimate behaviour in construction. The department engaged in actions towards institutional creation by lobbying for evaluation criteria on social sustainability in the Danish version of the DGNB sustainability certification scheme (regulative). Furthermore, the department framed the developed principles for inclusion of unemployed residents in socially marginalised housing areas in the labour market as an approach to address societal demands on increasing the workforce and creation of social value in socially marginalised housing areas (normative). Finally, the department advocated for the value of social procurement internally in the company to recruit talented workforce and strengthen the company's CSR-profile (cultural-cognitive).

FINDINGS

In the analysis, we have provided insights into how the marketing department devises new social and environmental ventures aiming to bridge the commercial interests of the company and emerging demands on sustainability in context of construction. In this section, we first discuss challenges related to mediating commercial and sustainability interests at the same time. Subsequently, we categorise activities performed by the marketing department to create, disrupt, and maintain institutions.

Mediating commercial interests and societal demands on sustainability

Efforts to meet commercial interests and societal demands on sustainability at the same time is a tricky endeavour for a company. If the company manages to meet commercial interests but fails to deliver the promised sustainability results, the company may be confronted with accusations of greenwashing or CSR-washing (e.g., Delmas and Burbano, 2011). Alternatively, if the company manages to deliver the promised sustainability results but neglect the commercial interests it may jeopardise the company's growth and survival (Fisher, 2021). Thus, an important task for the company is to strike a balance between commercial interests and societal demands on sustainability. In the analysis, we have showed how Enemærke and Petersen's marketing department, by devising social and environmental ventures, endeavoured to mediate the company's commercial interests and emerging demands on sustainability in construction. In this regard, we have also demonstrated that the marketing department, in collaboration with other field level constituents, performs institutional work by challenging institutionalised patterns of legitimate behaviour in construction.

Institutional work performed by marketing department in the ventures

In the two ventures, the marketing department engaged in actions aiming at creating, disrupting, and maintaining institutions. Actions towards institutional creation entailed the promotion of new ideas and practices on waste management and social procurement in the form of a building concept for reuse and recycling of building materials, evaluation criteria for social sustainability and guidelines for job creation in socially marginalised housing areas. Moreover, the marketing department attempted to generate social support thereby legitimising the new practices (Fisher, 2020) by framing the ventures as solutions to problems in construction regarding waste production and social exclusion. Actions towards institutional disruption entailed delegitimising existing institutionalised patterns of behaviour (Zietsma and Lawrence, 2010) in construction by framing them as counteracting the fulfilment of societal demands regarding waste reduction and increasing the workforce. More specifically, the marketing department framed the building code requirements as a barrier to the wider propagation of waste management practices and the labour structures as inadequate in terms of creating jobs for people who are excluded from the labour market. Finally, actions towards institutional maintenance entailed the reproduction of ideas and practices (Lawrence and Suddaby, 2006) on waste management and social procurement. In this pursuit, the marketing department internally advocated for the ventures by linking these with the achievement of commercial benefits as well as compliance with societal demands on sustainability.

The study contributes to existing literature on institutional change and innovation in construction with an understanding of how a marketing department performs institutional work to promote notions of sustainability in construction. Marketing departments are rarely the subject of analysis in construction management research, which is likely due to the supporting and peripheral position (Zietsma and Lawrence, 2010) of such departments in project-based construction companies. However, as shown in this study, marketing departments fulfil a critical role in the social and environmental ventures of construction companies, and we therefore suggest that actors operating in such peripheral positions are devoted greater scholarly attention.

CONCLUSION

Our interest in the study was to obtain an understanding of the marketing department's role in the social and environmental ventures of construction companies. In the study, we showed that the marketing department under scrutiny, besides conventional marketing disciplines such as branding, communication, public relations, and sales support, also strived to promote sustainable solutions in construction by devising new social and environmental ventures. We also argued that the two examined ventures, Next shed and Social employment, illustrated the efforts of the marketing department to bridge the company's commercial interests and emerging societal demands on sustainability in construction. In this regard, the marketing department performed institutional work in the ventures to mediate at thereby strike a balance between the company's commercial interests and societal demands on sustainability. The institutional work performed involved both regulative, normative, and cultural-cognitive work aimed at creating, disrupting and maintaining institutions. On this basis, we conclude that the marketing department plays a critical role in the social and environmental ventures of construction companies. First by devising the venture. Second by framing the venture as a solution to social and environmental problems. Third and finally by promoting new practices and beliefs in the company that support the stated aim of the venture. In addition, we conclude that the institutional work performed by the marketing department to establish new venture legitimacy (Fisher, 2020) is crucial to bridge the company's commercial interests and emerging societal demands on sustainability in construction.

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AN INSTITUTIONAL ANALYSIS OF HOW THE CONSTRUCTION INDUSTRY'S COMPLEXITY AFFECTS WASTE: AN ALTERNATIVE RESPONSE TO FUTURE MARKET DEMANDS FOR SUSTAINABILITY

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As a main consumer of resources and an important economic driver, supranational authorities (UN/EU) are expecting the construction industry to address sustainability issues, making the construction process an extremely complex activity. A response to this complexity is often expressed through technologies, strategies, and organisations. However, the effect of waste, defects, and failures affecting both productivity and sustainability has increased due to e.g., tough competition, temporary exchanges, and individual utility maximisation. This has been discussed for many years, where knowledge on the institutional causes for waste is still needed to qualify and target future initiatives stressing the 'Build Back Wiser' theme. We analytically address the waste phenomenon through a lens of institutional theory and a mixed-method inquiry; interviews, literature search and index data linking societal expectations and industry responses. We contribute with understandings on how strategic partnerships can be a response to supranational authorities and future market demands for sustainability.

Keywords: complexity; partnerships; productivity; sustainability; waste

INTRODUCTION

The construction industry is an important part of the global economy, creating growth, jobs, and welfare. However, its activities lead to global warming, pollution, and resource scarcity. The construction industry accounts for 38% of the global CO2 emissions, of which less than 1% comes from constructing the buildings, almost 10% from material manufacturing, and the remaining 28% from the use phase (UNEP, 2020). The construction and maintenance of buildings and infrastructure represent almost 50% of the global material consumption, and in return generates 40% of solid waste streams, while around 10-15% of building materials are wasted during construction and 54% of demolition materials are landfilled (Eberhardt *et al.,* 2021).

Considering the significant societal impact of the construction industry, an immediate response to ensure a more ambitious sustainable development is needed. Thus, supranational authorities (EU/UN) are expecting the construction industry to address

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different issues, e.g., resource scarcity, CO2 emissions, and productivity, making the building process a complex activity. The Danish construction industry is trying to handle this complexity through different technologies, strategies, and organisations. Yet, the effect of defects, failures, waste, and rework collectively referred to as 'waste' has increased over the previous two decades. This is reflected in a recent study of waste in the Danish construction industry (de Place Hansen *et al.,* 2021), including a development of a 'waste index', created in 2007 (Nielsen and de Place Hansen, 2007).

Figure 1, highlighting the Danish construction industry waste index during 2004-2019, shows that the amount of waste, in 2004 estimated to make up 10% of the construction activity and costs, still must be taken seriously. This indicates that while the extent of waste has remained practically unchanged, or in some isolated instances even decreased, the overall effect of waste correlates with macroeconomic factors. In 2004, the total construction waste in Denmark was estimated to 10% of the production value EUR 1,6B, which is equal to EUR 3B in 2021 (Erhvervs- og Byggestyrelsen, 2004).

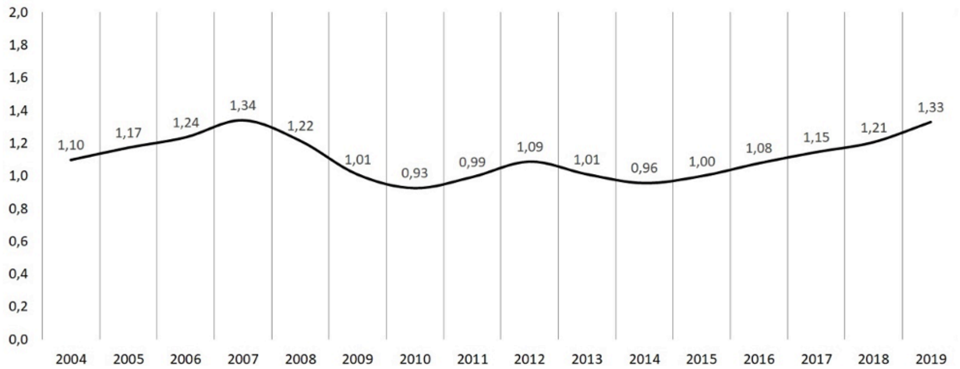

Figure 1: The Danish construction industry waste index during 2004-2019

To assess the waste phenomenon a holistic definition is adopted as: 'any unnecessary deviation with a negative impact on the overall organisational result or project performance' (Love and Smith, 2018). This definition can be divided into two types: 'process waste', e.g., erroneous decisions and actions that produces an incorrect result, and 'product waste', e.g., building defects and excess use of materials. The waste phenomenon causes significant loss of value and impacts, e.g., resource consumption, CO2 emissions, and productivity, involving direct and indirect costs. Although having been discussed for many years, systematic knowledge on the causes for waste is still needed to qualify future initiatives. The waste phenomenon is being neglected due to its complex nature, which we believe are related to competing institutional settings. Thus, revisiting this complex issue, is a pivotal step towards the 'Build Back Wiser' theme intriguing new knowledge on how the waste phenomenon is related to both productivity and sustainable development in the Danish construction industry.

The objective of the paper is to scrutinize the interplay between institutional pressures and organisational responses in relation to the waste phenomenon. The analysis is made at project, organisational and industry level to understand the consequences of different industry mechanism and dynamics in an institutional perspective. This involves a mixed-method approach using semi-interviews, waste index data, and background literature creating more nuanced insights. The paper proceeds as follows: first, the theoretical perspective is presented, which is based on institutional theory. Then the method is described before moving on to the multi-level analysis. This approach creates an understanding of how competing institutional logics leads to complexity and an increased amount of waste. Next, the analytical results are discussed and related to the sustainable development of the Danish construction industry. Finally, the conclusions and suggestions for further research are presented.

Due to the Danish construction industry's institutional structures and pluralistic characteristics, the waste phenomenon become equally multifaceted and complex. The pluralistic characteristics originate from a myriad of demands and perceptions (or logics) that coexist and competes based on legitimacy. Pluralism can be difficult to handle, involving multiple societal demands creating, e.g., contradiction between productivity and sustainability requirements. When these different demands and perceptions are incompatible, complexity arises. Analysing institutional complexity involves central institutional theory concepts, e.g., pluralism, complexity, logics, agency, and legitimacy, all of which describes how norms and conventions affects change in social structures. In a general sense, pluralism denotes diversity and societal coexistence, complexity: intricacy and numerosity, logics: modes of reasoning, agency: exertion of power in temporal engagements, and legitimacy: conformance to recognized principles (Greenwood *et al.,* 2011). By perceiving the construction industry as a social system or field, i.e., as a group of actors that abides to different logics in a shared construct, we apply a more systemic approach for understanding how the interrelatedness between different levels, e.g., project, organisation, and industry, defines complexity in relation to analysing the waste phenomenon.

Thus, we argue for an institutional theoretical perspective that addresses systemic complexity, which we find appropriate for analysing the interplay and competition between different ideal institutional logics, i.e., professional, corporate, and market (Goodrick and Reay, 2011), as well as the community logic (Thornton *et al.,* 2012) introduced in the discussion. The professional logic applies when professionals work with other professionals in the same profession and are often supported by pragmatic legitimacy. The corporate logic applies when professionals are employees in a firm, and managers, not professionals, determine the content and organisation of work and the necessary credentials and sanctioning, and are often supported by regulatory legitimacy. The market logic applies on neoliberal understandings (or capitalism) and are often supported by normative legitimacy. Finally, the community logic are the embodiment of local beliefs, norms and rules which are rooted in efforts to ensure the commitment of individuals to a network through means of culture, identity, and values, and are often supported by cultural-cognitive legitimacy (Deephouse *et al.,* 2017).

METHOD

A mixed-method approach is chosen, as it enables an abductive and qualitatively driven research paradigm with complementary strengths. The abductive approach is expressed through an empirical problem (the waste phenomenon), where the analysis and discussion create contexts and patterns across the empirical data through a lens of institutional theory (Dubois and Gadde, 2002). A qualitative coding has been created across the empirical data involving a literature search, index data, and semi-structured interviews. The literature search has been conducted in the Scopus database targeting process and product themes, e.g., defect, waste, risk, rework, failure, and error in the construction industry. The waste index data was generated based on the 'Danish index of construction defects' (Nielsen and de Place Hansen, 2007) and the recreated index (de Place Hansen *et al.,* 2021), involving data on waste from Danish sources, focusing on macroeconomic statistical data regarding construction costs and activity.

Eleven representatives from the Danish construction industry were interviewed, representing five roles: client, architectural consultant, contractor, researcher, and insurer. The interviews were based on an interview guide addressing different open questions about how e.g., project processes, organisations, company structures and industry environments influences the waste phenomenon as well as more reflective questions on productivity and sustainability. The statements were transcribed and coded according to different 'identify patterns', which was used to qualitatively capturing the different institutional logics, i.e., professional, corporate, and market in the empirical data (Reay and Jones, 2016). Initial results have been coded in Table 1, stressing various solutions and problems mechanisms as well as linking institutional theory and the empirical data to the multi-level analysis of the waste phenomenon.

Levels and logics	Empirical problem mechanisms	Empirical solution mechanisms
Project: Influenced by the professional logic and pragmatic legitimacy	Low influence, client changes, and narrow cost focus counteracts performances. Time and economic pressure reduce motivation and poor initial planning affects the entire operational process.	Early involvement practices, operational awareness and focus on buildability through the different construction phases. Better process management, planning, coordination, and stronger professionalization.
Organizational: Influenced by the corporate logic and regulatory legitimacy	Difficult to meet societal pressures, high-risk scenario, low earnings, and hidden economical buffers. Lack of leadership, communication, learnings and academization creates organizational misalignments.	Risk and quality management, and better alignment between formal strategies and the operational process. Stronger strategic handling of the uncertainty and variation that defines specific construction processes.
Industry: Influenced by the market logic and normative legitimacy	Competitive tendering, re-tendering, deadline pressure and many legal disputes. Lack of stability and continuity. Project-based organizations, fragmentation, and short-term relationships.	A partnership and process-oriented approach focusing on planning and coordination of common workflows and cooperation throughout the value chain creating e.g., repetition effects and a more solution-oriented culture.

Table 1: Various mechanisms of solutions and problems of the waste phenomenon

In sum, the mixed-method approach creates an opportunity to triangulate the empirical data to better analyse the waste phenomenon in the institutional setting of the Danish construction industry. Yet, generalisations are not universal, but context based and require understandings of how this study differs from other studies (Siggelkow, 2007).

ANALYSIS

Institutional complexity refers to the experience of incompatible prescriptions from different logics that coexist or compete in the same field (or industry). The field perception is utilized in the analysis to dissect and understand institutional complexity in the Danish construction industry across different levels, i.e., project, organisational and industry. Thus, emphasizing an analytical focus on how different institutional logics dominate and influences these different levels creating complexity and waste.

Project Factors and the Professional Logic

A construction project can essentially be seen as a temporary social system involving a set of agreements made between different actors to complete a specific task. In the early project stages a multitude of decisions for the functionality of the finished building are made, which will affect the outcome of the construction project - the physical building. Even at this early stage, the professional logic may be at play involving pragmatic legitimacy (it must be buildable). This often applies to early involvement practices, where there are interactions between e.g., client, architect, and engineer, and to some extent the contractor. However, a high level of abstraction is present at this stage, as the proposed building is still an abstract idea that is being specified and designed, which does not necessarily create a high influence of the professional logic. As for subsequent project complexity and waste, this is where the first errors are made that will potentially permeate the rest of the construction project.

The client is often subject to entering agreements with the cheapest contractor heavily influenced by the market logic, but only 56% of construction projects meet the agreed budget and only 48% comply within the time frame (Eke *et al.,* 2019). This calls for a greater focus on buildability instead of a narrow cost focus. Moreover, the client's change of materials, designs, plans, or objectives have the greatest negative impacts on costs, quality, and waste (Hwang *et al.,* 2014). These issues are supported by the architects' respondents, stressing that the client is the culprit for waste. This is allegedly due to a lack of understanding for the subsequent production processes, which is dominated by professional logic. Yet, there are different attitudes to early involvement and influence of the professional logic expressed by an architectural respondent: "If you focus on buildability too early, you might miss requirements for what it is you're building. So, if the contractor is involved too early, they will likely be more occupied by how to build, more than what to build". In contrast, one of the contractor respondents argues that: "early involvement is essential for reducing waste and stresses the importance of getting involved in the early project stages".

Lack of motivation caused by changes appears to be a significant cause of waste but can also be accredited to commitment if the actors can't find meaning in their work. This is emphasized by a culture of perpetual time pressure and intense competition of lowest price, where time and economic pressure has a negative effect on behaviour (Josephson and Hammarlund, 1999). This is unveiling an inefficient influence of the market logic, which is normative legitimized or what is considered appropriate on a neoliberal market. The client's primary interests are arguably economical and temporal; the architect's interest - especially when acting as the client's consultant - reflects the client's interest, needs and requirements into a realisable project material; and the contractor's primary interest is in buildability and biggest possible earning, which, naturally, applies to competition between the market logic and the professional logic. This competition is manifested by various inconsistencies across the construction phases leading to complexity and waste. The result is that the production is initiated before the project is ready to handle the execution, with frequent rework, delays, interruptions, and complications leading to both process and product waste.

Organisational Factors and the Corporate Logic

In the field of the construction industry, there are embedded different organisations, where the dominant and major contractor companies are guided by the corporate logic. The corporate logic is based on regulatory legitimacy through formal structures and sanctioning. In an organisational perspective, the contractors' success is based on its ability to create market legitimacy by responding to societal expectations, e.g., digitalisation, sustainability, and productivity. However, efficient handling of institutional pressure is expressed through a high-risk scenario. Thus, handling risks plays a crucial part in the company's performance and especially in relation to a low earnings margin of 3-5% in the Danish construction industry. Contractors seek to respond to institutional expectations and risks through strategies, organisations, and management. Yet, the corporate logic competes with the professional logic, and within major organisations, where there often is a misalignment between the main organisation and the project organisation. Moreover, contractors often employ hidden economical buffers due to risks, which conflicts with the overall intent of reducing waste, as any protective buffers can be regarded as waste (Ortiz *et al.,* 2018).

This problem is expressed through an ongoing implementation of formal quality management, but errors and defects continue to arise in the construction industry (Jingmond and Ågren, 2015). This indicates that it is difficult to produce building components, systems, and installation processes, adapted to specific dimensions, variations and insecurities that characterizes a construction project. Seemingly, these problems can be accredited to human errors on the operational level, which is influenced by the professional logic, but they can often be related to organisational factors in the form of a lack of leadership and communication on strategic levels (Love and Smith, 2018). This misalignment between the corporate logic and the professional logic was pointed out by a contractor respondent, who emphasized that managerial 'academisation' of the construction industry has impacted the production process in a negative way: "Academics can do a lot of things very well, but there tends to be a lack of practical understanding of what aspects are needed when the operational phases start". Despite a somewhat reluctant stance towards including academia (or business school understandings) into management, the interviewees agree that a more practical understanding plays an important part in reducing waste.

To a contractor, waste is not just temporal and economical, but also physical, i.e., construction materials. And to reduce waste, different perspectives on waste must be considered when designing an effective project-organisation, as these perspectives are not only determined by the professional logic but are also heavily affected by the company's formal business models and strategies involving the corporate logic. Yet, an ongoing academisation of the construction industry is taking place, as claimed by a contractor respondent: "I think there’s a tendency to the early project phases getting academicized. Often, a practical understanding is missing". The contractor elaborates through describing how it used to be a tradition that you started your career in the production, then progressed to engineer, and then you could become an architect or part of senior management in a contractor organisation. Yet, formal organisations are dominated by the corporate logic (or business school understandings) leading to misalignments and thereby waste between the formal organisation and the production.

Industry Factors and the Market Logic

When different types of construction organisations are enclosed by the same field, a common set of structures and norms is defined and enforced by a dominant market logic, e.g., conjectures, tender forms, and cooperation models. The market logic is apparent in the way that different organisations respond to societal expectations, where waste is about financial means, more than a consideration of sustainability. The market logic is characterized by neoliberalism (or free market forces) involving competitive tendering, which is a cause for waste. This is evident by an architect respondent: "the way these projects are put out to tender and the competition it creates, causes a magnitude of issues and consequent waste, defects and errors, that are very apparent in construction”. This is a general issue with many interfaces, including time pressure: "Add time pressure to competitive tendering, then you are sometimes forced to send a project out to tender before it is buildable, so you can meet the deadline". Thus, the market logic competes with other logics, e.g., the corporate and professional logic, which emphasizes a constellation of several logics that affects the construction processes throughout the different phases and activities.

One solution mechanism to accommodate this issue of competitive tendering and time pressure, is initiatives aimed at increasing cooperation throughout the value chain, as indicated by Fernandes *et al.,* (2018), who argue that partnerships or strategic alliances can make construction more efficient and less resource demanding through repetition effects and stronger relationships. These approaches can potentially foster more cooperation, trust, and solution-oriented culture, than what is traditionally associated with the construction industry. This would in turn reduce the extent of e.g., errors, defects, and legal disputes. However, this approach necessitates effective interactions and adjustments between the various logics rather than competition and dominance of only one logic stressing a more pluralistic response to institutional expectations and demands (Fredslund, 2021). Thus, a productive and quality conscious construction industry prerequisites a more partnership and process-oriented approach focusing on planning and coordination of common workflows, resulting in a higher construction quality (Sacks *et al.,* 2017). Reduction of general waste are achieved by continuous notification, assessment and indication of work processes focusing on stability, continuity, and evaluations. This approach means increased focus on involving all parties in the early project processes or the adoption of a partnership organisation creating cooperation, knowledge sharing and communication across the value chain.

Such approaches are significant for e.g., minimizing erroneous deliverances and unfit products on the construction site, as well as reducing waste in the construction processes (Alves *et al.,* 2020). Despite this premise, few organisations in the Danish construction industry assess their quality costs, understood as internal costs, e.g., errors and rework and external costs, e.g., negative reputation before and after a product or service has been delivered (Love and Li, 2000). This problem may help to explain why the waste percentage has been constant in recent decades. In sum, a reproduction and focus on the market logic fails to reduce waste in the Danish construction industry.

FINDINGS

The findings of the multi-level analysis indicated that the Danish construction industry is characterized by complex business processes and project-based organisations that fosters uncertainty, risk, and inadequate quality, despite its societal significance. The level of complexity is high in the Danish construction industry due to inefficient competition between logics, e.g., professional, corporate and market, which leads to both process and product waste. A partnership organisation is highlighted across the literature and respondents as a significant solution mechanism among other potential initiatives. The assumption is that a partnership approach creates effective interactions and adjustments between the different logics involving a more pluralistic response to different institutional pressures, demands and expectations. This approach is stated through new forms of strategic partnerships in the Danish construction industry, focusing on interactions and adjustments between logics, rather than an ineffective competition and dominance of one logic obviously increasing waste and negative externalities. As such, the strategic partnership approach has created fewer disputes, stronger productivity, repetition effects, long-term cooperation, and less waste.

In advocating the need for partnerships and organisational harmonisation across the Danish construction industry in general, we argue that there is a misalignment between how waste is perceived and created at different levels, e.g., project, organisational, and industry stressing an inefficient competition between logics. This misalignment significantly adds to the institutional complexity that permeates the construction industry, and consequently maintains the level of waste. The metrics for the first Danish index of construction defects (Nielsen and de Place Hansen, 2007) did not take macroeconomic factors into account, whereas the new Danish waste index (de Place Hansen *et al.,* 2021) reflects the overall level of waste in the Danish construction industry relative to surrounding factors, e.g., development of construction activity and costs. More activity and higher costs equal a larger waste impact affecting productivity and the sustainable development of the Danish construction industry.

It is based on these issues that we will introduce the community logic, which is legitimized by conforming to meanings that supports the overall sustainable development of the society. In a sustainability perspective, the community logic is currently supported by different supranational ambitions, e.g., the UN 2030 Agenda for Sustainable Development and the EU Taxonomy on Sustainable Activities, involving a transformation to the circular economy. The circular economy is interesting since waste does not exist in an ideal form and actors work together in more aligned and long-term relationships, creating different product or service loops. Thus, the community logic is based on the constitution of a community through shared values and ideologies involving a more 'cooperative capitalism' (Thornton *et al.,* 2012) or solidarity-based economy with a greater regard for both sustainability and circularity.

In a historical perspective, economic needs have preceded environmental needs, as the former legitimized itself before the latter. Sustainability did not receive attention before the issue of climate change was legitimized relatively recently as an all-encompassing concern. In the Danish construction industry, public tendering is governed by EU legislation, which we argue is reproducing the market logic intended to govern fair market competition. However, it contributes to loser/winner benefits, contractual cooperation, conflicts, and waste affecting motivation, cost, reputation, and the environment. This is an example of how different sustainability aspects, i.e., economy, social and environment are affected through waste and a reproduction of the market logic. Hence, sustainability ought to be recognized as a new core premise in the institutional field of the Danish construction industry, involving a stronger influence of the community logic adjusting the 'taken-for-grantedness' of the current market logic. We therefore argue that relevant attributes of the community logic must be involved in the constellation of logics affecting the overall structures and practices of the Danish construction industry. In this pursuit, we advocate for a more pluralistic response to the waste phenomenon addressing an ambitious sustainable development.

CONCLUSION

The institutional perspective has helped to better understand the ineffective and self-replicating practice that perpetually produces waste through institutional complexity in the Danish construction industry. Apparently, waste did have an increasing effect over the past two decades, understood by an ineffective competition between different logics, e.g., professional, corporate and market. The Danish construction industry should potentially focus on a strategic partnership approach, involving a pluralistic constellation and interactions of different logics, to reduce disputes, misalignment, and waste. The partnership approach not only entails a reduction of waste, but at the same time creates an opportunity to involve other empirical solution mechanisms, e.g., early involvement, process management and organisational alignment. At the same time, this creates a better opportunity to respond to supranational ambitions (EU/UN), which is highly influenced by the community logic e.g., the EU Taxonomy on Sustainable Activities or the 17 UN SDG 'Partnerships for the Goals'. Thus, a future pluralistic constellation of logics must seek relevant influence from the community logic stressing a more solidarity-based economy with a greater regard for both sustainability and circularity. As such, the paper contributes with a more holistic and institutional understanding on how the waste phenomenon can be related to relevant empirical problems and solutions in the Danish construction industry including the overall sustainability challenge. This approach stresses the 'Build Back Wiser' theme creating new knowledge about how to handle historical and well-known issues in the Danish construction industry by addressing relevant problems of the future. Further and more empirical research into radical change of the waste phenomenon is of course necessary, and particularly how waste can accurately be converted into CO2 values.

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ENERGY-SMART BUILDINGS: A CONCEPTUAL FRAMEWORK TO IMPROVE BUILDINGS' ENERGY PERFORMANCE

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Buildings contribute to nearly 40% of the carbon dioxide emissions in the United Kingdom, and a significant proportion of this energy is consumed to control the indoor environment (i.e., heating, cooling, and lighting). Several efforts have been undertaken to reduce the energy consumption of buildings. However, existing approaches often fail to capture a comprehensive image of the buildings and their occupants and, consequently, fail to forecast their energy consumption accurately. This paper aims to address this gap by proposing a novel framework for forecasting occupants' energy behaviour based on real-time video data processing and agent-based modelling (ABM) and, consequently, predicting buildings' energy consumption. The proposed framework is expected to improve the accuracy of energy simulation techniques by capturing the most realistic features of the building and its occupants through a mix of data- and law-driven techniques. The architecture of the proposed framework is presented in this paper as a proof of concept, and the feasibility of this framework is discussed.

Keywords: low carbon; energy behaviour; multi-agent modelling; energy simulation

INTRODUCTION

According to the International Energy Agency (GABC *et al.,* 2019), buildings consume 36% of the global energy and contribute to 39% of the global carbon footprint. In the UK alone, the carbon emissions caused by buildings during their operational phase account for 25% of the national carbon footprint. These statistics show the significant contribution of buildings to the national energy consumption and carbon emissions, thus, confirming the importance of developing energy-efficient buildings for the realisation of the Net Zero Strategy (HM-Govenrment, 2021) for building back the UK economy greener. To achieve this, several efforts have been made to predict buildings' energy demand profile (EDP) and minimise buildings' energy consumption.

However, an accurate prediction of a building's EDP requires the modellers to accurately simulate its occupants' energy behaviour (OEB) (Bahadori-Jahromi *et al.,* 2022). Existing predictive models for OEB often rely on a few static parameters (e.g., number of occupants) and static predictive techniques (e.g., artificial neural networks) and fail to deliver accurate predictions of OEB since they ignore two key features of

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OEB: (I) social interactions between buildings' occupants (Ding *et al.,* 2019); and (II) the dynamic behaviour of occupants — in terms of their actions, clothing, and energy characteristics, which cannot be captured by static models (Kashif *et al.,* 2013). Accordingly, to increase the reliability of EDP predictions, OEB needs to be captured effectively in different scenarios. This paper addresses this gap by introducing a hybrid framework for forecasting OEB by integrating computer vision (CV) and agent-based modelling (ABM) techniques.

The proposed hybrid framework is developed using a modular architecture, in which the modelling modules exchange data in real-time. The CV module can effectively process the real-time video data captured from the occupants and forecast their individual energy consumption based on the most realistic data; consequently, it can improve the accuracy of OEB predictions compared to the conventional time-based schedules (Anand *et al.,* 2022). However, there are three drawbacks of the CV-based frameworks that limit their widespread applications for OEB predictions, namely (I) reliance on large training/testing data; (II) their context-dependency; and (III) the limited number of features captured. These limitations of CV-based frameworks can be addressed in integration with ABM. ABM is a recently developed simulation technique that is suitable for modelling complex systems, in which the overall system behaviour is generated by the several interactions that occur among different types of agents within a complex environment (Seresht *et al.,* 2018). The application of ABM in the proposed framework helps capture the several interactions between the buildings' occupants (Ding *et al.,* 2019). Additionally, combining CV with ABM reduces the dependency of the proposed framework on training and testing datasets and helps with developing more scalable models by reducing its context dependency. Finally, the combination of CV and ABM allows the proposed framework to capture the several aspects of occupants' social behaviour, which may, in turn, affect their energy behaviour. Accordingly, the proposed hybrid CV-ABM framework is expected: (I) to improve the accuracy of OEB forecasts in energy simulation practices; (II) to facilitate the development of more scalable predictive models; and (III) to reduce models' reliance on context-specific training and testing data.

METHOD

Addressing the adverse environmental impacts of human activities in the built environment is of the key concerns in several countries around the globe, as reported by the United Nations Environment Programme (UN-Environment-Programme, 2022). Buildings as one of the key contributors to global greenhouse gas emissions (GABC *et al.,* 2019) have received great attention from the global research community. Several efforts have been made to reduce the carbon footprint of buildings by minimising their energy consumption during the commissioning phase, and this can be best achieved by developing accurate predictive models for forecasting buildings' energy consumption in the first place. Most efforts made in this context can be categorised into two distinct groups: (I) basic building energy simulation (BES) models that solely rely on buildings' characteristics and often overlook the impacts of occupants' behaviour on buildings' energy consumption; and (II) advanced building energy simulation frameworks that capture both the buildings' energy characteristics and occupants' energy behaviour for more accurate simulation results. Figure 1 presents the different categories of BES frameworks that exist in the literature.

The proposed BES framework in this paper combines the three BES modelling techniques highlighted in black in Figure 1. The limitations and strengths of each modelling technique presented in Figure 1 are discussed in this section. The proposed BES framework in this paper can be categorised as an advanced BES framework, which combines the capabilities of the CV-based and simulation-based models to increase the accuracy of energy simulations and the scalability of models.

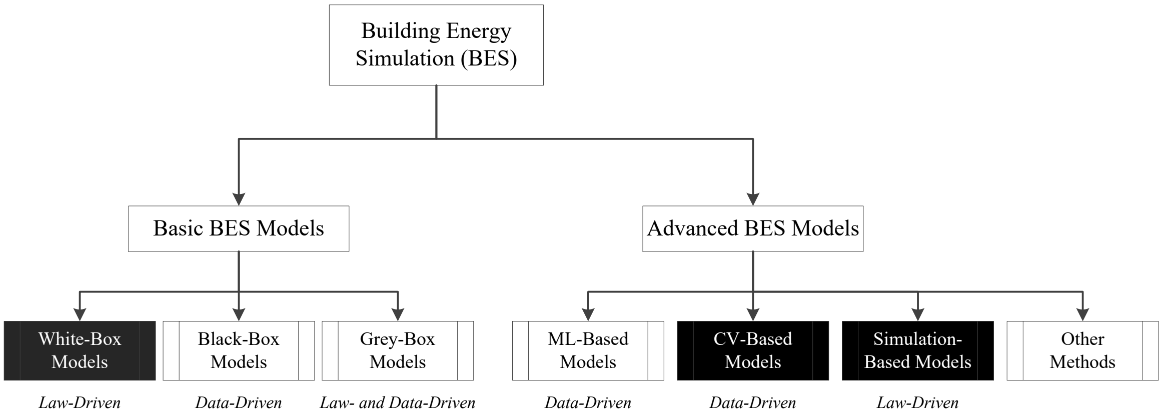

Figure 1: Building Energy Simulation Categorisation

Basic Building Energy Simulation Frameworks

The BES frameworks have been significantly improved since the introduction of building information modelling (BIM), which assists these frameworks in capturing and analysing the several characteristics of buildings that affect their energy behaviour (Li *et al.,* 2020). The basic BES frameworks are generally categorised into three distinct groups:

- White-Box Models**:** The white-box models the energy characteristics of buildings and their surrounding environment and simulate the energy performance of buildings using the fundamental laws of mass, energy, and momentum conservation. In this context, the white-box models are categorised as law-driven prognostic models, in which the predictive model functions based on scientific laws rather than empirical data collected from a known phenomenon. Additionally, the white-box models are more scalable than any other type of BES framework since the simulations are made only based on the fundamental laws of physics rather than the features of a given building. However, white-box models need the architectural design to be completed before simulating energy consumption, and these models ignore some of the detailed energy characteristics of the building, such as lightning and curtains thickness. Numerous efforts have been made to simulate the energy consumption of buildings using white-box models, such as the model developed by Wei *et al.,* (2021) for predicting natural consumption in office buildings; and the solar energy conservation model developed by Zhang *et al.,* (2022).
- Black-Box Models**:** Like any other data-driven prognostic models, the black-box BES models use empirical data to map a number of buildings' features (i.e., input space) to the energy consumption of the building (i.e., output space). These models may use several different modelling techniques, such as statistical modelling (Fu *et al.,* 2021) or artificial neural networks (ANN) (Elbeltagi and Wefki, 2021). Unlike the white-box models, the black-box models are developed and trained using empirical data — often collected from a limited set of buildings — and the predictions of these models are most reliable for the same or similar buildings. As a result, these models are limited

in terms of their scalability, and their accuracy heavily relies on the selection of input parameters, quality and comprehensiveness of empirical data, and the methodology used for modelling (Tian *et al.,* 2020).

- Grey-Box Models: These frameworks are an integration of white- and black-box frameworks, in which a white-box model is first developed; and then, for enhanced prediction accuracy, some energy characteristics of the building are evaluated using black-box models and empirical data. Accordingly, these models can address the following limitations of the white- and black-box models: (I) the grey-box model can capture the very detailed energy characteristics of buildings using empirical data; thus, their prediction results are expected to be more accurate than the white-box models; and (II) the grey-box models simulate buildings' energy consumption based on the fundamental laws of mass and energy conservation; thus, the model is expected to be more accurate and scalable, as compared to the black-box models. Li *et al.,* (2021) have done a critical review on the applications of grey-box models for BES.

As the illustrations in this section reveal, the basic BES models solely rely on two sets of parameters for predicting the energy consumption of buildings: (I) buildings' characteristics that define their energy behaviour, such as thermal resistance of walls and windows; and (II) the environmental parameters (e.g., climate) of the surrounding area and geographical characteristics of the building (e.g., orientation).

Advanced Buildings' Energy Simulation Models

The basic BES models can only capture a few static attributes regarding the occupancy of buildings for simulation purposes — mostly the fixed schedule of the buildings' occupancy — and often ignore the dynamic attributes of occupants' behaviour that affect buildings' energy consumption. According to Delzendeh *et al.,* (2017), the basic BES models may have significant prediction errors (up to 300%) due to overlooking the impact of occupants' behaviour on buildings' energy consumption. To remedy this limitation, the advanced BES models were introduced to account for the OEB in addition to the buildings' energy characteristics and environmental factors. The development of advanced BES models has been emerging in recent years, utilising several different methodologies for modelling the occupants' behaviour, ranging from psychological and cognitive behavioural models (Von Grabe, 2016) to the deep learning and computer vision (CV) algorithms (Tien *et al.,* 2020).

The advanced BES models based on CV algorithms - called CV-based models, hereafter - are one of the most common variations of these models due to the high potential of image processing algorithms for capturing realistic features of occupants and buildings. However, like several applications of CV algorithms, these BES models are challenged by the requirement of large data sets for the training and testing of the CV algorithms. To remedy this limitation, the existing CV-based models often ignore several attributes of the occupants' behaviour and only focus on those few features for which training, and testing data are publicly available; or can be captured by the universal computer vision models (Redmon and Farhadi, 2017). As a result, existing CV-based models ignore several key features of the occupants' behaviour and their interactions with the building, which can significantly reduce the accuracy of these models. As an example, Tien *et al.,* (2020) introduced a CV-based BES model for office buildings and used the publicly available image processing libraries to assess the number of occupants and the amount of equipment in use at each point of time inside the office buildings.

Their model succeeded in improving the accuracy of energy consumption predictions, as compared to the basic models, by capturing live data about the number of occupants and equipment-in-use. However, they ignored several key features of OEB, including occupants' actions, their interactions with the building, and clothing. Finally, the CV-based models are categorised within the data-driven prognostic models; thus, the scalability of these models can be challenged if the data used for training and testing purposes relate to the unique characteristics of the building and/or occupants. To address these research gaps, this paper presents the architecture of a novel advanced BES framework using CV and ABM, in which the CV component captures the live and generic features of the occupants' behaviour, and the ABM component captures more unique characteristics of occupants and their interactions with the building.

Proposed Hybrid Building Energy Simulation Framework

The proposed BES framework in this paper is comprised of three distinct modules: (I) the white-box module captures buildings' features and utilises the mass and energy conservation laws to model the building energy behaviour; (II) the CV module utilises image/video processing algorithms to capture the most realistic features of occupants and the building in real-time; and (III) the ABM module models the occupants' interactions with the building and one another. The architecture and data flow between the different components of the proposed framework are presented in Figure 2.

White-Box Module for Energy Simulation

The white-box module reads the characteristics of the building from its BIM model and utilises mass and energy conservation laws to deliver an accurate estimate of the building's energy consumption. As discussed earlier, the white-box models are arguably the most accurate energy simulation models if the predictions are made only based on the building's energy behaviour. Additionally, the white-box models are scalable since they make all the forecasts based on the fundamental laws of physics rather than the characteristics of given buildings. In the proposed framework, the main limitation of the white-box models — ignoring the occupants' energy behaviour — is addressed by connecting this module to the CV and ABM modules, which capture the realistic occupants' behaviour features from the real-time video data and simulate the aggregated OEB and its impact on the building energy consumption.

Computer Vision Module for Object/Condition Detection

The computer CV module is responsible for detecting the different objects within the building and predicting their current conditions for further analysis of their energy consumption and/or generation. Existing methodologies commonly focus on the number of buildings' occupants and their energy needs, though some research (Tien *et al.,* 2020) confirms that buildings' occupants — depending on their actions — and equipment can play a key role in energy generation as well. To address this limitation, the CV module detects the different objects located inside the building, including occupants and equipment, from the real-time video data and detects their current conditions. As discussed earlier, the CV-based energy simulation models are commonly criticised for requiring large training and testing datasets. The proposed framework addresses this limitation by reducing the scope of predictions made by the CV module and allowing this framework to utilise the pre-existing and open-source libraries of image and video processing. In other words, the CV module of the proposed framework only detects the number and current conditions of the building's occupants and equipment-in-use by utilising open-source object detection libraries, such as MMDetection (MMDetection, 2022). The objectives of this module are delivered in two steps, as presented in Figure 3.

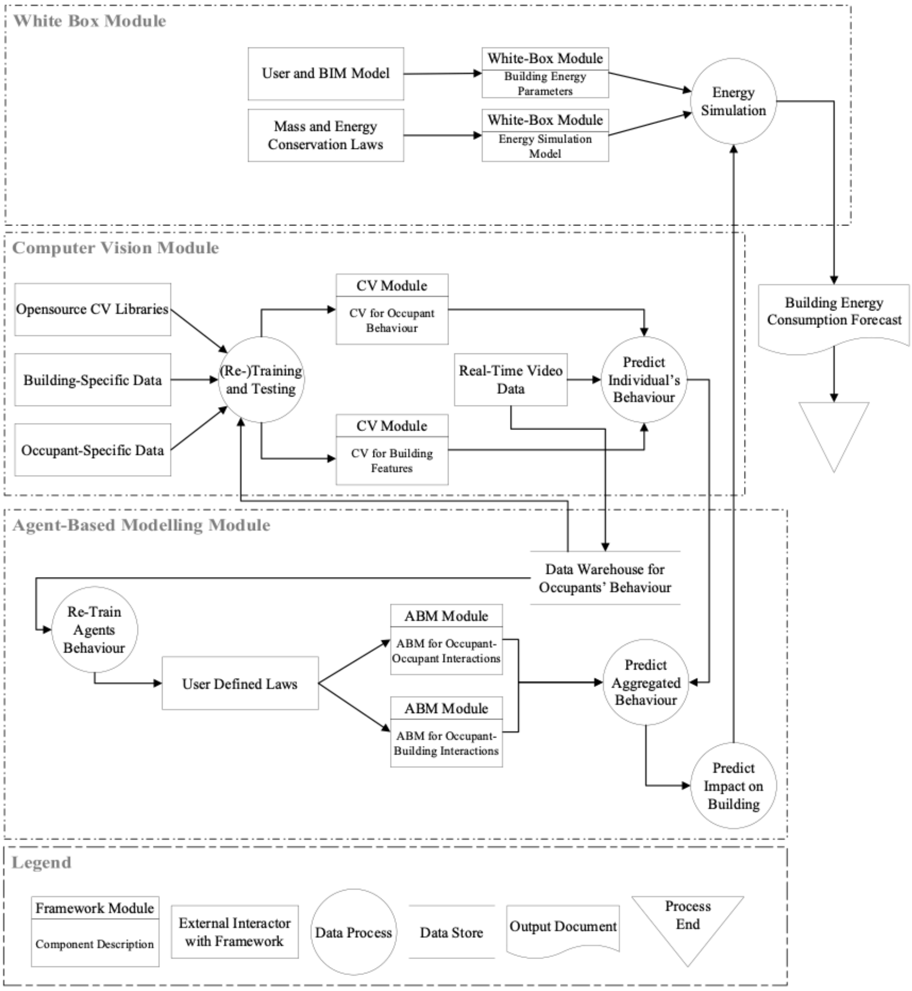

Figure 2: Proposed Framework Architecture and Data-Flow Diagram

As shown in Figure 3, first, the object localisation component localises the different objects inside the building from the real-time video data and determines the space in which the live (i.e., occupants) and steady agents (i.e., equipment) are located. Next, the object detection component detects the type of each live and steady agent inside the building, considering their several different features, including the number of occupants, the clothing state of occupants, and the state of equipment (e.g., on or off for computers). These two components can be delivered using one of the several available open-source object detection libraries, including YOLO V.3 (Redmon and Farhadi, 2018) or Fast R-CNN (Ren *et al.,* 2015). Additionally, since these components only detect the very generic features of the live and steady agents, no context-specific data are required for their training and testing purposes, and the scalability of the proposed framework will not be reduced. Once the agents are localised and detected, the pose detection component is activated to detect the current action of each live agent from the real-time video data using Open Pose (Cao *et al.,* 2021). This is achieved by detecting their "pose key points" (Cao *et al.,* 2021), which refers to the key points of the human body, based on which the deep learning algorithms can detect the human pose.

