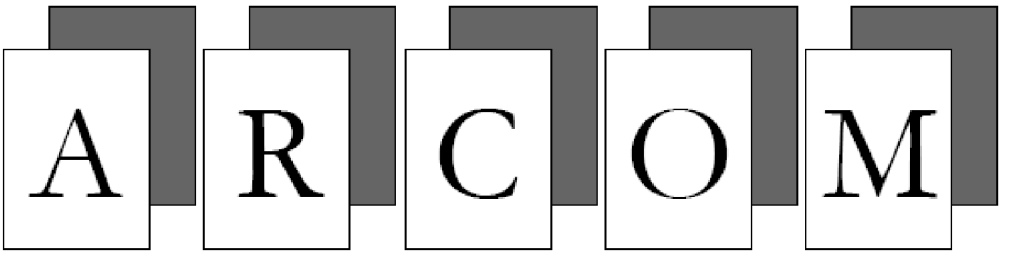

ARCOM Doctoral Workshop
on
Emerging Technologies in Construction

School of the Built Environment
University of Salford

10th November, 2006

Workshop Chair: Dr Vian Ahmed
Workshop Secretary: Raju Pathmeswaran

Venue: The Think Lab, University of Salford

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INTRODUCTION

There is no doubt that the construction industry is no different from the fast changing world of businesses. Yet, such change is still slow within this industry, and lags behind other industries. This implies that more radical changes will take place in the forthcoming future, with Information Technology being central to these changes.

Influenced by new policies, new models of management approaches and variety of products and services, our industry has to face up to new challenges and cultural changes. These may be seen as barriers due to the fragmented nature of this industry, which may be translated as reluctance to acknowledge the use of Information Technology as a strategic opportunity for new ways of doing things, rather than merely automating manual processes.

Investments into the field of Information Technology are continuously increasing, through academic research, software developments, knowledge based systems and virtual reality and simulation tools, suggesting new ways of embracing construction processes and products. This is partly evidenced by the range of publications included in this workshop programme.

Emerging technologies in construction, is the central focus of this research workshop, to benefit our community of researchers by sharing their views and their research interest with key figures and leaders in the field. This workshop integrates diverse approaches to the use of Information Technologies within the supply chain, to improve: construction procurement between partners, site management and Health & Safety processes; planning techniques using 3D and 4D visualization tools; knowledge processes and organizational learning; and last but not least, educational tools for skills enhancement and collaborative approaches to learning.

The workshop chair and convener, would like to thank all of those who contributed to this workshop, including the key speakers, authors, co-authors and presenters for sharing their research ideas and outcomes with their colleagues in the community. Last but not least, thanks to Raju Pathmeswaran, Azmath Shaik and Sabri Abouen of the host University of Salford for their help and support with the organisation of this event.

Dr. Vian Ahmed
Workshop Chair

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ARCOM DOCTORAL WORKSHOP PROGRAMME
Emerging Technologies in Construction

Time	Subject	Speaker	Institution
10:00-11:00	**Registration and Coffee**	**All**	
11:00 - 11:10	Opening	Prof Ghassan Aouad	Dean, Faculty of Business, Law and the Built Environment University of Salford
	Welcome	Dr Vian Ahmed	Workshop Chair University of Salford
11:10 - 11:25	Think Lab and Associated Research	Prof Terrence Fernando	Director, Future Workspaces Research Centre and Think Lab University of Salford
11:25 - 11:40	BuHu's leading role in advancing IT agenda	Prof Mustafa Al-Shawi	Director, Research Institute for Built and Human Environment University of Salford
11:40 - 11:55	Construct IT - Uniting IT organisations in the UK	Prof Farzad Khosrowshahi	Director, Construct IT University of Salford
11:55 - 12:10	Whither visualisation in design & construction research	Prof Lamine Mahdjoubi	University of West England
12:10 - 12:25	VR - Roadmap: A Vision for 2030 in the Built Environment	Prof Nash Dawood	Director, Centre for Construction Innovation & Research University of Teesside
12:25-13:00	**Panel Discussion**	**All**	
13:00-13:30	**Lunch**	**All**	
13:30 - 13:45	Enabling technologies for e-learning in Construction	Raju Pathmeswaran	University of Salford
13:45 - 14:00	Identification and development of key performance indicators to establish the value of 4D planning	Sushant Sikka	University of Teesside
14:00 - 14:15	A problem-based knowledge management approach to improved site management	Sarajul Fikri Mohamed	Loughborough University
14:15 - 14:30	A Conceptual CBR Model for Health and Safety Competence Assessment	Hao Yu	University of Wolverhampton
14:30-14:45	**Coffee**	**All**	
14:45 - 15:00	Collaborative benchmarking process between construction companies for facilitating knowledge process and organisational learning	Dayana Bastos Costa	University of Salford
15:00 - 15:15	Partnering - Strategic Tool of Integrating Supply Chain in Construction Industry	Shuwei Wu	Northumbria University
15:15 - 15:30	Developing Spatial Visualisation Skills in a New Era	Xiandong Feng	University of Wolverhampton
15:30-15:45	**Summary and Closing**	Dr Vian Ahmed	Workshop Chair University of Salford