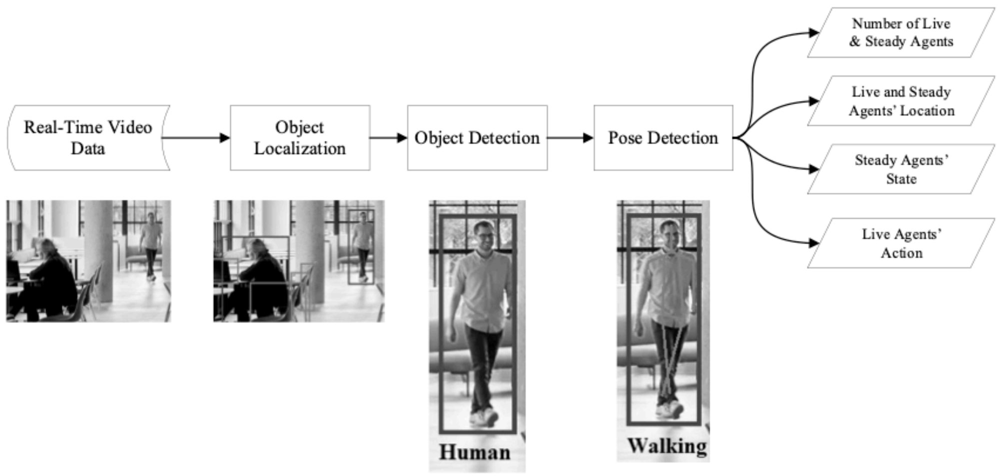

Figure 3: Computer Vision Module - OEB Process Chart; Photo: Corey Gaffer Photography

As a result, the CV module delivers four pieces of information to the ABM module for further analysis: (I) the number of live and steady agents; (II) the location of each live and steady agent; (III) the state of each steady agent; and (IV) the action of each live agent.

Agent-Based Modelling Module for Simulating Occupants' Energy Behaviour

The ABM module is responsible for determining the aggregated behaviour of occupants based on the information it receives from the CV module regarding the live and steady agents. Then, the ABM module simulates the different interactions between the live and steady agents inside the building, as well as their interactions with the building and deliver the aggregated energy behaviour of the occupants and its impacts on the building's energy consumption. The ABM module facilitates the simulation of energy consumption in two major aspects. First, the ABM technique enables the proposed framework to capture the several complex occupant-occupant and occupants-building interactions, which cannot be captured by the CV algorithms due to their variability and extreme complexity. Such interactions may occur in several different shapes and formats. Thus, collecting sufficient historical data for training and testing of the CV models to directly capture them from the video data is non-feasible.

In the proposed framework, the ABM module captures these interactions based on the simulation logic (i.e., social behaviour laws) defined by the user rather than historical data. An earlier study by Seresht (2022) confirms that the ABM technique can effectively capture the social interactions between the occupants of the built environment and determine the aggregated system's behaviour. Ding *et al.,* (2019) used ABM to simulate the energy consumption of student residences. Their efforts reveal that this modelling technique is well-suited for simulating the OEB in energy simulation frameworks, especially if the buildings being studied are occupied by many occupants. The second contribution of the ABM module relates to the scalability of this module and how it facilitates delivering a scalable energy simulation framework at a higher level since the rules of the ABM technique can be defined by the user and be further tuned by historical data (Ding *et al.,* 2019; Tian and Chang, 2020). As a result, the proposed framework is more scalable as compared to the black-box models or the CV-based models since this framework predicts the energy consumption based on a mix of data and user-defined laws rather than empirical data only. The spatiotemporal structure of the ABM module is presented in Figure 4, in which the different states of the live agents are illustrated, and the process of calculating the energy generation and consumption of individuals are depicted graphically.

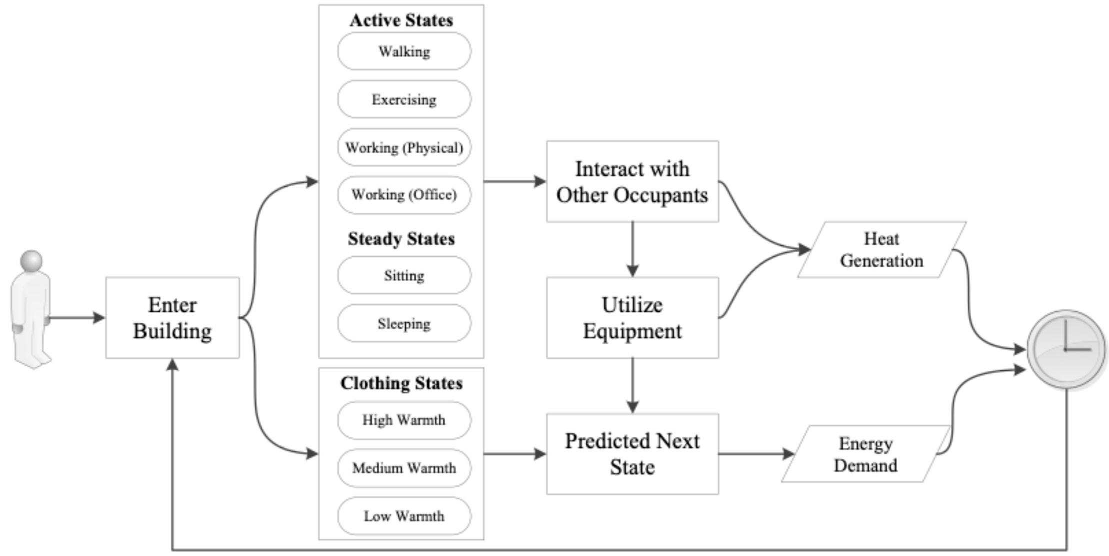

Figure 4: Spatiotemporal Structure of the ABM Module

The ABM module considers four agents' attributes for simulation: (I) the state of each occupant at each simulation time step - hourly time-steps are suggested, which allows the ABM module to determine the heat generated by each occupant based on the information provided by CIBSE (2015); (II) the clothing state of each occupant that facilitates the calculation of thermal energy demands; (III) the interactions between each occupant and the other occupants, which can affect their energy consumption or heat generation; and (IV) The interactions of each occupant with the building and the equipment (e.g., stove for cooking, computers for work, HVAC system), which may affect the energy consumption and heat generation. By capturing these four attributes, the ABM module predicts the heat generated by each live and steady agent, as well as the energy demands of the live agents until the next simulation time step.

CONCLUSIONS

Reducing the energy consumption of buildings has become a major concern in several developed countries, including the United Kingdom. The optimisation of buildings' energy consumption requires accurate predictive models to analyse buildings' energy consumption in different scenarios and to allow the designers and engineers to select the optimum setting for the buildings' design. This paper introduces an innovative hybrid framework for building energy simulation (BES) that enables the modellers to develop accurate and scalable models to forecast the energy consumption of buildings in different scenarios. The proposed framework is comprised of three modules: (I) the white-box energy simulation module that captures buildings' energy behaviour; (II) the CV module that captures the realistic features of the buildings' occupants; and (III) the ABM module that determines the aggregated energy behaviour of the occupants while considering the individual occupant's features captured by the CV module and simulating the occupant-occupant and occupant-building interactions. The proposed hybrid framework in this paper introduces a novel architecture for BES models, which is expected to deliver more accurate and more scalable models for predicting and optimising the energy consumption of buildings. This paper presented the architecture of a hybrid BES framework as a proof of concept and built the foundation for further developments in this area. The proposed hybrid framework can improve the accuracy of building energy simulation frameworks and, in turn, improve the energy efficiency of buildings by helping the researchers and practitioners to implement the most effective building energy management strategies. In future works, a prototype of this framework will be developed using the data available from the open data repositories and potential industry partners will be approached to realise collaborative research opportunities toward the proposed objectives.

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EXPLORING SUSTAINABILITY AND IDENTITIES FROM AN INVESTOR'S PERSPECTIVE: AN AUTOETHNOGRAPHY

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Research has paid attention to the drivers and inhibitors of sustainable construction. However, how the tensions between different constraints and options are negotiated in practice needs further exploration. The role identification with sustainable construction plays within this process is still under-researched. Therefore, my autoethnographic exploration aims to better understand the connection between decisions regarding sustainable construction and the self-identification with sustainability. As a construction contractor, and more importantly as an investor, I investigate my fieldnotes and recollections during a project I realized in 2012/2013. I explore my decision-making and the role of my identification with sustainable construction to understand how my identification with sustainable construction influences my decisions about environmental, economic, and social aspects. I demonstrate how my identification with specific green solutions drives but also inhibits sustainable building. As the insights I offer come from my unique perspective as an investor, they are not generalisable but can provide insights into how identification with green building has an impact on decision-making. I show how apparently rational decisions are subjectively mitigated. Hence, I underline the importance of identification with sustainability to promote sustainable construction.

Keywords: autoethnography; identity; investor; practitioner research; sustainability

INTRODUCTION

Sustainability has been on the agenda of construction management research for a considerable time. Even before the term became prominent, the idea of building for future generations was a core concern of construction. However, because of the rapid increase in carbon dioxide emissions, climate change has added to the importance of sustainability. It is predominantly the zero-carbon-target that dominates discussion about sustainability. Yet, besides environmental sustainability, one has to consider economic and social sustainability (Scoones and Stirling, 2020). It is the consideration of all three of these aspects that makes design decisions regarding sustainability so complex.

Operational assessment schemes have been introduced and researched to support this decision-making (e.g., Leiringer *et al.,* 2022; Schweber, 2017). Yet there appears to

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be a lack of research in how tensions of commercial and sustainability considerations are negotiated "on the ground" (Schweber, 2017, p. 302) and of the role played by the identification with green building (Darko *et al.,* 2017).

Therefore, this paper investigates choices about these aspects from the perspective of a construction entrepreneur and small-scale property investor. To work towards a sustainable project, one must balance all three perspectives within both roles. Drawing on my personal experiences and reflections, I seek to reveal how I, my identities and the ensuing identity work play a central role while reconciling these perspectives. The paper aims to highlight the connection between choices about sustainable building and the identity of the investor.

The paper is organized into four sections. First, I briefly introduce autoethnography and how I use it. Second, I set out the research problem - how identification with sustainability influences decision- making Third, I showcase, reflect, and analyse my personal experiences. Finally, I summarize my interpretation.

METHOD

To understand these processes better, I employ an autoethnographic approach. Autoethnography is closely related to ethnography. Ethnographers research a culture through observation, participation, and conversation with participants (Hammersley and Atkinson, 2007). They collect their experiences in what they call fieldnotes. Fieldnotes are a form of diary or journal for research purposes (Emerson *et al.,* 2011). Through reflection, analysis, and interpretation, they seek to better understand the culture, or often just an aspect of it. Autoethnography distinguishes itself in that the researchers explore the culture they are already part of. They research in their backyards (Wolcott, 1999).

The primary material for my research is my own experiences and observations in my business. I am writing from a dual position. I am an entrepreneur in the Berlin area (Germany) where I employ almost 30 permanent staff members. Most of my employees are bricklayers and carpenters, and we build concrete and brickwork construction. But I am also an investor in small residential buildings on the outskirts of Berlin. I want to highlight the dual role and the competing identities here.

For this paper, I skimmed my fieldnotes but predominantly recollected events. I did what Ellis *et al.,* (2022) call 'memory work'. These experiences and reflections illustrate the points I would like to convey in this paper. Therefore, I include vignettes produced from these fieldnotes and memory. The vignettes are printed in italics. Undoubtedly, one may argue that I only report from my singular perspective. I do not want to contest this; it is a subjective picture that I draw here. However, I also provide insight into my inner decision processes that might inform others. They, in turn, might explore my findings further using their preferred methods.

Background

There is an abundance of studies into policy driven initiatives to promote sustainable building, cost and marketing effects of sustainable construction and its economic viability (Darko *et al.,* 2017). However, use of, for example, Building Environmental Assessment Methods (BEAMs), has done little to change the "norms, values, beliefs, practices and taken-for-granted assumptions" of actors on construction projects (Leiringer *et al.,* 2022, 113). Murtagh *et al.,* (2016b, 68) suggest, many only comply with rules and some regard certifications as a 'tick-box' exercise. Similarly, Jowkar *et* *al.,* (2022, 169) argue, motivations to invest are more due to "comfort and aesthetical features than for energy savings". Therefore, I seek to understand the motivations of actors from the perspective of identification with sustainability. The identification appears to play a significant role for small architectural practices, as Murtagh *et al.,* (2016a) show. There is, however, little research available about the relation between identity and sustainability. Apart from the work of Murtagh *et al.,* (2016a) - who explored environmental sustainability - only Troje and Gluch (2020) explored the relation of identity to social sustainability.

To learn more about identity's relation to sustainable building, I will try to investigate my experience investing in a small-scale residential building. How did my sense of self impact on the decisions I took regarding sustainability? This highlights my personal considerations and exchanges with business partners. As, "the reality of the construction industry is seen to be shaped by the dominant management discourse" (Green, 1998, 384), I provide an insider's picture of the industry. Hence, I contribute to a better understanding of how "tensions" between sustainable building and commercial demands are "negotiated on the ground" (Schweber, 2017, 302).

Exploring Decision and Identity

Four storey building

I commence my exploration using a project I began developing in 2011. That summer, I bought a plot of land in the suburbs of Berlin. With the help of an architect, I successfully filed for building permission, which I obtained in 2012. In the summer of 2012, building work began, and in the following year, the four-storey apartment building was finished.

> Summer 2013
>
> It feels good to see the new building - Four 2-bedroom flats - my first own project. A conventional brickwork and concrete construction, outer walls, cellar floor, and roof massively insulated, triple glazing, underfloor heating, geothermal heat pump, solar water heating, and a ventilation system. The calculations suggest a very low energy consumption for heating and hot water supply.
>
> The price of the building was relatively high, although I secured a subsidised loan from the KfW (State-owned investment and development bank) and received some direct subsidies. Therefore, the cold rent - excluding the cost of energy consumption - was comparatively high. Now, I had to find tenants for the apartments.

I must admit I was proud of the building I saw before me. My company's workers had done a significant part of the work on the project. However, there was a lot of work to be done by others after the bricklayers left the site. There was some pride in having developed a project, but perhaps even more in the specific nature of that project.

It had a high standard thermal insulation and a low energy heating system. It was not rocket science, but decent, tested design and technology, which promised to be very energy efficient. The high standard contributed to the cost of the building, which was above other developments of similar size. Still, I was convinced that I had done the right thing.

Energy costs would rise in the future. I used to say during this time, the price of oil, gas, or electricity would go up by about 100%. It was a belief - something I anticipated without having proof or certainty. Yet, it worked as a heuristic for legitimising my choices. Of course, it was a qualified guess. Often, the decision to opt for the more or the less efficient system was not supported by economic data available at the time. For example:

> Autumn 2012
>
> When we talked about the hot water supply, the engineer suggested solar water heating during summer and a gas boiler during winter. "At the end of the day," he said, "it's the cheapest."

All costs considered; he may have been right. The investment in a geothermal heat pump was immense. It turned out to be more than 10-fold, although subsidies from the KfW helped to shoulder the bill. However, opting for the geothermal heat pump was more a decision of conviction than a purely rational economic choice. Economically, the heat pump was at the time the more expensive choice. Yet, the additional cost did not amount to an inhibitor, as often observed (e.g., Jowkar *et al.,* 2022). I could have used cost as argument, but I did not. At the same time, the engineer seemed to prefer the greener solution. When I expressed my preference for the heat pump he immediately sided with my choice. This certainly added to my confidence.

When I reflect on that decision, and similar choices, I see that my professional identity played a significant role in these decisions. It felt as if I had to build and equip the house in this way. I did not go for the cheapest solution because the project was sufficiently financed. I could afford to invest more in sustainable design and technology.

That raises the question of what kind of sustainability I was pursuing here. It incorporated three aspects. First and foremost, it should have a low environmental impact and consume as little as possible energy while in use. But it had to remain economically viable. That, in turn, limited the possibilities regarding environmental sustainability. I could not spend an infinite amount of money (and resources) on eco-friendliness. I could not ask for too high rents for the house since that would have made it socially unsustainable. As I later learned, I was on the brink of precisely doing that.

Becoming Landlord

When I began advertising the apartments, I left the role of the entrepreneur behind and became the landlord. Now I had to 'sell' my product. The litmus test for my strategy was the market - the potential tenants to whom I showed the apartments. The recollection here originates from that period.

> Autumn 2013 - One potential tenant complained the rent was too high, and he did not believe that the energy cost would be as low as I said. Therefore, he did not rent the flat.
>
> However, during the coming years, it turned out, the energy bill was more than half the price I anticipated.

When I offered the apartments, I promised certain costs for the energy bill. However, the contract and German law leave the risk with the tenant. Except for specially drafted contracts, tenants pay the energy bill according to some formula incorporating their apartment size and specific energy consumption. Although I was not entirely sure about the energy consumption, I had sufficient belief the cost would exceed the advance payments I had asked for in the contract.

Here it becomes evident that my sense of self - my identity - played a role in this situation. I do not promise something I am myself not convinced I can deliver. Of course, I take risks, and I sometimes must disappoint others. However, as a business owner and landlord, I do not promise anything I know from the outset I will have difficulties delivering. It is the sense of being a fair business partner I have already explored elsewhere (Grosse, 2019)

I confirmed my identity to myself through this promise and by delivering on this promise (Sveningsson and Alvesson, 2003). At that time, I was new in the landlord role. So, I had to draw on other images to define how to act and what self-image I maintained. Yet acting fair and making a decent profit were again guiding principles. In the investor and landlord role, making choices about designs and technologies became more prominent than it had in my entrepreneur role. Usually, as a construction contractor, I build what architects and engineers prescribe. Although I know how to build energy-efficient houses, I can only raise concerns and give recommendations but am very seldom in the position to decide. Yet, even in this subordinate position, I can decline to build designs contrary to my principles. Most of the time, I can refuse to sign a contract. In any case, I have some discretionary power to influence what I build. However, the last word remains with the client and their design team. With my own project, it was different.

Building something long-lasting

For the first time, I could do what I usually only recommend to clients and their design teams. Yet here, I faced the dilemmas my clients and their teams had already encountered. Finally, however, I applied my conviction to my own project.

In general, I wouldn't want to build something that is not long-lasting. I tend to convince my clients (and others who ask for advice) to opt for the most energy-efficient option. It's a deep belief that buildings with low energy consumption will sustain in the future.

The interesting point in this reflection is the grey area - the range where it is unclear which choice is the best - the economically necessary or the ecologically defensible. Within this grey area, subjective preference can play a decisive role. I wonder what impact it has to identify oneself with sustainable construction something to aim for.

I ask myself how far I recognize "the quest for zero carbon as an essential part of [my] identity" (Green and Sergeeva, 2020, p. 499). Again, I cannot disregard the social and economic constraints I find myself trapped in. The quest for zero carbon must allow for economic and social sustainability. But that does not imply the dominance of the economic considerations, which are often disguised as economic necessities. It is rather, as Murtagh *et al.,* (2016a, p. 72) state, that "autonomous motivations of personal commitment and an ethical imperative, as well as self-identity, pursuit of quality and awareness of impact on people, were found to be more salient drivers of sustainability." Self-identity appears to be more potent than other motivations.

One may frame the thinking about sustainability and identity around three aspects - I have to maintain a living through my economic activity's economic sustainability. In other words, I have to make a profit through my business, and the properties I develop must sustainably attract tenants to yield a rent. This also points to the social sustainability of my endeavours: I must align my activities with my staff members so that they can identify themselves with the firm as a form of social identity and make a living from their income. As a landlord, I need to maintain a space the tenants want to call their home and can afford to live in. In both roles, the third aspect - environmental sustainability - provides a sense of purpose and moral responsibility. However, it continues to pose an ongoing struggle of competing demands. Therefore, I will explore how I identified more with sustainable building and how it impacted my decisions.

The decision on the heating system for the building was based on different considerations. First, there was a financing scheme of the KfW in place, which offered low-interest loans and direct subsidies to achieve low energy consumption standards (KfW 40 Standard). For each flat, it amounted to €5,000 in subsidies. Additionally, I could claim a €50,000 loan per flat at 1.5 % less than market interest. Therefore, the subsidies and the loan made it economically much more attractive. However, this still did not cover everything as there were other costly requirements to get the loan and subsidies. Consequently, calculating the exact cost versus interest gains and subsidies remained difficult.

Second, there were long-term considerations that made a difference. For example, if I invest in insulation and a lasting, low-consuming energy system I have to invest more today but I will have the edge over comparable flats with higher energy consumption in the future.

Evaluating which design option is the most sustainable in environmental terms is often very difficult and depends on many different factors. For example, a gas boiler needs little energy to build compared to drilling 400 metres of geothermal pipes in the ground and producing two heat pumps, as was in my project. However, the energy consumption during use turns the tide against the boiler. Still, I am not knowledgeable enough to calculate the total carbon footprint of either option. Hence, simplifying heuristics is the only way to cope.

I knew burning gas would produce enormous amounts of carbon dioxide over the years. A heat pump produces only a fraction of this amount during use. Indeed, one could opt for green electricity and avoid even more carbon dioxide emissions. If my main concern is to build an eco-friendly solution, the installation of a geothermal system only had to be economically defensible. It just had to not be entirely off-track economically. Accounting for the subsidies and the interest deduction, the renewable option fulfilled the minimum economic requirements.

Still, the gas boiler was a tested system with a low risk concerning the anticipated energy cost. The geothermal system was not so well tested and was a riskier option concerning potential energy consumption. Again, I did not have the opportunity to assess the cost in detail. Or maybe I did not spend time and effort to assess. To a large extent, I had to rely on informed guesses.

In this example, I appear to be asking specific questions and not raising other questions. For example, I raised the question which led me to the decision on the geothermal heat pump. I subjectively picked questions that served my intention to build an environmentally friendly solution. As Pirsig (2014) says, the questions prescribe a range of possible answers. Even if we answer the question by employing objective science - which would be very difficult here - we choose the questions subjectively. Hence the answers we produce are a mere reflection of our subjective choices. This clarifies how important it is to identify oneself with a green agenda.

Limits of eco-friendliness

The importance of identification becomes evident when I turn to the example when I opted against the most environmentally sustainable solution.

Spring 2012 - Passive house

> Early in the design phase, the architect and I very briefly discussed whether or not to build a 'passive house'. He argued that it would require too many compromises in design and would be pretty expensive. I didn't explore this option any further, and it

> hasn't been discussed again. Retrospectively, I must admit I did not feel comfortable with the prospect.

I did not honestly consider building a passive house. It felt too farfetched. I had often seen some people involved in these projects appear idealist. Similar to the sustainability experts Troje and Gluch (2020, p. 66) describe:

> "It would also be reasonable to assume that sustainability experts would enact the identity of the idealist, as it is likely that people who work with sustainability are interested in improving the social environment, might have an activist agenda and engage in educational work tasks aimed at 'spreading the good word' of sustainability."

I cannot say whether the passive house planners and owner were as described above, yet they somehow left this impression. It may have been this that led me to dismiss the passive house option. Again, as with the geothermal heat pump, I did not explore it in sufficient depth. Maybe because I lacked the time, but more likely because I did not have the necessary motivation. I did not identify with the passive house option - it was just not me. Apparently, identification with green construction can be a driver for green building, however the absence of identification can also inhibit green building.

The 'bricks and concrete' company
In a similar vein, I did not question whether to build the house from concrete and bricks. At that time, I had run the business for 13 years. All our jobs comprise of some brickwork and concrete. This is a substantial part of my professional identity; I am not into timber houses, and neither are my staff. I could not imagine building a 4-storey building from wooden frames - not even parts of it.

There was, of course, the economic perspective to this choice of bricks and concrete. I could let my staff members do the job. I had full control over the cost and could develop the most cost-efficient solution due to my familiarity with the material. Yet, there was no argument about the choice of materials. This had to fit within my company's capabilities.

It was clear from the very outset that it could only be brickwork and concrete construction. Everything else would have clashed with the company's identity. If I had chosen a different material, I would have been asked to explain myself and that would have been a difficult discussion. How on earth could I not use the very material we sell to all our customers with such great confidence? Choosing something else would have undermined this confidence in what we are and what we stand for - hence our organisational identity. Again, I had subjectively chosen the questions I asked. In hindsight, the narrow choice becomes obvious, yet I did not reflect on it during the decision process.

Recent developments
While the COVID disease gripped the world, prices for construction materials soared. In recent weeks, however, fuel and energy prices have almost skyrocketed. These price hikes have forced me to reconsider my reluctance to invest in photovoltaics. The cost-saving potential and the income from selling electricity appeared too small to make a case for such an installation.

Again, I needed to identify with the new realities. A big boost in that direction came from my direct co-worker who pushed for that system. This convinced me to explore it. What happened was an alignment with the group in my office. In one way, they ran into already open doors. But some identity work took place to align my professional identity with the organisational identity I perceived in my office. An incident that contributed to this identity work was the following:

> Late Autumn 2021
>
> "Actually, you could do a bit more for the environment, couldn't you?" a staff member said and hinted that I could install a photovoltaic system on the firm's roof. Less than a half year later I took action.
>
> March 2022 - I called an old classmate. Years ago, his firm renewed the roof of my company's office, garage, and shopfloor building. In the meantime, he took on business installing solar panels on roofs too. So, I called him to come over to my office. He visited the building and took some measures. A few days later, I received his quotation for photovoltaic panels that could easily produce the energy my company needs to run and heat the office and charge some electric vehicles.
>
> Once I got the numbers from him, I went to my desk and created an Excel spreadsheet to explore whether it was economically viable. It seems to make sense. Hence, I called him to order the panels and asked him to see whether it was feasible to install a photovoltaic system on the residential house.

I needed the severe disruption of the energy market - exploding diesel and electricity prices - to give me a wake-up call. I may not reduce the cost of electricity by installing photovoltaic panels, but I vastly reduce the exposure to volatilities in the energy market. Furthermore, once the system is up and working, I am only supposed to buy a remainder of 30% from the grid. The rest I could produce myself.

When I turn back to my initial example of the geothermal heat pump, the recent price hikes have a reaffirming effect. I anticipated higher prices, but I did not think it would happen so abruptly. However, the higher prices justify my decision even more. It also influences my thinking about the photovoltaic panel, and I am more confident it will be a reasonable choice to install them.

The Processual Nature of Change

These changes of identities are, as I demonstrated above, gradual processes and often incorporate all three aspects. Sometimes the changes take place more rapidly. However, as in the case of the photovoltaic system, the groundwork had already been done and only the visible change - pursuing the project of installing the system - appeared to be a rapid shift.

It is necessary to work towards the identification of single actors in turn but also organisations with sustainable construction. I consciously use the vague term 'organisation' because it can, and should, entail groups of individuals in the sector from different firms and different occupations. As one sees in my case, it is certainly not enough to convince the executive management to opt for sustainable solutions; it must trickle through the organisation. For example, most of my employees buy-into the idea of well-insulated houses and care for the quality of their work (e.g., being mindful of thermal bridges). Therefore, building houses that are sufficiently well-insulated turns out to be not too difficult to manage because it is ingrained in the organisation's self-image. However, this organisational identity developed over time and maybe my effort to educate and train staff members to embrace this approach contributed to it.

CONCLUSIONS

Turning Identity Into Action

Building on Murtagh *et al.,* (2016b) I demonstrated by my personal example as investor that decisions about sustainability are more closely related to identity and identity work than to rational choices. If I identify myself as one who cares about sustainability, I develop a specific notion of myself - not unnecessarily exploiting resources and not polluting the environment beyond sustainability. As coined by Alvesson and Willmott (2002), dealing with ambivalence and dilemmas amounts to identity work. Yet the identity I am maintaining leads me to ask predominantly questions which implicitly prescribe or yield answers that support or maintain the identity I have built. These processes I have demonstrated above in detail. The identity operates similarly to the notion of quality in Pirsig (2014). A higher order dominates rationality ('classic thought', as Pirsig would term it). Hence, we deliberately ignore questions that could yield answers which challenge our identity.

I ignored arguments against a sustainable solution (e.g., the geothermal system). Still, I also ignored arguments in favour of it (e.g., the passive house or my earlier thoughts about photovoltaic panels). Hence, identification - on individual and organisational levels - with sustainability and, in particular, with the environmental aspect of sustainability can shift the balance for many decisions to be taken. Considering the reaffirming effect - decisions favouring environmental sustainability will positively affect the future decisions of an individual (as in my case), of an organisation (as in my company), and across organisations.

LIMITATIONS

The claims I make are based on my personal experience and therefore not generally applicable. That said, they might inform others. Still, I argue from a privileged position. My project was comfortably financed and through my business I had easy access to resources others in the industry do not have. Being so privileged it was often easy to opt for the eco-friendlier solution. Hence, my conclusions must be handled with the appropriate caution. Nevertheless, I believe identification with green building can tip the balance in many cases toward more eco-friendly solutions.

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MAPPING SUPPLY CHAIN ACTORS FOR INNOVATIVE BUILDING RETROFIT

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New retrofitting approaches, including off-site modular, are being developed with the aim of improving energy efficiency at the scale and speed needed to achieve net zero greenhouse emissions. Despite this, little attention has been paid to the supply chains emerging for innovative building retrofit. Using nine semi-structured interviews with stakeholders in two innovative off-site retrofitting projects, this research aims to address this gap. Through this, 'trio' and 'powerhouse' supply chain structures are identified, formed by three key stakeholders: the Housing Partner; the Intermediary and the Solution Provider. An interdependent four-stage communication is identified which is used for determining relevant sub-contractors and problem solving. The consistency of this pattern in both projects, despite different supply chain structures, indicates the importance of shared objectives among building professionals for successful retrofitting. This insight is valuable for policy makers looking to support innovative techniques for delivering large scale retrofitting schemes.

Keywords: building retrofit; off-site; modular; supply chain actors

INTRODUCTION

A crucial part of delivering net zero greenhouse gas emissions is ensuring that the built environment is as energy efficient, including widescale retrofitting to improve the fabric and energy technologies in existing buildings (CCC, 2019; Wade and Visscher, 2021). Such retrofit at scale could also make buildings more comfortable to live in (Maby and Owen, 2015), cheaper to run (CCC, 2019), create new jobs (Maby and Owen, 2015; Killip *et al.,* 2021), and boost the broader economy (Wade and Visscher, 2021). Retrofitting therefore represents a key aspect of building back wiser following the COVID-19 pandemic. Despite this, rates of retrofitting remain low: 'deep energy retrofit' that aims to reduce energy consumption by 60% is carried out in only 0.2% of the building stock per year (EC, 2020).

The retrofitting sector has been slow to employ industrialised supply chain constructs (Genovese, Lenny Koh and Acquaye, 2013), potentially contributing to slow rates of energy retrofitting. To address this, new retrofitting approaches are being introduced; one of these is off-site modular. In this approach, components are prefabricated and assembled prior to being delivered and installed on the construction site (Arif and Egbu, 2010). Prefabrication enables the move of certain activities to a controlled environment such as a factory, which can increase the speed of retrofit, whilst

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lowering costs and labour requirements (Goulding *et al.,* 2015). In addition, various retrofitting measures can be performed by a single contractor; this can potentially remove the need for individual homeowners to coordinate between trades (Brown, 2018), and support an industrialised supply chain (Fawcett and Topouzi, 2019).

However, prefabricated solutions have met with 'distrust and reluctance' and a 'generalised lack of knowledge' from the building industry (D'Oca *et al.,* 2018, p.4). Research in this area has to date focused on large housebuilders who apply off-site construction to the development of new homes (Pan, Gibb and Dainty, 2007), but there has been limited study of the supply chains emerging for off-site building retrofit. This is particularly surprising since off-site construction could represent a marked shift in the configuration and operation of retrofitting supply chains, which are currently characterised by a high degree of fragmentation with limited communication between individual trades that complete specific tasks (Maby and Owen, 2015). As illustrated in the case of UK Green Deal, failure to anticipate the business capacity of different supply chain participants severely limits take-up (Gooding and Gul, 2017). This paper therefore explores the configuration and dynamics of supply chains emerging to deliver off-site building retrofit.

The next section presents insights into the configuration of building retrofit supply chains, followed by a description of the two case study projects and interviews used for data collection. The Findings section explores the supply chains emerging for these projects, with a focus on three key stakeholders: the Housing Partner; the Intermediary and the Solution Provider. The Discussion provides insights about the dynamics of innovative retrofitting supply chains and concludes with implications for scaling up future energy efficiency retrofits.

A supply chain is defined here as stakeholders that make exchanges of products and services for the purpose of satisfying final users' demands (Christopher, 1998). The relationship between stakeholders in a supply chain is often considered as linear: resources such as raw materials are exchanged and transformed into a finished product, before being delivered to final consumers (Porter, 1985). Most published research in operations and supply chain management tends to treat supply chain processes as in mass produced, fast moving and high turnover markets (Womack, Jones and Ross, 1990; Han, Caldwell and Ghadge, 2020). This linear production process, however, does not often apply to the retrofitting sector where future demand is not certain and streamlined (Dubois and Gadde, 2002; Killip, 2013). The construction industry can be characterised as a series of professionals, often operating within their own field with no shared understanding of the built environment (Hartenberger *et al.,* 2013). Further, for retrofitting, there is often a lack of systematic integration between these different professionals, leading to the installation of individual measures rather than whole-house approaches and spontaneous, temporary use of sub-contracting for specific projects (Clarke, Gleeson and Winch, 2017; Killip, Owen and Topouzi, 2020). Despite this complexity, very few people have studied the structure of retrofitting supply chains, with only two studies proposing a typology for these.

The first of these suggests that traditional retrofitting projects can be: led by general builders who may sub-contract aspects of work to specialised trades; coordinated spontaneously without a general builder and managed by a householder who will assign work to different trades without sub-contracting (Maby and Owen, 2015). These configurations often apply to small scale retrofitting projects.

For larger-scale retrofitting projects, Genovese, Lenny Koh and Acquaye, (2013) introduce the 'trio' and 'power house' configuration. In the 'trio', local authorities act as intermediaries between microbusiness and householders (Figure 1a). Here, local authorities identify and coordinate with private householders to install energy efficiency measures through local businesses that belong to a pre-selected qualification list. Key decisions on products and are driven by both local authorities and microbusinesses. Local authority coordination can increase the volume of participating households, encouraging the economies of scale, and helping to increase capacity amongst local microbusinesses (Genovese, Lenny Koh and Acquaye, 2013).

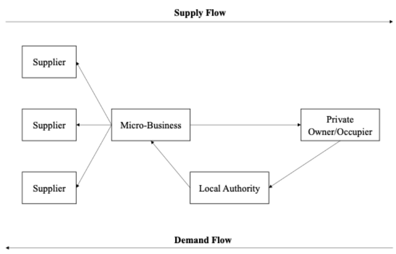

Figure 1a: The 'trio' supply chain configuration. Source: Genovese, Lenny Koh, and Acquaye (2013)

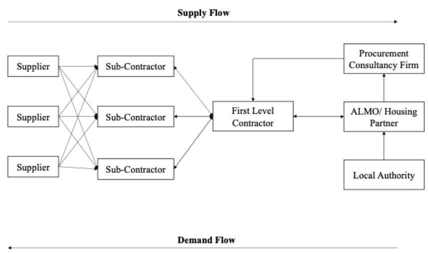

Figure 1b: The 'power house' supply chain configuration. Source: Genovese, Lenny Koh, and Acquaye (2013)

In the ‘power-house’ configuration (Figure 1b), key decisions are made by multiple stakeholders, including local authorities, housing partners (typically social housing landlords), procurement consultancy firms, and tier-one contractors. The role of a tier-one contractor is like the general builder in the traditional retrofitting arrangement: they are responsible for all building tasks but sub-contract to specialised trades. In this, subcontractors do not have any power in deciding product and project specifications. Nevertheless, public procurement practices in this arrangement can bring economies of scale and operational efficiency (Genovese, Lenny Koh and Acquaye, 2013).

Genovese, Lenny Koh and Acquaye's (2013) work provides a starting point to explore the supply chain configurations emerging for innovative building retrofit. It summarises key stakeholders and their role in shaping different supply chains. However, there is little detail on how these supply chains form or operate in practice. For example, it is unclear how different actors are recruited in the first place. In addition, the specific roles of key stakeholders, the decisions they make, and the activities they perform are unknown. It is therefore important to explore how supply chains for innovative retrofitting approaches take shape. As such, this study aims to answer two questions:

- RQ1: What communication patterns drive the formation of innovative retrofitting supply chains?
- RQ2: How do these patterns vary with different supply chain configurations?

METHOD

This study focuses on two innovative off-site retrofit projects in a case study UK city. This city was selected as the only UK region that applies off-site construction techniques for energy retrofitting. The cases selected represent distinctive approaches to delivering energy retrofit at scale, and therefore offer an opportunity to compare emerging supply chain structure (Yin, 2018). Project 1 aims to provide whole house retrofit for 165 social houses. It applies an innovative model based on a set of performance indicators such as room temperature, installation time, net energy consumption and indoor air quality. To achieve this performance, this project uses innovative energy-saving and energy-generating measures, including prefabricated, highly insulated walls and windows, a solar roof and a state-of-the-art heating system. Project 2 adopts an incremental approach to provide whole house retrofit for 104 homes. Instead of installing various measures ‘in one go’, Project 2 provides a roadmap for the whole house upfront, then implements all necessary retrofit measures in several batches. It focuses on social houses that do not need all retrofit measures (i.e., solid wall insulation only), or require less investment. This project aims to test the delivery of an incremental retrofit in a cost-effective way that still achieves net-zero.

Table 1: Interview participants' profiles

Interviewee code	Supply/Demand/ Intermediary	Organisation role	Interviewee’s job title
FC1_Solution provider_Director	S	Solution provider	Managing director
D1_Local Authority_LEP1	D	Local authority	Sector Engagement Manager
SC3_Control design_Director	S	Control system provider	Director
D3_University_Skill	D	Research and development	Principle Lecturer
D3_University_R&D	D	Research and development	Deputy Dean
I_Intermediary_Representative 1	I	Innovation intermediary	Representative 1*
D1_Local Authority	D	Local authority	Senior Energy Projects Officer
I_Intermediary_Representative 2	I	Innovation intermediary	Representative 2*
D1_Local Authority_LEP2	D	Local authority	Head of Energy Hub

**Note: For anonymity reasons, these two interviewees are named as 'representatives', rather than their official job title*

Project information, including the different organisations involved, was first collected through desk-based research on media coverage, the websites of the local authority and the Intermediary, a project progress blog, and published minutes of meetings from project executive boards. This information was further consolidated using nine semi-structured interviews with key project stakeholders; their job titles and roles of their organisations are detailed in Table 1. The interviews were obtained through snowball sampling (Noy, 2008). We first approached a tier one contractor to discuss their delivery of the pilot for Project 1, through whom we identified the sub-contractors, suppliers, clients, along with the remaining members of the supply chain for both Project 1 and Project 2. The semi-structured interview questions were designed to identify how different individuals have found their place (on the supply side, demand side, or as intermediary) in the supply chain for the two retrofitting projects, whilst allowing flexibility to explore emergent phenomena (Dubois and Gadde, 2002). The collected data was assembled and analysed by drawing on the supply chain typologies developed by Genovese, Lenny Koh and Acquaye (2013). Specifically, analysis sought to identify key decision makers, and the ways in which they have shaped the supply chains emerging for innovative building retrofit.

FINDINGS

Figs 2 and 3 show the supply chain configuration of the two projects. There are three categories of stakeholders: demand side (striped boxes), intermediaries (dotted boxes), and supply side (shaded boxes). Stakeholders on the supply side are further categorised as first level contractor (FC), sub-contractor (SC) and product supplier

(PS), depending on their contractual positions. Lines between boxes indicate the communication links between different organisations.

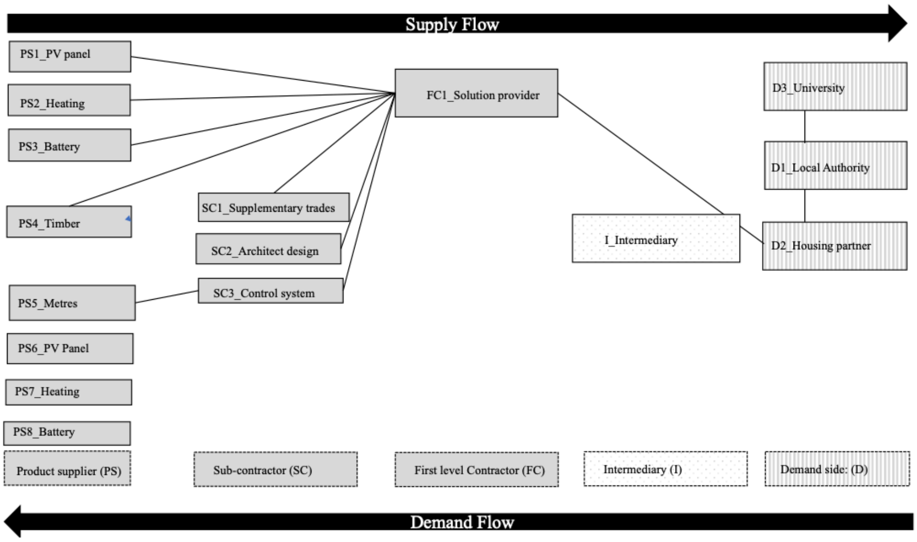

Figure 2: 'Power house' supply chain configuration in Project 1

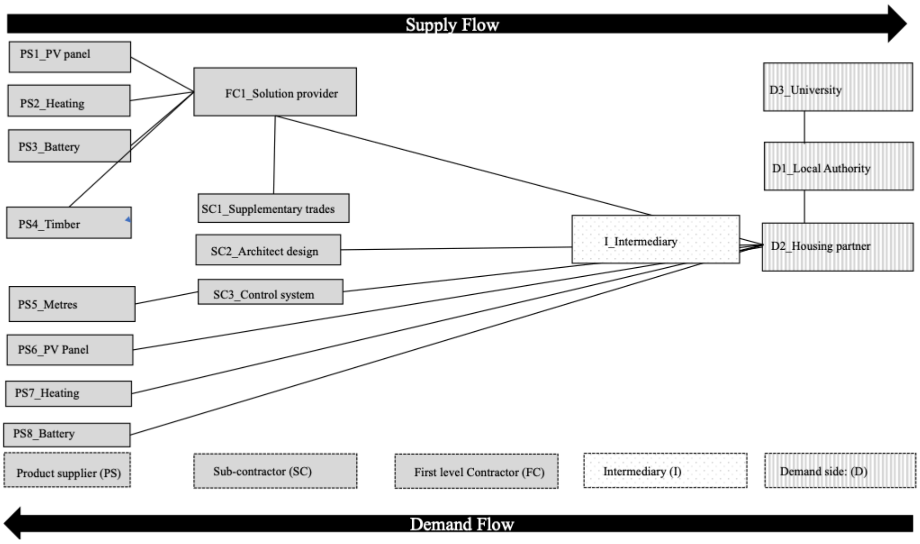

Figure 3: 'Trio' supply chain configuration in Project 2

The following results explore the three key actors (the Housing partner; the Intermediary and the Solution Provider), as well as their activities in driving the formation of supply chains across the two projects.

Housing Partner

The Housing Partner manages the local authority's social housing stock; they therefore initiate large-scale energy retrofitting and acts as a crucial demand-side stakeholder. In Project 1, the Housing Partner is responsible for managing and contracting retrofitting tasks to the first level contractor but does not have direct involvement in the procurement of sub-contractors or product suppliers. In contrast, in Project 2 the Housing Partner has direct communications with sub-contractors and product suppliers. The procurement and project management processes are largely replicated from Project 1, but solely performed by the Housing Partner.

Situated on the demand side of the supply chain, the Housing Partner is actively engaged in applying for pioneering research and innovation funding. These funds are used by the Housing Partner to test retrofitting pilots in various forms: from pre-existing scientific models originating overseas, to tentative adaptations in their own region. Support from the local authority provides a solid foundation for the Housing Partner's activities.

The Intermediary

The intermediary is made up of a small, knowledge-intensive team including architects, engineers, public policy experts, and social housing organisations. They are a not-for-profit organisation, and this was highlighted as being particularly beneficial for allowing flexibility to "bring in resource when it's needed" to address a range of challenges. The intermediary plays a strategic role in both projects, determining how the project and contracts can fulfil the performance indicators specified in their model. This was explained by one interviewee from the local authority:

> "[The Intermediary] are helping with communications and wider learning and strategic supply chain development of the retrofit world. They are [asking] 'what do we need the industry to look like to make this work?'" [D1_Local authority].

Indeed, for these innovative retrofitting projects, the development of supply chains is predominantly supported by the intermediary. This is achieved through arranging competitive bidding to first level contractors and holding events to find potential sub-contractors and product suppliers. One of these events was explained by an intermediary representative:

> "We ran an accelerator day so we invited all of the supply chain people we could […]and we asked them to fill out some information in advance so that we could match make them […] with suppliers, architects, contractors, manufacturers and put together a proposal […] From that we have newly formed [teams]coming up with new ideas for retrofit" [I_Intermediary_Representative2].

Thus, the intermediary run competitions and to help create new supply chain collaborations. This competition process, according to the control system contractor in Projects 1 and 2, gave them a strong sense of scientific reassurance and highlighted the need for monitoring the performance of energy retrofit, therefore helping to remove the need for burdensome efforts to sell their ideas.

The intermediary also plays a mediating role in communicating technological and operational issues during project delivery. For example, when innovative suppliers encountered challenges, the intermediary would make sure that supply and demand actors could solve problems together:

> "…when [an offsite wall system supplier] installed the innovative system there were some technical challenges […].and they're a very small company [so] their cash flow was not sufficient. [The council] had to find more money to continue with the project […] and there we'll do the relationship management with the funder" [I_Intermediary_Representative2].

In this way, this actor is an intermediary between demand and supply. The intermediary can be both a gatekeeper, deciding which innovative supplier gets to be involved or excluded from a project and as mediator, coordinating between relevant stakeholders to distribute the burdens and challenges that innovation can bring.

Solution Provider

Project 1 also features a third key stakeholder, the Solution Provider, who is required to design a set of technical specifications themselves to fulfil the performance indicators specified in the innovative model, before contracting specific tasks to sub-contractors and product suppliers.

Following the principles of the innovative model, timber panels are pre-fabricated offsite to create highly insulated external building envelopes. However, a factory that manufactures these products for retrofit was not available when Project 1 started. The Solution Provider initially tried to partner with a manufacturer that make prefabricated timber frames for new homes; however, they found that the manufacturing process was unable to accommodate with the nuanced nature of retrofitting (for example, slightly different window positions across each property). This led the Solution Provider to develop their own factory, specifically for building retrofit. This idea was quickly supported by the Housing Partner, who provided a dis-used factory space.

Simultaneously, the Solution Provider played a crucial role in shaping the local supply chain by directly employing factory workers and specialised trades. This was supplemented by sub-contracting other self-employed local trades for temporary works:

> “The directly employed teams have come from either [specialised trades] that we know. The teams onsite are generally experienced construction workers […] The team in the factory, we’ve worked with the job centre who’ve identified candidates and then we do our normal recruitment and interviewing process. In the factory there is no requirement for any pre-existing experience.” [FC1_Solution *provider Director*].

Thus, there are roles for specialists, skilled and unskilled workers in off-site retrofitting. As the supply chain is emerging, some specialist contractors are still operating at a very small scale which can create challenges. For example, in Project 1, the renewable heating and electrical products are two separate systems and innovative design was needed to integrate them. The Solution Provider initially relied on the design of a ground source communal system proposed by a control specialist, but found the restricted capacity of this small business challenging:

> “Because they were a small company, they struggled to deliver all of the aspects that we needed […] a lot of the knowledge was in one person’s head and it was very difficult to get it on paper within our timeframe […] The solution we ended up with wasn't actually a robust solution, it wasn't reliable enough.” [FC1_Solution provider_Director].

Following this experience, the Solution Provider reported this challenge to the Intermediary to start another round of competition for an updated design, leading to an air source heat pump proposal by another control specialist.

Situated at the supply side as a first-tier contractor in Project 1, the Solution Provider develops product supply chains through the creation of dedicated factory facilities and employing and training people that work specifically in off-site building retrofit. These newly created resources made the delivery of fabric improvement components readily available for Project 2. Additionally, there is strong communication and collaboration between the Solution Provider, the Housing Partner, and the Intermediary. Challenges such as a lack of warehouse space can be communicated with other project partners and resolved. In addition, any emerging technical and operational challenges are summarised and reported back to the intermediary for an updated solution.

DISCUSSION

Project 1 follows the ‘power house’ supply chain structure, with the Housing Partner, the Intermediary and the Solution Provider acting as key decision makers. Project 2, meanwhile, follows the ‘trio’ layout, where key decision makers are the Housing Partner and the Intermediary, with microbusinesses sub-contracted to perform aspects of the work. Crucially, both projects have a set of pre-specified performance indicators, with responsibility for the project outcome shared across these key decision makers. This shared outcome helps to create clear allocation of tasks among all stakeholders, but also fosters close communication.

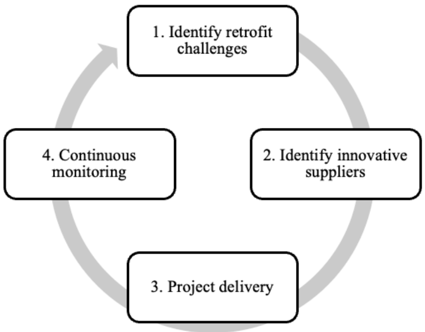

Figure 4: Activities and communication pattern in Project 1 and 2

In both the 'trio' and 'power house' layout, a four-stage communication pattern among the three key stakeholders (Figure 4) began to emerge. In this, the Demand-side (D) Housing Partner identifies general challenges to meeting the desired outcomes (Stage 1). The intermediary (I) then holds events and competitions to make suggestions for which sub-contractors (SC) can address the challenge (Stage 2). The identified supplier is invited to deliver the proposed solution (Stage 3), which is then continuously monitored by the Solution Provider in Project 1, and the Housing Partner in Project 2 respectively (Stage 4). Any deviations to the expected outcome are reported to and mediated by the intermediary (I), and further challenge identification and problem solving occurs iteratively.

In this way, the determination of which suppliers are incorporated into innovative supply chains is distributed across all three stakeholders. The Intermediary plays a particularly important role in initiating this pattern. Through a closed loop between demand and supply, mediated by an intermediary, stakeholders become tightly coupled with clear expectations of other members’ obligations in the supply chain. This ensures coordination across an activity chain that encompasses engineering, procurement, production, expedition, delivery, and payment, and emphasises the significance of a shared identity and goals amongst built environment professionals for delivering sustainability goals (Hartenberger *et al.,* 2013). This shared identity, mediated by impartial intermediaries could become an important pathway to scale up energy retrofitting, with the inclusion of currently fragmented supply chain actors.

CONCLUSIONS

This paper has presented a first attempt at mapping the supply chain configurations for off-site building retrofit. The research presented here is a preliminary step in capturing the social interactions between actors in innovative, off-site building retrofit networks. Future research will continue to develop a map of these supply chains to further explore who is able to participate in innovative energy retrofitting.

Although the two projects studied herein followed different supply chain structures, they had a clearly defined goal and shared expectations across different stakeholders. These shared goals supported close collaboration and iterative problem solving, regardless of whether the supply chain followed a 'trio' or 'power house' configuration. This represents a marked shift from traditional retrofitting approaches, which often rely on fragmented supply chains in which individual professions complete standalone tasks. Building Back Wiser through retrofitting at scale can therefore be supported by creating shared understanding and goals amongst the professionals responsible for delivering building retrofit.

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EXPLORING DYNAMICS IN CONSTRUCTION CIRCULAR SUPPLY CHAINS USING A SYSTEMATIC LITERATURE REVIEW: NEW SUPPLY-PUSH AND DEMAND-PULL PERSPECTIVES

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A full transition to Circular Economy (CE) in construction requires a rethinking of its operations from a supply chain viewpoint. The transition to Circular Construction Supply Chains (CCSC) can be discussed from supply-push (SP) and demand-pull (DP) perspectives; however, this understanding is underdeveloped in the literature. The study aims to explore barriers to the transition to CCSC and associated SD/DP countermeasures and investigates whether the current configuration of CCSC is SP- or DP-driven. A systematic review of 81 peer-reviewed articles was conducted. Thirty-seven barriers were identified, combined into nine factors, and further classified into three groups: technical, managerial, and contextual. Countermeasures to these barriers were linked to SP/DP and their level of control (macro, meso, and micro). Findings revealed countermeasures are mainly SP-related and used to create a DP environment. This new "push-to-pull" attribute shows the dynamic nature of CCSC transition that requires greater collaboration of actors at different levels.

Keywords: circular economy; circular construction; supply chain; barriers

INTRODUCTION

Circular Supply Chains (CSCs) in the Construction Industry

The concept of Circular Economy (CE) has gained increasing momentum among academia, industry, and policy agendas (Jones and Comfort, 2018). It seeks to sustain the circulation of resources within a quasi-closed system and keep them in usage for the longest duration possible to maintain their value (Nasir *et al.,* 2017). It provokes a rethink of construction Supply Chains (SCs) to reduce construction waste and improve resource efficiency by adopting CE concepts (Chen *et al.,* 2022). As opposed to process-based industries (e.g., manufacturing), construction SCs are typified by instability because of fragmented and project-based characteristics (Loosemore, 2000). A typical construction SC comprises clients and designers in the upstream preparing for the on-site production, and main contractor, subcontractors, and suppliers in the downstream performing project delivery tasks (Akintoye *et al.,* 2000). Unlike manufacturing sectors where standardised and repetitive processes are

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undertaken in a controlled environment, construction deals with unique and bulky units, and the associated production processes are conducted on-site that suffer from variability (Solomon *et al.,* 2006). Challenges in construction SCs, such as a lack of information transparency, and incompatible business purposes (Behera *et al.,* 2015), often lead to a significant amount of rework and waste generation (Chen *et al.,* 2022). Rethinking construction SCs is in line with the widely spreading idea of Build Back Wiser that seeks new solutions to the issues of industrial concern.

The linear SC follows a cradle-to-grave process starting from raw materials and ending up with final products (Beldek *et al.,* 2016). The incorporation of CE replaces the end-of-life concept (or 'grave') with new input (or 'cradle') and features a 'cradle-to-cradle' process by enabling products at the end of lifecycle to re-enter the supply chain through reuse, recycling, or remanufacturing (Nasir *et al.,* 2017). Various research endeavours were paid to explore the potential of circular construction supply chains (CCSC). For instance, Leising *et al.,* (2018) developed a conceptual framework to assist the collaboration of CCSC. Moreover, Nasir *et al.,* (2017) made comparison between the linear SC and CSC focusing on building insulation products regarding their environmental impact. Through a wide review of literature, Chen *et al.,* (2022) identified an array of CE strategies relevant to different SC stages ranging from design, manufacturing, construction, operation, and maintenance, to end of life. This aligns with calls by Abadi *et al.,* (2021), to adopt a project life-cycle assessment (PLA) approach to facilitate the transition of construction SCs to CCSC.

Supply Push (SP) and Demand Pull (DP) in the Circular Transition

As part of SC management strategies, SP and DP describe different patterns of production and control. SP features a produce-to-stock model that is seen as forecast-driven production based on historical data and projections, whilst DP is typified as a produce-to-order model based on actual customers' orders (e.g., Pyke and Cohen, 1990). Delivery of construction projects is characterised by Engineer-to-Order (i.e., a ‘pull’ system), but production activities might be pushed towards the contracted due date (Kalsaas *et al.,* 2015). Besides physical products, the literature also addresses SP and DP in relation to knowledge promotion. In innovation research, SP (also known as 'technology-push') and DP are used to explain technical changes, where SP connotes knowledge development drives the direction and rate of innovation and DP considers innovation derived from unmet needs in the market (e.g., Nemet, 2009). Besides, push and pull are also used to study switching behaviour, where push factors are negative perceptions that motivate people to leave an origin and pull factors are appealing attributes that drive people to initiate changes (e.g., Hazen *et al.,* 2017).

Discussions were retrieved in the literature about SP and DP relevant to promoting CE. For instance, Kiefer *et al.,* (2019) investigated how different types of eco-innovations contributed to the circular transition in firms and considered collaboration with universities, research centres and consultants as SP and with clients as DP. Besides, Moon and Lee (2021) summarised that CE in digital TV industry can be shaped through technology-oriented strategy by adjusting its tangible and intangible resources to seize opportunities (SP), market-oriented strategy by sensing market changes and consumer needs (DP), and adaptive follower strategy that integrates the features of both two strategies. In addition, CE transition is often discussed from a policy perspective, where policies are conducive to boosting both the supply of circular projects through SP measures (e.g., imposing eco-design standards, strengthened producer responsibility schemes and R&D funding) and increasing the demand for them via DP measures (e.g. differentiated VAT rates, recycled content mandates, green procurement) (OECD, 2019). By comparison, Hazen *et al.,* (2017) examined consumer behaviours in terms of switching from traditional SCs to CSCs through the lens of theory of migration, where 'push' factors (e.g., high price, low quality and poor service) are assumed to be negative in nature that drive individuals to abandon current consuming patterns and 'pull' refers to positive factors (e.g. superior product performance, government incentives and tax breaks) that encourage behaviour changes in desired directions.

SP and DP measures are weighed differently depending on varying contexts and there seems to be a trade-off between these two approaches. For instance, Nemet (2009) claimed that current policies about promoting innovations were overwhelmingly dominated by DP measures whose effectiveness of inducing non-incremental innovation was largely doubted due to the technological incapability resulted from SP negligence. A rational allocation of resources between SP and DP instruments should exist based on the need for non-incremental technical improvements (Nemet, 2009). Conversely, Motoyama and Malizia (2017) posited that current practices of promoting entrepreneurship relied heavily on SP factors, although they proved that some SP factors had with no correlation with start-up rates in high-tech industries.

Using the 'Innovation Chain' Model to Describe Dynamics in CCSC

The challenges in CE implementation nowadays are not only involved with institutions pushing the development of new ideas or technologies, but also the market and society players creating the demand for them (Bezama, 2018). The overwhelming implementation of either SP or DP measures can result in a growth plateau (Nemet, 2009). For example, 'waste-to-value' CE approaches, e.g., production of bioplastic from sewage sludge (Bluemink *et al.,* 2016), is technically feasible but not yet economically competitive in the market, thus not commonly seen in practice. Considering SP and DP are open to various interpretation, this study stands on the perspective of innovation promotion and specifically built on the understanding of innovation chain (shown in Figure 1) proposed by Grubb *et al.,* (2021). The rationale is twofold: firstly, CE is relatively new to the construction industry, and it is fair to be considered from innovation wise; secondly, the presented innovation chain provides ideas of trade-off between SP and DP measures in different stages of development. It indicates different weighting between SP and DP as a new concept matures. This would provide a new thinking about the status quo of current CE implementation in the construction industry. Considering the above discussions, in this study, SP measures are defined as initiatives to promote CCSC by actors who mainly provide and communicate new solutions, whilst and DP measures refer to CE initiatives arising from actors who apply CE in their business practices.

Although the literature shows some discussions about SP and DP in CE context, it lacks an explicit definition of DP and SP resulting in ambiguous understanding of their application. The transition to CE in construction has initiated extensive discussions about associated barriers/enablers in the academia. However, the literature has not investigated the application of DP and SP measures in the CCSC context. The 'wiser' aspect of this study lies in that it provides a new understanding of the transition to CCSC by considering a dynamic balance between SP and DP measures. However, it is unclear about whether SP or DP predominates the driving forces to CCSC. Thus, this study aims to explore barriers to the transition to CSC in construction and associated SP/DP measures used to overcome these barriers and investigate the current configuration of CCSC in terms of whether being SP- or DP-driven. This can be achieved by the following four objectives: 1) to identify the focus of CCSC literature; 2) to identify barriers to the transition to CSC in construction; 3) to identify measures used for their mitigation and classify these measures according to their nature whether SP or DP; 4) To explore the interplay between SP and DP measures.

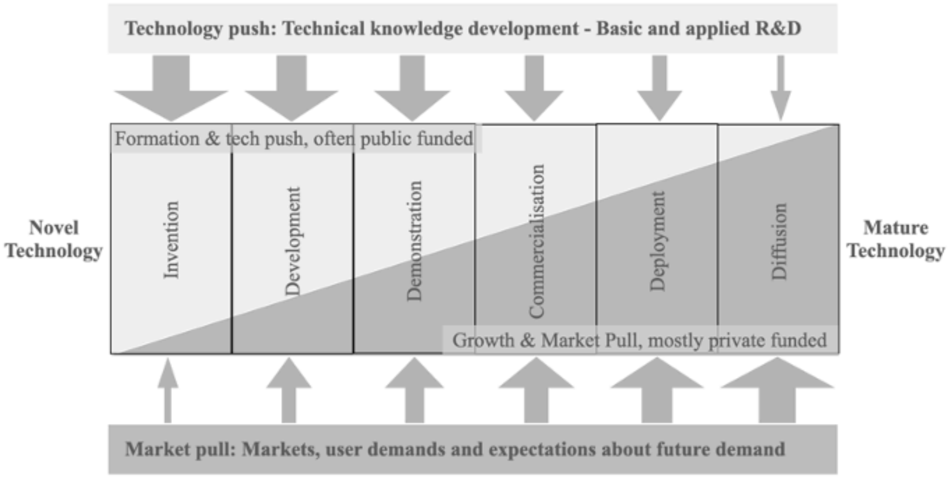

Figure 1: Innovation chain from novel to mature technology (Grubb et al., 2021)

METHOD

A systematic review of 81 peer-reviewed journal articles was conducted. Figure 2 depicts the review process including data collection and analysis: search engines, keywords used, number of articles, screening procedure followed, and analytical strategies. 'Google Scholar', 'Scopus' and 'Web of Science' were adopted to retrieve relevant articles. Keywords used comprise 'circular', 'green' and 'sustainable' due to the conceptual overlap of these terms in CCSC literature. The development of sustainable and green SC is also considered to be in parallel with CSC discourse (Nasir *et al.,* 2017). This enabled a comprehensive capture of relevant articles.

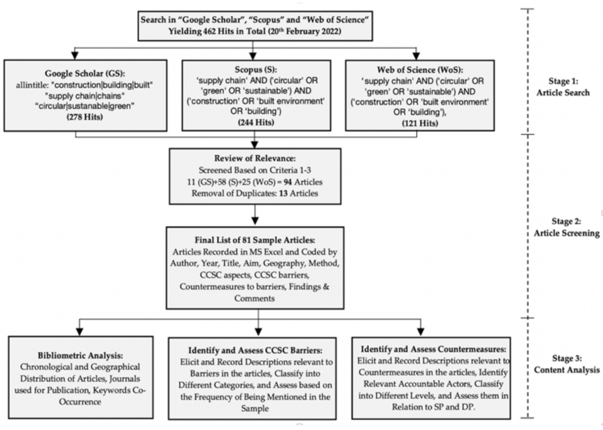

Figure 2: Schematic design of the systematic review

The actual search was conducted in February 2022, and the 462 "hits" returned from the initial search were screened using three main selection criteria: 1) peer-reviewed journal articles to improve research rigour, 2) published after 2013 when CE gained ground thanks to a series of seminal reports by the Ellen MacArthur Foundation, 3) research scope in close proximity to CE principles applied in construction SCs in light of CE strategies in construction SCs identified by Chen *et al.,* (2022). The selection resulted in a final sample of 81 articles recorded in MS Excel for further analysis (the full list of articles is available upon request). In general, an upward trend of research is witnessed in the sample focusing on CCSC with most articles (35/81) published in 2021, indicating a growing awareness of this topic in the academia.

FINDINGS

A relational diagram (Figure 3) aided by VOSviewer was used to show co-occurrences in a network of 39 keywords generated by setting 'the minimum number of occurrences' of a keyword in the research sample at '5'. The size of each node reflects its occurrence in the sample, whilst the thickness of a line between two nodes infers the frequency of their co-occurrence. The top eight keywords whose occurrences and link strength are above 19 and 100 respectively are 'supply chains', 'construction industry', 'sustainable development', 'sustainability', 'circular economy', 'recycling', 'supply chain management' and 'waste management'.

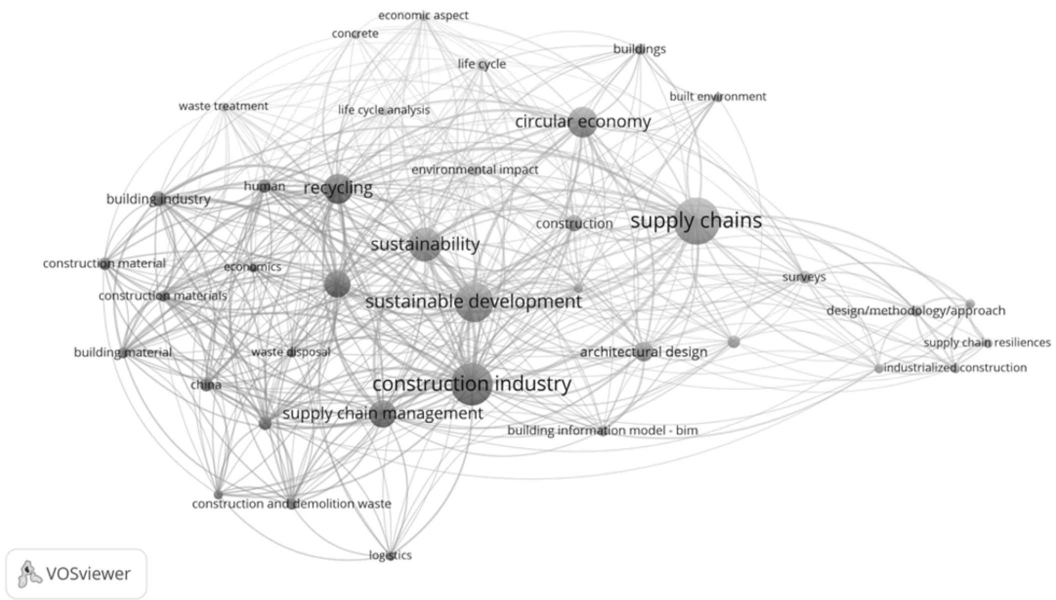

Figure 3: Keyword co-occurrence network

Two points are worthy of note here. Firstly, a high linkage between 'sustainability' and 'circular economy', which echoes the perceptions of Geissdoerfer *et al.,* (2017) who summarised three types of relations between "sustainability" and "circular economy", i.e., pre-condition, a beneficial relation, and a trade-off. However, the impact of keywords used should be admitted on the resulted high relation. Secondly, "recycling" and "waste management" are of high relevance to "circular economy", which is also reflected in the sample where 62.97% (51/81) of articles mentioned R-related principles in the waste hierarchy (i.e. refuse (2/81), rethink (2/81), reduce (26/81), reuse (46/81), repair (6/81), refurbish (5/81), remanufacture (9/81), repurpose (2/81), recycle (50/81), and recover (6/81)), among which 3Rs (reduce, reuse and recycle) were found to be the most common combination mentioned in 24.69% (20/81) of the sample.

This is consistent with Kirchherr *et al.,* (2017) who reviewed 114 definitions of CE and found that "recycle" was the most common element mentioned in 78.95% (90/114) of definitions and 3Rs were the most commonly elements of CE definitions.

This finding aligns with claims by Adam *et al.,* (2017) that construction CE has been largely limited to waste management and recycling and has a little relevance to other compelling requirements of CE highlighted by Abadi and Sammuneh (2020) concerning 'design for circularity' and 'new SC business models'. In addition, the four clusters in different colours in the network show different focus with "building materials" (red) (e.g., fit-out waste, bioplastics…), "industrialised construction" (green) with 30.86% (25/81) of relevant articles, "building information modelling" (blue) with 37.04% (30/81), and "environmental impact" (yellow) echoing Geissdoerfer *et al.,* (2017) who revealed that most CE studies focused on environmental aspects of CE.

Barriers and Countermeasures Associated with CCSC

A Sankey diagram was used for the visualisation of barriers to the transition to CSC in construction identified from the research sample (Figure 4). Thirty-seven barriers were identified in total from the research sample; these were combined into nine factors and further classified into three groups according to their nature (technical, managerial, and contextual). The width of flows in Figure 4 represents occurrences of different barriers in research sample, which indicates the level of attention they received in the CCSC literature, given that each article in the research sample may address several barriers/factors at the same time.

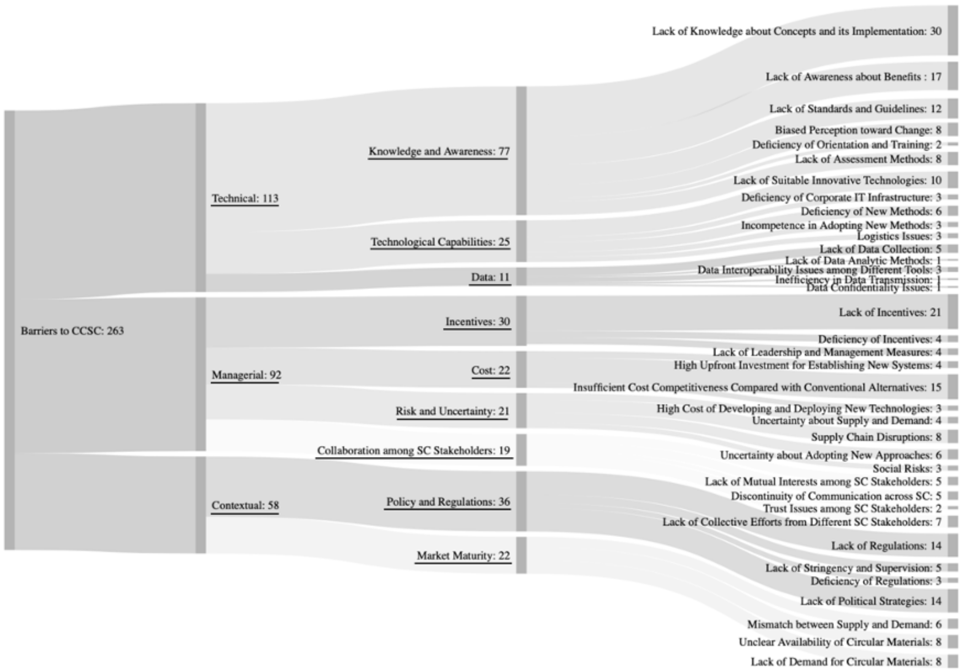

Figure 4: Barriers to CCSC identified from the research sample

Figure 4 shows that 'Knowledge and Awareness' is the most important factor identified in 29.28% (77/263) of the articles, with 'Lack of Knowledge Concept and its Implementation' being the predominant barrier mentioned under this factor (11.41% (30/263)). This is also evidenced by a compelling argument by Adam *et al.,* (2017) who discerned a lack of awareness of CE adoption in the construction industry where SC actors (i.e., clients, designers and subcontractors) were the least informed. As Wijewickrama *et al.,* (2021) revealed that designers were aware of the importance of designing out waste, but they did not have sufficient knowledge to take actions. A few articles also show that some practitioners were conducting CE practices, but they were unaware of the concept perhaps due to some similarities between sustainability and CE. This fact is also seen in the sample where 59.26% (48/81) of articles studied CE-related topics in construction SCs, but they did not literally specify CE.

A relational Sankey diagram was used to depict CCSC dynamics; these include barriers to transition to CCSC, associated countermeasures, and responsible actors and their level of control (Figure 5). Twenty-nine countermeasures were elicited from the research sample and their links to different barriers listed under the nine factors discussed earlier were established. Moreover, the accountable actors responsible for individual countermeasures were identified and classified into three groups according to their level of control in CCSC as suggested by Wijewickrama *et al.,* (2021). The three levels include: firstly, the micro, i.e. project supply network, level including actors contracted by the need of a project (e.g. developers, architects, contractors, suppliers… etc.); secondly, the meso level including non-governmental organisations (e.g. Association of Project Management APM, and the Ellen MacArthur Foundation), research institutions providing knowledge and guidance for project delivery (e.g. universities, and research centres); thirdly, the macro level including governmental bodies and policy makers. In Figure 5, the three levels of control were colour-coded, and flows were configured with the same width since the purpose is to identify dynamics in CCSC and associated frequencies are insignificant in this context.

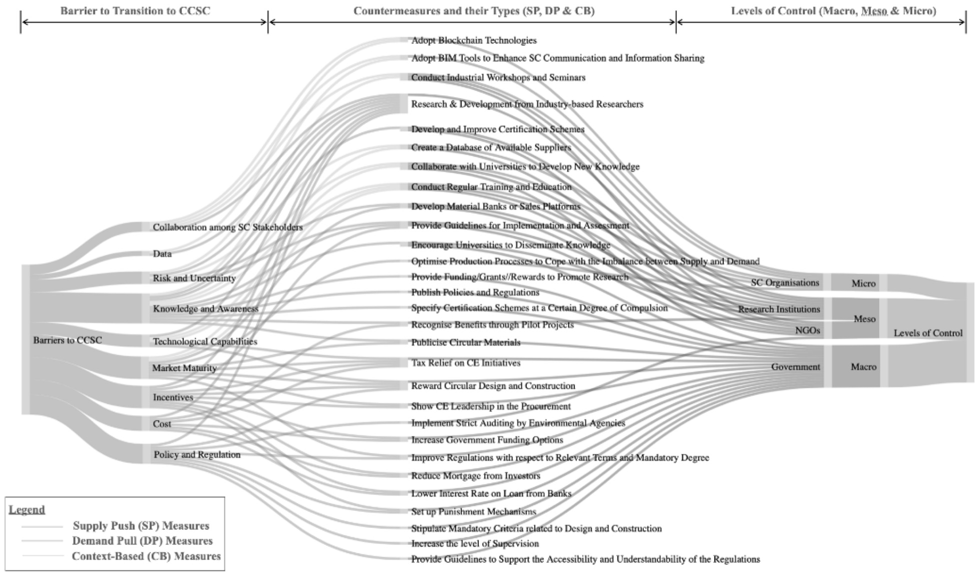

Figure 5: A relational diagram of CCSC dynamics

Two points are worthy of note in terms of dynamics of the transition to CSC in construction. Firstly, the 'macro', i.e., government and policy makers, level is of high expectation to develop strategies and policy to support the transition to CSC in construction. Secondly, Figure 5 reveals that the transition to CSC in construction has a complex nature and requires greater collaboration of all actors at different levels of control (micro, meso and macro). Each of the identified countermeasures can be used to tackle different barriers; for example, 'Tax Relief on CE Initiatives' can be used to mitigate barriers listed under 'Technological Capabilities', 'Maturity of Market', 'Cost' and 'Incentives'. Similarly, each barrier can be tackled using different countermeasures, and consequently, actors responsible for these countermeasures that may exist at different levels would be involved in its mitigation.

The Interplay Between SP and DP Configuration in CCSC

Reflecting on SP and DP configurations in CCSC, countermeasures identified from the research sample were classified into three groups: 'SP-related', 'DP-related', and 'Context-Based'; these three groups were colour-coded in Figure 5. Findings reveal that the identified countermeasures are mainly SP-driven focusing on providing appropriate contexts to support the transition to CCSC from a level of control higher than the micro level, i.e. project supply network, instead of being initiated from the demand side. However, no clear evidence has shown any DP measures initiated by the micro-level actor to tackle the barriers. Moreover, some countermeasures can either be SP or DP depending on the context within which they are applied, and thereby classified as 'Context-based'. For example, 'Conduct Regular Training and Education' can be classed as 'SP-related' if it is devised by actors at the 'macro' or 'meso' levels to promote new strategies at the micro level and classed as 'DP-related' if devised by actors at the micro level reacting in response to their own needs.

Despite the SP-driven nature of CCSC, findings interestingly reveal that SP measures, e.g., 'Tax Reliefs on CE Initiatives' and 'Provide Funding/Grants/Rewards to Promote Research', are devised to reduce the environmental impact of construction activities as well as gradually create a DP environment in CCSC by mitigating barriers to adoption, raising awareness of actors at the micro level about benefits of CE, creating opportunities and establishing demand for circular materials. This indicates that barriers to CE implementation are not static, but instead they change over time with the SP effects. Although this systematic review cannot reflect the changing process of SP and DP due to the different contexts in the sample articles, the dynamics in CCSC can be explained considering the 'Innovation Chain' model. Based on this model, measures of promoting CCSC would gradually move from SP- to DP-driven with increased CCSC maturity (i.e., a transitional process), and more initiatives would come from actors at the micro level (i.e., project supply network) and a DP environment eventually develop once benefits have been widely acknowledged. Given CCSC is currently primarily SP-driven, it is fair to assume that CCSC is still in its early stage of development, which is also supported by views of Hossain *et al.,* (2020). On the other hand, as CE is perceived as a combination of relevant strategies and concepts, its adoption in CCSC would need to undergo continuous iterations from SP to DP to support/embrace emerging CE strategies and concepts (i.e., 'transformational' process).

CONCLUSIONS

This paper explores dynamics of construction circular supply chains (CCSC) from new supply-push (SP) and demand-pull (DP) perspectives by systematically reviewing 81 peer-reviewed articles. First, data analysis revealed that the CCSC literature is still engaging with concepts related to waste management, e.g., waste hierarchy and Rs concepts, overlooking more compelling concepts of SC management, e.g., 'design for circularity' and 'sharing economy'. Second, the transition to CCSC is still associated with barriers; with 'Knowledge and Awareness' being the most common barrier revealing a nascent stage of CCSC development. Third, analysis of dynamics of this transition (barriers, countermeasures, and actors) revealed a complex system, as overcoming individual barriers requires the use of multiple countermeasures and greater collaboration of various SC actors at different levels (micro, meso and macro). Fourth, governance in CCSC showed a supply-push dominance with more influence of actors at levels higher than the micro level, i.e., project supply network, to facilitate the transition. Fifth, findings revealed that "push" measures are usually devised to gradually create a "pull" environment in CCSC (e.g., by easing barriers to adoption, raising awareness, creating opportunities, establishing demand for circular materials), and "push" measures can be revoked when a "pull" environment has been created. Sixth, this new "push-to-pull" environment justifies the use of the 'innovation chain' model to describe dynamics in CCSC, and the fact that CCSC are currently more SP-driven provides extra evidence that CCSC is still at an early stage of development. Finally, the circular economy (CE) paradigm includes a long list of strategies/ concepts, and their adoption in construction SCs requires continuous iterations between SP to DP measures to embrace emerging CE strategies/concepts reflecting a complex 'transformational' rather than 'transitional' nature of CCSC. This complex understanding of CCSC dynamics provides directions for future research. It brings the concept of resilience in CCSC into view and suggests potentials of system dynamics modelling for informing decision-making and policy design. This will, eventually, shift the attitude of SC actors toward the transition to CE from 'passive' (i.e., externally stimulated by policies and arrangements devised on an ad hoc basis), to 'active' (i.e., actor-inclusive initiatives well-informed by deep understanding of CCSC dynamics).

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CHALLENGES CONFRONTING ENVIRONMENTAL IMPACT ASSESSMENT PRACTICES IN TANZANIA: CONSTRUCTION INDUSTRY PROFESSIONALS' PERSPECTIVE

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The construction industry is among the fastest growing industries in Tanzania, thus making the integration between the construction industry and the environment inevitable. Activities of the industry poses considerable destruction to the environment and peoples' lives. The purpose of this study is to examine the critical challenges construction industry professionals face in undertaking Environmental Impact Assessment (EIA). A mixed method approach was adopted. Quantitative data was analysed through descriptive statistics whereas qualitative data was analysed through content analysis. Based on the findings, the top three identified challenges included Stakeholders inadequate knowledge regarding the environmental protection laws; environmentally friendly materials not specified/known by stakeholders and lack of government enforcement and support. The results of this study will foster better understanding of the challenges to enable the development of solutions towards addressing the identified challenges and the improvement of EIA practice in Tanzania. Also, the mitigation of the challenges will enhance environmental sustainability within the developing countries such as Tanzania.

Keywords: challenges; environmental impact assessment; sustainability; Tanzania

INTRODUCTION

Climate change as a result of global environmental degradation and pollution is a topical issue worldwide, and as a result, any measure to protect the environment at proto or global level, becomes of immense interest to many including governments, private organisations, the public and the environmental stakeholders. The environmental impact assessment (EIA) has emerged as a key component of environmental management (Morgan, 2012). It originated in the United States in the late 1960s and early 1970s (Li, 2008) however, since then it has been extensively adopted across the world. Mbala *et al.* (2019) asserts that construction sector is one of the major contributors of environmental damages.

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This is highly contributed by the need to develop more infrastructure to sustain the growing. The severe growth of environmental damages caused by human activities has led to the emergency of EIA as a strategy towards environmental management (Morgan, 2012) to foresee the impacts of development projects on natural resources and the environment at large. Furthermore, EIA is one among the essential strategies towards achieving sustainable development (SD). According to Brundtland, (1987) report, environmental protection is amongst the three fundamental components to SD others include economic growth, and social equity. But despite the usefulness of EIA in contributing towards sustainable development, in some instances EIAs have been considered ineffective due to institutional behaviours such as governance and public participation. There have been arguments that the EIA has lacked enabled capacity by the mandate authorities to the extent they can be manipulated (Sosovele, 2011).

Furthermore, it is alleged that the EIA has very limited effectiveness in the developing countries compared with the developed countries (Sosovele, (2011; Arun, 2013) due to various existing challenges. For instance, it is reported that, EIAs in Africa is challenged by insufficient budgets, a lack of trained people, and the fear that EIAs might hold back economic development (Nyamazana and Ozumba, 2018) since the assessment process takes much longer time making developers viewing it as a hurdle. This is also supported by Onalenne, (2017) who reported that in India, EIA has become one among the reason why potential investors set up their investments elsewhere to avoid such delays. Even though, EIAs in developing countries particularly Sub-Saharan Africa (SSA) are established on similar set of principles, but their implementation frequently falls short of international standards because of inadequate consideration of impacts, alternatives, and public participation (Li, 2008). Therefore, the purpose of this study is to examine the critical challenges construction industry professionals face in undertaking EIA in Tanzania.

Environmental Impact Assessment (EIA) is defined as a legal and technical system used in environmental management to support sustainable development (Ritter *et al.,* 2017). The overall aim of carrying out the assessments is to predict the likely environmental, social, and economic impacts before projects take off. Prediction of impacts at an early stage of the project design helps in several precautionary measures, to reduce the effects of the project to be implemented on the environment, to suit the present environment and giving more suitable options to the decision makers. The negative environmental impact is a result of human action, which has become a major global issue affecting both developed and developing countries. However, the situation is more severe in SSA as they frequently suffer from inadequate considerations of impacts, alternatives, and public participation (Gubena, 2016). To address the challenge, the Tanzanian government enacted Environmental Management Act 2004 to provide legal basis for the execution of EIA.

The legal framework prohibits developers to implement a project for which an EIA is required. The requirements for undertaking EIA in Tanzania are like those in the UK as they both depend on whether the project fall under Type 1 (projects requiring a mandatory EIA) or Type 2 (projects requiring preliminary assessment to determine the extent). Both categories depend on the size and nature of the project as specified in the Regulations. Similarly, EIA procedures have been integrated in the planning and decision-making arrangements in all ministries, local Government and private sector activities through policies, legislations, guidelines, and other provisions. Stakeholders involved in the EIA process include project proponents, professionals, reviewers who undertake screening process, decision makers and the public. Nevertheless, this study only focused on obtaining the perspective of construction professionals and regulators.

Despite the presence of legal framework, different authors such as (Abaza *et al.,* 2004; Li, 2008 and Gubena, 2016) highlighted that EIA is still not willingly understood and fully accepted in developing countries due to their disbelief/myths perceived as stumbling block hindering development. On the other hand, EIA was perceived as complex, and does not yield useful results, costly and delays projects and is just an add-on and occurs too late to do any good. Furthermore, developing countries perceived EIA as a strategy imposed by developed nations with the intention of preventing them from overcoming poverty (Gubena, 2016).