ENABLING TECHNOLOGIES FOR E-LEARNING IN CONSTRUCTION

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ABSTRACT
Learning content is the core of learning activities and also expensive to produce. The arrival of new technologies makes learning content out of date and thus often leads to reinvent the wheel. However, learning content can be broken down into smaller objects called learning objects. Sharing knowledge and expertise through the exchange of learning objects is one way of enabling education and thus, sharing of learning objects became one of the priority areas in the e-learning research. The emerging Semantic Web technologies have not yet been applied widely to deliver learning objects. Semantic Web technologies offer several benefits to e-learning and are also a stronger approach to interoperability than standards-based approaches. This paper describes an approach adopted to develop an online digital repository of learning objects using emerging technologies, and through the development of construction metadata and ontologies.

Keywords: content package, e-learning, learning object, ontology, semantic web

INTRODUCTION

Learning is the process of acquiring knowledge and skills through study and experience. With the ever increasing availability of the information and Internet technologies, the way of teaching and learning and delivery of learning materials are changing. As a result e-learning has begun to evolve. E-Learning has a plethora of definitions. Hall and Snider (2000) define e-learning as the process of learning via computers over the Internet and intranets. Sharing knowledge and expertise through the exchange of learning objects is one way of enabling education. A learning object is a "self-standing, reusable, discrete piece of content that meets an instructional objective" (ADL et al. 2002). The IEEE Learning Technology Standards Committee(LTSC) defines learning objects as "any entity, digital or non-digital, which can be used, re-used or referenced during technology supported learning"(LOM, 2003). It also suggests that learning object can be a multimedia content, instructional content, learning objectives, instructional software and software tools, persons, organisations, or events referenced during technology supported learning. Although LTSC definition is too broad to actually define a learning object, Wiley (2000) defines learning object as "any digital resource that can be reused to support learning". This definition includes anything that can be delivered across the network on demand, be it large or small.

Learning content has to be labelled in a consistent way to be discovered by various search engines. It also needs to be packaged in a standardised way to be delivered to different learning systems. Therefore, there is a need for the standardising and labelling of learning objects by using metadata and packaging standards. There are however, different types of standards that exist for these purposes which can be classified into some general categories for the delivery of e-learning objects. This paper is focused on the understanding of metadata standards and their integration within learning objects repository for sharing content.

Learning Object Metadata is referred as the labelling of learning objects so that they can be identified via search engines (Qin and Hernandez, 2004).

This paper identifies the relevant metadata elements for developing reusable learning objects, proposes enabling technologies for developing intelligent learning objects repository and demonstrates how the pedagogy can be integrated in developing such a repository by using the ontologies and semantic web technologies.

LEARNING OBJECTS AND METADATA

Content is the core of learning activities and also expensive to produce. Content can be divided into small chunks of learning that are defined as learning objects. The notion of learning object came from the object-oriented paradigm of computer science where objects can be reused. According to Mohan & Brooks (2003), a learning object is a digital learning resource that facilitates a single learning objective. It may be labelled, reused and mixed or matched in different learning contexts. Current research with learning objects are much concerned with the metadata and content packaging aspects. There has been a significant research done in developing sharable learning objects with pedagogical elements (Ahmed & Shaik, 2004). A learning object repository is a collection of learning objects enabling educators to share, manage and use educational resources.