These misconceptions watered down the significance and contribution of EIA in many developing nations. But different studies have identified different challenges hindering the EIA process. A study by Agbazue and Ehiemobi (2016) in Nigeria, identified low awareness on the laws governing environmental protection; low public participation; substandard EIA reports are produced and some with plagiarism in which same facts are being used in two different projects. In South Africa (SA), Nyamazana and Ozumba, (2018) acknowledged that there is lack of adequate knowledge and positive attitude of project stakeholders, Political influence (viewing EIA as a hindrance towards socio-economic development), skills shortage in SA's environmental sector; poor mitigation of social impacts while more emphasis is on biophysical impacts; lack of commitment to mitigate and monitor impacts in EIA reports; lack of public environmental awareness and participation in the EIA process.

Similar findings were identified by Dilay et al.., (2020) and Ahmed, (2018) highlighting that India also faces challenges on EIA process, including high costs, lack of awareness among the actors, gaps in the EIA report i.e. (deliberate omission of vital information, which may alter the fate of projects) and absence of public participation. Furthermore, bulkiness of the EIA documents has been identified as a source of delays in decision making in India. For the case of Tanzania, a study by Sosovele, (2011) reported that, lack of EIA experts; lack of environmental awareness; Ignorance of EIA and illiteracy and Land management problems were key EIA challenges. For the case of Kenya which shares similar economic conditions, Kakonge, (2015) identified Lack of capacity, corruption, lack of political influence and the poor quality of the EIAs as major challenges facing the EIA process. Generally, it is evidenced that lack of capacity, awareness, knowledge, poor public participation, and high costs are the most critical challenges in developing countries.

METHOD

This research adopted a concurrent mixed methods approach utilizing both questionnaires and semi-structured interviews to collect data. The goal was to obtain different but complementary data to answer a single research question. Further justification for embracing the mixed method approach is based on its ability of increasing the validity and reliability of the results (Easterbrook *et al.,* 2008. Each type of data was analyzed independently, and both had the same priority status (Molina-Azorin 2007). The qualitative data was analyzed through content analysis whereas the quantitative data was analyzed through descriptive statistics and inferential statistics.

A non-probability sampling approach was used, whereby judgmental and snowball sampling design approaches were adopted because the researcher wanted to obtain information from respondents having extensive EIA knowledge and practical experiences to gain reliable and adequate information about the EIA challenges within the Tanzanian context. For that reason, the key criteria used for identifying prospective respondents included: (1) having experiences with the EIA processes, (2) must have conducted or taken part in at least one EIA for a project. This was a critical requirement for respondent's identification because they were likely to have sufficient understanding, knowledge and experience required to give reliable and valid answers from the professional viewpoints. The targeted population for the quantitative study included all construction stakeholders including Civil Engineers, Architects, Quantity Surveyors and Environmental Engineers. Likewise, for the interviews, included the Environmental Officers from National Environmental Management Council (NEMC). The role of NEMC is to oversee all the environmental management issues across the country. For that reason, it was considered necessary to collect insights from them as the government authority. Since it was not possible to determine the sample size, data was collected until it reached a saturation point where no newer information was being obtained.

FINDINGS

A total of 60 questionnaires were administered to the targeted population. A total of 50 questionnaires were returned which is equivalent to 83.33%. Likewise, 12 semi-structured interviews were undertaken. Table 1 indicates the professional background, experiences, and number of projects of the questionnaire respondents. The profile shows that majority (66%) of the stakeholders are Civil Engineers and Environmental engineers this could be contributed by the fact that these are the key professionals involved in the EIA process. Besides, it is important to note that, EIA is usually carried out by a multidisciplinary team comprising of varying professionals and expertise. Further examination of Table 1 demonstrates that 70% of the survey respondents had over 5 years' experience in the construction industry whereas 62% had been involved in more than five EIA projects. It is evidenced data was collected from reliable sources hence increasing the reliability and validity of the findings.

Table 1: Summary of questionnaire respondents

Profession and Experience	Number (n)	Overall (%)
Professional Category		
Civil Engineers	17	34.0
Quantity Surveyors	9	18.0
Environmental Engineers	16	32.0
Architects	8	16.0
Totals	50	100.0
Experience (in years)		
1-5 years	15	30.0
6-10 years	18	36.0
11-15 years	8	16.0
Above 16 years	9	18.0
Totals	50	100.0
Number of EIA Projects		
1-5	19	38.0

For the interviews, the profile of the 12 interviewees according to their individual characteristics is depicted in Table 2 below. Examination of Table 2 shows that, out of 12 interviewees, education-wise, 50% had master's degree, and the other 50% had a bachelor's degree. Level of experience-wise, five had over 10 years of experience, four had 5-7 years and three had less than five years of experience.

Table 2: Summary of Interviewees

Interviewees	Position	Experience	Qualifications
Interviewee A	Environmental Officer	15 years	Masters Degree
Interviewee B	Environmental Officer	7 years	Bachelor Degree
Interviewee C	Environmental Officer	5 years	Bachelor Degree
Interviewee D	Environmental Officer	3 years	Bachelor Degree
Interviewee E	Environmental Officer	3 years	Bachelor Degree
Interviewee F	Environmental Officer	4 years	Bachelor Degree
Interviewee G	Environmental Officer	12 years	Masters Degree
Interviewee H	Environmental Officer	7 years	Bachelor Degree
Interviewee I	Environmental Officer	12 years	Masters Degree
Interviewee J	Environmental Officer	10 years	Master's Degree
Interviewee K	Environmental Officer	5 years	Masters Degree
Interviewee L	Environmental Officer	11 years	Masters Degree

Ranking of the Challenges Confronting the EIA

The ranking of challenges construction industry professionals face in undertaking EIA was based on the mean score and standard deviation. In response to the question about the challenges the construction professionals face in undertaking the EIA, respondents were asked to rate their opinions using a five-point Likert Scale. Table 3 shows the results of these mean agreement responses of the 21 identified challenges. For the purpose of this study only the top three ranked challenges will be discussed.

"Low awareness on the laws governing the environmental protection" was the highest ranked challenge with the highest mean score of (m=4.43) and lowest standard deviation (SD) of 0.675, implying a consensus among respondents and the most perceived challenge. Similar findings were reported by Gubena, (2016) study undertaken in Ethiopia. This is contributed by the fact that EIA is not considered as a key requirement to make the decision on whether to allow the investment to be implemented or not. Practically, due to this weakness some projects are given approval without being guided by the EIA results/reports. Numerous studies (Dilay et al.., 2020; Nyamazana and Ozumba, 2018; Ahmed, 2018 and Agbazue, 2016) further confirms that EIA is very little known by the stakeholders in many developing countries, hence making its implementation difficult.

One of the main reasons for low awareness could be originating from the fact that local communities who are the main stakeholders were never consulted during the law-making process. Instead, EIA has been considered as the bottleneck (anti-development) to their economies. Additionally, Zuhair and Kurian (2016) also reported that lack of awareness of the procedure and guidelines was identified as one among the challenge that reduced public willingness to participate in the EIA process in Maldives. Therefore, this demonstrates the need for creating awareness on the laws and guidelines to enhance the participation of all the required stakeholders.

The interviews as conducted further confirmed the findings from the survey and literature review. As seen in Table 4, all the Interviewees confirmed there is lack of awareness among the stakeholders on the role and importance of EIA. Example Interviewee G explained that,

> "We face challenges not just from the clients and local communities but also from the ward leaders especially when they are asked to produce certain information within their locality instead, they insist to be paid huge sums of money before they can agree to share the required information".

Table 3: Ranking of challenges and constraints faced by the EIA stakeholders

Challenges faced by the stakeholders in EIA	N	Mean	SD	Rank
Low awareness on the laws governing the environmental protection.	50	4.43	0.675	1
Non-specification of environmentally friendly materials	50	4.35	1.027	2
Lack of government enforcement and support	50	4.08	0.971	3
Poor implementation of the mitigation measures and monitoring	50	3.96	1.037	4
Low awareness of the EIA process in the construction industry	50	3.83	0.984	5
High cost of employing environmental consultants	50	3.75	0.954	6
Poor standard of the EIA report	50	3.73	0.784	7
Lack of trained and experienced staff	50	3.65	0.864	8
Plagiarism in EIA reports, the same facts used for two different projects	50	3.60	0.810	9
Environmental clearance is granted despite of public objection.	50	3.45	0.904	10
Hiring an Environment Consultant after project take off	50	3.43	0.902	11
Lack of cooperation of subcontractors due to lack of experience / familiarity	50	3.43	0.984	12
EIA process is too expensive	50	3.38	0.952	13
Lack of EIA experts	50	3.38	1.125	14
Environmental clearance is granted without public participation.	50	3.25	0.981	15
Consultants lacking adequate capacity on the EIA	50	3.23	1.143	16
Deliberate omission of vital information which may alter the fate of project	50	3.08	1.141	17
lack of client support	50	3.05	1.176	18
Wrong notion that after site clearance, environmental clearance will follow	50	2.95	1.037	19
Bulkiness of the EIA documents delays decision-making	50	2.88	1.114	20
Land management issues	50	2.70	1.203	21

"Non-specification of environmentally friendly materials" with mean value of 4.35 and a standard deviation (SD) of 1.027 was the second ranked challenge. This challenge is also consistent with the finding in the South African study by, Nyamazana and Ozumba, (2018). But surprisingly, this finding was never mentioned by the interviewees. However, it appears that there is a need to specify the environmentally friendly materials to guide the stakeholders in their environmental analysis and decision as well as in material selection. The benefits of these materials are that they contribute towards healthier living, better quality life and cost saving.

The third ranked challenge was the "lack of government enforcement and support" with mean value of 4.08 and a standard deviation of 0.971. Similar finding was identified by Bradley and Swaddling, (2018) study undertaken in the Pacific Island countries which stressed that weak compliance monitoring and enforcement could lead into several risks, including unmanaged impacts and serious environmental harm. Besides, the weak enforcement could question the general value and efficiency of the EIA process, because there is no monitoring or checking of whether the proponents have fulfilled their environmental management responsibilities. Therefore, such flaws jeopardize the whole aspect of achieving sustainable development in a developing country like Tanzania.

Interview Survey Findings

The interviewees who are the Environmental officers entrusted with the role of environmental enforcement, compliance, reviewing, and monitoring were asked by the researcher to explain what challenges do they encounter in monitoring/controlling and reviewing EIA reports? Based on Table 4 below, "lack of awareness on EIA among the stakeholders (n=12) was mentioned by all the 12 interviewees signifying that this is the most critical challenge despite their role of undertaking research and awareness creation. This interview finding is strongly supported by the survey findings and existing literature as previously explained thus increasing the reliability and validity of the data collected.

Table 4: Summary of challenges faced by the EIA Officers (interviewee perceptions)

Challenges	Interviewees												
	A	B	C	D	E	F	G	H	I	J	K	L	No.
EIA involves many stakeholders with varying interests							✓	✓	✓	✓	✓	✓	6
Lack of awareness on EIA among the stakeholders.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	**12**
Existence of on-going projects which have already caused pollution that need environmental audit	✓	✓		✓	✓								**4**
Each project has specific conditions for the EIA certificate	✓		✓	✓	✓			✓		✓		✓	**7**
Avoidance of expenses by ignoring environmental issues and EIA laws and regulations	✓		✓		✓			✓	✓			✓	**6**
Political influence	✓	✓						✓		✓		✓	**5**
EIA Consultants handling many projects hence causing delays to clients							✓	✓	✓	✓		✓	**5**
Some EIA officers lack enough capacity to assess the submitted reports							✓			✓		✓	**3**
Some clients provide wrong/incorrect information which are not relevant to the project in order to change the fate of the project								✓			✓	✓	**3**
Non submission of necessary documents such as land ownership documents required to facilitate the assessment process hence causing delay							✓		✓		✓	✓	**4**
Inadequate community participation.							✓	✓	✓	✓	✓	✓	**6**
Bribing behaviour of clients who wants to get away with the EIA process								✓			✓	✓	**3**
Insufficient/poor EIA reports submitted by consultants to the environmental council for review.							✓	✓	✓	✓	✓	✓	**6**

A number of reasons were put forward by the interviewees in support of the awareness challenge. These ranged from "the lack of willingness of some community members to participate in the process, clients refusing to disclose all the required information and documents, as well as clients involving incompetent consultants".

The second identified challenge with the highest frequency (n=7) was "Each project has specific conditions for the EIA certificate" this implies that every project is unique with distinctive features thus its assessment and process is also unique before being granted certification. In this case EIA requires strong human capacity to be able to monitor and review every individual project. This is also confirmed by Zuhair and

Kurian, (2016) who contended that lack of finance and human capacity is the major challenge in EIA process in developing countries.

Other identified challenges which received high frequency count (n=6) as seen in Table 4 include EIA involves many stakeholders with varying interests, to further elaborate this challenge Interviewee L explained that:

> "EIA process involves many stakeholders including the National Environmental Management Council, proponent (client), the affected community, experts, registered consultants, and the Government. All of these work in chain so if one delays a particular stage then the whole process is delayed".

Not only that but also the involved stakeholders have varying goals therefore sometimes it is difficult to achieve the goal which is environmental Management and protection.

The other ones with the same frequency (n=6) are 'avoidance of expenses by ignoring environmental issues and EIA laws and regulations; 'Inadequate community participation" and 'Insufficient/poor EIA reports submitted by Environmental consultants to the environmental council for review'.

The avoidance of expenses by ignoring environmental issues and EIA laws and regulations was mentioned by six interviewees indicating that it is among the common challenge. Interviewee A, C and E, reported that,

> "…majority of proponents (project developers) don't like to incur the cost of paying the consultant as a result some decides to ignore the whole process of EIA and starts the project with no Government certification."

This finding is also reinforced by Soria-Lara *et al. (*2020) arguing that, EIA cost is high in comparison with the project cost under evaluation. On the other challenge "Inadequate community participation" this finding is never surprising as several studies (Soria-Lara *et al.,* 2020; Bradley and Swaddling, 2018; Morgan 2012) identified it. Despite Public participation being a novel feature introduced through EIA in the last two decades (Zubair 2001), still it is the source of many challenges in the actual EIA (Morgan 2012).

The last identified challenge by the interviewees with (n=6) is 'Insufficient/poor EIA reports submitted by Environmental consultants to the environmental council for review. This finding is not very new because it has been a common concern reported in other developing countries such as Sri Lanka (Zubair 2001), Maldives (Zuhair and Kurian, 2016) complaining on the poor quality of EIA information. If this is not intervened once noted then, their results will have little or no effect on policy decisions thus compromising the environmental protection agenda (Ritter, *et al.,* 2017).

CONCLUSIONS

This study examined the the critical challenges construction industry professionals face in undertaking Environmental Impact Assessment (EIA). The findings revealed that there were both similar and contrasting challenges faced by the professionals and the Environmental officers working with NEMC in Tanzania. Based on the survey results, the top three ranked challenges among the construction professionals were "Low awareness on the laws governing the environmental protection" (mean =4.43) and (Std= 0.675), "non-specification of environmentally friendly materials" (mean =4.35) and (Std= 1.027), and "Lack of government enforcement and support" (mean =4.08) and (Std= 0.971). Whereas, for the interviewees' findings, "Lack of awareness on EIA among the stakeholders" (n=12); "Each project has specific conditions for the EIA certificate" (n=07) and "EIA involves many stakeholders with varying interests"; "Avoidance of expenses by ignoring environmental issues and EIA laws and regulations"; "Inadequate community participation" and "Insufficient/poor EIA reports submitted by consultants to the environmental council for review" all four of these were mentioned six times by the respondents.

The findings of this study are important to the EIA stakeholders and the country at large in several ways. First, it is evident that the lack of awareness on the EIA is the most critical challenge. This implies that the level of environmental awareness of the different stakeholders is limited and there is a need to revisit the role of NEMC in raising awareness to achieve the intended goal of environmental protection to achieve sustainable development.

Furthermore, the Government should make deliberate efforts through its Environmental units and Council to create awareness on laws, policies, and protocols as well as training people on the significance/impact of undertaking EIA by establishing continuous programmes and offering of training to the nation at large. Likewise, to enhance public participation, there is a need for the Government to incorporate EIA lessons in primary and secondary education from the grassroots level so that it becomes a culture and is accepted as a tool for Sustainable Development. Lastly NEMC should make sure that they adequately fulfil their role of enforcement so that it discourages those who bypass EIA review to seriously strengthen compliance monitoring and enforcement system.

Therefore, these findings strongly suggest that if EIA continues to be hampered by these challenges, Governments will fail to adequately manage the environment hence destroying its natural resources which to a country like Tanzania these resources contribute to more than 70% of the national Gross Domestic Product and livelihoods of majority of the people (URT, 2021). These findings have created the need to address the challenges to sustainably manage the environment for the benefit of the present and future generations. Future studies should further analyse the perception of each professional based on their relationship/role to the EIA process to clearly identify problematic areas/stages because construction professionals involved relate to EIA differently

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DEVELOPMENT OF INDICATORS FOR SOCIAL SUSTAINABILITY ATTRIBUTES ACROSS THE CONSTRUCTION PROJECT LIFE CYCLE

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Sustainability in construction refers to the adherence to the three primary pillars of sustainability, which are environmental, economic, and social practices that influence projects' performance. However, the social pillar is still being side-lined and inadequately defined, owing to its subjective nature, which highly depends on the uniqueness of a site and the surrounding culture and community. Consequently, the question that remains unanswered is, what are the social sustainability indicators that should be considered in construction projects, accounting for the different stakeholders across the construction project life cycle? This study aims to establish the indicators of social sustainability in construction projects, further relating those indicators to the various stages of the construction project life cycle. The methods for this study included literature reviews, focus group discussions, and structured interviews. The findings would enable objective assessment of the social sustainability dimension across the construction project life cycle, subsequently assisting industry practitioners to continuously monitor and improve the social aspect of their project towards achieving sustainable construction.

Keywords: indicators; project life cycle; social sustainability

INTRODUCTION

It has been well acknowledged that the construction industry has a significant contribution to sustainable development. Nonetheless, the activities that occur during the life cycle of a construction project do result in inherent societal consequences (i.e., economic, environmental, and social consequences) (Dong and Ng, 2016). Among the "triple bottom line" principles of sustainable development, social sustainability (SS) is the least explicit dimension, particularly in construction projects (Karji *et al.,* 2020). Meanwhile, Rostamnezhad and Thaheem (2022) also claimed that little literature has been done to investigate the social attributes of construction projects. The term "SS in construction projects" refers to specific social implications of construction projects on the human population that affect how people live, work, interact and organise to meet their needs (Sodangi, 2019). Therefore, SS is an important part of sustainable development and the exclusion of the social attributes in construction project developments will have detrimental short and long-term effects on the entire project life cycle.

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Previous researchers have offered different approaches to improve SS in the construction industry, including green innovation technologies of construction methods (Randeree and Ahmed, 2018), development of the fuzzy analytical hierarchy process (FAHP) method to evaluate the social performance of hospital redevelopment projects (Xiahou *et al.,* 2018), development of a quantitative model that uses efficacy index to determine the actual efficacy level of SS (Sodangi, 2019), and implementation of SS-centric analysis techniques for feasibility study (Goel *et al.,* 2020).

Since most of the previous efforts have concentrated on technological or process improvements, which affects only single or several phases in the construction project life cycle, their benefits or impacts on the overall project were limited. On the other hand, researchers have also developed different industrial or national indicator systems to evaluate the sustainability of the construction sector in a country (Dong and Ng, 2016; Randeree and Ahmed, 2018). Although such SS evaluation systems were more comprehensive in assessing certain construction project life cycles, they are less useful for developing effective strategies to improve the overall SS in a construction project. Thus, this study attempts to identify the SS indicators in construction, further designating the SS indicators over the project life cycle in construction. The determination of the SS indicators would be based on the earlier findings by Kordi *et al. (*2021) where 9 main and 20 sub-attributes of SS has been established. The proposed indicators are beneficial for construction stakeholders, to achieve sustainability in a more effective manner throughout the construction project life cycle.

LITERATURE REVIEW

Social sustainability (SS) seeks to address the requirements of people at every stage of a construction project's life cycle, to ensure effective collaborations with stakeholders, suppliers, employees, and local communities for customer satisfaction. Several prior research (Almahmoud and Doloi, 2015; Rohman *et al.,* 2017) have produced assessment frameworks, some of which were focused only on certain indicators of SS. Li *et al. (*2018) provided a breakdown of multi-stakeholder-related SS, whereas Doloi (2018) provided a methodology for assessing community-specific SS. Earlier, Andreas *et al. (*2011) looked at LEED ND, CASBEE, Cascadia, CEEQUAL, and Green Globes to identify indicators for infrastructure system sustainability. Fowler and Rauch (2006) who researched on rating systems around the world found BREEAM, CASBEE, GB Tool, Green Globe US, and LEED to be the most suitable rating systems for General Service Administration (GSA) projects. Nguyen and Altan (2011) reviewed and analysed five well-known grading systems, including BREEAM, CASBEE, LEED, GREEN STAR, and HK-BEAM from various perspectives, and concluded that BREEAM and LEED were the most developed. The recent study on sustainability rating systems was conducted by Karji *et al. (*2020) who identified the SS indicators from reviewing the existing systems. Nonetheless, the limitations of the previous studies stem from the lack of comprehensive breakdown of SS indicators into objectively measurable and reliable taxonomy for the entire process project life cycle. Some of the SS indicators also included economic and environmental indicators, which were not the focus of SS. These limitations place researchers, policy makers, and practitioners in a tough position; they must conceive and expand on the conceivable hierarchies of SS to conduct an appropriate and representative analysis of the social implications of a construction project (Rostamnezhad and Thaheem, 2022). Nevertheless, not all components of SS were represented, and certain significant features run the risk of being overlooked due to the limited space-time views and considerations from the relevant decision-makers. This lacking imposes additional work on practitioners and decision-makers in locating existing frameworks and compiling a comprehensive breakdown of SS for the entire project life cycle. The inherent shortages on the coverage and concentration of SS justifies the need for additional efforts regarding this subject matter, which coincides with the intention of the current study.

METHOD

This study started with the conduct of literature reviews in identifying the relevant SS indicators across the construction project life cycle. This was followed by focus group discussion and structured interviews with expert panels for the review and verification of the SS indicators. The three main methods are described as follows:

(1) Literature review
The study was planned for the identification of relevant SS indicators in construction projects through literature reviews. The process of identification was guided by the main and sub-attributes established from the previous study by Kordi *et al. (*2021). Subsequently, thematic analysis was conducted by defining the relevant themes and sub-themes. During the development of the indicators, the researchers have brainstormed on the potential inconsistencies, different thoughts or ideas that could arise from having various interpretations of the data until reaching the point of consensus on the developed indicators, regarding the main and sub-attributes.

(2) Focus groups discussion (N=15)
The purpose of conducting focus group discussion, in the form of an open interview was to create an environment with opportunities to impart and discuss the identified SS indicators with the experts. The indicators identified from the literature were grouped into the three stages of construction life cycle: namely, pre-construction, construction, and post-construction. Afterwards, the grouped indicators were sent to the expert panels one week before the focus group session, as an initial reference. This has allowed the panels to preview and familiarise themselves with the SS indicators before the focus group session.

The recommended size for a focus group is often between five to twelve participants (Ho *et al.,* 2021), to allow for maximum interaction between the participants and to elicit as much information from the participants. In total, 15 expert panels were selected for the focus group discussion that were conducted in September 2021. All the expert panels had at least ten years of working experience with 7 panels having more than 20 years of working experiences. During the session, the expert panels with diverse backgrounds were further divided into three groups (5 experts in one group) to ensure the discussions were more focused (Table 1). Each of the focus group sessions lasted between one to two hours.

Regarding the focus group session's protocol, the facilitator has started by describing the goal of the study, the meeting's ground rules (e.g., participants are welcome to make comments and share their experiences), and the preservation of panels' anonymity. The 48 indicators were then presented to the panels. Throughout the discussion, participants were directed to refer to the indicators' definitions (with application examples) with guidance from the facilitator.

Table 1: Details for the group of experts (N = 15)

Group 1		Group 2		Group 3	
ID	Position	ID	Position	ID	Position
A2	Associate Professor	A1	Senior Lecturer	A-5	Senior Lecturer
I-6	Civil Engineer	A-4	Senior Lecturer	A-3	Senior Lecturer
I-7	Senior Manager	I-11	Managing Director	I-14	Project Manager
I-8	Director Manager	I-13	Architect Manager	I-15	Design Manager
I-9	Architect Manager	I-12	Director of Facility Management	I-16	Senior Structural Engineer

The panels were persuaded to engage in open discussion about SS issues relevant to their own personal project's experience in order to assess the robustness of the indicators. Each SS indicator was brainstormed to allow the retrieval of additional information from the experts. Modifications were made until agreement were achieved among the expert panels. Based on the 'theoretical saturation' (Saunders *et al.,* 2018) concept, we have continued the session until reaching the point of no additional or relevant insights into the research issue. Comments and suggestions from all the groups were consolidated and incorporated in the final version of the SS indicators.

(3) Structured interview (N=25)

As suggested by Yeung *et al. (*2009), quantitative measurements allow for objective assessments of indicators. Outcome from Stage 2, which was the consolidated set of SS indicators were then placed in the form of a questionnaire survey for the conduct of structured interview. The structured interviews were aimed to obtain objective assessment of the consolidated indicators from the previous stage. The structured interviews were conducted with industry practitioners who had prior experiences in sustainable construction projects, particularly SS.

Finally, 25 expert respondents were selected for the structured interviews conducted over the span of two months (October - November 2021). During the structured interview, the experts were required to indicate the appropriateness of the social sustainability indicators in measuring the practice of social sustainability in projects. The experts were then asked to rank the level of suitability in accordance with the following 5-likert scales: (1) definitely not suitable; (2) probably not suitable; (3) unsure; (4) probably suitable; (5) definitely suitable. Once the appropriate level of suitability was identified, the final set of social sustainability attributes and indicators is established. The general workflow of the process is illustrated in Figure 1.

FINDINGS

Profiling of Respondents

The expert panels in Stage 2 were identified among experienced academicians and construction industry practitioners. There were five experts from the academics and ten from the construction industry for the focus groups. One expert was a senior manager, seven were project managers, and two were engineers from the industry. The respondents' backgrounds were diverse, including main contractors (n = 4), developer (n = 1), government departments (n = 2), and consultants (n = 3).

For the respondents in Stage 3, 30 relevant experts were initially contacted, where 5 of them claimed that they were not qualified to participate due to their limited knowledge and experiences with sustainability projects. Therefore, the list of interviewees was cut down to 25. Among the 25 interviewees, 16 were industry professionals (11 property developers and 5 planners), 4 were government officials (from planning departments), and 5 were scholars (from 2 public universities).

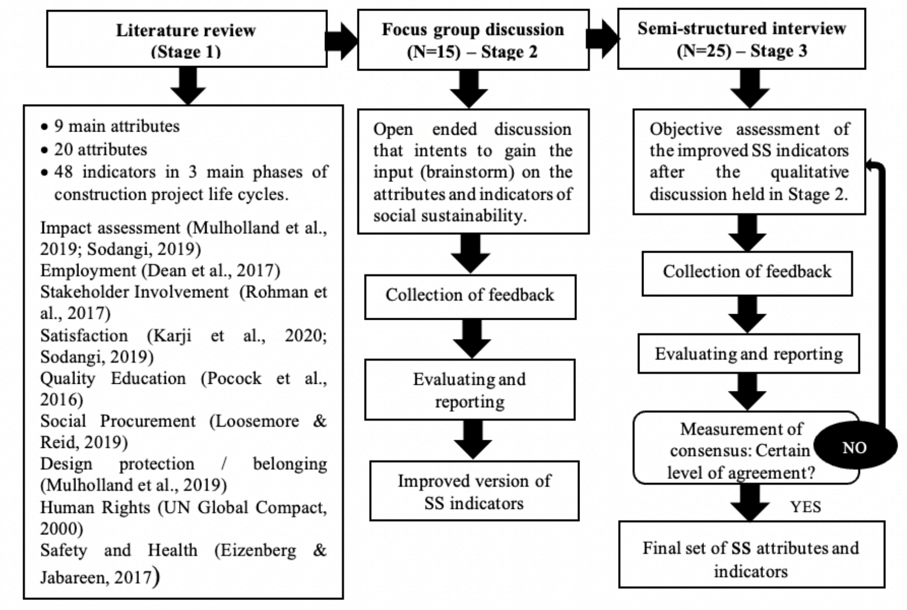

Figure 1: Key steps of the method

Social Sustainability Attributes and Indicators

Findings from the literature review and focus group discussion have resulted in 48 SS indicators, which were further acknowledged its practicality and suitability by 25 practitioners through structured face-to-face structured interviews. The average score given by the 25 practitioners regarding the established indicators was 4.84, out of 5. The high score indicates that the SS indicators were appropriate and fit to be applied as a SS assessment measure in construction project life cycle. Table 2, Table 3, and Table 4 shows summary of the finalised list of SS main attributes, attributes, and indicators categorised in accordance with the three phases of construction project life cycle. In summary, 25 indicators are placed in the construction phase, 19 in the pre-construction phase and another 4 in the post-construction phase.

In the pre-construction phase, planners need to clearly and systematically provide a plan to minimise disruption that could occur during the construction phase. The development of the Social Impact Assessment (SIA) report may require identifying the impacts of construction to the user and the projection of employment (job creation, job stability, et cetera). In this phase, the organisation must plan for employment opportunities that will be advantageous to the community, such as job opportunities to local people, employee benefits programs, ethical aspects of employee appointments, and gender diversity within the organisation.

Opportunities to obtain professional certification and annual funds to support employees' continuous professional development (CPD) training programs may motivate future employees towards SS. In order to ensure the SS of a project, the organisation must identify and engage a team that may deliver SS in a project, such as being capable of doing design quality and producing socially sensitive design that also protects the cultural heritage. The organisation must be willing to interact and engage with other stakeholders on SS implementation in projects. The timeliness and transparency of communication are key in addressing projects' SS (Kordi *et al.,* 2021).

Table 2: List of social sustainability main attributes, attributes, and indicators for the pre-construction phase

Main Attributes	Attributes	Indicators
Impact Assessment (IA)	User consideration	1. Plan to minimise disruption
	SIA	2. SIA documentation
Employment (E)	Job creation	3. Job opportunities
	Job stability	4. Full-time employment
		5. Turnover rate
	Professional ethics	6. Deviation from a gender-balanced labour force
		7. Process and documentation
		8. Policy on integrity
	Employee performance plan	9. Performance plan
	Employee social benefit program	10. Benefit program
Stakeholder Involvement (SI)	Stakeholder participation	11. Collaboration
	Team formation	12. Selection of team
Satisfaction (S)	Design Quality	13. Design quality survey
Quality Education (QE)	Education and training	14. Policy to obtain and maintain professional
		15. Annual fund for professional development
Social Procurement (SP)	Social procurement	16. Policy on engage with disadvantages group when tendering
Design protection / belonging (DP)	Cultural heritage	17. Collaboration
	Socially sensitive designs	18. Element of inclusive design in project life cycle
Human Rights (HR)	Human rights	19. Following the United Nations Global Compact principle and International Labour Law

Therefore, a policy requiring the involvement of the construction team with disadvantaged groups during the tendering process may be necessary in the social procurement process. The project must strictly follow the United Nations Global Compact principle and International Labour Law by abiding to all the stated principles. The consideration of SS indicators at the pre-construction phase acts as the basis for the incorporation of SS in the construction and post-construction phases.

As for the SS indicators in the construction phase, 14 indicators were placed under the Safety and Health category. During construction, the organisation needs to purchase healthcare security coverage for site-based employees, prepare proper welfare facilities, consideration of employees' wellbeing, safety plan and safety training. Organisation should also report any injuries or fatalities involving worker or public at the construction site, as well as having awareness on public safety and health. Respondents also articulated the importance of creating local employments among local communities, locally supplied material, and work-life balance at the operational levels.

Table 3: List of social sustainability main attributes, attributes, and indicators for the construction phase

Main Attributes	Attributes	Indicators
Safety and Health (SH)	Employees' health and well-being	1. Physical / medical check-ups
		2. Insurance plan
		3. Welfare facilities at construction sites
		4. Platform for sharing session
		5. Policy of well-being program
	Safety provisions at the workplace	6. Formal safety plan
		7. Occupational Safety and Health (OSH) training
		8. Reportable injuries involving worker
		9. Reportable fatal involving worker
	Public safety and health	10. Project progress
		11. Accessibility for public safety
		12. Safety and engagement session
		13. Reportable injuries involving public
		14. Reportable fatal involving public
Impact Assessment (IA)	User consideration	15. Precautionary notification
		16. Channels for complain
	SIA	17. SIA documentation
Employment (E)	Local employment	18. Workforce hired locally / foreign
	Local community	19. Involvement of local community
		20. Involvement of local supplied material
	Employee work-life balance	21. Practices
Satisfaction (S)	Public satisfaction	22. Channels for complain
		23. Numbering of complain
Quality Education (QE)	Education and training	24. Numbering professional license or certificate
		25. Hours for training

Table 4: List of social sustainability main attributes, attributes, and indicators for the post-construction phase

Main Attributes	Attributes	Indicators
Satisfaction (S)	End-user satisfaction	1. Channels for complain
		2. Timing for complaints resolved
Quality Education (QE)	Innovation	3. Management support on R&D
		4. Grant / incentive

User consideration, SIA, public satisfaction, and the opportunity for workers to obtain and maintain professional certification during construction were generally identified as key indicators in promoting SS in the construction project.

At the post-construction stage, the indicators of assessing satisfaction through feedback channels are required to assess public/end-user satisfaction to ensure timely resolving of complaints. To encourage research and development (R&D), organisation have to give support by providing initiatives, such as grants and incentives for knowledge transfer, training, and information sharing.

CONCLUSIONS

This article contributes to the current gap in knowledge by establishing the SS indicators associated with the project life cycle, namely, pre-construction, construction, and post-construction. Most of the identified indicators were at the construction stage as this stage involves the most numbers and types of stakeholders (design team, owner, engineers, supplier, authorities, society, site workers) through various encounters. Thus, the reason for the domination of SS indicators at the construction stage, as compared to the pre-construction and post-construction stage.

The establishment of specific SS indicators at every phase of a project life cycle encourages and improves the value, understanding and adoption of SS in construction, further inspiring construction stakeholders to build back wiser in achieving long-term effective and sustainable construction. This study highlights that the subjective criteria or nature of SS could be objectively addressed, thus providing a realistic and alternative approach for measuring and monitoring SS throughout the construction project life cycle that fits the needs of stakeholders in achieving sustainable construction.

A project's social projection should be systematically planned by producing comprehensive SIA report at the core of the planning and monitoring by Social Monitoring Report and Social Audit Report. Therefore, SS can be used to improve project safety and health, justice, wellbeing, productivity, and transparency while also considering the present and future needs. The findings presented here could be generalised, as the experts providing diverse perspectives come from various institutions and organisations. The current findings are significant because there were no previous study conducted on this, even within a particular organisation, group, profession, or country. Additionally, this research has provided various levels of information for diverse stakeholders, allowing for future interactive interpretations. Thus, these findings should be of interest to both practitioners and academic communities.

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DIGITAL TWIN AND BUILDING PERFORMANCE: A REVIEW AND PROPOSED FRAMEWORK

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The use of Digital Twin (DT) as an emerging technology-led development encompasses data-driven methods which bring the benefit of enhancing better understanding of building performance and providing relevant information for decision making. Extensive reviews intersecting the DT concept with building performance are lacking. The aim of this paper is to present such a review and propose a framework for using DTs to develop predictive models to improve the performance of buildings. The review analyses recent studies on energy prediction performance and fault detection in building maintenance using data-driven models, and further identifies the remaining gaps in the literature. The framework incorporates artificial intelligence (AI), machine-learning (ML), and cloud computing technology in a scalable prototype solution to efficiently capture, process, and integrate real-time building data in a timely manner. The framework is expected to help decision-makers gain valuable insights into the building performance, which will then inform interventions for improving the energy efficiency.

Keywords: digital twins; ML; AI; building performance; predictive models

INTRODUCTION

Recent advances across technologies and smart buildings have led to the increased adoption of Internet of Things (IoT) and sensors within the built environment. This is resulting in an increasing amount of data that are continuously generated from various sources. Consequently, new data-driven opportunities for understanding and improving building performance are becoming available. These data, which are often unstructured or complex, need to be transformed to provide enhanced insights for decision making. To transform this mass of data into useful information, big data analytics along with Machine Learning (ML) can be used to create analytical and predictive models. The major challenge in this process is collecting, storing, analysing, and integrating heterogeneous data that are constantly being generated. As a result, the newly generated data need to be incorporated into their related asset models in real time or near real time, and the models need to be frequently updated to provide actionable insights in a timely manner.

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Another challenge in this process is to protect the data, and store and share them safely and securely. Al-Sehrawy and Kumar (2020) have also noted the contributory advances in technologies like Internet of Things (IoT), big data, Artificial Intelligence (AI), cloud computing and cyber-physical systems which together form the context for the emergence of the DT concept. Originating at NASA as an "Information Mirroring Model" and initially focused on product life-cycle management for manufacturing (Al-Sehrawy and Kumar 2020), DTs are well established concept in several industries (including manufacturing, aerospace, and automobiles). In the architecture, engineering, construction, and operation (AECO) industry, however, the concept is relatively new. DTs for the built environment and the AECO industry have been defined in many ways but there has not yet been a consensus on a formal definition. Nevertheless, all seem to agree that a DT is a representation of a physical asset, and a DT must be coupled with its physical counterpart to reflect its change (Shahzad *et al.,* 2022).

Kritzinger *et al.,* (2018) illustrated the development of a DT by differentiating three terms, namely: digital models (with no automated data exchange between the physical and digital counterparts), digital shadows (where the data flow is one-way), and a (true) digital twin (where there is a bi-directional data flow, and if a physical object's state changes, the digital object changes as well and vice versa). Bolton *et al.,* (2018 :10) defined a DT as "a dynamic model of an asset, with input of current performance data from the physical twin via live data flows from sensors and feedback into the physical twin via real-time control." In the building industry, DTs have become a favoured method for managing, planning, predicting, and demonstrating buildings and infrastructure (Lu *et al.,* 2019). Moreover, DTs can be dynamic digital models that are able to learn and update the status of the physical counterpart from multiple sources (Lu *et al.,* 2019).

A DT with a pool of enriched data provided by building sensors and IoT holds the promise of addressing the challenges of handling real-time building data. To fulfil this promise, the technology needs to be able to run analytics in real time or in a relatively short timeframe, to provide high-level prediction accuracy, and integrate heterogeneous data from disparate and initially incompatible sources. To achieve this goal, AI is proposed as the way to fully harness the benefits of digitalisation. By leveraging DTs along with AI, the building industry can benefit from combining historical and real-time data along with predictive analytics for detecting anomalies, predicting failures, and preventing unplanned outages affecting building operation and maintenance.

Therefore, this research aims to develop a framework integrating AI techniques and DTs to provide valuable insights about the building performance to decision-makers. This can impact the optimisation of building energy performance. The main objective of this study is to review existing literature and identify the main gaps in current research on building performance, and subsequently propose a framework to bridge the identified gaps.

LITERATURE REVIEW

Over the past few years, several studies have been conducted on enhancing building performance by utilising the rapid evolution of data-driven techniques including AI and ML. As indicated by Luo *et al.,* (2020), building energy management relies on the ability to predict the building energy consumption correctly and reliably, and implement predictive maintenance strategies efficiently. Therefore, many of these studies have focused on using different ML techniques for these two challenges: 1) building energy consumption and 2) building maintenance and fault detection. To conduct this literature review, the focus was on the recent studies (mostly published in 2020 and 2021) related to these two challenges and indexed in Web of Science and Scopus databases. The following sub-sections present the findings of the literature review. Table 1 categorises the studies developing data-driven models for enhancing building operation. Table 2 defines the abbreviations used in Table 1.

AI Methods For Building Energy Management

There are notable environmental issues associated with the building industry since the total energy consumption of buildings represents a large percentage of global energy consumption (Lim *et al.,* 2021). As reported in the World Energy Balances, the building sector contributes to nearly 40% of global carbon dioxide emissions and consumes over 30% of the world's final energy (IEA 2019). Carbon emissions and energy consumption are predicted to rise further in coming years (IEA 2019). For improving energy consumption, several studies (Hu *et al.,* 2021; Ngo *et al.,* 2021; Shapi *et al.,* 2021; Solmaz 2020, and Truong *et al.,* 2021b) have utilised conventional ML algorithms while others (Alanbar *et al.,* 2020; Hwang *et al.,* 2020; Khan *et al.,* 2020; Wang *et al.,* 2020a; Alduailij *et al.,* 2021; Cao *et al.,* 2021; Truong *et al.,* 2021a; and Tsoumalis *et al.,* 2021) have used Deep Learning algorithms. Additionally, studies have used reinforcement learning techniques including model-free reinforcement learning (MFRL) (Haddam *et al.,* 2020) and model-based reinforcement learning (MBRL) methods (Ding *et al.,* 2020). In MFRL, trial-and-error learning is possible by interacting directly with the systems of a building or by observing an external simulated environment (Zhang *et al.,* 2021). However, because MFRL depends on trial-and-error learning, often with no pretraining, there is a significant live training period before model convergence. Simulated data can be used to accelerate the training process, but MFRL requires a high-fidelity model of a building to be calibrated. On the other hand, MBRL is an approach that learns the dynamics of the system, which requires more complex models to explain the interactions between building system components (Ding *et al.,* 2020).

AI Methods And Building Maintenance

The lifespan of many building components is shorter than that of the building, necessitating the repair or replacement of such components to maintain performance of the entire building (Grussing and Marrano 2007). According to Errandonea *et al.,* (2020) adopting a good maintenance strategy can reduce production downtime, reduce breakdowns, save costs, improve productivity, eliminate ambiguity in maintenance tasks, expand equipment service life, improve customer service and reputation, reduce energy waste, and improve facility security. AI-based predictive maintenance has been explored by researchers in various fields. It has been shown, for example, that AI outperforms statistical methods in maintaining aircraft engines (Baptista *et al.,* 2018). Biswal and Sabareesh (2015); Prytz *et al.,* (2015); Amihai *et al.,* (2018) and Praveenkumar *et al.,* (2014) have developed AI models for predictive maintenance of wind turbines, air compressors, industrial pumps, and automobile gearboxes, respectively.