However, in order to exchange, share and integrate learning objects within learning environments and repositories, it is necessary to adopt educational standards such as metadata standards to develop interoperable learning objects. Learning Object Metadata is referred as the labelling of learning objects so that they can be identified via search engines (Qin and Hernandez, 2004). There are number of standardisation bodies that are in the process of creating metadata standards for example, the IEEE (Institute of Electrical and Electronic Engineering) Learning Technology Standards committee produced a standard called Learning Object Metadata standard (LOM, 2003). The Dublin Core Metadata Initiative also developed a different metadata standard with less elements compared to IEEE LOM. Dublin Core metadata is widely used by libraries, publishers and government organisations. The IMS Global Learning Consortium and the Advanced Distributed Learning Initiative (ADL) have adopted IEEE LOM as their metadata standard. The table shows the definition of the chosen elements to integrate in the repository as originally identified by IEEE LOM.

Table 1 Most Relevant Metadata elements

Metadata elements	Definition
Title	Name given to the learning object.
Language	The primary human language or languages used within this learning object.
Description	A textual description of the content of this learning object.
Object Type	The type of Learning Object.
Keywords	Keywords or phrases describing this learning object.
Version	The edition of this learning object.
Contributor Name	The entities i.e. people, organisation that have contributed to the state of this learning object during its life cycle.
Contributor Role	The role of the contributor .
Date	The date of the contribution.
Format	Technical data type(s) of the learning object.
Location	A string that is used to access this learning object.
Level	The educational level of this learning object.

The metadata of the learning object can be used to form some relations between learning objects and other entities. We proposed to relate learning objects with individuals who create or use the learning objects. Riding's learning style analysis (Riding and Sadler-Smith, 1997) address two types of learners; those who are "Verbalisers" (i.e. they learn best from abstract concept), and those who are "imagers" (i.e. they learn best from visual content). These styles were found to be a simple and easy way of associating learning styles to suit individuals' preferences. Figure 1 shows how the learning objects can be related to the attributes to the person object. Individuals can be identified as learners, curriculum developers and educators. Author of the learning object can be associated with the name of the person and similarly the keywords of the learning object can be associated with research interests of the person.

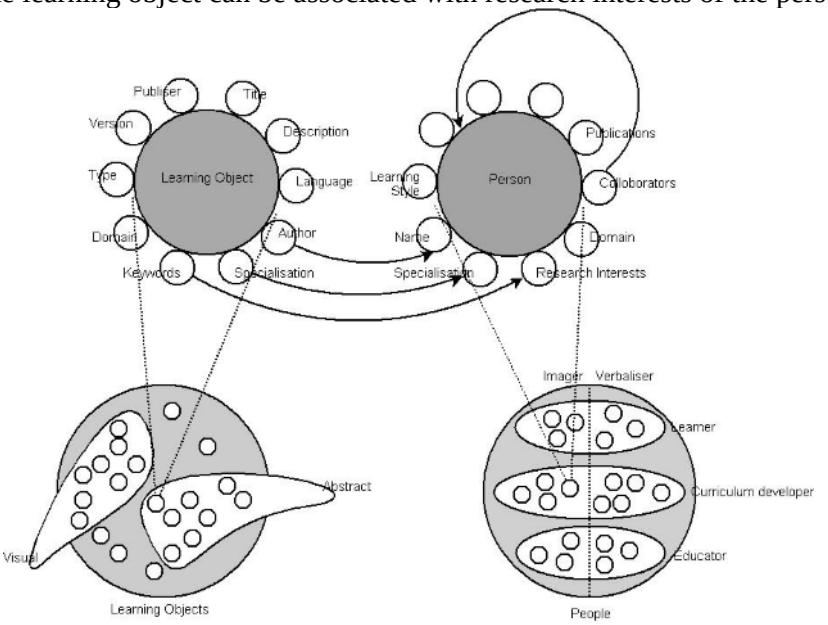

Figure 1: Learning Object and Person Relationships

The metadata make learning objects more reusable and enable various web services and search engines to find them dynamically. The next section identifies the relevant technologies that facilitate the development of intelligent learning objects repository.

ENABLING TECHNOLOGIES

There are number of technologies that enable the development of learning objects repository. However, ontologies and Semantic Web technologies are the core technologies that enabled the development of the repository.

Ontology

Ontologies are specifications of the conceptualization and corresponding vocabulary used to describe a domain (Gruber, 1993). In the other words, ontology is an explicit description of a domain and defines a common vocabulary as a shared understanding. It defines the basic concepts and their relationships in a domain as machine understandable definitions.