In terms of building maintenance, Dahanayake and Sumanarathna (2021) have proposed the integration of IoT data with Building Information Modelling (BIM) for facility management, and Cheng *et al.,* (2020) have used BIM, IoT and ML for developing a data-driven predictive model for maintaining Mechanical Electrical and

Plumbing (MEP) installations in buildings. The main drawback of the existing studies is their reliance on stationary historical data, ignoring the dynamic and rapidly changing building operation environment, and causing limitations for using these models in real cases.

Additionally, several studies have been conducted using simulated data which makes the practicality of the proposed approaches questionable as the model does not learn from the real environment and the efficiency of the model is not evaluated in practice. To bridge this gap, some researchers have attempted to use DTs for acquiring the real-time data from the system and continuously incorporating this data into the models. Most of the existing research on the application of a DT is related to predictive maintenance in manufacturing (Aivaliotis *et al.,* 2019), aerospace (Chowdhury *et al.,* 2019) and wind turbines (Sivalingam *et al.,* 2018) and little research has been on the use of DTs for building predictive maintenance.

In most cases, previous studies can be classified based on the following characteristics:

1. The type of techniques and algorithms employed
2. The type of data used in the models (historical data from a real environment or simulated data from a lab environment)
3. The theme of studies including building energy consumption and fault detection of building systems (which falls under the umbrella of predictive maintenance); and
4. The granularity (depth) of the study, such as energy consumption of entire buildings (building level) or sub-systems of buildings (system level).

Proposed Framework

The problem investigated by this research is an applied technical problem that depends on functional use cases of building energy consumption prediction and building predictive maintenance. Therefore, this research requires a 'Design Science Research Methodology' (DSRM) approach which is an outcome-based information technology research methodology, that offers specific guidelines for evaluation and iteration within research projects.

The proposed framework focuses on the creation of a data pipeline and computational technology (i.e., AI and cloud computing) for data processing with the assumption that the sensor technology and the communication infrastructure for data transfer are in place. This requires the streamlined integration of the data collection, data transfer and data processing. The proposed framework for these functions is shown in Figure 1.

The first step, as shown in Figure 1, is data collection from sensors, textual records, DTs, and other sources such as technical specifications, and manufacturing documents. In this step, DTs play the main role for providing interoperable, and traceable input data. A DT is a structured and centralised repository of up-to-date physical and operational building data such as geometry, energy performance, scheduled and accomplished maintenance of the building components as well as sensor data. This characteristic of a DT reduces the computational effort required for collecting heterogenous real-time data initially generated from disparate sources.

The next step is to exploit, integrate and process the collected data through data analytics and AI techniques such as Natural Language Processing (NLP), computer vision and deep learning. The processed data sets are curated to include a variety of features that represent building conditions for the use cases of energy performance, and predictive maintenance.

Table 1: Categories of the recent studies

	Technique/ Algorithms	Historical/ Simulated	Theme	Granularity (depth) of the study
Zhou *et al.,* (2022)	LSTM and RL	S.H.D.	El.C.	B.L.
Fang *et al.,* (2021)	T.L., LSTM-DANN NN	S.H.D.	El.C.	B.L.
Hu *et al.,* (2021)	ANN	S.H.D.	En.C.	S.L. (HVAC)
Tsoumalis *et al.,* (2021)	LSTM, CNN, GA	S.H.D.	G.P.	S.L. (boilers)
Ngo *et al.,* (2021)	Hybrid ML	S.H.D.	El.C.	B.L.
Bassi *et al.,* (2021)	GB	S.D.	En.C.	B.L.
Cao *et al.,* (2021)	GB, LSTM	S.H.D.	En.C.	B.L.
Shapi *et al.,* (2021)	SVM, ANN, K-NN	S.H.D.	En.C.	B.L.
Truong *et al.,* (2021b)	Additive ANN	S.H.D.	En.C.	B.L.
Du *et al.,* (2021)	MF-DRL	S.D.	En.C.	S.L. (HVAC)
Pinto *et al.,* (2021)	LSTM, DRL	S.D.	En.C.	S.L. (multi system)
Truong *et al.,* (2021a)	DNN	S.D.	En.C.	B.L.
Alduailij *et al.,* (2021)	Reg, ARIMA ANN and DNN	S.H.D.	En.C.	B.L.
Haddam *et al.,* (2020)	MF-RL	S.D.	En.C.	B.L.
Ding *et al.,* (2020)	MB-RL	S.D.	En.C.	S.L. (HVAC)
Akbar *et al.,* (2020)	M.R., ANN	S.H.D.	El.C.	B.L.
Zeng *et al.,* (2020)	G.P.R.	S.H.D.	El.C.	B.L.
Khan *et al.,* (2020)	Hybrid.CNN LSTM	S.H.D.	El.C.	B.L.
Zhou and Zheng (2020)	NN	S.H.D.	El.C.	B.L.
Hwang *et al.,* (2020)	SVR, ANN, DNN, LSTM	S.H.D.	El.C.	B.L.
Solmaz (2020)	SVM, B.O.	S.D.	El.C.	S.L. (multi system)
Kim *et al.,* (2020)	M.R.A, ANN	S.H.D.	En.C.	B.L.
Wang *et al.,* (2020b)	ML stacking model	S.H.D.	En.C.	B.L.
(Bourhnane *et al.,* 2020)	ANN, GA	S.H.D.	En.C.	B.L.
Alanbar *et al.,* (2020)	DNN	S.H.D.	En.C.	B.L.
Wang *et al.,* (2020a)	LSTM	S.H.D.	En.C.	S.L. (cooling system)
Taheri *et al.,* (2021)	DRNN	S.H.D.	F.D.	S.L. (HVAC)
Liu *et al.,* (2021)	T.L., CNN	S.H.D.	F.D.	S.L. (chillers)
Wang *et al.,* (2021)	BN	S.H.D.	F.D.	S.L. (chillers)
Bouabdallaoui *et al.,* (2021)	Autoencoder	S.H.D.	F.D.	S.L. (HVAC)

To this end, suitable criteria for evaluating the effectiveness of the prediction are established for each AI technique. The output of the models is evaluated based on relevance in improving decision making for building operation management including building energy performance, anomaly detection, maintenance requirements and visualisation of the operational performance data. To streamline these processes and provide the output in a timely manner, the data pipeline and AI models are developed and analysed using cloud services such as Amazon Web Services (AWS), Microsoft Azure or Google Cloud Platform (GCP).

Table 2: Definition of Abbreviations used in Table 1

Abbreviation	Definition	Abbreviation	Definition
ANN	Artificial Neural Network	T.L.	Transfer Learning
B.L.	Building Level	K-NN	K-Nearest Neighbours
B.O.	Bayesian optimization	LSTM	Long Short-Term Memory
BN	Bayesian Network respectively	M.R.	Multiple Regression
CNN	Convolutional Neural Network	M.R.A	Multiple regression analysis
DL	Deep Learning	MBRL	Model-based Reinforcement Learning
DNN	Deep Neural Network	MF-DRL	Model-free Deep Reinforcement Learning
DRL	Deep Reinforcement Learning	MFRL	Model-free Reinforcement Learning
El.C.	Electricity Consumption	NN	Neural Network
En.C.	Energy Consumption	DRNN.	Deep Recurrent Neural Network
F.D.	Fault Detection	RL	Reinforcement Learning
G.C.	Gas Consumption	S.D.	Simulated Data
G.P.R.	Gaussian process regression	S.H.D.	Stationary Historical Data
GA	Genetic Algorithm	S.L.	System Level
GB	Gradient Boosting	SVM	Support Vector Machine

The main advantage of this framework over the existing studies using stationary data is that data are captured continuously, and the models are dynamically updated with real-time or near real-time data, it is expected that this can make the predictive models more comprehensive and realistic.

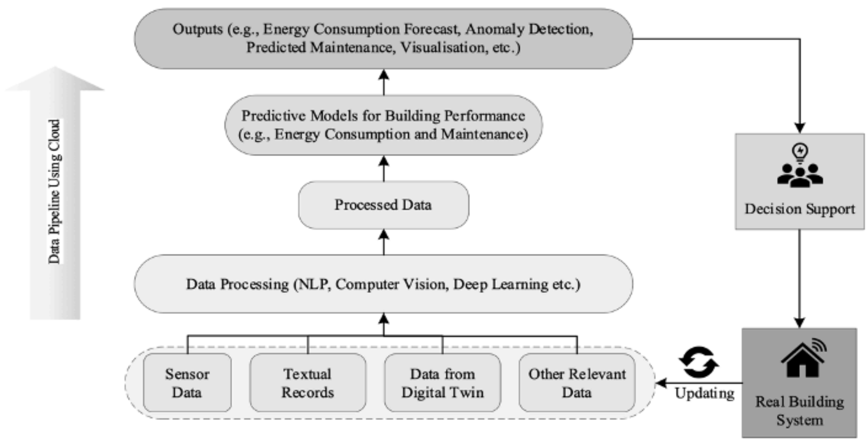

Figure 1: Overview of the proposed framework

CONCLUSIONS

As seen in the literature review section, the existing studies relating to building energy and fault detection have relied on stationary historical data and models that are not being updated with new data. This compromises their scalability, responsiveness, and practicality in real-time, real-world conditions. Additionally, most of the studies that were reviewed have concentrated on the energy consumption at building level or detecting faults at individual asset or building system level. In response and considering recent technological advances, the proposed framework uses a cloud-based digitalisation approach that integrates advanced technologies including DT, AI, and cloud computing. These technologies are used to efficiently capture, process and integrate real-time building data in a timely manner. The framework integrates heterogeneous building data from different sources including DTs and process the data using AI and cloud computing to predict and improve building operation and performance.

The proposed predictive AI-enabled models are scalable and dynamically updated with real-time building data and they are not based on historical data only but also use the newly emerging data. It is hypothesised that this can improve the accuracy and reliability of the building performance predictions.

The proposed data pipeline utilises high performance and low-cost cloud computing solutions that lead to time-efficient and secure building data collection, data transfer and data processing for building performance analytics.

In future research work, the proposed framework will be implemented by building AI-based DTs that address the gaps identified and will contribute to the development of advanced models for energy consumption and building maintenance with fault detection. The research will evaluate models trained from a combination of historical data and data drawn from the physical environment and the efficiency of the model will be evaluated in practice.

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QUANTITY SURVEYORS INCORPORATING CIRCULARITY AT EARLY PROJECT DESIGN STAGE: A LITERATURE REVIEW

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Consumption of natural resources has followed a linear approach known as the 'take, make, use, dispose model'. Whereas, the Circular Economy, where the leading design principles are to eliminate waste and circulate products / materials at their highest value possible. The architecture, engineering and construction sector is recognised as one of the largest consumers of raw materials and to be systemically linear in its processes and delivery, therefore, this presents an opportunity to achieve effective change at scale. All built environment disciplines and their skillsets will be required for effective implementation of 'Circular Construction'. With attention to Quantity Surveyors and their role, they must be prepared to cost a circular proposal or present alternatives. This area is still within its infancy and presentation of circular costs continues to evolve, lacking in consistency and standardisation. The literature review seeks to scope what guidance is currently available at early project design stages to realise the full potential of circularity.

Keywords: circular construction; circularity; costing lifecycle; quantity surveyors

INTRODUCTION

The pressing matter of addressing climate change and its devastating effects has become more prominent within society, from personal endeavours, business strategies to government legislation, global climate pledges and more. With an ever-growing human population, the need for food, shelter, and infrastructure increases - particularly in cities, where 75% of the world's production of natural resources is consumed (ARUP and BAM 2016). The consumption of virgin natural resources (minerals, water, gasses etc…) has predominantly followed a linear approach known as the 'take, make, use, dispose model'. The industrial revolution, urbanisation and consumerism has accelerated the use of virgin materials, depleted their stores and resulted in other negative effects such as excessive waste, ecosystem pollution and rising carbon emissions (ARUP 2016). The global community is urgently seeking alternate solutions to the scarcity of the planet's resources due to excessive human consumption. Thus, there is a gathering interest and conversation surrounding the Circular Economy as a potential solution to help mitigate the pressures of excessive waste and reduce consumption.

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Globally, the architecture, engineering, and construction (AEC) sector is recognised as one of the largest consumers of raw materials and is also recognised to be systemically linear in its processes and approach to delivery (McDonough and Braungart 2009). As a large consumer and polluter producing structures of substantial scale that are taking possession of land and the natural environment with significant lasting effect, this sector presents an opportunity to achieve effective change on a considerable scale by adopting circular economy principles. Often targeted by climate pledges and government legislation, the sector is urgently exploring solutions to design out waste and pollution, lower their carbon emissions, optimise operational costs, and extend the lifecycle of its structures, whether existing or new build.

This aspiration to reduce consumption and minimise waste is a challenge for the sector that requires everyone involved, from design to operations, to be conversant and educated within circularity as it is the most promising solution currently. ZeroWasteScotland (2017) identified that the skillsets of both project management and data categorisation would be required for effective implementation of circular construction; both of which are key skillsets of built environment disciplines. Similarly, an understanding of the whole building lifecycle, and the construction value chain can enable built environment professionals to leverage the opportunities afforded by circular construction (ARUP and BAM 2016).

With specific attention to cost consultancy and surveying, Fischer (2019) believes that by supporting the balance of risks and future potential of circular buildings with detailed financial modelling, circular construction can, and will, be successful. Consequently, utilising the existing skillset of construction professionals with the evolving upskilling in more sustainable and circular approaches such as, specifying and forecasting the use of reclaimed materials within projects from the early stages, can greatly benefit in achieving the environmental targets required to mitigate the over consumption of the planets' resources.

Thus, considering the foregoing, the aim of this paper is to explore what influence a Quantity Surveyor (QS), primarily those operating within Cost Consultancy, may have and what guidance is available to them to incorporate circularity at the early-stage design and briefing of a project.

This scoping literature review seeks to define circular construction and what is currently available to the Cost Consultant for influencing circularity at early-stage design and briefing. Initial and early review of source material indicated a gap within the literature for Quantity Surveyors/Cost Consultants in terms of how they, specifically, may practically apply circular principles within their practice and why it may be beneficial. The literature is primarily sourced from Industry Professional bodies, such as the Royal Institute of British Architects (RIBA) and the Royal Institution of Chartered Surveyors (RICS), and leading industry research projects/reports in circular economy - principally from Arup and their affiliated co-partners. Arranged thematically, the definitions are established and the information available currently to the sector is explored with a focus on the applicability for the Cost Consultant.

Circular Economy

Founded for the purpose of championing the Circular Economy, the Ellen Macarthur Foundation is a leading authority who define the circular economy as a 'systems solution framework that tackles global challenges like climate change, biodiversity loss, waste, and pollution'. To achieve this, the leading design principles of a circular economy are to; eliminate waste and pollution, circulate products and materials and, thirdly, regenerate nature (Ellen MacArthur Foundation 2021). Essentially, the linear take, make, use, dispose model evolves to a more circular and 'looped' approach such as; take (from reclaimed materials), make, maintain, reuse (or, hierarchically, repurpose or lastly recycle) with very little, yet responsible, disposal at the end of life. Circle Economy (2021: 8) in their annual Circularity Gap Report in 2021 stated that 'combining the twin agendas of circular economy and climate mitigation gets us on a path to…prevent the worst effects of climate breakdown,' therefore, the circular economy certainly has the potential to alleviate resource consumption issues. Worryingly, their fifth and most recent report also states the current economy is still only 8.6% circular; the same percentage as 2021 and a decrease from the first Circularity Gap Report in 2018 where a figure of 9.1% was established (Circle Economy 2022: 14). As the conversation of both circular economy and climate agendas has intensified, it would have been anticipated that circularity increases in tandem with climate aspirations, however, the downward trend within the Circularity Gap Reports is certainly a point worthy of note that globally, circularity has decreased.

Circular Construction

Whilst the global overview of circularity identified a downward trend, there are pockets of practice within the architectural, construction and engineering sector that are beginning to incorporate circular principles within their practises, thus the terming of 'Circular Construction.' A distinction is made within the circular economy between the biological cycle, whereby biologically based materials are designed to be integrated and regenerate, whilst the technical cycle primarily focusses upon recovery and reuse of non-living products and materials.

The architectural, engineering and construction sector can largely be aligned to the technical cycle, yet not exclusively as there are exceptions to the rule which successfully merge both cycles such as green roofs and living walls. There are a number of different processes and ideas that fall under the umbrella term of circular construction; however, they can almost exclusively be aligned with one of the three guiding principles of circular construction which are identified as; 1) urban mining (the recycling and reuse of materials from existing built assets), 2) transformation and life extension of existing buildings and 3) designing for disassembly and flexible construction (Charlsson 2021). Each of the guiding principles are briefly outlined here.

Urban mining is essentially centred around the reclamation and reuse of elements, products, or materials (EPM). Viewing a building as several layers, or skins, and retrieval of EPM is largely attributed to Fischer (2019) within their landmark report 'Building Value: A Pathway to Circular Construction Finance.' There is a hierarchy to the reclamation and reusing of materials; reuse of an element, material or product for the same purpose is true circularity and is operating at maximum value (including refurbishment of existing assets), repurpose of EPM comes next and includes recovery of materials/products from on site or from other sites and, lastly, recycling is seen as a last resort as this is downgrading of an asset.

Transformation and life extension of existing buildings is the retrofit and regeneration of existing assets in order to provide a building which operates at its optimal performance possible. There are inevitably areas of an existing building which, even when retrofitted, may not perform as efficiently as new build, however, with careful consideration to the retrofit design, it can achieve comparable efficiencies in use of materials to construct, maintain and operate. Extending the life through repair and maintenance of an existing asset prolongs the use and value of it, thus maximising the justification for the initial use of the resources in its' creation (ARUP 2016).

Ghaffer *et al. (*2020) advocate that designing for disassembly and flexible construction incorporates designing for future adaptation, or even future disassembly. When designing for adaptation or disassembly, recovery of the materials is also considered. Thus, several layering of materials with adhesives and the like are problematic for disassembly/recovery, and as such, the material specification and construction is carefully considered. Furthermore, they found in their study with industry stakeholders that legislation for re-use and recycling would substantially improve circularity. Some other areas of practice that enhance and are within the remit of circular construction are the standardisation and modularisation of the industry - standard sizes should result in less wastage of materials due to cutting on/off site to nonstandard sizes.

Servitisation too is a practice whereby the product used remains under the ownership and maintenance of the Supplier, or 'Provider,' as is more appropriate in the scenario. ARUP and BAM (2016) note that servitisation is most known for lighting currently, however, there is scope for this to be used with other products too, particularly given the digitisation of the sector and 'smart' buildings. Magrini *et al.,* (2021: 2) have stated that the circular economy 'benefits from digital, online platforms and technologies. The digitisation of the AEC sector is occurring at a rate perhaps never seen, largely due to the acceleration in adopting digital practices as a necessity in responding to the COVID-19 pandemic and need to work from home, however, also with the range of digital technologies now available to the sector. This correlates with the findings of Cetin, De Wolf and Bocken (2021) who have developed a Circular Digital Built Environment Framework which maps digital technologies to circular construction practises in a bid to encourage practitioners to apply sustainable innovation in the sector.

Each of the guiding principles and practises have their own strengths, situational suitability, and barriers to implementation. Barriers to implementation can occur throughout the phases of a project, however, as much research suggests, successful projects begin with a strong, clear project brief and intent at the early stages, hence the focus within this scoping review on incorporating circularity at early-stage design.

The Design Team and Project Stages

Fischer (2019: 10) advocates that collaborative working in the sense of clear communication and cooperation between the stakeholders is key to successful implementation of circular construction as the 'the design, construction and harvesting process need to interlink closely'. Given construction projects have many stakeholders and involvement from a variety of disciplines, for clarity, this paper will focus upon the Client, Architect, Quantity Surveyor (Cost Consultant) and make occasional reference to the commercial entity of a Main Contractor.

To provide a framework and definition to 'early-stage design,' the paper utilises the most used, widely recognised and understood framework, which is that provided by the Royal Institute of British Architects (RIBA). Known as the RIBA Plan of Work, it provides a standardised framework for use by those in the construction industry, so everyone knows what is meant by a particular term, and what activities should be carried out at a particular stage. The RIBA Plan of Work, currently in the 2020 edition, divides a project into the various 8 stages of pre-tender (pre-contract) and post contract activity, commencing with Stage 0 'Strategic Definition' and ending with Stage 7 'Use' when the building is completed and starts its life as a fully operating facility.

In this paper, the focus will be on Stages 0 and 1, with elements of Stage 2. It is at these stages where the client must define their needs in terms of time, cost and quality before the design and cost activities can proceed. The main aim of a Quantity Surveyor is to link design and cost, to not only provide a balanced design but also ensure, as far as possible, value for money for the client. In practice, this means that a system is introduced and followed which allows both design and cost to be "tracked" at any stage of a project. The relationship between design and cost at every stage of the pre-contract process can be tabularised as follows:

Table 1: Design and Costing Activities mapped against RIBA Plan of Work

RIBA Stage	Design Activity	Cost Activity
0: Strategic Definition	Briefing by Client Initial Proposals	Feasibility Study / Preliminary Order of Cost Estimate
1: Preparation and Briefing	Feasibility studies: site, planning, etc.	Preliminary Order of Cost Estimate (to set the authorised budget)
2: Concept Design	Development of design / Alternative design proposals	First Cost Plan Estimate / Comparative Estimates
3: Spatial Coordination	Development of design Final Design proposals	Elemental Cost Planning
4: Technical Design	Full design of all elements, components, and specification	Pre-Tender Estimate Tender documentation e.g., bill of quantities

When considering each of the activities carried out under Design at any stage of the process, there is a corresponding activity under Cost. Initially we have the client identifying a need for the project, be it new build, refurbishment, or repair, and requesting some indication from the Design Team, which includes the Cost Consultant, of what can be achieved and for what cost. Construction is largely accepted as a client driven exercise and at the initial stages, it is imperative that the Client objectives are established for them to be successfully achieved and not diluted as a project - and the inevitable changes that occur - progresses. It is therefore key that circularity is considered from the outset for effective implementation. This is supported by Munaro *et al. (*2020) who evidenced the importance of incorporating, and discussing, circularity at the planning stage instead of the end-of-life stages to enable more informed decision making.

The Role of the Quantity Surveyor and Their Sphere Of Influence

The Cost Consultant has an integral role in the Design Team at the early stages and has a unique influence in relation to the cost of a project as they undertake Feasibility Cost Estimates, establish an Authorised Budget (or 'Cost Limit'), conduct Option Cost Appraisals, Whole Life Costs and Value Management/Engineering exercises. The activities a QS undertakes at these stages are intrinsically linked to one another and offer the potential of including circular construction; either to suggest the inclusion of circularity or ensure it remains within the design and cost parameters of the project - i.e., not removed or 'stripped out' due to being cost prohibitive.

The predominant professional body for surveyors is the Royal Institution of Chartered Surveyors (RICS). They regulate the practice of members and firms whilst providing guidance and market insights to the sector. One such insight related to the business case for the circular economy within the sector and, the then Chief Executive Officer Tompkins (2020) said:

> "RICS professionals will be uniquely placed to realise circular economy practices. Among the other built environment professions, it is our profession alone that is engaged at every stage of an asset's lifespan"

Whilst the statement arguably may not be inherently true that the profession is the only one engaged at every stage, the sentiment that it is one of the professions engaged throughout the lifecycle of an asset is important as this is critical to the 'loop' of the circular economy, making, maintaining, and reclaiming. As a client driven exercise, construction professionals respond to the needs of their client, which may or may not include circular principles. If not driven from the Client themselves, the design team could introduce circular principles into the design - this infers that designers, such as Architects and Engineers as the specifiers of materials and the design will have the greatest opportunity to influence. Yet, in many cases, cost is a driver and deciding factor in many material choices and design decisions.

As the QS discipline is present and integral to each stage, they do not have a bias to any one stage and can balance the needs of a given stage/time against those of, say, stages further in the lifecycle of an asset. That is to say, they have an appreciation for not only the capital expenditure of a project, but the Whole Life Cost (WLC). To a client, the actual cost of construction may be only one part of a wider picture. There are likely to be many other associated costs which the client will have to pay, and this is known as the Whole Life Cost. Potts and Ankrah (2013: 138) state that one of the most important of the many benefits of WLC is the communication it fosters between stakeholders; it encourages true interrogation of the proposed design and material choices and thus maximises the value to be obtained. They further discuss the importance of including the whole supply chain as early as possible in the design as "80% of the future costs of running maintenance repair is fixed in the first 20% of the design process." Interestingly, the guidance provided by RICS to its' members for Whole Life Costs has begun to evolve and be more holistic by its inclusion of sustainable construction concepts. The most recent publication on these matters, the RICS Cost Prediction Practice Statement is mandatory to comply with for its members and firms. The document contains a more fulsome diagram that is shown in Figure 1.

A more holistic view is being taken and that guidance now incorporates further standards. Interestingly, it is noted the phrase 'cradle to grave' is used in lieu of the more circular sentiment of 'cradle to cradle'. This does intimate that the tools and processes at the Quantity Surveyor's disposal do not necessarily promote and enable circularity, rather that they still tend towards more traditional linear approaches. To refer directly to the establishing of a Cost Limit, preparation of Cost Estimates and Plans at Stages 0 through to 3, possibly 4, it is the RICS New Rules of Measurement (NRM) 1 document the Cost Consultant will refer to. The RICS NRM is a suite of documents issued by the RICS Quantity Surveying and Construction Professional Group. The suite consists of 3 documents: NRM1, NRM2 and NRM3. The rules have been written to provide a standard set of measurement rules that are understandable by anyone involved in a construction project. RICS define the NRM documents as a 'Guidance Note' which essentially means it is recommended good practice - not mandatory compliance.

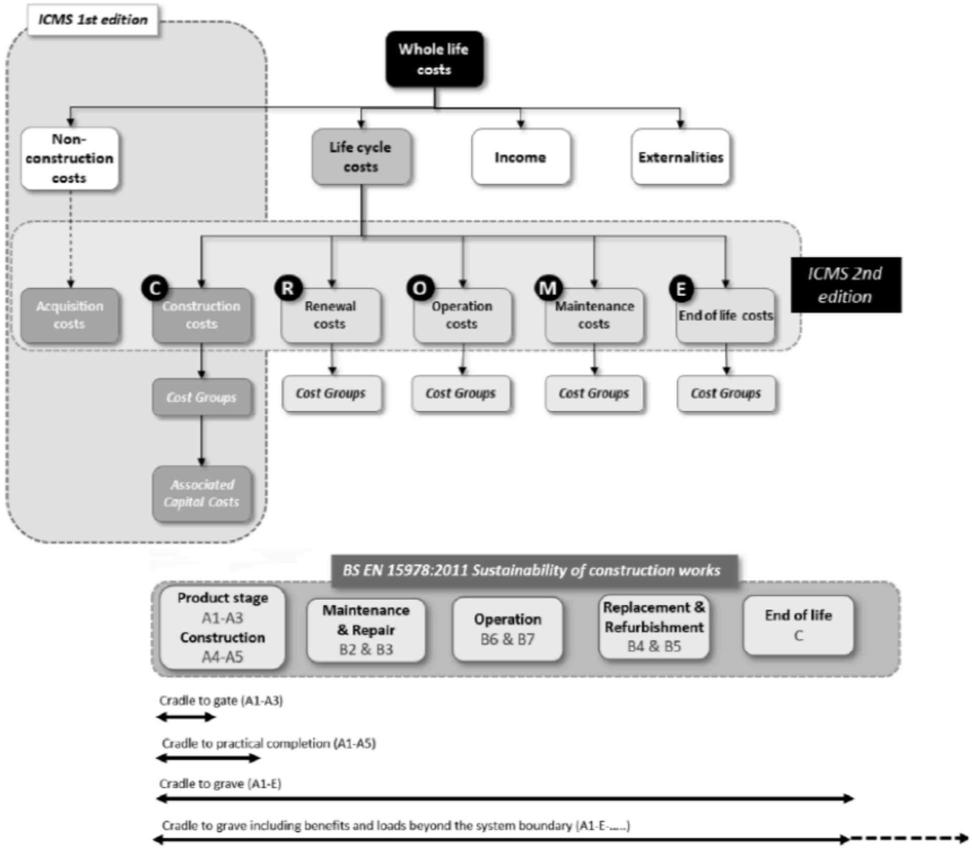

Figure 1: ICMS 2nd Edition mapped against ICMS 1st Edition and BS 15978:2011 (RICS 2020)

It is NRM1: Order of Cost Estimating and Cost Planning for Capital Building Works that concentrates on Pre-Contract Cost Forecasting; both Cost Estimating and Cost Planning - i.e., early stages of a project. RICS state the document to be 'indispensable guidance on the quantification of building works for the purpose of preparing cost estimates and cost plans' (RICS 2012: 2).

The three RICS issued guidance notes which are integral to the activities undertaken by a Cost Consultant at the stages critical for encouraging circularity; NRM1, Cost Prediction and Life Cycle Costing all currently fail to include any mention of circular principles. NRM1 does allude to sustainability strategies and in terms of incorporating any 'sustainability aspirations,' rely upon the information provided by the Architect. This appears to correlate with the findings of Fischer (2019) and Acharya, Boyd and Finch (2018) whereby both authors identified a challenge for circularity within the sector to be awareness and 'misalignment' between the various disciplines, business planning cycles and the built environment asset life cycle. The foregoing has predominantly focussed upon the Cost Consultant and Early Stages of Design/Costing; however, it is also important to note that to include circularity by way of reclaimed materials, contracting organisations and 'commercial' surveyors must also have an appreciation of circularity. For instance, there must be a market supply of elements, materials and products with consideration given to their quantity, testing, anticipated timing for programming purposes and their location for delivery and carbon considerations - many of which are considerations for the commercial surveyor (Fischer 2019).

How the QS Discipline Relates to the Architect

A professional discipline within the AEC sector which has set a precedent and included circularity principles within their issued guidance for embedding in practice is that of the Architect and the RIBA Plan of Work, complemented too by their Sustainable Outcomes Guide. RIBA (2020: 74) in the Plan of Work within the Sustainability Strategy strand begins in Stage 0 to explicitly include circular principles: 'Undertake a Site Appraisal of sustainability opportunities and constraints of potential sites and building assets. Prioritise total or partial reuse of existing facilities, buildings, components, or materials.' The prioritisation of reusing an existing asset in its totality or partially, is a fundamental principle of circularity. Furthermore, each of the Plan of Work stages has a sustainable strategy which corresponds with the RIBA Sustainable Outcomes, one of which is the Sustainable Life Cycle Value. RIBA (2019) explain this is the operational running costs of a building in use, with a metric of £/m2, compared against the return value, which is inclusive of rental, building value and, interestingly, social value.

The activities to be undertaken include the development of a whole life cost plan incorporating the value of sustainability outcomes at stage 0, progressing in stage 1 to 'define an outcome target for life cycle value for key building systems, determining the scope of life cycle assessment and specifying measurable outcomes and targets for whole life carbon, whole life costs, building life span, refurbishment rates, end of life and circular economy' (RIBA 2020: 77). Given the nature of the metric and the activities outlined, the design and cost balance reach an optimal intersection with circularity that requires both the Architect and cost consultant to contribute collaboratively for the most effective implementation. Equally, this inclusion of circularity by a professional body to its members and firms sets a strong precedent and an opportunity for a best practice collaborative framework which could be integrated into the tools and processes of the cost consultant to better enable them to influence and incorporate circularity into cost plans in a standardised approach.

CONCLUSION AND THE GAP IN KNOWLEDGE IDENTIFIED

As an exploratory literature review seeking to scope what guidance is available to the cost consultant at early project design to incorporate circular construction concepts, it was prudent to firstly define the circular economy and circular construction itself to provide context and distinguish the differences between the linear traditional approach currently most used, and understood, in the AEC sector today. Thereafter, the review focussed upon providing a framework and noted the activities undertaken by a Quantity Surveyor at early-stage design which were attributed, in the current, predominant linear practice of the AEC sector to be most likely conducted by a Cost Consultant as opposed to a commercial surveyor. In analysing the tools and processes available to the QS consultant at those stages, as issued by their regulatory professional body, it was found that they are not yet inclusive of circular principles or approaches, and indeed, may not even be conducive towards them.

The guidance for producing industry standard Cost Estimates and Plans fail to mention circularity or associated ideas and are more suited toward the traditional linear approach. The guidance and presentation of costs at early stage are largely focussed upon the Capital Expenditure of a project and do not feature the whole life cost as standard unless as a wholly separate report at the Clients request. It can be concluded that the driver for including circularity, and indeed even whole life costs, is largely from the Client and their requirements and not from the QS; not that the QS can, or should, be the sole driver of circularity, however, they are a key and integral member of the design team. The influence on the procurement and material choices of a project, largely driven by the Client objectives and cost do place the QS in a unique position within the team as they attempt to strike the optimal balance. Unfortunately, as a profession, it is concluded that they currently lack the standardised approach for inclusion of circularity and are thus not realising the potential of the influence they could have upon a project. As the sector seeks smarter and more sustainable methods and models of building, circularity could be a wise option at this inflection point of change in the industry and world.

In terms of limitations to this paper, literature specific to the cost consultant and circularity is sparse; their professional bodies and industry literature are exploring, and advocating circularity, however, the guidance and process have yet to evolve in tandem. A more systematic literature review could be conducted to identify parameters from the early scoping and then further interrogation of the topic by developing an appropriate methodological research design to investigate the extent of influence a cost consultant could have and whether there could be effective practical application. Until the inclusion of circularity within the tools and processes available to the cost consultant, it is likely to be the minority innovator or at the bequest of the client, that circular concepts become the norm. As more traditional, linear methods of procurement and material usage are ingrained within the culture of the industry, circular construction could be the disruptive model the industry needs to rectify the over consumption of resources and provide the built environment that the future generations will need - and of the climate conscious type they will want. This is indeed an opportunity to build back wiser.

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CONSIDERING, CREATING AND DELIVERING SOCIAL VALUE: PROBLEMATIC POLARISATIONS

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Social value as a concept has evolved rapidly over the last decade or so. We observe polarisation in the understanding and appreciation of what it means to consider, create, and deliver social value. Divergence and tensions are arising between those who run value-based businesses and do social value, and those who focus on measuring social value as an 'added value'. We explore these different approaches to conceptualising and operationalising social value using case examples from industry. Deontological theory of ethics and accounting principles offer the analytical framework for our critical discussion. We voice concerns about the development of a 'social value industry' and the aspiration to devise a single definition and list of all things social value vis-à-vis a values-driven and contextual approach. At the heart of our discussion is a fear that the polarisation may begin to devalue the concept, and the well-intended principles behind social value that have made it visible over the past decade may be lost. We forward an argument for social value to be seen and used as a tool to address one of the grand challenges of our time, the 'planet, people and prosperity' agenda connected to the UN Sustainable Development Goals (SDGs) and Building Back Wiser.

Keywords: social value; ethics; polarisation; sustainable development goals; SDGs

INTRODUCTION

Social value in the built environment refers to the social impact any individual, organisation, project, or programme makes to the lives of the stakeholders affected by its activities. Raidén and King (2022: 4-5) identify polarisation in the understanding and appreciation of what it means to consider, create, and deliver social value as a central problem in the development and future of the concept. We examine this polarisation from three different but interconnected viewpoints: defining social value, social value practice, and measuring social value. We present a critical essay exploring and dissenting the concept using case examples from industry as empirical touch points.

Our discussion is motivated by our observations of divergence and tensions arising between those who run value-based businesses and do social value, and those who solely focus on measuring social value as an 'added value' (ibid). People and

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organisations who see social value as an added value tend to look for simple and measurable activities and outputs that can be reported. To facilitate this, several consultancy organisations that can be employed to produce such reports are gaining market presence and contribute to the development of a 'social value industry'. Should this stance become the norm, then organisations who only symbolically engage with social value receive the same legitimacy and benefits as those who substantively engage. Arguably, such legitimacy translates into success in tendering and procurement and that means contractors and consultants are winning work but fail to deliver social value. Areas of society that need social value are then left deprived.

We fear that "a reductionist 'biggest number wins' gaming will become prevalent; and those who have always sought to do the right thing, even where it is difficult to report explicitly, will find it difficult to continue in business in the way they have done because their tender packages do not show significant added value. Seeing social value as added value may actually discourage organisations from doing the right thing." (ibid) As a response, we forward an argument for social value to be seen and used as a tool to address one of the complex grand challenges of our time; to help resolve the 'planet, people and society' agenda connected to the United Nations (UN) Sustainable Development Goals (SDGs) (United Nations, 2020).

We progress through discussion of different, but interconnected, viewpoints examining the polarisation (defining social value, social value practice, and measuring social value) in three moves. We first consider the tensions between taking a universalist versus contextual approach to conceptualising and defining social value. We then illuminate the diversity of social value in practice and how this derives from differences in the purpose of organisation, their values and approach. Finally, deontological theory of ethics and accounting principles offer the analytical framework for our critical discussion of measuring social value.

Conceptualising and Defining Social Value

Social value as a concept has evolved rapidly over the last decade or so. Many different definitions have emerged, often because they are tailored to specific circumstances or organisational priorities. For example, the British Standard (BS 8950) defines social value in broad terms as,

> "a net positive change in human wellbeing and assumes that the enhancement of social value is in the long-term interests of all of us" (Levitt, 2020: 2).

Others, such as the Salford Social Value Alliance (2022) relate social value specifically to procurement:

> "'If £1 is spent on the delivery of services, can that same £1 be used to also produce a wider benefit to the community?'. This involves looking beyond the price of each individual contract and instead looking at the collective benefit to a community."

This link to procurement is commonly visible in different definitions, and many refer to 'added value' (for lists of definitions by different organisations see for example Raidén *et al.,* 2019: 5; UK Green Building Council, 2021: 22-23).

Polarisation, and how it influences the way social value is conceptualised and defined is symptomatic of a bigger problematic - that is, the tensions between a universalist and contextual approach (see Carey and Crammond, 2017). Many industry guides call for a single, unified definition of social value. This kind of universalist approach has merits: it makes it easier for everyone to be working to the same understanding and expectations, direct comparisons are possible, and it would help standardise practice.

However, what is does not allow for is the necessary contextualising and contingencies relevant to the specific and ever-changing circumstances and needs of the local communities within which construction and infrastructure works are built. Important nuance is lost.

A single agreed definition is a difficult fit to suit the industry, organisation, project, community, or individual needs that are most pressing at any one time. Also, the universalist approach potentially constrains innovation; there is less need to think about what is specifically important in a particular place and time to a certain group of people or the environment.

The contextual approach places emphasis on the relationship between individuals and organisations and their physical, cognitive, and social worlds. This means that there will be variability in the use of terms, and so it can be difficult for project partners to understand, agree upon, and meet differing requirements. Nevertheless, a tailored approach to social value allows for flexibility and an opportunity to engage a variety of partners and respond to their points of view in developing responses that are unique to the specific organisation, project, and community situations (Raidén and King, 2022).

In short, the drive towards a single, unified definition signals an aspiration to make social value a top-down pre-prescribed and imposed model instead of a contextual and nuanced practice that responds to local circumstances.

Social Value in Practice

The problem with polarisation is also reflected in the diversity of practice and how social value means different things to different people and different types of organisations. Just as an individual is unique, so is each organisation, with a distinctive mission and vision, purpose, organisational structure, strategy, and systems, culture, values, and employees.

The purpose of the organisation differs by sector: Private sector organisations have a primary responsibility to provide return on investment to their shareholders (although there is a growing movement to shift the dial towards focusing on stakeholder capitalism, which takes account of the needs of all stakeholders, as well as society at large). They tend to have a shorter-term, transactional project focus. Public sector organisations work to so called 'public sector ethos' (see for example Booth-Smith and Leigh, 2016). Although there is much variation in what this means, values like integrity, honesty, objectivity, impartiality, accountability, community responsibility, altruistic motivation, bureaucracy, and customer service, are often associated with the public sector ethos. Public sector organisations often have long-term goals. The third sector includes voluntary and community organisations (both registered charities and other organisations such as associations, self-help groups, and community groups), professional bodies, social enterprises, and co-operatives. They are values-driven and motivated by the desire to achieve social goals, for example, improving public welfare, the environment or economic wellbeing, rather than the desire to distribute profit. They reinvest any surpluses generated in the pursuit of their goals (for examples of third sector organisations in construction see Raidén *et al.,* 2019: 188-193).

There are also differences within the sectors, for instance between best practice pioneers and those who take a compliance approach. Even in the UK, where the Public Services (Social Value) Act (2012) places emphasis on the public sector in leading on social value, adoption by local authorities has been inconsistent: less than half of local councils have a social value policy (Social Enterprise UK, 2019). Furthermore, disparities arise from the differences in organisational value-base and social value orientation of those in leadership positions (see Raidén and King 2022: 24-27). Troje (2020) found that an organisation's maturity and experience with social value related activity impacts upon the support and resources that are committed to projects. Finally, since the built environment is made up of a wide variety of professions (for example, architecture, planning, surveying, and engineering of various forms, and facilities management), which all focus on different aspects of the sector, such as design, construction, or management, it follows that a diversity of social value practice occurs by default.

To exemplify this point, Table 1 showcases key highlights of social value practice from two different organisations, one private sector consulting firm where social value activity level is closely correlated with business performance (for full details see Osbon, 2022) and the other a third sector organisation that is explicitly focused on values driven way of doing business (see Plowden, 2020; Plowden *et al.,* 2022).

Table 1: Examples of social value practice from two organisations

Private sector consultant perspective on social value	Third sector housing association
Drives good practice and social value from the top-down with support for employee-led initiatives	Social value is integral to the business purpose, mission, and vision
SMART objectives	Focus on well-being
Formal, measurable, and demonstrable action, activities, and outputs	Well-being is central to and communicated through all activities, including design and construction work
Fundraising, volunteering, employment support, knowledge transfer and mentoring, the environment	Collaboration is a key element of design: projects are co-governed, co-designed, co-commissioned, co-delivered, and co-evaluated
Investment in socially important projects fuels a virtuous circle that leads to framework agreements and business opportunities	Employee and customer well-being at the heart of workspace design and build
	Sustainable materials selection
Social value investment hierarchy shows a direct correlation between the company performance and social value activities	Both process and outcomes (for people, the environment, and value for money) matter

Deontological Theory of Ethics and Accounting Principles

The third aspect to our discussion about the polarisation relates to a hot topic in this space: measuring social value.

Interest in the topic is increasing monumentally, to the extent that some refer to an emerging 'social value industry' as we alluded to earlier. This relates to the growing number of tools, frameworks, and resources for measuring social value, along with the new British Standard on Social Value (BS 8950), and ISO standards (for example, ISO26000 and 37000), and a growing number of consultancy businesses specialising in this area. Theoretically, our concern can be expressed and analysed using the theories and principles of ethics. We draw on deontological theory of ethics (doing the right thing) and accounting principles as the analytical framework for our discussion. In essence, these two approaches can be seen to represent the opposite ends of a continuum and hence usefully illustrate the polarisation problematic. We introduce each in turn below (after Raidén and King, 2022: 259-276), before using this framework to connect the three different, but interconnected viewpoints to examine the polarisation (defining social value, social value practice, and measuring social value) together.