The OWL (Web Ontology Language) is a language for defining and instantiating Web ontologies. The OWL language provides three increasingly expressive sublanguages designed for use by specific communities of implementers and users. OWL Lite supports those users

primarily needing a classification hierarchy and simple constraint features. OWL DL (Description Logic) supports those users who want the maximum expressiveness without losing computational completeness and decidability of reasoning systems. OWL DL includes all OWL language constructs with restrictions such as type separation. OWL Full is meant for users who want maximum expressiveness and the syntactic freedom of RDF with no computational guarantees. OWL Full allows an ontology to augment the meaning of the pre-defined RDF or OWL vocabulary.

Semantic Web

Semantic Web is an extension of the current web in which information is given well-defined meaning, better enabling computers and people to work in cooperation (Berners-Lee et al, 2001). The current web, called Syntactic Web can only be accessed by humans and just provides information in a syntactic manner. But in Semantic Web concept, information is given well-defined meaning that can be accessed by both humans and machines. Semantic Web has been developing a layered architecture with the technologies and standards. These form the basic buildings blocks for the Semantic Web to support the development of meaningful web. The following Fig. 3 shows the latest architectural layer for the Semantic Web.

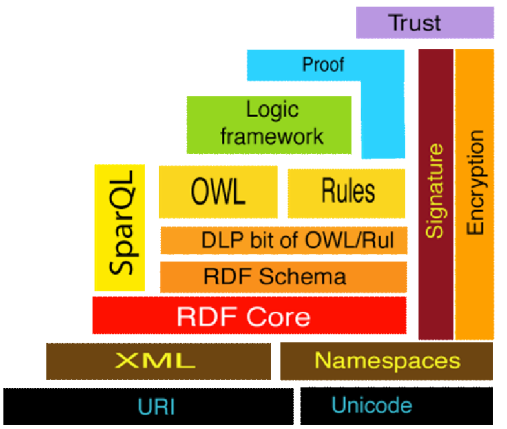

Figure 2: Semantic Web Layer (http://www.w3.org/2005/Talks/1110-iswc-tbl/#(12))

Unicode is the standard for computer character representation while URI is the standards for identifying and locating information on the web. URIs can be used to identify definitions for concepts. XML separates data from presentation and forms a common way of structuring data on the web. It also associated with some other related standards such as Namespaces and Schemas. The Resource Description Framework (RDF) is the first layer that forms the Semantic Web. RDF represents metadata using URIs to identify and locate resources and information on the Web. It provides a graph model for describing and defining relationships between resources. RDF Schema is a modelling language for defining and describing classes of resources in the RDF model. Logic and Proof layer provide reasoning support for the ontologies and to make new inferences while SPARQL is a query language for getting information from such RDF graphs.

The next section outlines the framework for developing intelligent, sharable and dynamic learning objects.

FRAMEWORK OF THE LEARNING OBJECTS REPOSITORY

The online repository which serves as a portal for learning community consists of learning objects that can be searched, retrieved and delivered to other learning management systems. The aim of the repository is to develop an environment for learning objects that are interoperable, transparent and sharable by the community of educators and learners, and to be accessible anywhere anytime. However, there are three main challenges that the learning objects face in order to develop such environment, that are, making learning objects;

- Intelligent by developing semantic metadata,
- Sharable through various learning environments via content packaging and
- Dynamic using ontologies and the Semantic Web concepts.

The challenges are studied further to develop a framework which is shown in Figure 2 for the repository. The semantic aspects of learning objects are developed using metadata, pedagogy and ontology. Similarly, the delivery of learning objects is associated with the ontology, content package and Semantic Web. The structure of the learning objects mainly created using pedagogy, construction domains and content packaging standard.