Deontological Theory of Ethics

Deontology is a normative, duty-based, and non-consequentialist approach to ethics where the morality of an action is assessed on whether the action itself is right or wrong under a series of rules (rather than being based on the consequences of the action). Deontological ethics tend to focus on giving equal respect to all human beings, which provides the basis for human rights. It forces due regard to be given to the interests of a single person even when those may be at odds with the interests of a larger group.

The deontological approach deals with the intentions and motives underlying action, which fits with 'ordinary' thinking about ethical issues. Most people pay attention to whether a person’s act was carried out with ‘good’ or ‘bad’ intentions. However, sometimes conflict arises between different duties or rules: how can everyone matter, as a group, equally, while at the same time due regard be given to each one of them individually?

We draw on three specific deontological theories of ethics that can help in deciding what matters most in assessing and measuring social value: Kantian duty and principle, Rawls’ justice as fairness, and the ‘do no harm’ maxim.

In terms of duty and principle, the German Philosopher Immanuel Kant (1724-1804) argued that our actions must be guided by universalist principles, without consideration of context or consequence. He termed this objective the categorical imperative and deemed it a rationally necessary unconditional principle that must be obeyed without exception. This is the highest order of moral behaviour, a supreme principle. Kant identified that a good will satisfies this test, and this forms the basis for thinking about the intentions and motives underlying action within deontological ethics.

A good will is not contextual, nor dependent on the consequences. As such, good will is shared because it is the moral law, the right thing to do, a duty. Also, Kant argues that a good will is shared because such a moral law applies to everyone, and this gives rise to the principle: equal respect to all human beings, with due regard being given to the interests of a single person, even when it may be at odds with the interests of a larger group. The saying “do unto others as you would have them do unto you” is associated with Kantian ethics. For Kant, thinking about the actions we take needs to be carried out in a serious and philosophically rigorous manner so that we can behave in a way that satisfies the test of the categorical imperative; doing the right thing simply because it is the right thing to do.

By this logic, considering, creating, and delivering social value is the right thing to do, regardless of the consequences.

John Rawls, an American philosopher (1921-2002) developed the justice as fairness theory, which advances the equal respect to all human beings’ deontological principle. Rawls argued that there are three conditions that will make a universal system of fairness possible: firstly, rational people can arrive at a contractual agreement of sorts about how resources are to be distributed. This agreement was not intended to reflect present reality, but rather a desired state of affairs among people in the community.

Secondly, a veil of ignorance (imagining that people have no identity regarding age, sex, ethnicity, education, income, physical attractiveness, or other characteristics) is required to reduce their bias and self-interest in decision-making. And finally, unanimity of acceptance is needed, whereby all must agree to the contract before the system can be put into practice.

Rawls's aim was to provide a minimum guarantee of rights and liberties for everyone, but with the provision to maximise the welfare of the most disadvantaged persons. The theory was built on the belief that the proper place for fairness is above utility and the bottom line.

Justice as fairness has distinct appeal when applied in practice: fairness is a value that is cross-cultural, embraced by different social groups, and understood by nearly everyone, albeit an interpretation of what is fair varies, for example, by an individual's social value orientation. The terminology and discussion relating to justice and fairness are accessible and can be connected to organisational policy and practice on managing equality, diversity, and inclusion; community engagement; social procurement; and training and development, for example.

In seeking to do the right thing, it follows that organisations must critically reflect upon their policy and practice internally, as well as in conjunction with external stakeholders, and consider the fairness of their policies and practices by asking: are there provisions to maximise the welfare of the most disadvantaged persons?

Kantian duty and principle-based ethics, and Rawls's theory of justice as fairness, both highlight the ethical importance of not privileging oneself. A good will and fairness should take primary importance since these are the highest order of moral behaviour within the deontological school of thought in ethics.

The default position, the lowest point within deontological ethics, is called 'do no harm', and this should only be used in the absence of any higher imperative. It states that if one cannot act well, one should at least avoid acting badly. Focus is on prevention of harm rather than doing good; action must be taken to limit any likely causes of harm. This is most commonly expressed via organisational risk management strategy and practice, workplace health and safety measures, and consideration of the environmental impacts of projects and programmes of work.

Deontological ethics places a range of key stakeholders, including people and the community, at the centre of measuring social value, and so it aligns with mixed-method assessment. Mixed-method assessment (or multi-method assessment as it is sometimes called) refers to the processes of collecting different types of data, both qualitative and quantitative, and employing a variety of techniques in analysing that data (see, for example, Knight and Ruddock, 2008). This is an inclusive and comprehensive way of assessing and measuring social value. It is particularly well suited to contexts and/ or circumstances that are complex. Mixed methods can offer greater depth and answers to nuanced 'why and how' questions as well as the certitude of metrics, coverage of large sample sizes and affirmative results (Abowitz and Toole, 2010).

In relation to infrastructure works, Doloi (2018) argues that the needs and requirements of the community should be at the core in planning for infrastructure projects. Therefore, it is important to reach out and identify the key stakeholders' perceptions of value and the kind of change that may benefit them. This is often difficult to achieve by any other means than open conversations and other ways of gathering qualitative data. Mixed-methods assessment allows for understanding what is 'the right thing to do', what the needs of the community are, and what kinds of social value activities, interventions, or programmes of change will make the biggest impact. Focus and attention are not on items with the largest financial proxy value. Raidén *et al.,* 2019 advocate that,

> "…it is society that dictates social value, not experts, and the creation of social value must be built on an intimate understanding of what value means to those communities".

Accounting Principles

Where deontological (non-consequentialist) ethics are focused on doing the right thing, currently the most prominent approach to measuring social value uses accounting principles, monetary values, and other numerical forms to measure the outputs and outcomes of social value activities. Cost-benefit analysis is the principal method of measuring social value that employs monetary valuation (Fujiwara, 2014), although there are many other methods, tools, and models available, for example Social Return on Investment (SROI), cost-utility analysis, cost-effectiveness analysis, and multi-criteria analysis.

Monetary measurement of social value is commonly undertaken for the benefit of an organisation or others in decision-making roles that are connected to the organisation in some way, for example potential clients looking at tender documentation. In addition, funders who want to direct their money to the most effective projects, policy makers and government officials who must account for their decisions and spending, and organisations throughout the supply-chain who need to demonstrate their impact to funders, partners and/ or beneficiaries, all have an interest in measuring social value quantitatively. Hence, although the community is a key stakeholder in social value, the key stakeholders in measuring social value tend to be decision-makers, and this has important implications on the decisions about what gets measured, and how they are measured, valued, and reported.

Organisations commonly report on visible social value related policy and activities: equality of opportunity, school visits, litter picking, face painting, and supporting workers' charitable activities. These are mostly output measures, such as the number of people employed who belong to recognised minority or vulnerable groups; number of school visits, litter picking, face painting events and the total sum raised in support of, or in conjunction with, workers' charitable activities. However, the real value would be best expressed through measurement and reporting of the outcomes of these activities, such as metrics that showcase enhanced employee engagement and perceptions of procedural fairness, improved industry/sector image, and/ or cleaner natural and built environment.

This is not to say that output measures are not important. Assessing and measuring social value is important because it helps in making explicit and communicating social value related activity, which, in turn, can help those tendering for work. It also helps produce clear and convincing evidence to substantiate the case for social value (Sacks, 2002: 3). The world of work is largely metrics-driven, and accordingly, monetised ways of assessing and measuring social value attract significant attention at the moment. It is important to remain cognisant, however, that social value is about co-creating value and achieving social impact, and both the process and outcomes may be difficult to measure in numerical form.

Summary: Problematic Polarisations

We have illuminated the problems of polarisation using three different, but interconnected, narratives: defining social value, social value practice, and measuring social value. The key motive for our discussion was to draw attention to the dangers inherent in recent developments, and to broaden the critical discussion of social value so that we can build back wiser. Considering the tensions between a universalist versus contextual approach to conceptualising and defining social value, looking at two examples of social value in practice and how differences derive from the organisational purpose, values and approach, and discussing deontological theory of ethics and accounting principles as ways of understanding measuring social value has allowed us to highlight how even well intended concepts like social value can be manipulated and mutated to suit a variety of stakeholder interests.

Values-driven people and organisations have naturally integrated social value into the way they work over the years; they have sought to do the right thing and social value has only emerged as a timely descriptor or a useful label for their activities. Others are hijacking the concept to achieve self-interest. At this juncture, it is important to re-energise the core of the concept. Social value is about co-creating value and achieving social impact. The SDGs offer a more broadly understood framework against which social value can be considered.

Sustainable Development Goals (SDGs)

The most universal and widely adopted grand challenge is the set of 17 SDGs (United Nations, 2015; George *et al.,* 2016: 1881):

1. No poverty
2. Zero hunger
3. Good health and wellbeing
4. Quality education
5. Gender equality
6. Clean water and sanitation
7. Affordable and clean energy
8. Decent work and economic growth
9. Industry, innovation, and infrastructure
10. Reduced inequalities
11. Sustainable cities and communities
12. Responsible consumption and production
13. Climate action
14. Life below water
15. Life on land
16. Peace, justice, and strong institutions
17. Partnerships for the goals.

The SDGs are a universal call to action to end poverty, protect the planet, and ensure that all people enjoy peace and prosperity. All United Nations member states are committed to an agenda for sustainable development; "a plan of action for people, planet and prosperity" (United Nations, 2015: 1); the same underpinning principles that are relevant to social value.

While the SDGs are big and bold, and perhaps overwhelming, Raidén and King (2022) argue that social value can act as the practical tool for achieving the SDGs, something that organisations, projects and people can do, and put in practice. In the same way that social value is about an integrated view of social, economic, and environmental sustainability, the SDGs are interconnected. Raidén and King (2021) report a nexus of SDGs that naturally aligns with the nature of work and production in the built environment, most notably SDGs 11 Sustainable cities, and communities, 12 Responsible consumption and production, and 17 Partnerships for the goals, but also SDGs 9 Industry, innovation and infrastructure, 10 Reduced inequalities, and 16 Peace, justice and strong institutions, which emerges from different stakeholders' varied accounts. Other SDGs directly connected with the social value agenda include SDGs 3 Good health and wellbeing, 4 Quality education, 8 Decent work an economic growth, and 13 Climate action, but at least indirectly, social value is really about all the SDGs.

> "The elegance of the SDGs is in the articulation that human progress stems from achieving these clear targets through collective, collaborative, and coordinated effort." (George *et al.,* 2016: 1881)

CONCLUSION

We have examined what the polarisation in the understanding and appreciation of social value means. Our critical essay progressed through the discussion of three different, but interconnected, viewpoints: defining social value, social value practice, and measuring social value. We considered the tensions between taking a universalist versus contextual approach to conceptualising and defining social value, illuminated the diversity of social value in practice, and drew on deontological theory of ethics and accounting principles as the analytical framework for our discussion of measuring social value. We forward an argument for re-energising social value as a concept; that is, co-creating value and achieving social impact. The SDGs offer a more broadly understood framework against which social value can be seen as a tool to address one of the grand challenges of our time, the global 'planet, people and prosperity' agenda connected to the SDGs and building back wiser.

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URBAN DECARBONISATION: A MULTI-LEVEL PERSPECTIVE ON ENERGY CONSUMPTION BEHAVIOUR IN SUSTAINABLE SMART CITIES

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Sustainable Smart City (SSC) leverages smart technological innovations to mitigate carbon. However, the technocratic solutions alone won't deliver decarbonisation since it involves the energy consumption of urban actors. The study aims to investigate SSC technology's impact on energy consumption behaviour as a decarbonisation pathway. A systematic literature review was conducted using the Multi-Level Perspectives (MLP) Lens on SSC's socio-technical transition into the established urban regime as an indicator for sustainable transformation. Upon screening, 65 papers were used for thematic analysis that is then synthesised using three MLP socio-criteria for technological transition: LP - learning process, EV - expectations or visions for the innovation and SN - participation of a broader social network. The findings reveal that the disparate complexity of SSC discourse is related to its early phase of innovation status, as evidenced by the highest gap in the SN requirement. Consequently, enabling SSC technology as a pathway towards urban decarbonisation requires it to break through the established urban regime level. To achieve this necessitates more robust policy advocacy that impacts energy consumption behaviours, which would then drive the technological transition in the direction of urban decarbonisation.

Keywords: energy consumption; multi-level perspective; sustainability, smart city

INTRODUCTION

Decarbonisation was identified as a critical step to the Paris Agreement as part of the sustainability pathway (UNFCCC, 2021). Consequently, many cities worldwide are seeking ways to reduce excessive carbon emissions. As a result, Sustainable Smart Cities (SSC) Has become increasingly popular to tackle this problem with its technological innovation (Meijer and Thaens, 2018). At the regional level, the discourse around decarbonisation initiatives focuses on the household sector as a source of significant carbon emissions. In the United Kingdom (UK) Alone, households contribute about half of the national carbon emissions through energy consumption in the home and personal transport choices (DECC, 2013). As Davoudi *et al.,* (2014) Argued, reductions in household energy use could be much more

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significant if improved domestic technologies and products were more rapidly adopted and used effectively.

However, domestic energy conservation may contribute to the "rebound" effect, in which consumers increase their energy consumption after being 'miserly'. The result indicates that reducing energy demand is not simply about developing energy efficiency measures and technologies but also about changing energy consumption behaviour (Davoudi *et al.,* 2014). Consequently, technocratic solutions via SSC for decarbonisation are often challenged by most scholars (Yigitcanlar and Kamruzzaman, 2018). This is because, while SSC emphasises technological interventions to achieve decarbonisation, it cannot effectively do so without also introducing interventions that necessitate behavioural change (Azizi and Thurairajah, 2020).

Therefore, to explore Sustainable Smart Cities (SSC) As a viable decarbonisation pathway, the diffusion of SSC technologies within the household is investigated using the Multi-Level Perspective (MLP) Lens as a socio-technical transition indicator. Socio-technical refers to a particular analytic perspective which works from several basic assumptions and conceptualisation of technology, human action, and social structure interaction (Geels, 2012). Hence, MLP aids in the identification of issues and obstacles addressed in SSC discourse about energy consumption behaviours as decarbonisation concerns and urban system interactions (Kallman and Frickel, 2019). The findings could inform city planners, builders, and smart city designers to facilitate cities' transition to a more sustainable model and support urban decarbonisation efforts.

SSC technology has gained traction as a means of enabling the intelligent use of digital information to provide improved city administration, energy management, education, and transportation in urban areas to meet sustainability goals. Therefore, the development of techno-centric solutions to support low carbon transitions foregrounded the role of SSC technology in achieving a sustainable future (Stripple and Bulkeley, 2019). However, a disparate and varied definition of SSC has complicated the discourse further. The ambiguity caused by the diverse range of descriptions and models has left it open to various interpretations (Alawdah, 2017). As a result, it isn't easy to establish whether SSC delivers decarbonisation solutions or is a techno-centric fantasy to control the effects of environmental challenges by using modern technology.

Further, the literature indicates an insufficient focus on energy consumption behaviour in SSC models as decarbonisation solutions at the local level (Albert and Flournoy, 2010) And even less so in urban technology transition studies (Carvalho, 2015). The research gaps pose a potential for this study to explore the sustainable aspect of SSC, where its sustainability claims are commonly scholarly contested. It achieves this by investigating the extent to which SSC literature addresses the relationship between SSC technology and energy consumption behaviour at the household level based on the Multi-Level Perspective (MLP) Framework. The MLP is a heuristic approach for analysing how major socio-technical shifts occur and how they can be directed towards a more sustainable path (Geels, 2012).

Referring to Figure 1a, MLP conceptualises the complex and nonlinear interactions that occur in urban structures between three analytical levels:

SL - Socio-technical landscape level: the broader context of societal changes as exogenous macro-developments and influence

SR - Socio-technical regime level: a system of practises and rules created by multiple actors such as market, government, culture, and science

NT - Niche level: innovation and technology formulation

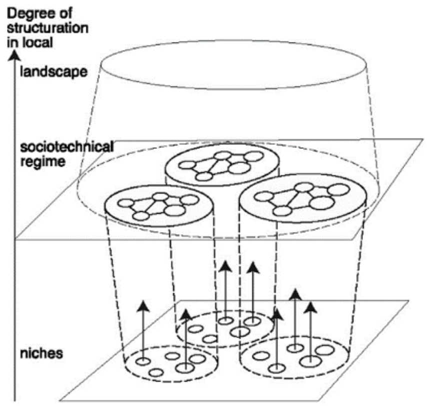


Figure 1a

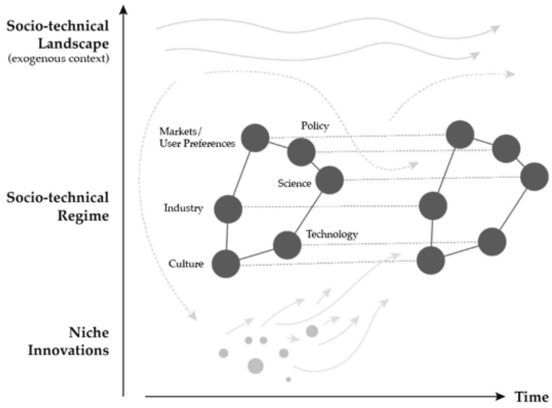


Figure 1b

Figure 1a. A nested hierarchy of the three societal levels in the Multi-Level Perspective. Adapted from Geels (2012)

Figure 1b. The Multi-Level Perspective analysis framework by Geels (2012)

According to Figure 1b, MLP observes technological transition in a city to take place at the niche level where technical experimentation occurs. A bottom-up creative evolution and solutions often result in the technology breaking into the socio-technical regime (SR), thereby transforming the system, and establishing new sustainable pathways (Geels, 2012). Nonetheless, the SR comprises systems of incumbent technology, culture, and social conditions that are hard to break. This level often resists technologies attempting to diffuse into the larger social framework as it often disrupts the established systems. However, regime transformation occurs when the socio-technical landscape level exerts pressure on it and makes it more vulnerable to reform, such as through an urban sustainability agenda, which drives the niche technology to shift the regime in response to urban climatic challenges. Furthermore, MLP asserts that, for SSC transition to occur, it involves unequivocal social acceptance, which demands social support for the SSC technological niches to diffuse within the social-technical regime (Geels, 2012). Therefore, Smith (2012) Proposes a niche analysis based on these indicators to predict a successful technologically driven urban transition to sustainability:

LP: "Learning processes" deal with various dimensions; about imperfections of technology and how they may be overcome, issues of the organisation, market demand, user behaviour, infrastructure requirements, policy instruments and symbolic meanings.

EV: The articulation (and adjustment) Of "expectations or visions", which on the one hand, provide guidance and direction to the internal innovation activities, and on the other hand, aim to attract attention and funding from external actors.

SN: Building "social networks" and enrolling more actors expand the social and resource-based niche innovations.

METHOD

Phase 1: Systematic Literature Review

Socio-technical studies posit that SSC technology requires to successfully transition into the established urban system to have considerable influence on household energy consumption as more users will engage with the technology. A systematic review approach was used to examine this discourse by studying the energy consumption behaviours addressed in the SSC literature. Then the MLP lens was used to synthesise the findings in the second phase of the methodology.

The systematic review method followed the work of Tranfield *et al.,* (2003). A combination of three keywords was used to form a search string. All preliminary searches, therefore, included the key terms "energy consumption behaviours" with "sustainable smart cities" and "SSC technologies" in the publication titles. The initial search acquired 1,224 articles. Screening of relevant articles were executed to ascertain whether the documents were likely to meet pre-determined inclusion and exclusion criteria.

The inclusion criteria included:

Published papers from the current time of writing to 10 years ago (2021-2011)

Papers/articles in the English language

Papers/articles relating to households

Papers/articles with empirical and non-empirical evidence

In addition, the following exclusion criteria were applied:

Papers/articles published in magazines and newspapers

Papers/articles that only provide a review of a conference

Table 1: Search results, thoroughly reviewed papers, and included papers

	Search results	
Initial search		1,224
Preliminary screening	(932)	192
Abstract screening	(83)	109
Full-text screening	(21)	86
Final in-depth review		65

Table 1 summarises the screening and review process of the search results to only 65 articles included for in-depth analysis to be used for synthesis using the MLP lens. After a preliminary screening of the initial search results, abstracts were filtered based on the notion that households generate significant carbon imprint through energy use at home and personal (domestic) Transportation (DECC, 2013). Thereby limiting articles to households' energy consumption behaviour and smart mobility choices as observable components in the urban environment inspected at the household level. The full-text screening examined key terms such as "SSC technology" to determine relevant discussion in the literature. It excluded any that did not explicitly discuss it or detailed energy consumption behaviours discourse, reducing the in-depth review to 65 papers.

Phase 2: Multi-Level Perspective (MLP) Synthesis

The insights into energy consumption behaviours found in all reviewed articles and the gaps discovered are carefully analysed through the MLP lens. Set theory is then used to gauge the relationship presented via Venn diagrams of the three niche processes as the niches analysis method adapted from Smith (2012) Discussed earlier. The observation was made to determine the barriers and challenges SSC technologies encounter at the niche level when attempting to break into the established socio-technical regime by noting SSC technology's influence on households' energy consumption behaviour. Finally, the results are used to postulate SSC technology as a possible urban decarbonisation pathway and address the previously stated research gaps.

FINDINGS

A total of nineteen types of technology were found relating to energy consumption behaviours in the 65 SSC literature reviewed. The highest discussed technology was the smart meter (19), followed by general "smart technology" (13), smart home (6), and smart grid (4). Two articles detailed the Internet of Things (IoT) With electrical vehicles (2) And smart buildings (2). Three papers discussed smart mobility and ICT (3). Other individual papers were about the electric bicycle, smart traffic lights influencing household mobility choices, smart load management, big data analytics, smart net-zero energy homes, Wechat, Web of Things (WoT), smart thermostat, fog computing, and Renewable Energy Sources (RESs). There exist myriad types of SSC technology with a wider range of SSC discussions that determining SSC technology as a decarbonisation pathway becomes challenging. However, taking smart meters as the dominating technology in the analysis, researchers agree on the importance of behaviour in impacting technological initiatives at the household level that would have a more substantial result in changing energy consumption within that sector (Al-Marri *et al.,* 2017).

Synthesis Through MLP Lens

The study observes the dimension of interactions of SSC technologies with energy consumption behaviour in the household sector through MLP levels, namely:

SL Socio-technical landscape observed through climate change (CC) And sustainable future (SF) Factors

SR Sociotechnical regime observed at the household level that SSC technology has to break through

NT niche technology observed as SSC technology/ innovation

It then inspects the SSC technology through Smith (2012)'s niche analysis (LP, EV, SN), as previously mentioned. The finding showed a significant relationship with the dimension of interaction to postulate SSC technologies as a decarbonisation pathway and is described as follows:

Figure 2 reflects the findings where LP intersects with EV but excludes SN as the most interactive relationship ($LP \cap EV = 46$). Since most papers reviewed SSC technology as a niche innovation, findings indicate that it is still in the exploratory phase. Therefore, it is not widely diffused to the socio-technical regime level and is yet to be broadly adopted to replace the incumbent system. As a result, it has a low SN, which means more actors need to utilise the technology to make a significant decarbonisation impact.

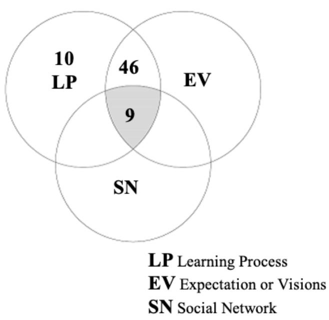


Figure 2: MLP analysis

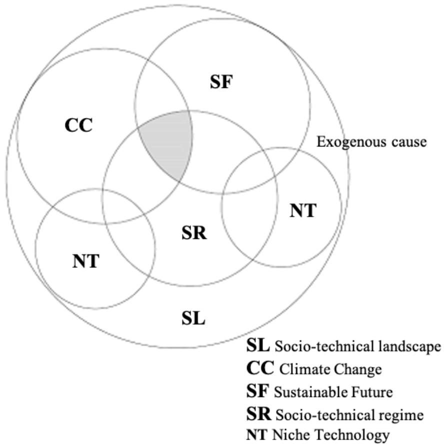
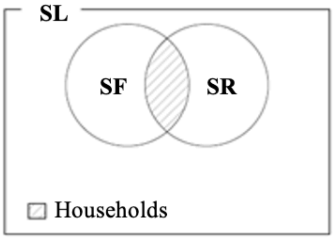


Figure 3: SL components interaction

Therefore, the study perceives SSC technology generally stagnates at the niche level, indicative of SN having a minor intersection. For example, literature discussed smart meters as widely diffused in many households, yet they are still considered a novel innovation compared to more commonly used household technologies. Thus, it may not have a considerable impact on energy consumption behaviours.

Meanwhile, only ten papers discoursed the LP (LP ∩ EV' ∩ SN' = 10) Of technology transition without engaging both EV and SN processes. The learning components for lowering energy consumption include technological potentials (Oki *et al.,* 2019), technical solutions through automation (Mashayekhi and Heravi, 2020), market relation (Al-Marri *et al.,* 2017; Davoudi, 2014), user behaviours (Lopes *et al.,* 2017), privacy issues such as cyber-attacks and health issues (Alamaniotis *et al.,* 2019; Aliero *et al.,* 2021), infrastructure requirements for smart grid system (Masseck *et al.,* 2017; Soares *et al.,* 2016) And policy instruments (Kapoor and Dwivedi, 2020).

Finally, nine papers are considered holistic because they have observed all MLP's socio-criteria of analysis and interact with all three areas to attempt successful technology transition (LP ∩ EV ∩ SN). Using these papers, the study goes on to investigate the relationship of niche smart technology (NT) With other interacting characteristics and themes through the interlocking relationship of socio-landscape (SL) Pressuring socio-technical regime (SR) Explored in Figure 3. This Figure shows that the exogenous cause indicated at the socio-technical landscape level (SL) Are pressurising factors identified as climate change (CC). Changing public environmental awareness and broader social pressure are revealing CC concerns. Secondly, the sustainable future (SF) Factors concerning technological adaptation by addressing urban problems, modern growth, and energy scarcity. As both CC and SF exert pressure on the SR level, it allows the SSC technology breakthroughs from the niche level. The intersection (shaded in grey) Is linked to the relationship between SSC technologies emerging from NT. Despite the climate change factor driving this technology diffusion, it was also found that community-wide initiatives also reduce carbon footprints by 17-27% after two years of intervention in household consumption (Iweka *et al.,* 2019). This indicates that the sociological solution should not be overlooked when technology is used as an urban carbon solution for a sustainable future. The sustainable future (SF) Connections are further explored with explanations through subsequent diagrams.



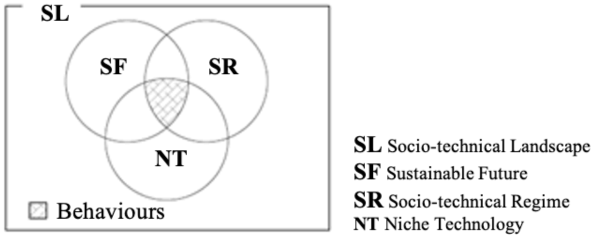
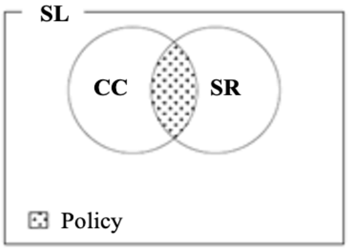


Figure 4: Technology impact in SL *Figure 5: Smart meter impacts behaviour*

When related elements (SF and CC) Within the SL from Figure 3 were dissected, five papers (Chen *et al.,* 2017; Fjellså *et al.,* 2021; Gupta *et al.,* 2018; Iweka *et al.,* 2019; Westermann *et al.,* 2020) Resulted in the household as the constant intersecting component with SF ∩ SR. As a result, sustainable future (SF) Literature themes are frequently framed around technological adaptation as technocratic solutions aimed at targeting consumption behaviours within the household sector at the SR level, as illustrated in Figure 4. Fjellså *et al.,* (2021) Correlated the irregular behavioural pattern of consumption in most households provided energy providers to rely on automation through technology to bypass the issue. Therefore, when SF ∩ SR ∩ NT interacted, as shown in Figure 5, the technology found to offer a solution to the challenge of behavioural irregularities was the smart meter. The study then analysed the challenges of smart meter application as a niche innovation. Literature indicates that while SSC technology has been adapted as a solution for reducing the carbon footprint at the household level to promote sustainable futures (SF), the influence of household behaviour as an influencing factor cannot be minimised and is the foundation for sustainable futures.



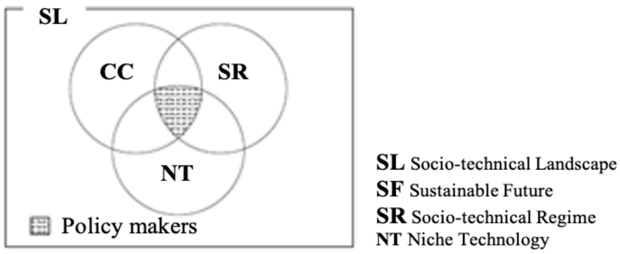


Figure 6: Policy influences in SL *Figure 7: Disrupting cause in SL*

Nonetheless, concerning climate change (CC) Factors, all four papers (Essletzbichler, 2012; Ingle *et al.,* 2014; Schill *et al.,* 2019; Schröder *et al.,* 2019) From the nine papers examined associated policy, either intervention, the instituting policymakers, or encouraged policy discourse at SL level as the interacting component of CC ∩ SR, as depicted Figure 6. Meaning that policy has the potential to influence sustainable household energy consumption behaviour. When interaction CC ∩ SR ∩ NT in Figure 7 was plotted, the study observed policymakers as the most substantial disrupting factor and barrier to technology transition. Schröder *et al.,* (2019) Posited that niche innovation may disrupt policymakers at the regime level because it involves institutional changes and governance innovation. In contrast, other factors such as socio-politics, human behaviour (Schill *et al.,* 2019), and energy providers (Essletzbichler, 2012) Are also recognised as barriers within the SR components for SSC technology to transition into the regime and impact behaviours toward urban decarbonisation goals.

CONCLUSIONS

City planners are expected to face significant future challenges from overpopulation growth in urban areas. As a result, smart city initiatives are recognised as having the solution that uses connected technology to facilitate efficient city planning and management, with sustainable urban solutions relying heavily on SSC technology to offset carbon concerns. Therefore, by employing the MLP lens, the study concludes that attempting to conceptualise the decarbonisation pathway through SSC technology requires successfully transitioning into the established urban system. Furthermore, ensuring sustainable transition at the household level is crucial since the city population lives in homes, so impacting their energy consumption behaviour infers mitigating carbon footprint at the urban level, and thus may offer sustainability solution in SSC envisioning.

By plotting the relationships of the socio-technical components, the study examined the challenges of SSC technology as a decarbonisation pathway and determined influential sustainable transition factors. Climate change (CC) Factors were found to be the exogenous cause exerting pressure on the established regime that supports the creation of SSC technology as a sustainable future (SF) Solution. However, SSC technology stagnates at the niche level because it is a niche innovation that has not yet achieved widespread adoption. Suggesting that SSC technology may not have the desired influence on household energy consumption behaviour as it has not broken through the regime level.

To counter such a challenge, broader participation at the household level with SSC technology is required, leading to wider technological diffusion at the regime level and a significant urban decarbonisation impact. Therefore, using the MLP framework, the study determined that more robust policy advocacy on the adoption of SSC technology could affect household energy consumption. A bottom-up sociological approach was also established to promote the transformation of the urban fabric to a more sustainable path through SSC technologies adopted in households. Finally, the study's findings contribute to improving the built environment by highlighting the sociological significance of people's participation with SSC technology at the household level resulting in urban decarbonisation and thus supporting the sustainability aspect of the Sustainable Smart Cities to be realised.

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EXPLORING DESIGNER'S ATTITUDES AND CHALLENGES IN THE LIFE CYCLE ASSESSMENT OF BUILDINGS IN DENMARK

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Requirements on building's carbon footprint are being incorporated into various European countries' legislative frameworks. By 2023 the Danish legislation requires performing Life Cycle Assessments (LCA) for all new buildings. However, studies show that few designers have experience in LCA or are yet equipped to work with it, lacking research on designers' attitudes and experienced challenges in LCA application. Through Activity Theory analytical framework, this study explores designers' attitudes in LCA application, unfolding the perceived challenges. Semi-structured interviews were conducted with six respondents involved in building design, including architectural technologists and engineers with various experiences in LCA. Results reveal that organisations use increased resources in an LCA, as it is a complex and demanding task. The main challenges were lack of LCA experience, lack of information, and data inconsistency. However, results indicate an overall green transition within the organisations, understanding the expected consequences of adapting LCA and the importance of materials choice. Establishing standards to support LCA in building regulations is necessary, designing buildings back wiser.

Keywords: life cycle assessment; building design; challenges; activity theory

INTRODUCTION

Buildings contribute significantly to global resource consumption and environmental emissions from operational energy and material use. Hence, several countries have issued rules for assessing CO2 emissions based on the life cycle assessment (LCA) method (Kanafani *et al.,* 2021). In the EU, increased use of LCA for an environmental performance assessment is evident in the scientific and policy communities. Greenhouse gas emissions must be reduced by at least 55% by 2030, becoming climate neutral by 2050 (European Commission, 2020). Some European countries have included requirements for LCA results to deal with the environmental impacts of buildings (Lützkendorf, 2018).

The Danish political agreement, March 2021, has set CO2 requirements for new construction in Building Regulations by 2023 (BR23) as buildings above 1000 m2

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Selman, A D, Heiselberg, H L, Gade, P N and Gade, A N (2022) Exploring Designer's Attitudes and Challenges in the Life Cycle Assessment of Buildings in Denmark *In:* Tutesigensi, A and Neilson, C J (Eds) *Proceedings of the 38th Annual ARCOM Conference,* 5-7 September 2022, Glasgow, UK, Association of Researchers in Construction Management, 721-730.

must not emit more than 12 kg CO2-equivalent/ m2/ year over a 50-year life span. Also, the climate impact must be calculated for all construction. In BR23, the voluntary sustainability building class requires a maximum CO2 limit of 8 kg CO2-equivalent/ m2/ year (National Strategy for Sustainable Buildings, 2021). Informed design decisions mitigate potential environmental impacts by using LCA in the early project stages (Lykke *et al.,* 2020). LCA is applied in building certification schemes, e.g., BREEAM or DGNB, and for environmental labels (e.g., Environmental Product Declarations (EPD)) to quantify, communicate and manage environmental impacts from buildings (Schlanbusch *et al.,* 2016).

To mitigate CO2 emissions, designers strongly need LCA tools for making informed design decisions (Kanafani *et al.,* 2021). In 2015, the Danish LCA tool LCAbyg was launched under the auspices of Danish building authorities. The LCA database Ökobaudatas was selected as a source for national generic environmental data (Kanafani *et al.,* 2021). Both research and experiences from involved practitioners recognise challenges linked to tools used for sustainable buildings and LCA application. Performing an LCA is complex and time-consuming (Schlanbusch *et al.,* 2016). According to Rasmussen *et al. (*2020), applying LCA in early design phases is a new challenge for practitioners and collecting data for LCA calculations is complex. Actors expect that when LCA becomes a mandatory task, it can add difficulties for organisations with no or minor experience in LCA. Hence, supporting organisations to fulfil CO2 requirements and strengthen LCA application is essential. Thus, this paper aims to explore designers' perceived challenges, attitudes, and experiences with LCA, raising the research question: "What are the attitudes of designers and their perceived challenges when assessing the environmental impact of buildings in Denmark?"

Rossi *et al. (*2016) identified barriers to implementing sustainable design methods and tools concerning their structure, lack of knowledge and time-consuming efforts. Ipsen *et al. (*2021) reveal that a lack of suitable sustainability tools hinders the sustainability design of buildings. Kanafani *et al. (*2021) argue that to mitigate CO2 emissions, designers strongly need LCA tools to make informed design decisions, especially in the early design stages, where significant sustainability decisions are made. However, the complexity of LCA has often been perceived as a barrier to implementing LCA in building design. Hence, a well-considered tool design can deliver reliable and valid results while keeping the extra workload for LCA implementation in the design process to a minimum. A Nordic survey by Rasmussen *et al. (*2020) showed that designers generally feel professionally committed to applying LCA. However, a primary barrier for LCAs in building design is the perceived lack of incentives, sufficient data and information. Design practitioners perceive a moderate drive for integrating environmental performance assessments, needing to learn what drives and controls a project's results and converting results into understandable data for clients. Also, lack of designer expertise and consuming ample resources are critical barriers.

Schlanbusch *et al. (*2016) showed a growing use and Nordic market demand of LCA in recent years. However, lack of transparency and uncertainty of the inherent data affects the accuracy of LCA results, as an LCA analysis outcome should be the base for optimal decisions. Results revealed the difficulty of finding and collecting data in LCA, finding it resource-consuming. Also, handling the end-of-life phase of buildings in an LCA is challenging. The environmental benefits of recycling, reuse, and energy recovery present a critical knowledge gap in the building sector. The study emphasised the importance of further research on efficient LCA performance in early design. Anand and Amor (2017) consider LCA one of the most complex applications in analysing sustainable buildings due to numerous materials and processes, as the inventory data for LCA of a building highly depends on specific data of building components and materials.

Other challenges are building design, stakeholder criteria, cost, environmental targets, and users. Building inventory data is obtained from building industry databases or EPD. However, product data for LCA lacks environmental feedback for new and old products. In Denmark, Kanafani *et al.* (2021) defined four key areas for successful LCAbyg tool design: default information, flexibility, environmental design feedback, and transparent results. In the UK, Roberts *et al.* (2020) revealed that LCA faces barriers in methods and practice, preventing its ability to guide early-stage design decisions. Generally, it is used late in the design when too late to influence the design significantly. Incorporating LCA with building information modelling (BIM) or life cycle costing has the same challenges as undertaking a traditional LCA.

However, benchmarks, target values, and other information can incorporate life cycle thinking without undertaking a detailed LCA. Nwodo and Anumba (2019) reveal that a building life cycle inventory and LCA phases can be data intensive. Here, BIM-based LCA is suggested to overcome this challenge. Tally, a BIM-based LCA tool in the USA, was incorporated into Autodesk Revit (BIM) as a plug-in. In Denmark, the Department of Construction, Urban and Environment (BUILD) at Aalborg University is developing a BIM-integrated LCA tool using JSON format as a third-party integration in LCAbyg. GRAPHISOFT Center Denmark (2022) developed a BIM-based LCA tool to calculate a building's kg CO2-equivalent/ m2/ year, considering the building's use and materials, requiring Archicad and Excel software. A Finnish LCA software firm developed an LCA tool to reduce LCA workload (One Click LCA, 2022). The industry association DiKon (2022) aim to standardise the BIM model data to reduce manual tasks in LCA.

METHOD

A qualitative method was applied to explore designers' attitudes and perceived challenges in LCA application by conducting six semi-structured interviews (Kvale 1996) with two architectural technologists (A1 and A2) and four consultant engineers (E1, E2, E3 and E4) from middle-size (30-50 employees) and large organisations (>50 employees), selected via purposive sampling. They all support sustainability but have various levels of experience in LCA, evaluated according to the number of cases and years of experience in LCA to capture the controversies and diverging assessments, providing insights into their challenges in LCA.

Figure 1: Interviewee's job roles

Interviewee role	Architectural technologist and DGNB auditor	Architectural technologist and architect	Engineer	Engineer	Engineer and DGNB auditor	Engineer
Interviewee name	A1	A2	E1	E2	E3	E4
Organisation size	Medium	Medium	Large	Large	Large	Large
Experience in LCA	Medium	Low	Medium	Low	High	Medium

Interview Guide Using the Activity Theory Checklist

An interview guide was designed, following the strategy for semi-structured interviews (Kvale 1996), structured and analysed according to Activity Theory (AT) (Blunden, 2015) and AT checklist (Kaptelinin *et al.,* 1999). The premise of AT is that a collective work activity, with a basic purpose shared by others (community), is undertaken by people (subjects) who are motivated by a purpose or towards a problem solution (object), which is mediated by tools and signs (artefacts or instruments) used to achieve the goal (outcome). The activity is constrained by cultural factors, including conventions (rules) and social organisation (a division of labour) in the immediate context and framed by broader social patterns (of production, consumption, distribution, and exchange). AT provides a conceptual framework to understand the inter-relationship and contradictions between activities, actions, operations and artefacts, subjects' motives and goals, and aspects of the organisational and social contexts in which these activities are framed (Blunden, 2015). The main benefit of AT Checklist is to ensure that human collaborative activity is studied according to the theoretical underpinnings of what constitutes such activities. This helps ensure that all essential aspects of such activities are inquired to give the study scientific rigour. In addition, AT helped achieve a holistic perspective, analysing how activities play out between people, intentions, and technology [17], exploring in-depth actors' perceived challenges and attitudes using LCA.

According to Kaptelinin *et al.,* the AT checklist reflects the AT principles, resulting in four perspectives on the use of target technology to be evaluated (1999): 1: Means and goals: the extent to which the technology facilitates and constrains the attainment of users' goals and the impact of technology on provoking or resolving conflicts between goals. 2: Social and physical aspects of the working environment: integration of target technology with requirements, tools, resources, and social rules of the environment. 3: Learning and cognition in LCA: internal versus external activity components and support of mutual transformations with target technology. 4: Development of LCA: the developmental transformation of preceding components. Based on the four perspectives, interview questions were devised. Interviews were recorded, transcribed, and results were coded according to the answers themes rather than constricted to the checklist's four perspectives.

FINDINGS

According to AT checklist, the results are divided into five areas: The organisation's means and goals, the impact of LCA on designers' work and attitudes, learning with LCAs, LCA development, and insights into the building sector's green transformation.

Organisations' Means and Goals in LCA
Interviewees A2, E1, E2, E3 and E4 declared a significant focus on LCA in their organisations, and their preparations for BR23 are already proceeding, consuming ample time and resources, as also experienced when working with LCA as an essential part of the DGNB certification. In contrast, A1 declared less focus and effort in LCA application. However, they all perceive an increased focus on LCA, expecting an increased client demand, especially when it becomes mandatory to document buildings' CO_2 emissions by 2023. So, actors aim to understand the new CO_2 requirements and advise the clients on the most environmentally friendly decisions, e.g., making variant comparisons on building materials, as a foundation for discussion and decision making.

Furthermore, all interviewees agreed that LCA is an interdisciplinarity task involving building designers, producers, and contractors as they should all participate in a building LCA process, contributing with their area of expertise. In larger organisations, the sustainability department is mainly responsible for conducting an LCA in collaboration with the IT specialist responsible for BIM models and the architect. Various parameters can influence an LCA process, such as conservative actors, lack of fixed and transparent procedures and uncertainty due to lack of consistency in the building model. A2 stated that the ability to influence the input to LCA when the model is developed externally prevents proceeding with the calculations. However, it proceeds well when architects draw in the BIM software Revit. The variables influencing LCA application were explored, revealing that early intervention, defining materials and construction principles are essential. E2 mentioned that much input to LCA is initially estimated due to a lack of detailed material data.

According to E3 extracting quantities works well with BIM software but is challenging with other software or 2D methods. Other challenges are diverse interpretations of how, when, and by whom the building models data must be delivered and the required information level. E3 and E4 stated that DiKon has recently developed such standards. However, results indicate limitations with LCA, lack of experience and exact material data with uncertain estimations, and many manual tasks when importing materials EPDs to LCA, which are unavailable in EPD Danmark's database. E2 stated that this increases resources' use early in the projects, especially when updating and verifying materials and their quantities, revealing the need to automate LCA input. E4 declared that LCA's products database is built very specifically, so it can be challenging to find if, e.g., plasterboard is not explicitly named "Gypsum Gyproc". Also, LCAbyg has a difficult and not standard format (JSON format).

Impact of LCA on Designers' Work and Attitudes

Interviewees agreed that LCA work creates a change of attitude and adds greater knowledge to organisations. Overall, interviewees expressed that the actors have become more aware of the choice of materials in construction. Thus, materials are now considered more carefully. A2 stated that designers recommend building materials with lower CO2 impact, facing some client resistance, being a wake-up call for those who do not accept untraditional materials. It is revealed that LCA highly impacts architects in design limitations, forcing them to use new solutions. Also, materials origin must be considered when selecting products. Here, the economy plays an essential role, e.g., higher cost of energy used for materials production. Specifically, wood construction is considered, recognising its environmental benefits. Along these lines, A2 argued for an increased awareness of using less concrete. Generally, the awareness of material choices has spread among other professionals as there is a significant focus on this from all manufacturers, adding that leaders must promote sustainability and ensure it by raising competencies and specialists. A2 stated that LCA work is becoming more structured since they first started using it, and cooperation between involved actors is the best way to achieve satisfying LCA work processes. E2 revealed that certain building parts are not included in the LCA. Thus, an LCA can hide specific facts.

E4 declared a significant contradiction reflecting on LCA experts' workload: "The process towards providing complex decisions should be simpler. It cannot be right that our sustainability experts spend 80 percent of our time finding information and only 20 percent on creating a more sustainable building". Buildings' design is getting more complex, as many decisions must be made earlier than usual, which is challenging when the rest of the project is not geared towards it, creating the risk of some late design changes and adding economic challenges. Moreover, working with LCA has significantly affected project documentation work and data delivery, changing design processes, revealing that the LCA should run the design process, requiring an earlier and greater flow of information than usual.

E4 stated: "I often see that an LCA is used as a documenting tool rather than a real design tool...it is improving, and I can feel the paradigm shift towards using it as a real design tool". On the other hand, the interviewees confirmed a positive impact of LCAs. Besides the environmental benefits documented and visualised via LCA, focusing on building materials generally provides a better understanding of materials and their properties, e.g., less degassing from materials will provide healthier buildings. LCA also provides extra quality assurance by detecting incorrect quantities via LCA calculations in the early design stages. In addition, it generally provides greater knowledge of a building and opens a discussion about materials' lifetime, maintenance, and potential for circular strategies at the end of life.

Reflections on Learning with LCAs

The interviewees were asked whether learning LCA calculations require an excessive investment of time, effort and resources. A1 admitted the need for more extensive investment in learning and developing in LCA as they have not reached the desired level of expertise. Despite spending much time on it, admitting that smaller organisations might not be able to lift the task at the same level as larger organisations. Similarly, all interviewees declared that ample time was consumed in learning LCAs. Also, A2 revealed a learning period for the first projects before one gets self-driven.

E1, who works in a larger organisation, does not perceive LCAbyg as a difficult tool. They have a sustainability department with LCA specialists. However, he admits challenges in the work process, e.g., how the information is obtained, disclosed, and communicated, adding that learning is iterative. E2 stated that exchanging experiences with LCAs is a prerequisite for learning and expanding specialists in this area. Furthermore, the learning process in LCA involves communicating with all interdisciplinary specialities and pulling resources from other departments across the organisation. According to E3, learning LCA requires regular use and strategical work via a specialised sustainability department.

The interviewees were asked whether any activities in LCA work have changed over time since they started working with it. A1 revealed a higher focus on influencing the project in the early phases. According to A2, LCA work is getting more structured, and the process has become more standardised with fewer templates. E1 mentioned: "It is generally easier for larger organisations to control quality and share knowledge between organisations' branches". E2 stated that they learn fast from their own mistakes, doing things smarter, especially when working with new aspects: "I have certainly learned something, but mostly how I can optimise my processes" E2. According to E4, some tasks became simpler; others are still complex, e.g., requirements for expanding the building model's data with materials and their parameters, revealing that a digital platform (Dalux) is used to share LCA results. The interviewee's capability to master the tools they needed in LCA work was explored.

Responses varied, as engineers indicated that using LCAbyg is easier for them while roles with a more general function (A1 and A2) find it extremely difficult. According to A1, it is difficult to have control over LCAbyg, considering it frustrating as it is challenging to navigate the data, understand it, and further communicate the results. E1 declared that it is getting easier after consuming many hours with LCA. E2 mentioned that the tool is simple, but understanding its mechanisms is challenging, as it can be relatively complex. They seek help internally from colleagues and externally by referring to BUILD and their network. A2 stated that LCA methods develop continuously, e.g., considering the building's renovation phase, which requires continuous learning. However, results reveal some uncertainty about the voluntary sustainability class. E1 declared a lack of knowledge in defining the transport in the construction phase. A1 mentioned that they learn from competitors in finding practical ways to convey and present LCA results. A2, E1 and E2 clarified that they have a library to save previous LCA work and variant studies as a benchmark to compare.

E1 and E2 proposed that the manual work of defining quantities must be automated, requesting requirements for defining quantities in the tender phase. Generally, responses showed that it is imperative to reduce resource consumption when performing LCA analysis. However, A1, who lacks experience in LCA, requests to consume more resources to learn more about LCA, taking the challenges more seriously. All interviewees indicate the need to work with more practical and user-friendly tools. E2 stated that LCA results must include all environmental indicators, though the CO2 global warming potential is the most critical, adding that a reference period of 50 years is defined in LCA, which can be optimised. It was indicated that LCA users prefer to be less dependent on other disciplines in collecting data. Also, E1 requested a synergy between the Danish buildings' energy calculation tool (Be18) and LCA. E3 proposed developing methods of working with LCA, such as visualising the results with the building model and developing a drag and drop function.

All interviewees agreed that the available tools do not fully support users' needs. LCAbyg is too complex, requesting further improvements due to extensive manual work and a lack of integration between the data in the programs used. LCA users require a plug-in for Revit to automate the data flow between Revit and LCAbyg or import materials quantities from Excel into LCAbyg. E4 argue that it is troublesome to use JSON format raising technical challenges. Other aspects relate to the export and import of EPDs into LCAbyg, as it works well when choosing products from EPD-Denmark database but is challenging with other EPD databases. Finally, the satisfaction of available LCA standards was discussed. Here, E4 mentioned: "despite adequate standards for LCA, many uncertain areas still lead to confusion and incorrect calculations, which should be clarified". A1 stated that it is unclear which life cycle phases are included in BR23 CO2 requirements. E2 specified the need to clarify which building components to include in an LCA. Moreover, E3 and E4 pointed out the lack of standards for methods to present LCA results, as they can vary among projects and users.

The interviewees were asked about their insights into the building sector's expectations regarding the LCA progress. They shared similar visions in developing methods to make LCAbyg more operational and user-friendly with an automated link between Revit models and LCAbyg, along with standardised output from LCAbyg. Moreover, interviewees expect the development of a broader range of EPDs. The interviewees suggest improving actors' attitudes, accepting various approaches with increased LCA recognition, and integrating LCA early in the design process. According to E3, LCA application will be a more competitive parameter in the future than it currently is, and it will be relevant to evaluate and optimise their work with LCAs. E4 expects BR23 CO2 limits to include all buildings, not only buildings over one thousand square meters. Also, expectations for more explicit specifications on which building parts will be assessed in an LCA. Finally, E3 stated that smaller organisations would likely need to hire external consultants for LCA, at least in the short term, until they adjust and fit into the LCA demands. E4 argued that this would be a considerable challenge, leading to increased expenses, while larger organisations can easier adapt to these changes.

It is evident from the analysis of interviews that building practitioners perceive an increased focus and demand for LCA applications. Preparations for the upcoming CO2 requirements are proceeding, expecting an increased demand for it when it becomes mandatory in 2023, considering it a competitive parameter. The BR23 CO2 requirements will accelerate the adoption of LCA. Results show a knowledge gap perceived among LCA users, reflecting the complexity of LCA and the need for knowledge exchange. LCA specialists in larger organisations have adequate knowledge of LCA and are more confident with their experiences. In contrast, designers in organisations with fewer experiences are eager to learn more and request more investment from the leaders' side in increasing the organisations' competencies to catch up with the rapid development. Thus, leaders have an essential role in boosting LCA application. Results from interviews and research by Rasmussen *et al. (*2020) agree that LCA is an extensive task with many manual activities and increased resources. It starts early in the design phase and runs until the building is handed over. Moreover, it is an interdisciplinarity task, requiring collaboration and extra resources in the design team and among other professionals. Results revealed that various challenges influence LCA work, such as conservative actors, lack of experience, lack of fixed and transparent procedures, lack of materials data and uncertainty due to lack of consistency in the BIM model. Schlanbusch *et al. (*2016) defined issues related to inconsistency, transparency, comparability, and data quality and availability, affecting LCA results accuracy. Interviews results declared the difficulty of influencing LCA's input when the building model is developed by various tools and lack of exact material data with uncertain estimations and many manual tasks when importing materials EPDs to LCAbyg.

Kanafani *et al. (*2021) argued that a well-considered tool design could deliver reliable and valid results while keeping the extra workload for LCA implementation in the design process minimum. According to Ipsen *et al. (*2021), more holistic assessment methods and tools are lacking in considering sustainability from a broader definition. Roberts *et al. (*2020) exposed that LCA is generally used late in the design process when too late to influence the design significantly. This study confirmed that several factors impact designers' work and attitudes toward LCA. Here, the choice of materials in buildings is crucial; designers have become more aware of it, indicating the building sector's positive green transition and willingness to change its traditions. Clients got a wake-up call to choose new materials. There has been a significant architectural upheaval, impacting architects to design buildings more flexibly, considering untraditional building materials like using more wood instead of concrete, reflecting that buildings design is getting complex. Many decisions must be made significantly earlier than usual, with a greater flow of information, which is challenging when many design aspects are estimated, leading to the risk of late design changes. Thus, an LCA tool must be used as a design tool to document the environmental impact of buildings, designing buildings back wiser. The economy is also a key factor when choosing materials with lower CO2- emissions, as they can be costly. Moreover, LCA work has positively affected practitioners. Their work has become more structured and standardised using their own templates with improved collaboration between actors. LCA also provides extra quality assurance by detecting faulty materials quantities and gaining a more profound knowledge of a building, such as materials' lifetime, maintenance, and potential for circular strategies at the end of life. However, Schlanbusch *et al. (*2016) found that handling the end-of-life phase of buildings in LCA is challenging, and the environmental benefits of recycling, reuse, and energy recovery represent a critical knowledge gap in the building industry.

Also, learning and working with LCA requires much effort and resources. Interviewees, challenges in LCA mainly exist in the work process itself, e.g., how the information is obtained, disclosed, and communicated, rather than the LCAbyg tool itself. Generally, it is less challenging for larger organisations with higher experience and options to exchange knowledge internally than smaller organisations with less or almost no experience who most likely need to hire external LCA consultants, leading to higher consultation costs. Moreover, learning about LCAs requires exchanging experiences across the building sector. Actors learn faster by making mistakes and regularly working with LCA. Generally, engineers are more capable of mastering LCAs. Actors requested a more user-friendly tool to reduce manual work in LCAbyg, and an automated process by incorporating BIM to LCA and developing LCA standards to clarify uncertainties. These results aligned with Nwodo and Anumba (2019) and Rasmussen *et al. (*2020). BIM must go in hand with LCA application early buildings design to eliminate the risk of extra resources, requesting common standards for LCA-based tools for early design stages. Other LCA development potential involves expanding the materials in the Danish EPD database, including all environmental indicators in LCA, and defining other reference periods than 50 years. Finally, using AT assisted in a holistic analysis. Despite the limited number of interviews, answers gave valuable insights into the designer's LCA work.

CONCLUSION

To mitigate CO2 emissions, building designers use LCA tools for making informed design decisions. Previous research has highlighted several challenges in LCA application. Thus, this study aimed to explore designers' attitudes, perceived challenges, and benefits in LCA. Based on interviews with LCA practitioners, the results showed that LCA creates a change of attitude as actors have become more aware of the choice of materials in construction. LCA is an interdisciplinary task and must start in the early design stages. The main challenges involve extensive use of resources in LCA work, lack of experience, lack of exact material data, and lack of standards in methods to extract data from building models and formats to present results. Regarding LCA development potential, actors demand automation efforts between BIM and LCA, supplemented by common standards for LCA-based tools for early design stages. The study contributes to research and development in LCA application, aiming to support actors in increased understanding and use of LCA, indicating the need for more effective tools for sustainable buildings assessment.

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ENHANCING BUILDING ENERGY EFFICIENCY ESTIMATION BY INTEGRATING MICROCLIMATE CONDITIONS

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The building sector accounts for over a third of greenhouse gas emissions nationwide and 36% of energy consumption globally. Urban settlements alone are responsible for around 70% of carbon dioxide emissions. Building performance simulation tools (e.g., EnergyPlus) are frequently used to conduct energy calculations which use weather data (obtained from weather stations) as one of the boundary conditions. However, it is hypothesised that the energy calculations are more dependent on microclimatic conditions, leading to inaccuracy in energy estimations. Therefore, a new approach by integrating a microclimate tool (i.e., ENVI-MET) with a building performance simulation tool to enhance the accuracy of energy estimations is proposed in this study. A comparative analysis using computational tools was carried out for a real-scale typical UK residential settlement and it was observed that there is a distinctive difference (around 1°C) caused by the microclimate for both the summer as well as the winter period.

Keywords: building energy; CFD simulation; ENVI-MET; microclimate modelling

INTRODUCTION

With over 50% of the world's population, urban settlements consume between 60 and 80% of total energy consumption. It is responsible for up to 70% of carbon dioxide emissions (Un-habitat, 2016), becoming a significant contributor to climate deterioration. Climate change is causing an enormous risk to the environment and, subsequently, to the health of the population (Guțu *et al.,* 2021). Moreover, rapid urban development has caused a significant increase in urban air temperature (3-5 °C) as compared to adjacent rural areas, resulting in the urban heat island effect, which further contributes to the upsurge in energy consumption (Arshad *et al.,* 2021). All these factors further lead to an increase in human discomfort. To improve the thermal comfort level in a built environment while simultaneously reducing its share of carbon dioxide emissions, it is critical to first design the buildings efficiently, followed by operating them competently once they are built. Currently, designers use various extensively validated building performance simulation (BPS) tools (some examples are- EnergyPlus, eQuest, DesignBuilder, ESP-r, Indoor Climate and Energy, IES Virtual Environment, and TRANSYS) for the prediction of built environment behaviour in terms of energy consumption, emissions, and comfort level of occupants (Loonen *et al.,* 2017). These BPS tools also assist in accelerating and improving the

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design and planning process, optimising building performance, developing building controls, testing new products, and evaluating the market potential of novel concepts, along with enhancing operational performance (Magni *et al.,* 2021).

These computer-based BPS tools are frequently used to access energy-related credit points for various building rating systems, such as the United Kingdom's (UK) founded Building Research Establishment-Environmental Assessment Method (BREEAM) or the United States' (US) founded Leadership in Energy and Environmental Design (LEED) (Schwartz and Raslan, 2013). However, BPS tools require an enormous amount of data to predict the built environment's future behaviour. Occupancy load, occupancy schedule, lighting design, heating, ventilation, and air conditioning (HVAC) design, and lighting schedule are all essential data for BPS tools.

Weather data is also keyed in as one of the boundary conditions in any kind of dynamic simulation that is conducted to predict the energy consumption of a building. The EnergyPlus Weather (EPW) data format is the most used dataset for conducting building simulations (Shashwat *et al.,* 2022). Crawley *et al.,* (1999) first proposed the EPW data format for use in two major BPS tools, EnergyPlus and EPS-r. The EPW format has now become a standard format and is currently being used in over 20 BPS tools (Crawley *et al.,* 2015). Weather datasets are text based, comma-separated data files that contain hourly values for the parameters needed to run the energy simulations, such as dry bulb temperature, dew point temperature, relative humidity (RH), atmospheric pressure, wind direction and speed, global and diffuse horizontal radiation, direct normal radiation, total sky cover, and so on.

Weather stations, such as those in the WMO (World Meteorology Organisation) weather station network, provide the data for creating these standard climate files (Shi *et al.,* 2019). However, it is critical to recognise that buildings operate in distinct microclimate conditions that could differ noticeably from the specified typical weather dataset. Computational fluid dynamics (CFD) simulation is frequently used for analysing microclimate conditions. Therefore, this research aims at developing a new methodology that can enhance the accuracy of building energy estimation by integrating microclimate simulation using CFD tool (ENVI-MET) with building level simulation.

LITERATURE REVIEW

BPS tools can provide an accurate prediction of energy consumption along with maintaining an adequate comfort level for the occupants. Therefore, BPS tools are frequently used by designers and engineers to aid in the decision-making process during the development of building designs. However, it is often seen that the predicted energy performance of a building using BPS tools does not match the actual energy usage of the building, resulting in a performance gap (Hong *et al.,* 2018). According to Shi *et al.,* (2019) the major reasons for the performance gap are oversight of microclimate, occupant behaviour misjudgement, and discrepancies in construction from building design.

The microclimate has distinct environmental factors such as solar radiation, wind speed and direction, ambient air temperature, and many others which may vary drastically, even within a city. The distinct microclimatic conditions around the building are not included in the standard datasets (such as EPW files) as the building site may be located far away from the weather station data, which is commonly used for creating these standard datasets. There are studies which have considered the coupling method for building level and urban level modelling, highlighting the interdependency of building parameters and microclimate parameters (Yi and Peng, 2014, Bueno *et al.,* 2011). Bozonnet *et al.,* (2007) have computed that a difference of over 30% is observed in building energy consumption when outer conditions are considered for the calculation.

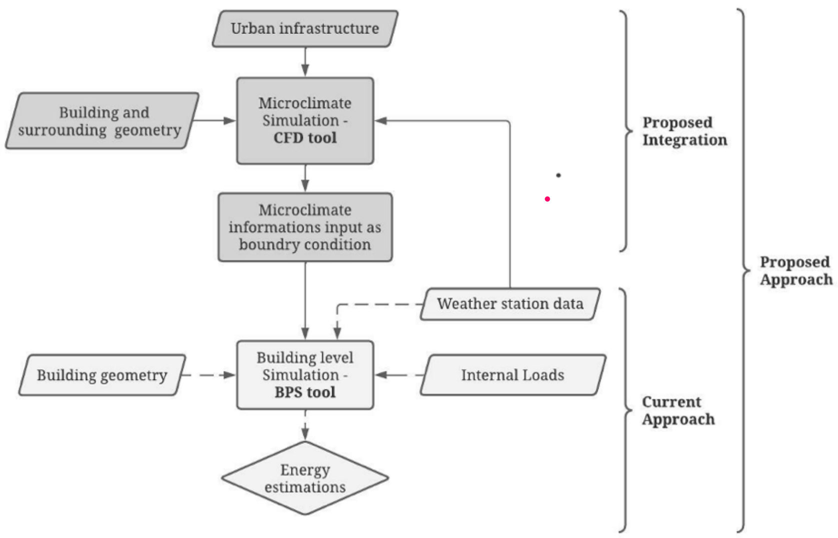
Also, one of the studies has concluded that including urban parameters to perform the coupling method of evaluation with energy modelling will have an advantage in improving the precision of building energy consumption data (Bouyer *et al.,* 2011). Therefore, it is important to investigate the impact of comprehending microclimatic conditions in building energy simulations for improved accuracy as related studies are lacking for the UK's climatic conditions. Existing BPS tools typically do not include the local microclimate while performing building level simulations due to the unavailability of local microclimate data. It is hypothesised that the integration of CFD (which estimates the microclimatic conditions) along with the existing BPS tools would enhance the accuracy of energy estimations.

METHOD

Proposed Approach

As compared to the current approach (Zingre *et al.,* 2015) of energy estimation, the proposed approach of this study consists of two distinctive successive stages (as can be observed in Figure 1). The first stage is to generate the local microclimatic data, which is then used as an input for the building level simulation. Observational methods have long been used for analysing local microclimates. However, with the significant advancement in computation capability in the recent past, digital tools such as CFD are now capable of performing microclimatic simulations (Blocken, 2015).

Figure 1: Proposed approach for enhancing the accuracy of building level energy estimations



The generated urban microclimate dataset (dry bulb temperature, in this study) can then be used (in place of the weather station dataset) in successive stages for conducting building level simulations using the BPS tool. Typically, a three-dimensional building model is developed in the EnergyPlus tool (or imported from a third-party visualisation tool) and weather data is inserted as one of the boundary conditions to conduct the building level simulation. A typical building level simulation needs various additional inputs for conducting the simulation. The first and foremost is the creation of the building geometry with all relevant physical parameters such as walls, roofs, and windows, along with their material specifications. Internal loads, which include occupancy load, lighting load, HVAC load, and their respective operational schedules, must be input into the model. The model is keyed in with the available weather data file which is nearest to the location of the building, and simulation is conducted. In the proposed approach, first a three-dimensional microclimate model is developed, focusing on the building of interest along with the other nearby building blocks.

The model is then populated with various available urban features, such as roads, pathways, and greenery. The model is keyed in with the weather data file and other necessary inputs. The microclimatic level simulation is conducted to generate local microclimatic conditions. This generated microclimatic data should be keyed in as a boundary condition in the EnergyPlus three-dimensional model where only the concerned building geometry is made. Multiple simulations are conducted to analyse the impact of local conditions on microclimate based on the weather data. The 3-D ENVI-MET model is shown in Figure 2, which consists of the residential buildings along with local infrastructure.

Development of ENVI-MET Model of a residential settlement
The proposed approach of this study (i.e., to integrate CFD simulations with building level simulations) was implemented on a real-scale residential settlement (as shown in Figure 2a) by developing an ENVI-MET model. This selected settlement (0.04 km2) represents homogeneous residential architecture across the UK. The settlement is arranged in six rows, with a few units aligned perpendicularly. The typical two-story residential houses are connected by asphalt roads and pavements.

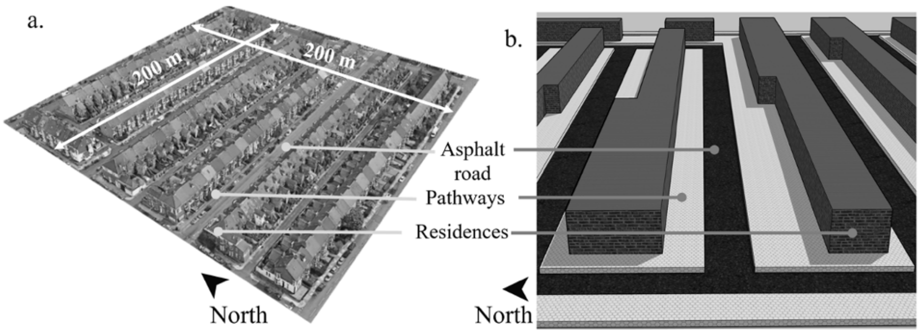


Figure 2: 3-D view of: a) a selected residential settlement in London; and b) birds eve view of the CFD-based model for the residential settlement

The model was further simplified and drawn with flat roof surfaces (as compared to existing sloped roof surfaces) since it will have a minimal impact on the pedestrian air temperature. Table 1 gives a detailed description of the input parameters for the model. The developed model was further simplified by removing the greenery, as this site has limited vegetation. Also, the windows were not modelled, as the small sizes of windows in residential buildings may not have a significant effect as compared to the considerable increase in computational time. The standard distance between the two opposite residential rows was modelled as 20m, and 8m of it was drawn as an asphalt road. The analysis was conducted on the central grid of the model, which lies between the two rows of residences 0.2m above the asphalt road. A sizable area was selected so that results are not influenced by other model elements. The model site was divided into 50 grids in both the X and Y directions, with two metre grids modelled along the Z-axis.

Table 1: Input parameters to ENVI-MET simulations

Parameters	Input Data and Boundary Condition
Site dimension	200 m x 200m
Model dimension	50 m in X-Y direction and 15m in Z-direction
Atmospheric boundary conditions	Meteorological data for wind speed & direction, air temperature, relative humidity, and solar radiation & cloud
Size of grid cell	4 m in X-Y direction and 2 m in Z-direction
Simulation Time-Step	1 Hour
Simulation Period	2 days - representative summer/winter days

Input parameters for ENVI-MET simulations

As shown in Figure 1, the ENVI-MET model requires several inputs such as weather data (shown in Figure 3), thermophysical properties of wall layers (Table 2), and surface radiation properties of model elements (Table 3).

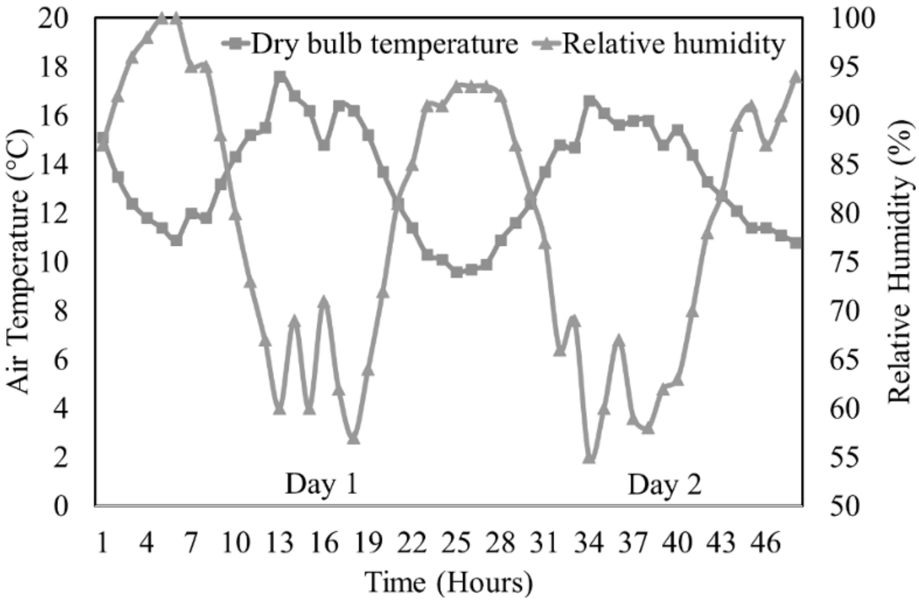


Figure 3: Dry bulb temperature and relative humidity for London, obtained from a typical meteorological year (EnergyPlus, 2022).

Weather data has a significant impact on energy estimates, which are primarily based on current or typical meteorological year weather conditions (Kikumoto *et al.,* 2015). Figs 3 and 4 illustrate the weather conditions for the days that were selected for simulation. Two consecutive days were selected for analysis so that the result reflects the validated trend, and any anomaly (in the case of single day selection) does not drastically influence the results.

The weather data (used in building level simulations) is commonly obtained from the nearest weather station, which is taken at approximately 15 m above ground surface level. The UK has a temperate climate with a mild-to-warm summer period and a cool winter period along with distributed high relative humidity (Ahmadian *et al.,* 2021).

Table 2: Thermophysical properties of wall layers

Layers (inside to outside)	Thermal conductivity (W/mK)	Density (kg/m3)	Specific heat capacity (J/ (kg K)	Reference(s)
Concrete	1.60	2400	850	Shafigh *et al.,* 2018
Polyurethane board	0.03	30	837	Asan *et al.,* 1998
Plaster	0.50	1300	1000	Asan *et al.,* 1998

Table 3: Surface radiation properties of various model elements

Elements	Solar Reflectance	Thermal Emittance	Reference(s)
Road	0.2	0.9	
Pavement	0.5	0.9	Santamouris, 2013
Wall / Roof	0.9	0.9	

The weather data used in this study is for London. The weather data set (refer Figure 3) shows that the daytime dry bulb temperature was relatively warmer with a high relative humidity, especially during the night-time. The solar radiation is also showing a regular pattern (shown in Figure 4) with a slight variation on the second day. Along with these, wind direction and speed were also forced into the simulation model.

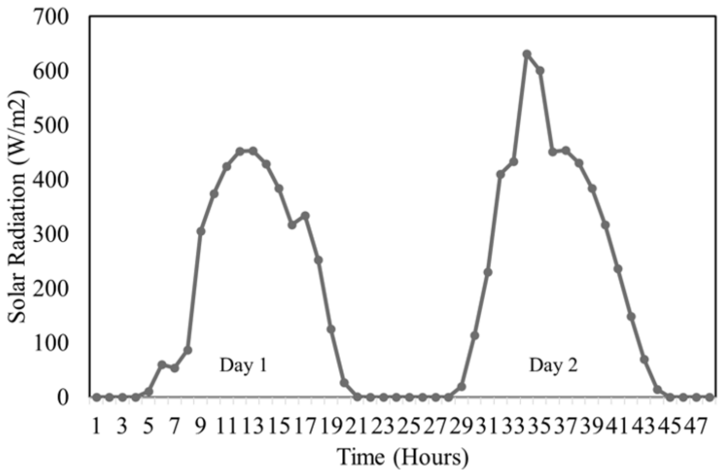


Figure 4: Solar radiation profile for London obtained from typical meteorological year (EnergyPlus, 2022).

FINDINGS

The developed ENVI-Met model (shown in Figure 2) was used to analyse the impact of the UK's local seasonal conditions on the microclimate of the selected buildings. The holistic impact was investigated over a typical 48 hours for the summer and winter periods, as well as the same was conducted for different weather conditions.

Comparison of proposed approach Vs current approach during the summer period

Figure 5 shows the comparison of the air temperature profile for two different approaches. It can be observed that there is a distinctive difference between the microclimatic data when compared to the weather data for the London summer period. For the duration of simulated days, a maximum difference of 2.30 °C is observed.

The effect is observed to be more prominent during the daytime as compared to the night. This could be potentially due to the lower outdoor temperature during the night, as can be observed from Figure 5. The overall average temperature difference (i.e., ΔT) between the simulated microclimate data and the weather data is 0.96 °C. The ΔT of 0.96 °C may appear insignificant, but a study has shown that a 1 °C temperature increase results in an 8% increase in cooling demand (Ortiz *et al.,* 2018).

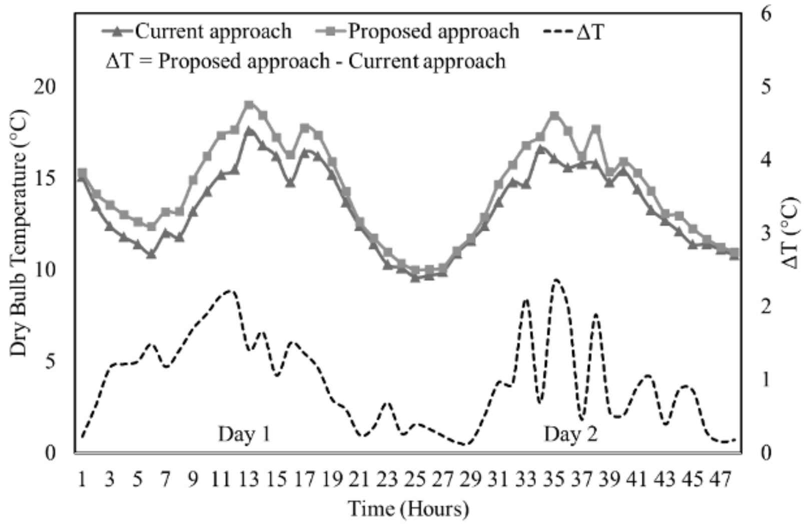


Figure 5: Comparison of estimated air temperature against Weather data for two representative summer days.

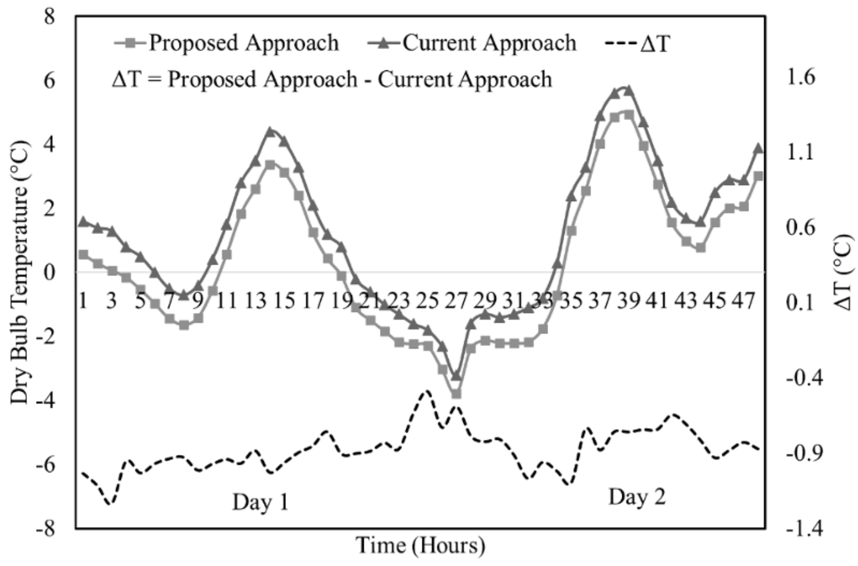


Figure 6: Comparison of estimated air temperature against Weather data for two representative winter days

The microclimate data results for the winter period (shown in Figure 6) also show a distinctive difference compared to the weather data. The absolute average difference for the winter period simulation is 0.88 °C. The maximum difference in air temperature is 1.23 °C. However, unlike the summer period where the weather data (current approach) was lower than the microclimate data (proposed approach), in the winter period the weather data shows a higher value than the microclimate data. The difference in air temperature between the two approaches is higher during the summer period as compared to the winter period. It can be interpreted that the higher the dry bulb temperature, the greater the difference. These results were further verified by conducting another set of simulations by comparing the impact of local conditions between two different weather data sets. A hot climate in Abu Dhabi (Alawadi *et al.,* 2021) was selected for the comparison of the proposed approach with London.

Comparison of proposed approach Vs current approach in different climate conditions

Weather data for Abu Dhabi (EnergyPlus, 2022) was used in the same residential model and a CFD simulation was conducted. The temperature difference between the two approaches for Abu Dhabi is plotted along with that of London's, which is illustrated in Figure 7. As expected, the higher the recorded dry bulb temperature in the weather data, the higher the difference between the two approaches. The average ΔT for Abu Dhabi is 1.17 °C which is higher than the average ΔT for London, which was 0.96 °C. Furthermore, the maximum T for Abu Dhabi is 3.60 °C, which is significantly higher than the 2.30 °C recorded for London. These results show a noticeable difference in the two approaches, and many conclusions can be drawn.

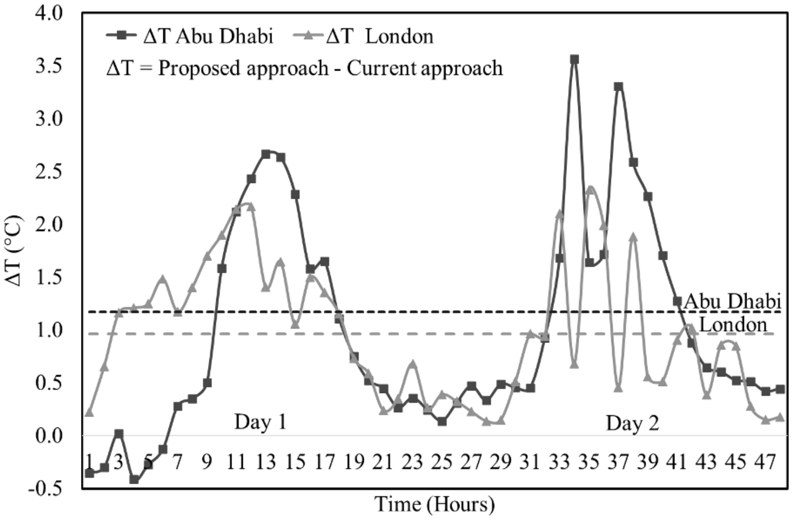


Figure 7: Comparison of ΔT for two different climate conditions - London Vs Abu Dhabi.

CONCLUSION

The proposed approach integrates CFD simulations (using ENVI-MET) with building-level energy performance tools in order to enhance the accuracy of energy estimations. The proposed approach was implemented by developing an ENVI-MET model of a real-scale (0.04 km2) residential settlement in London. The ENVI-MET model was divided into 50 grids in both X-Y directions, whereas the results were obtained at a grid height of 0.2m along the Z-direction. It was observed that there is a distinctive difference between the current approach (weather station data), which is commonly used for energy simulation, and the proposed approach (microclimate data). The difference is visible in both seasons, that is, summer as well as winter climate conditions. In summer, an average temperature difference between the proposed and current approach (i.e., ΔT) of 0.96 °C is observed, whereas in winter, an absolute ΔT of 0.88 °C is observed. For the given model, the variation of weather data and microclimate data is nearly 1°C. Furthermore, simulations were performed for the climate of Abu Dhabi and compared with those of London. It can be concluded from the results that there is a noticeable difference in both the simulated weather conditions performed in this study. In the climate of Abu Dhabi, the ΔT (i.e., 1.17 °C) is higher compared to the temperate climate of London.

Therefore, it is important in the building sector that the impact of microclimate is considered during energy estimations because, based on these estimations (energy modelling output), the building design, selection of construction materials, and selection of active systems (chiller capacity and fan size) and passive systems (U-value of wall/roof) are conducted. The improved energy usage prediction will give engineers and architects the liberty to make an informed decision during the design or retrofitting phase. Exclusion of microclimate consideration may also impact building construction budgets, comfort levels, whole life analysis, and eventually operation and maintenance. The improved accuracy in energy estimation will eventually lead to improved management and easier maintenance of buildings, eventually leading to a reduction in operational costs.

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SUSTAINABLE FACILITIES MANAGEMENT OF HOUSING PROPERTIES IN SWEDEN: CURRENT CHALLENGES AND FUTURE SOLUTIONS

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Despite the potential to contribute to sustainable development, facilities management (FM) work is complex and lacks clear direction, practices, and solutions in relation to sustainability. In response, current and future challenges within FM of housing in Sweden is investigated to understand what possible solutions and practices will be important moving forward. Building on FM research, the findings show how social sustainability is an important focus area. Issues such as unemployment and criminal activity are especially difficult to handle as this requires collaboration with other actors like law enforcement and social services. Increasing the use of digitalisation and AI in different properties is seen as useful solutions to increase sustainability, but it is difficult to know what efforts to prioritize and how much value it contributes. The findings contribute insight into the ongoing development of sustainable FM practices, and identifies possible solutions that may facilitate the transition towards more sustainable FM. Such insights are important not only for building wiser, but also for maintaining what we have already built in a wise way.

Keywords: digitalisation; social sustainability; facilities management; Sweden

INTRODUCTION

The construction and real estate sector have faced many grand challenges in the last few years, such as climate change, quickly diminishing natural resources, social unrest, and the COVID-19 pandemic (Thomson *et al. (*2021). The sector must find ways address these challenges and develop their practices to work more sustainably and to build more sustainable products. For this transition of developing practices and products to become more sustainable, the sector must find ways to think forward, and adopt a long-term perspective of its operations (ibid). The transition towards a more sustainable built environment is urgent for many reasons. For example, buildings account for approx. 40% of energy consumption and 30% of greenhouse gas emissions (Nielsen *et al.,* 2016), where most of those negative climate effects comes from the operations phase. Because the operations phase of a building is the lengthiest and most sustainably detrimental phase of construction, the transition towards more sustainable practices and products must happen also in the facilities management (FM) of the existing building stock, and not just in new production projects (Wood, 2006).

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This means that (FM) practices can contribute greatly to sustainable development both on the organisational level and society level (Nielsen *et al.,* 2016; Opoku and Lee, 2022). Practices within FM that needs to transition to become more sustainable concerns how to meet shifting customer demands for their living environment, managing and improving the housing stock in terms of waste management, energy consumption, and indoor climate, minor repair work, smaller refurbishment of individual dwellings, major renovation work of entire housing complexes, and supplementing the existing building stock with new production. The construction sector thus has an important role to play in working together with property owners to develop FM practices and improve the existing building stock in terms of making refurbishments and implementation of new, sustainable materials and technologies (c.f. Thomson *et al.,* 2021).

So, not only do we have to build wise in order address the aforementioned challenges and transition towards working more sustainably and building more sustainable products, but we must also be able to maintain and manage what we have already built in a wiser way. To understand how we can maintain and improve existing building stocks to contribute to sustainable development in the built environment, the purpose of this paper is to investigate how housing property owners in Sweden see current and future challenges within FM, and possible solutions to these challenges, in relation to sustainability, digitalisation, and other service and technical innovations. To fulfil this purpose, the following research questions are answered: What are the current and future challenges housing property owners see in their FM operations in relation to sustainability? and What does housing property owners see as possible service and technical innovations to help mitigate these challenges and increase sustainability within their FM operations?

FM research is scattered and weakly connected (Nielsen *et al.,* 2016), so this paper, which looks at challenges solutions, sustainability and digitalisation makes several contributions: (1) Gluch and Svensson (2018), who studied FM work of public clients in Sweden, argue that research must explore how to renew and add to existing building stocks while meeting new sustainability demands, and understand what new managerial and technical skills are required for this. This paper contributes such insight. (2) Focusing specifically on sustainability and innovative technologies and services is especially pertinent, as Bröchner *et al. (*2019) argue that digitalisation and sustainability are two major forces that influence FM development, already in the 1970's and even more so today. Because technology and business processes are constantly developing, FM activities also transform. These two forces, sustainability, and digitalisation should be considered in unison. (3) Overall, there needs to be a more holistic perspective on sustainability in FM where all pillars of sustainability are addressed simultaneously (Bröchner *et al.,* 2019), as previous research on FM has been quite limited and mostly addressed only the environmental pillar of sustainability (Nielsen *et al.,* 2016). (4) Future FM research must address real challenges of FM in practice, and address how professionals deal with those challenges (c.f. Bröchner *et al.,* 2019). (5) For contractors and other suppliers, studying how FM practices can become more sustainable provides insight into future client needs to accommodate new demands and address new grand challenges (c.f. Thomson *et al.,* 2021).

Facilities management (FM) is central to an organisation's core business practices and can be defined as a management function that focuses on the use, operations, development, maintenance, and improvement of physical assets (e.g., buildings), and integrates people, places and processes within the built environment (Nielsen *et al.,* 2016). This means that FM encompasses the technical aspects of managing building stocks, the lives of the users, and managerial practices connected to maintaining building stocks (Nielsen *et al.,* 2016). Due to increasing legislation and awareness of sustainability issues, FM have become more and more focused on transitioning towards more sustainable operations. FM practices have a great opportunity to contribute to sustainable development due to the built environment's large impact on the environment (Elmualim *et al.,* 2010), which has given rise to sustainable facilities management (SFM). SFM is a growing field within the wider field of FM research (Nielsen *et al.,* 2016), and combines FM with sustainability through the development of innovative technologies and business practices that considers the environmental, economic, and social benefits of FM operations (Opoku and Lee, 2022).

SFM practices must be holistic and address economic, environmental, and social sustainability simultaneously, and not just focus on specific environmental or technical problems, which has previously been the case in the FM sector. SFM practices must also be adopted and developed together with other stakeholders in collaboration (Opoku and Lee, 2022). To be able to fulfil all the "new" sustainability demands, FM professionals must develop new competencies and personal capabilities on how to manage new technology and programs for how to e.g., recycle smarter or reduce energy use (Elmualim *et al.,* 2012; Sarpin and Yang, 2012). Also, for FM to become more sustainable in practice, strategic sustainability targets must be translated into operational measures. The SFM perspective must therefore be present in several hierarchical organisational levels simultaneously so that operational measures driving SFM can be materialized in practice (Elmualim *et al.,* 2010).

There must be clear drivers to engage in SFM work as SFM work requires resources in terms of new practices and skills. Elmualim *et al. (*2012) and Zakaria *et al. (*2018) found that legislation, rather than corporate image, drives the commitment to sustainability. Commitment of senior management, internal sustainability policies, company ethos, and training of and available practical tools for FM personnel are other important drivers for engaging in SFM.

There are also barriers for engaging in SFM. For example, Elmualim *et al. (*2010; 2012) found several hindrances towards committing to SFM, such as: aligning legislative demands with existing business objectives, a lack of senior management involvement in and priority of sustainability issues, time constraints, financial constraints, FM not being sees as a strategic issue, lack of knowledge, and an overemphasis on financial targets rather than innovation. Also, Wood (2006) state that existing building stocks suffers from the fact that they were built according to old standards that are continually updated to meet steeper sustainability demands. However, there may not be enough incentives to update older building stocks to comply with newer standards, as this may have low economic return and where demolishing a building may be more cost effective, but less sustainable.

METHOD

To investigate how housing property owners in Sweden see current and future challenges within FM, and possible solutions to these challenges, a qualitative research design was used in order to capture the actions and perceptions (Silverman 2013) of people working with SFM. The focus in this paper is SFM of housing properties, which plays an especially important role in sustainable development due to its large resource consumption in terms of energy use, square footage within the built environment, and part in promoting sustainable lifestyles (Nielsen *et al.,* 2009). The housing companies that were included in the study was chosen to get a wide view of FM in Sweden. Therefore, the sampled organisations were both private and public, located in different parts of Sweden, owned different types of properties (high-income housing, low-income housing, student housing), owned building stocks of different age, and owned properties in neighbourhoods of different socio-economic status.

Interviewees who work with facilities management on a strategic level, and who set the agenda for FM work within their organisations, were purposefully sampled (Etikan *et al.,* 2016). Theywere chosen due to their influential positions within their organisations and overview of both operational and strategic SFM issues. This enabled getting their personal views on SFM as well as capturing the more formal work of their organisations. The interviewees worked mainly as CEOs, sustainability managers, FM managers, business managers, etc. To achieve interview flexibility, semi-structured interviews (Kvale 2007) with 11 people were held during the winter and spring of 2021-2022 (see Table 1). The interviews lasted approx. 1 hour and were digitally conducted via Zoom or Teams. The interviews covered three main topics, based on an initial literature review of SFM research and topics circulating in the FM professional field in Sweden. These three topics related to challenges and innovations connected to SFM: 1) Current state of SFM work, 2) Organisation of SFM activities, and 3) External monitoring, where the first topic is mainly in focus.

Table 1: Information on interviewees

Organization	Company profile	Professional roles	Interviewee codes
Public housing company A	Low-income housing	Business development manager, CEO, FM manager	PubA 1-3
Public housing company B	Mixed income housing	FM manager	PubB 1
Public housing company C	Mixed income housing	R&D manager	PubC 1
Private housing company A	High-income housing Student housing	CEO, FM manager, Technical FM specialist	PriA 1-3
Private housing company B	Mixed income housing	Development manager, Sustainability manager, Sustainability specialist	PriB 1-3

Observational data from two FM industry conferences were also collected. These one-day conference took place during the winter and spring of 2021-2022, and had several speakers from industry, non-profit organisations, public organisations like social services and law enforcement, and contractors and other suppliers. Detailed notes were taken throughout the day and complied as an additional data set.

The interviews and observational notes were transcribed verbatim and imported into the software program NVivo which allowed a systematic sorting and coding of the data. Using a thematic analysis (Braun and Clark 2006), the data were first coded according to the three interview topics, where the first topic (Current state of SFM work) was chosen as the focus in this paper. Then, the data within the first topic were recoded into smaller themes as more detailed patterns in the data were identified. After several coding rounds, where codes were abductively produced by iteratively going back and forth between previous research on SFM and the empirical material (van Maanen *et al.,* 2007), two themes were identified: Challenges to transition towards SFM, and Service and technological innovations to transition towards SFM.

FINDINGS

The interviewees explain how FM begins in the planning and construction phase. They emphasize the importance of building wisely so that houses can be maintained equally wise: “We build housing, and then we manage them, and then refurbish them, so we’re there for the whole life cycle. If you don’t build so there is low environmental impact also in the FM stage, then things won’t be very good twenty years later” (PriB 2). At the same time, FM is a never-ending type of work: “With FM you are never really done” (PriA 2). So, not only does FM work require tremendous foresight, but also a balance of short-term and long-term perspectives. Coupled with the need of continuously keeping up the building stock is also keeping up with the onslaught of new service and technological innovations that can increase SFM: “You should never be content with what you have, that is important. You see that in the houses we have from 2011, they’re not old, but they’re outdated” (PriA 3). The interviewees say how difficult it is to enact change to implement new practices and technologies and ingraining a sustainable ethos throughout their organisation:

> “I believe the largest challenge is to implement new working practices and services from north to south. It’s easy to sit up high and say that ‘this is how we're going to be more efficient’, but then you’re also in a situation where you need to fight fires on the local level. We need more competencies in change management” (PriB 1)

The foremost sustainability topic the interviewees talk about is social sustainability. It is clear that social sustainability is by far the most pressing, or at least complex, issue the interviewees work with. This complexity stems from several reasons. 1) There is a lack of housing in general, and more so for housing that caters to low-income or special need tenants. It is difficult to find a good level of refurbishments that do not force low-income tenants to move due to increased rent prices. 2) It is complex to manage the supply chain and different contractors to ensure fair working conditions. 3) Social sustainability is multi-faceted, vague, and difficult to measure. 4) Uncertainty for how to mitigate negative trends such as low graduation rates, unemployment, diminished feelings of safety, and criminality. One interviewee summarized this work as:

> “Social sustainability is very broad. Besides doing good social work within the company, you must also do good social work in your business affairs and good social work in relation to wider society” (PubA 1).

The very last point, regarding safety and criminality, was something that the interviewees spoke at length about. Despite property owners having no formal responsibility to fight crime, the interviewees emphasize how this is some of their most important work. Partly because diminished safety and increased criminality negatively impacts property values, but also because they have a moral responsibility to do so, for the sake of their tenants. Recruitment to criminal networks, unlawful renting, money laundering and tenant registration offenses are some of the specific issues being raised. However how to practically go about fighting these issues are unclear. The interviewees say that it requires extensive collaboration with other actors such as law enforcement, social services, and local non-profits, but that there are few formal practices in place to facilitate this collaboration: “I wish that there would be a coordinating unit, or person, in every city that you could email or call. Both to get information but mainly to give information [about ongoing criminal activity]. I feel very frustrated that I don’t have anywhere to provide information” (PriA 1).

Although social sustainability is on the top of the sustainability agenda for FM professionals, environmental sustainability is still a pressing issue:

> “The company’s environmental impact is largest when we build new housing, but at the same time only 1% of our housing stock is new production each year. So, the largest part is in the existing building stock where we see that there is lots to be done” (PriB 2)

Much of the issues circles on refurbishing buildings to handle new climate conditions, how to install new energy efficient technologies, how to work more with circular economy and recycled building materials, how to refurbish dilatated building stocks resource efficiently, or how to meet new customer demands from tenants having new preferences because of Covid-19, in terms of space, functionality, and sustainability of their housing. The question is how to find sustainable and profitable business models to enable these new practices:

> "How do you find the business model for change when you have an existing building stock?" (PubC 1).

Large technical solutions like BIM (building information modelling), digital twins or AI-run buildings are often spoken of in the Swedish real estate sector. Interviewees say that there is much potential in using digital solutions, especially to monitor and optimize indoor climate to maximize comfort but minimize energy use. However, although such digital solutions are possible useful tools to increase sustainability within the building stock, the interviewees spend more time talking about less conspicuous technical solutions, like digital name plates and locks on doors, apps that enable tenants to communicate with each other and the property owner, robotic lawn mowers, and sensors that monitor snowfall or the state of recycling rooms. Overall, the interviewees say that the sector is inert and slow to adopt new technologies. One future development that many interviewees wished to see was to adapt technologies and services from other industries to make FM and contact with tenants more efficient. For example, using online tracking services like delivery companies, using online communication like in healthcare apps, or using online booking systems to schedule renovation work:

> "You don't have to come up with everything yourself, you can look at what other organisations are doing, and it doesn't even have to be in the same industry. If you buy clothes no one is going to call customer services to see where their package is, but today we don't have the same tools to communicate with our customers like other industries do. We have a lot to learn" (PriB 1).

COVID-19 is said to have greatly increased the interest for these types of solutions. Much like social sustainability is said to be a major challenge due to its breadth and complexity, the range of possible solutions to increase social sustainability is equally broad. One solution that is used by several organisations is to hire unemployed tenants to work with simpler FM tasks like cleaning stairwells and managing green areas, either in-house, through contracting social enterprises, or by requiring contractors who does refurbishment work to hire unemployed tenants. This is said to decrease unemployment, which is high in disadvantaged neighbourhoods, as well as getting a better-quality service:

> "We hire women who are unemployed and live in our neighbourhoods. It's good for our finances, better than when we bought that service, we have higher quality in our cleaning, and safety is perceived to be higher when our women are working in the neighbourhood" (PubA 1).

Also, in disadvantaged neighbourhoods there is often issues with overcrowding, making it difficult for youths to do homework and leisure activities indoors, which in turn can increase the risk of youths being recruited into criminal networks. Therefore, new activity spaces have been created, and collaboration with different non-profits and sports clubs have been set up to help children in their education or to offer leisure activities. Other services, like job searching workshops have also been created to help unemployed tenants get closer to the labour market. Something that characterizes these social initiatives are collaboration with other actors, especially in crime prevention activities. New technology can also be used in crime prevention, e.g., to deter youths from loitering in basements or stairwells, which creates a sense of insecurity for other tenants, property owners have adopted a technology used to deter rats. It is a box that emits painful soundwaves, making lingering in such environments uncomfortable. Another solution to connect property owners with other organisations for crime prevention was suggested by a speaker at an industry conference: "We need speed dating or Tinder for property owners and municipal officers". In difference to solutions to increase social sustainability which are still emerging and somewhat undefined and unformalized, there are many concrete solutions to increase environmental sustainability, such as using new materials like ash from burnt rice peels in concrete, using more efficient heating systems, or using fossil free car fleets. The solution that seems to show most promise amongst the interviewees are practices related to circular economy and recycled materials, like reusing kitchens when refurbishing rather than installing completely new ones, using old batteries from electric buses to power buildings, or reusing old bricks from demolished buildings in new production:

> "I hope there will be better business models for resource efficiency, in terms of recycling. There is some reuse of bricks, but that is more expensive and more difficult than buying new, it's too cheap to buy new materials" (PriB 2).

The proposed service and technical innovations have their own challenges embedded in them, and there is scepticism about how environmentally sustainable technical solutions are, how financially sound such investments are, and how digital solutions can be embedded in older, analogue building stocks. There is a fear in investing in different solutions or services before they are tried and true and properly tested: "With digitalisation there are many choices to be made. You don't want to jump on too early, but not jump on too late. And most importantly not jump on the wrong thing. It's such large investments that must last over time" (PriA 1). The interviewees continuously emphasize how the transition towards SFM, and the adoption of new services and technologies must always be profitable, or at the very least not be detrimental to the financial bottom line. This is a main reason for why the interviewees are hesitant in implementing larger digital solutions like digital twins.

It is clear that FM professionals struggle with pursuing multiple sustainability goals, choosing between possible service and technical innovations, and that the work is complex with much uncertainty on how to balance financial and sustainable pressures and different time perspectives. Nevertheless, FM has large potential to contribute to sustainable development. Previous research has emphasized how FM has a large role to play in environmentally sustainable development as buildings are large contributors to negative environmental output (Nielsen *et al.,* 2016, Elmualim *et al.,* 2010). This study highlights how this is true also for socially sustainable development, e.g., hiring tenants had effects exponentially larger than just decreasing unemployment, it also increased service quality and perceived safety. So, in the case of social sustainability, the findings support Nielsen's *et al. (*2016) conclusion that FM goes beyond the maintenance of physical assets and encompasses the people who live and work in the physical assets. Such socially sustainable initiatives, although not directly linked to the physical assets of the buildings, thus have a large impact on FM practices. Besides implementing employment-generating initiatives, there are also other social practices such as mitigating criminal activity, creating summer sports activities, or creating hubs for homework support for children. Previous research concludes that

SFM practices must be adopted and developed in collaboration with other stakeholders (Opoku and Lee, 2022). This seems to be especially true for social initiatives where property owners lack the expertise to take on such issues on their own as it lies outside of the core business of owning properties. Collaboration is not inherently a problem, but it does require new ways of working, resources and commitment between actors who have different competencies, but also different goals and work practices. For example, having a coordinating unit between property owners, law enforcement and social services to exchange information for crime prevention would be a necessary, yet resource heavy, collaborative investment.

Previous research (Elmualim *et al.,* 2012; Zakaria *et al.,* 2018) highlights how SFM is driven by commitment of senior management and internal policies and tools. The interviewees from this study all have management or expert positions within their respective organisations, and all express a commitment to transitioning towards SFM. Also, there are, as shown by the breadth of different service and technical innovations mentioned by the interviewees, many possible tools available. However, available tools may cause new problems, in terms of providing too many solutions to choose from, without knowing which solutions are actually sustainable and contribute to the organisations' bottom line. In addition, the findings show how difficult it is to combine the financial bottom line with costly technological innovations, as well as difficult to create new business models that work for old buildings stocks. Wood (2006) made similar conclusions already 15 years ago and claimed that there are rarely incentives enough to spend money on updating old building stocks to newer standards, and that demolition may be cheaper than updating. The same sentiment is mirrored by this study where the interviewees express frustration that recycled materials are more expensive than new, and that there are few business models to support using recycled materials. So, it is not only legislation that may be difficult to align with business objectives, but the available business models, practices, and tools as well. In 2010 Elmualim *et al.,* found that there is often an overemphasis on financial goals rather than innovation, and the same seems to be true 10 years later.

Previous research found that FM professionals must develop new competencies and personal capabilities for how to manage new technology (Elmualim *et al.,* 2012; Sarpin and Yang, 2012). However, it may not be skills in managing new technology that is most important, but rather change management capabilities. Without skills for how to drive and manage organisation-wide change from top to bottom, local issues will likely overtake strategic development of SFM work in the organisation. Change capabilities are also vital to be able to translate strategic sustainability targets into operational measures and materialized practices on all hierarchical levels in the organisation, which is necessary to engage in SFM (Elmualim *et al.,* 2010). Thus, if there are not change capabilities embedded in the organisation, adopting and implementing new practices and technologies will be very difficult in the first place.

An interesting finding from the study that stands in contrast with previous research in FM is the focus on social challenges and solutions. Where previous FM research has tended to focus on environmental sustainability (Nielsen *et al.,* 2016; Opoku and Lee, 2022), the findings rather point to how social challenges and solutions are moving to the top of the FM agenda. Moving forward, it will be interesting to see how property owners will prioritize between spending time and resources on investing in more socially sustainable or more environmentally sustainable practices and technologies. These are not mutually exclusive but requires different types of investments: environmental technologies may be costly, while social investments are difficult because they are vaguer and more difficult to measure. Nevertheless, this wider view on SFM that focuses on both social and environmental sustainability is hopeful, as the FM sector have usually tended to focus on specific technical or environmental problems rather than looking at SFM holistically (Opoku and Lee, 2022).

Either way, the focus on the financial bottom line overshadows every conversation of environmental and social sustainability. It is clear that sustainability cannot be something one engages in to be nice; it must also be economically advantageous. This mainly manifests in terms of not wanting to invest in new solutions that may be costly, thereby creating inertia in the sector. Perhaps the main issue is not about doing things right like previous research has suggested (Elmualim *et al.,* 2010), but rather about doing the right things in the first place. There is a strong uncertainty amongst the interviewees on what the right path forward is, which leads to an aversion to being a first mover. This in turn means that it is unclear who will drive innovation and development of SFM in the sector. So, transitioning towards SFM may mean trade-offs between older, known challenges, and newer, unforeseen challenges embedded in new services and technologies. The question is, what trade-offs between solving old challenges and creating new challenges are more acceptable to bear?

CONCLUSIONS

This study sought to investigate how housing property owners in Sweden see current and future challenges within SFM, and possible solutions to these challenges. It is very complex to work with SFM, as this is a field which lacks clear direction, practices, and solutions to transition towards more sustainable operations. This is problematic, as FM work is never-ending where properties age and require continuous refurbishment and improvement. The findings highlighted how social issues are at the top of the agenda and must be balanced alongside environmental sustainability measures and financial constraints where an overemphasis on financial goals often overshadows the work with SFM. The findings showed how there are a multitude of possible service and technical solutions to enable SFM, but these solutions and their implementation have issues embedded in them as well. These findings contribute a more holistic insight into the ongoing development of SFM work amongst housing property owners, and identifies issues that needs to be mitigated to facilitate the transition towards more sustainable operations within FM (c.f. Nielsen *et al.,* 2016; Bröchner *et al.,* 2019). This includes issues such as how to prioritize between different environmental and social challenges and solutions, how the overemphasis on the financial bottom-line impacts SFM work, and how the challenges embedded in new technologies and services will be tackled. Practical problems of SFM have thus been identified, thereby meeting Bröchner's *et al. (*2019) call for research that focuses on real challenges of FM in practice. The findings also contribute insight to contractors and other suppliers in the construction sector by indicating what improvements property owners want to implement in their existing binding stock. Thereby contractors and other suppliers can foresee future client demands and develop their service and product offerings accordingly.

If the issues identified in this paper are not addressed, the transition towards SFM may be negatively impacted. This may cause property owners to be unprepared for coming regulatory changes, a changing business landscape, or new customer needs created by Covid-19, or new, unknown crises. If research can investigate these challenges and solutions more in depth, and most importantly, adopt a long-term perspective that goes beyond the construction phase, this could help outline not only how the sector can build back wiser, but also maintain what has already been built in a wise way, and thereby create long-term positive sustainable impact.

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EVALUATING HOW SOCIAL PSYCHOLOGICAL ASPECTS AFFECT THE CHOICES OF OCCUPANT BEHAVIOURS: A MODIFIED MOTIVATION, OPPORTUNUITY AND ABILITY APPROACH

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This study evaluates the impact of social psychological aspects on adaptive and nonadaptive occupant behaviours in offices. The evaluation is based on a survey synthesising previous research insights on social science theories, where subjective aspects were considered by adapting a modified motivation, opportunity, and ability framework. A questionnaire was distributed across the general office building population in New Zealand, and 247 valid answers were achieved. A Structural Equation Modelling (SEM) approach was used to evaluate the subjective effects on the choices of occupant behaviours. The results showed that the attitudes, personal norms, organisational support, behavioural interventions, and perceived knowledge (factor loadings >0.50) were significant indicators of adaptive behaviours and positively affected the choices of occupants' adaptive actions. Overall, the study outcomes enable the improvement of occupant energy saving behaviours by applying subjective aspects related to the office environment. Furthermore, this study provides insights for investigating occupants' social and psychological perspectives on energy saving in their workplaces amid the COVID-19 and post lockdown situations.

Keywords: ability; motivation; occupant behaviours; opportunity; social psychology

INTRODUCTION

Occupant behaviours (OB) are usually treated as static, deterministic schedules, or settings in building energy performance simulation, ignoring their diversified and dynamic nature (Hong *et al.,* 2018). Specifically, that kind of office design leaves occupants dissatisfied with the indoor environment and the fluctuations of thermal, visual, air quality, and aural conditions, leading to fewer opportunities to save energy (Wagner, O'Brien and Dong 2017). Additionally, the evolving flexible working practices because of the COVID-19 pandemic are expected to significantly affect the operation of offices (Mantesi, Chmutina and Goodier 2022). A significant opportunity is presented to reconsider the human-building interactions while promoting more energy efficient office buildings in the post-pandemic era (Mantesi *et al.,* 2022). It is vital to focus on reducing energy use and CO2 emissions to tackle

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climate change as buildings reopen with flexible working solutions and complex energy operations.

The influence of social psychological concerns is critical when understanding occupants' impact on building performance and energy (Day and O'Brien 2017). For example, D'Oca *et al.,* (2017) conducted an online survey across 14 universities and research centres in the United States, Europe, China, and Australia. The occupants' response to interacting with building control systems and intention to share controls were considered. The influential factors are motivational drivers, group behaviour, ease and knowledge, and satisfaction productivity. Most recently, the environmental, contextual, and personal factors were extracted from the relevant groups, and all other factors such as attitude: Behavioural beliefs, normative beliefs, subjective norms: Motivational drivers, and perceived behaviour control (PBC): Knowledge controls, ease to share, perceived comfort were categorised as subjective aspects (Bavaresco *et al.,* 2020). For example, the positive attitude of occupants motivates them to perform more energy saving behaviours (Li *et al.,* 2019). Evolving operations in future offices can achieve energy efficiency through technical and social dimensions (Mantesi *et al.,* 2022). These studies further suggest that the energy research practices based purely on objective factors of OB may not highlight valuable insights from subjective aspects of OB in buildings.

Researchers have recently given more attention to studying the impacts of social psychological factors that significantly improve occupant energy behaviour modelling for building performance simulation (BPS) (Ding *et al.,* 2018). Past studies adapted social science theories like the theory of planned behaviour (TPB) (Shi, Fan and Zhao 2017), social cognitive theory (SCT) (D'Oca *et al.,* 2017), and the motivation, opportunity and ability framework (Li *et al.,* 2019) to study the effect of social psychological aspects on energy saving behaviours. Structural Equation Modelling (SEM) analysis was considered appropriate to analyse these impacts (Li *et al.,* 2019; Shi *et al.,* 2017).

In New Zealand, it is yet to recognise how different social psychological factors influence the perceptions and behaviours of occupants in offices relating to their contribution to energy and climate impact. The organisations must understand occupants' attitudes, beliefs, personal norms, and knowledge to change their behaviours. Accordingly, the study aimed to identify the significant social psychological factors influencing occupants' energy behaviours by adapting a modified MOA framework. The paper contributes to better understanding OB in office buildings while considering subjective aspects derived from social science theories. Furthermore, the implications of this study can be used to rethink the human-building interactions to promote energy efficient offices in the post-pandemic era. The paper first explains the MOA framework adapted for the study to evaluate the impact of social psychology aspects on adaptive and nonadaptive OB in offices. The following sections of this paper present the research methods, results and discussions, and the conclusions, including research implications, limitations, and future research.

Application of modified MOA framework

Initially, Li *et al.,* (2019) developed an integrated MOA framework that includes the social psychological factors influencing occupants' energy saving behaviours in buildings. Accordingly, motivation (M) measures an occupant's concern over individual energy consumption and their behaviour involving saving energy.

Opportunity (O) measures the occupants' accessibility to the information related to energy conservation, environmental, and interpersonal factors influencing their energy saving intentions. Ability (A) is how occupants interpret the information on energy saving behaviour based on their past knowledge of energy use, impacts, and consequences.

In the integrated MOA framework, motivation includes measures like attitude, personal norms, the ascription of responsibility, and the awareness of consequences towards energy savings. Personal norm indicates occupants' self-obligation to commit energy saving behaviours (Schwartz 1977). Earlier studies have evident the direct impact of personal norms on occupants' environmental intention and behaviour (Kim and Seock 2019). However, the awareness of consequences and the ascription of responsibility that show the awareness and responsibility of individuals for taking energy saving behaviours are antecedent constructs contributing to personal norms (Zhang, Wang and Zhou 2013). Furthermore, Li *et al.,* (2019) explained the attribution of responsibility and personal norm load on the same factor based on the factor analysis.

The integrated MOA framework also includes subjective norm, descriptive norm, organisation support, accessibility to control, and time availability in the opportunity component. The subjective norm is the "perceived social pressure to engage or not engage in the behaviour" (Ajzen 1991: 188), while the descriptive norm captures the perceptions of others' behaviours (Forward 2009). However, integrating descriptive norms to identify the behaviours requires greater attention from individuals toward their co-workers in the office setting, especially in shared offices (Xu *et al.,* 2020).

Additionally, the commitment and encouragement of an organisation positively support its employees' pro-environmental behaviour (Xu *et al.,* 2017). Similarly, integrating behavioural interventions such as energy feedback and awareness messages promotes the occupants' energy saving behaviours (Mulville *et al.,* 2017). Accessibility to control assess the individual's degree of actual controllability over the building systems such as heating, cooling, lighting, and ventilation (Li *et al.,* 2019). For instance, when occupants have more control over the environment, they change their energy behaviours (McMakin, Malone and Lundgren 2002). Although time availability was considered in Li et al.'s framework, the subsequent factor analysis showed that the factor does not affect energy saving behaviours. The time required for those behaviours is possibly not much (Li *et al.,* 2019).

The ability component in the integrated MOA framework includes PBC, perceived knowledge, and the actual knowledge of the building occupants. According to Ajzen (2002), the PBC perceives the ease or difficulty of performing any behaviour. Moreover, perceived knowledge explains how occupants perceive their knowledge of energy saving, while actual knowledge has been used in existing studies to measure occupants' psychological abilities to perform behaviours (Li *et al.,* 2019). For example, occupants with higher perceived and actual knowledge of energy consumption and related savings are more likely to save energy than occupants without much knowledge (Abrahamse and Steg 2009).

Although the integrated framework provides researchers with a systematic approach to investigating the determinants of energy saving behaviours in the office environment, additional research is necessary to justify the performance of this framework on energy saving behaviours. Hence, the current study adapted a modified MOA framework in the context of New Zealand to verify the application of social psychological aspects to improve occupants' energy saving behaviours. The modified framework includes only the attitude and personal norms, while the aspects relating to individuals' awareness and responsibility can also be addressed under the personal norms. Furthermore, this framework includes all three ability indicators and subjective norms, organisation support, behavioural interventions, and accessibility to control under the opportunity component, as illustrated in Figure 1.

METHOD

Data collection

The participants for the study were selected from the general population of employees who occupied office spaces in New Zealand. The occupants who work full-time and part-time in any type of office (private room, shared, and open-plan offices) in New Zealand were selected for the study. The total workforce of New Zealand who employed full-time and part-time as managers, professionals, community and personal service workers, and clerical and administrative workers equals 1,869,481, according to 2018 Census data (Stats NZ 2022).

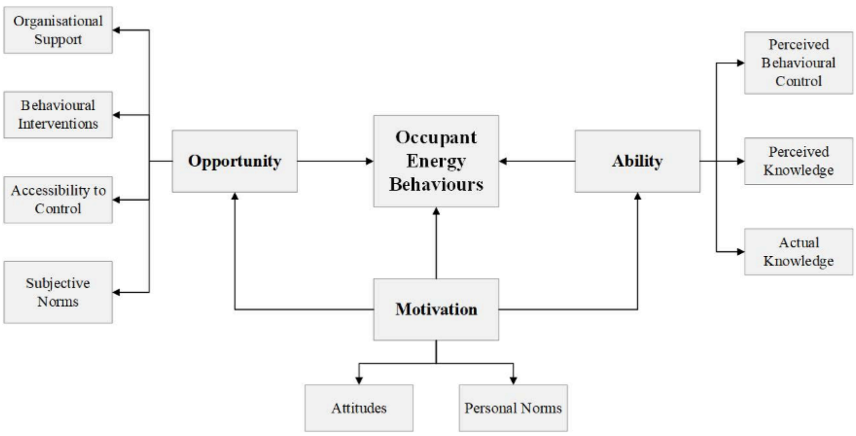


Figure 1: The Modified MOA framework (adapted from Li et al., 2019)

The study assumes a population proportion of 0.80 who regularly work in a designated office space. Specifically, this proportion was considered based on the New Zealanders' responses to remote working during COVID19 and post lockdown, where out of 2,560 respondents, only 22% suggested that they would like to work from home daily, and the majority (67%) prefer a mix of working remotely a few times a week or month (O'Kane, Walton and Ruwhiu 2020). Accordingly, the minimum sample size for the study equals 246 with 95% confidence and a margin of error of 5% (Saunders, Philip and Thornhill 2019). The survey was distributed in-person and online through the Qualtrics survey platform from July to November 2021. A total of 272 responses were received; however, only 247 proceeded for the data analysis after data removing the responses with missing data and screening out the responses with a standard deviation less than 0.25 value.

The selected sample included males (59.9%) and 85% of building occupants aged 30 or older. Most of the participants were New Zealand Europeans (50.6%), followed by Asians making up 19.4%. 88.7% of the participants indicated that they are employed full-time. Among the sample, 68.4% of the participants have been working for a year or more in the current workplace. Therefore, it can be assumed that most of the participants are familiar with the current workplace and their actions within the workplace.

Data analysis

Structural equation modelling (SEM) was used to analyse the collected data. IBM SPSS Amos 28 Network software was used to conduct an exploratory factor analysis and develop a measurement model. The SEM has been used in various contexts, especially in energy behaviour research, where many dependent variables exist (Bavaresco *et al.,* 2020; Li *et al.,* 2019). SEM is a statistical method that shows the relationships between manifest (observed variables) and latent variables and quantifies their impacts to test hypotheses developed based on the theoretical model (Schumacker and Lomax 2015). The latent variables are motivation, opportunity, and ability constructs and the observed variables are the defined social psychological factors presented in Table 1.

Table 1: Latent and observed variables (associated survey questions)

Latent variables		Observed variables/Indicators
Motivation	Attitude (At)	At1 - Saving energy at work is important to me
	Personal norms (PN)	PN1 - I feel responsible/obliged to save energy at work
Opportunity	Subjective norms (SN)	SN1 - My co-workers expect me to save energy at work
		SN2 - Most of my co-workers expect me to turn off electrical appliances
		SN3 - Sharing control over building systems with my co-workers is easy
	Organisation support (OS)	OS1 - My company encourages employees to save energy
		OS2 - My company rewards employees for saving energy
	Behavioural interventions (BI)	BI1 - The feedback on individual energy use by our building management team is important for me to change my energy-driven behaviour
		BI2 - Our building management team often sends energy use reports
	Accessibility to control (AC)	AC1 - I have personal control over most of the appliances (windows, doors, blinds, thermostat, lights, heaters, fans, computers) in my workspace
Ability	PBC	PBC1 - Saving energy during work is entirely within my control
		PBC2 - Actions I take to save energy depending on my comfort preferences
	Actual knowledge (AK)	AK1 - I am aware that reducing energy use at my workspace will reduce cost
		AK2 - I am aware that reducing energy use will reduce emissions
		AK3 - I am aware that reducing energy use in my workspace will improve my organization's image/reputation
	Perceived knowledge (PK)	PK1 - I often close windows, turn off the lights, heaters, fans, computers, etc., whenever I leave the office, and unplug appliances when not in use
		PK2 - If I feel slightly cold at the workplace, I would put on another layer of clothing instead of using the heater
		PK3 - If I feel slightly warm at the workplace, I would adjust my clothing level instead of using the air conditioner
OB	Nonadaptive behaviours (NAB)	NAB1 - I often report discomforts related to indoor environmental quality
		NAB2 - I am willing to accept and do nothing about the existing indoor environmental conditions in my workspace
	Adaptive behaviours (AB)	AB1 - I often adjust building appliances to satisfy my comfort preferences
		AB2 - I often adjust myself to the environmental conditions at my workspace by adjusting clothing, drinking hot/cold beverages, and moving through spaces

The survey questions included in Table 1 were adapted from previous literature. The questions relating to attitude, subjective norms, and PBC were adapted from Abrahamse and Steg (2009), personal norms from Zhang *et al.,* (2013), perceived and actual knowledge, organisation support, behavioural interventions, and accessibility to control were adapted from Li *et al.,* (2019), while OB related questions were adapted from (Hong *et al.,* 2018).

In the current study, the dependent variable was OB, and the social psychology factors were the independent variables. In SME analysis, latent variables or constructs are assessed through the impact of observed variables or indicators. Latent variables can be endogenous (denoted Y) and exogenous (denoted X). The occupant behaviour was an endogenous variable, while motivation, opportunity, and ability were exogenous variables in the current study. The indicators were measured using a 1-5 Likert scale representing strongly disagree, somewhat disagree, undecided, somewhat agree, and strongly agree.

The SEM includes a few steps: Model specification, model identification, model estimation, model testing, and model modification (Schumacker and Lomax 2015). The model specification was conceptualised based on the theoretical framework explained in Figure 1. The model identification was made by establishing the degrees of freedom (df), equal to or greater than 1. A df = 0 shows either a saturated or under identified model. A df < 0 indicates an over identified model. Model parameters were estimated for the assumptions of the Pearson correlation coefficient and tested for the stander error. Then the model was tested for fit, evaluating if the original variance-covariance matrix and the model inferred variance-covariance matrix was similar. In case of a model does not fit the data, the modifications are allowed using the residual matrix, modification indices, and previous theories.

FINDINGS

Measurement Model Analysis

A confirmatory factor analysis (CFA) was conducted using AMOS to test the measurement model to assess the reliability and validity of the observed variables for each construct or latent variable. The SEM model was identified, establishing the df value, which in the current analysis, df=22 (>1). A few of the observed variables were removed from the measurement model due to low factor loadings (< 0.5) and re-run the estimation. Accordingly, CFA only explains the causal relationship between various social psychological factors (exogenous variables: Motivation, opportunity, ability) and adaptive behaviours (endogenous construct: Composite of AB1 and AB2). As shown in Table 2, all loadings were significant ($p < 0.001$ level) and higher than the recommended threshold value of 0.50. The CFA results showed an acceptable fit between the measurement model and the data set. The model fit indices, such as $\chi 2/df$ (< 3.00), GFI, CFI, and TLI (> 0.90), SRMR (< 0.08), and RMSEA (≤ 0.08) were used to test the overall goodness of fit of the developed model (Kline 2015). The results indicated that the above measurement model had a good level of fit with $\chi 2/df=2.521$, GFI=0.953, CFI=0.951, TLI=0.919, SRMR=0.0719, and RMSEA=0.079.

The reliability and validity of the measurement model were assessed through construct reliability, convergent validity, and discriminant validity of the measurement model. According to Table 2, construct reliability was assessed using Cronbach's alpha (α) to evaluate how the model variables consistently measure adaptive behaviours. Cronbach's alpha values for the model parameters in the study ranged from 0.726 to 0.831 and were greater than the acceptable level of 0.70. Also, the study used Composite Reliability (CR) to assess the construct reliability. However, the CR value of each construct was less than the benchmark value of 0.60; thus, the model variables were not entirely established using the CR value (Kline 2015). The convergent validity measures how well the selected indicators measure the construct. The average variance extracted (AVE) was used to estimate the convergent validity of scale items. The AVE values of the scales were above the threshold value of 0.50, which shows the required convergent validity of the constructs (Kline 2015).

Moreover, the discriminant validity indicates the degree to which one construct differs from other constructs or the dependencies between latent variables, and this was assessed using Heterotrait-Monotrait (HTMT) Ratio. Accordingly, all HTMT ratios were less than the required limit of 0.85, and the discriminant validity was established (Henseler *et al.,* 2015). Additionally, Table 3 presents the study constructs' correlation estimates to show the relationships between latent variables. As shown in Table 2 and Table 3, all the correlations between constructs were lower than the SQRT of AVE values and support the discriminant validity (Henseler *et al.,* 2015). Therefore, considering the above results, the construct reliability and validity were established for each study construct.

Table 2: Results of confirmatory factor analysis

Constructs		Item	Standardized factor loading	Cronbach's alpha (α)	CR	AVE	SQRT of AVE	HTMT ratio
Motivation	Attitude (At)	At1	0.850	0.831	0.493	0.717	0.847	0.1704
	Personal norms (PN)	PN1	0.840					
Opportunity	Organisation support (OS)	OS1	0.550	0.726	0.358	0.515	0.717	0.5433
		OS2	0.910					
	Behavioural interventions (BI)	BI1	0.650					
Ability	Perceived knowledge (PK)	PK1	0.790	0.793	0.353	0.580	0.761	0.0654
		PK2	0.820					
		PK3	0.670					

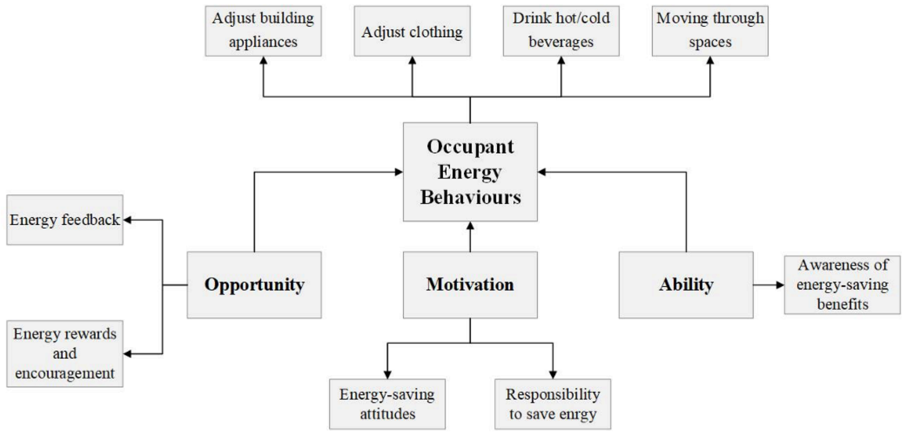
Table 3: Descriptive statistics and correlations

Constructs	Means	SD	At	PN	OS	BI	PK
Attitude (At)	4.1255	0.939	1.000				
Personal norms (PN)	3.8704	1.074	0.717**	1.000			
Organisation support (OS)	2.690	0.989	0.195**	0.239**	1.000		
Behavioural interventions (BI)	3.352	1.000	0.255**	0.315**	0.305**	1.000	
Perceived knowledge (PK)	4.172	0.788	0.434**	0.417**	0.167**	0.192**	1.000

Correlation is significant at the 0.01 level (2-tailed).

As revealed from the SEM analysis, only a few of the observed variables selected for the study related to the constructs of adaptive OB. The measurement model confirms that attitudes and personal norms contribute to motivation, organisational support and behavioural interventions contribute to opportunity, and perceived knowledge contributes to the ability of the building occupants. These relationships are illustrated in Figure 2. The motivation indicators attitude and personal norms have high factor loadings, and each shares a significant portion of variance with motivation (Li *et al.,* 2019). The finding also supports earlier findings that personal norms are a significant antecedent contributing to motivation (Kim and Seack 2019).

Figure 2: Social psychological factors influencing office occupants' energy behaviours



Similarly, organisational support and behavioural intervention improve occupants' opportunities and imply that the organisation's rewards and interventions, such as energy feedback and awareness messages, promote energy saving behaviours of the occupants (Mulville *et al.,* 2017; Xu *et al.,* 2017). Although Li *et al.,* (2019) emphasised the importance of organisational support and intervention to enhance subjective norms in energy savings, subjective norms did not contribute to opportunity in the current model. Similarly, the measurement model does not illustrate the relationship between accessibility to control and opportunity, while previous studies have opposite views (Li *et al.,* 2019; McMakin *et al.,* 2002). A likely reason for this could be the lack of personal control, while McMakin *et al.,* (2002) claimed that occupants change their energy behaviours when they have more control over the environment.

All three indicators of perceived knowledge showed high factor loadings in the current study as it implies that occupants' knowledge of saving energy improves the occupants' ability to exercise energy saving behaviours (Abrahamse and Steg 2009). However, interestingly, PBC and actual knowledge showed little influence in determining the occupants' ability. As saving energy in offices needs little effort and no detailed knowledge to perform the behaviour (Li *et al.,* 2019), the results on PBC and actual knowledge contrast with the previous causal relationship to ability.

Furthermore, the SEM measurement model developed for the study does not highlight the causal relationship between indicators of nonadaptive behaviours to the occupants' actions. This is a significant drawback that exists in past studies as well. The studies focused mainly on human building interactions such as lighting, heating, air conditioning appliances, and thermostats (D'Oca *et al.,* 2017; Li *et al.,* 2019; Shi *et al.,* 2017). Therefore, the current study results only provide the covariances between MOA constructs and adaptive behaviours. However, it is adequate to rethink the human-building interactions driven by social psychological aspects to promote energy efficient offices in the post-pandemic era (Mantesi *et al.,* 2022).

CONCLUSION

This study used a modified MOA framework to evaluate the impact of social psychology factors on OB in offices. As a result, the study established the significant social psychological factors influencing occupants' adaptive behaviours by developing the SEM measurement model. The results provide researchers with how social psychological constructs of occupants influence the decision-making of their behaviours. Hence, the study assists building designers and energy modelers in improving the internal environment and building systems that suit occupants' comfort preferences, thereby tackling climate change in a post-pandemic era. However, for future research, the authors will examine to what extent these factors affect OB by creating path coefficients of direct and mediating effect models on behaviour. Thus, the measurement model will be extended to a structural model to test the hypothetical dependencies between endogenous and exogenous variables. Also, the current study assumed a population proportion of 0.80 considering the COVID19 and post lockdown situation in New Zealand. However, when the exact population proportion is unknown, it is usually considered 0.50, which gives a much higher sample. Therefore, further studies are required to consider a higher sample to refit the structural model for more reliable predictions.

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