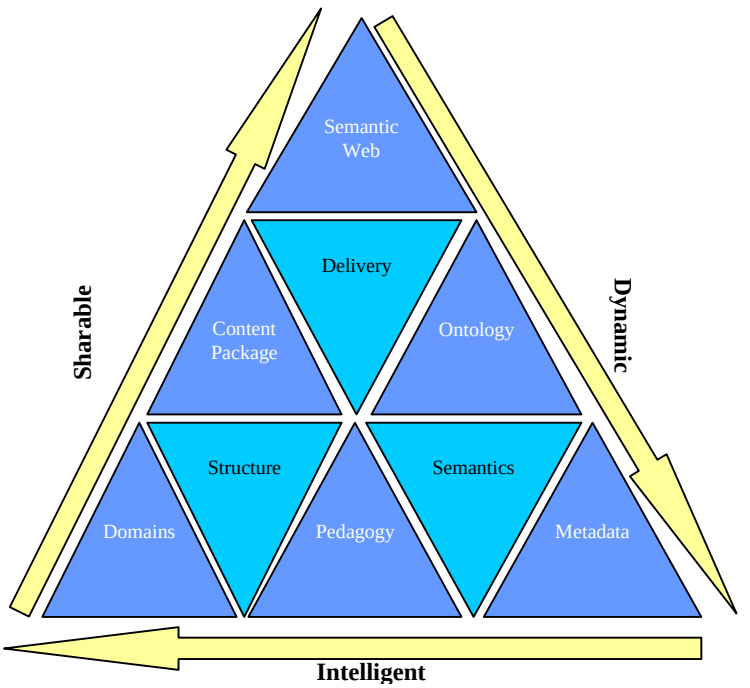

Figure 3: Conceptual Framework

The next section details the architecture of the learning objects repository and provides the overview of underlying technologies.

ARCHITECTURE OF THE LEARNING OBJECTS REPOSITORY

The learning objects repository is built using open source software and tools. The core of the system is the Semantic Web toolkit called Jena. Jena is a Java framework for building Semantic Web applications. It provides a programmatic environment for RDF, RDFS and

OWL, SPARQL and includes a rule-based inference engine. The repository has two separate systems that work together to function as a repository. The learning objects system is built using Semantic Web technologies and ontologies. The interface is built using Velocity template engine and the searching mechanism is provided using Lucene search engine. The content packages part is built using content packaging standard called SCORM (Sharable Content Object Reference Model).

Figure 4 shows the underlying technologies and relevant functionalities of the system. Learning objects can be uploaded, browsed and searched within the repository. Similarly, within the repository content packages can be created using learning objects, uploaded to the repository in a zip format and exported to the learning management systems such as Blackboard.

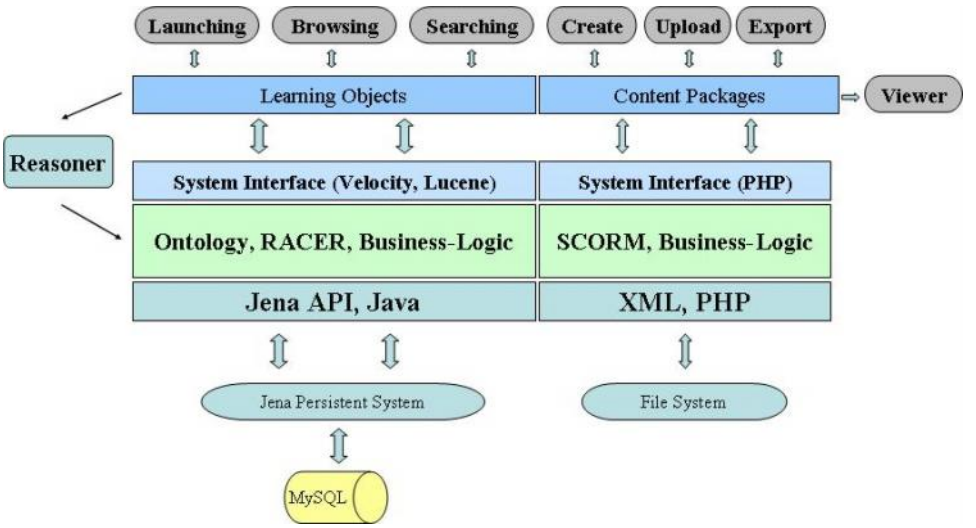

Figure 4: Architecture of the Repository

The next section demonstrates how the learning objects are uploaded into the repository together with metadata and then how it can be searched using simple search. The repository also provides mechanisms for performing advanced search.

FUNCTIONALITIES OF THE REPOSITORY

The online repository provides number of functionalities that enable users to submit, search and package learning objects.

Submission of learning objects

Learning objects can be submitted to the repository with its metadata. Figure 5 shows a 3D learning object that demonstrates 3D modelling concept which is one of the topics in the Digital Modelling module.

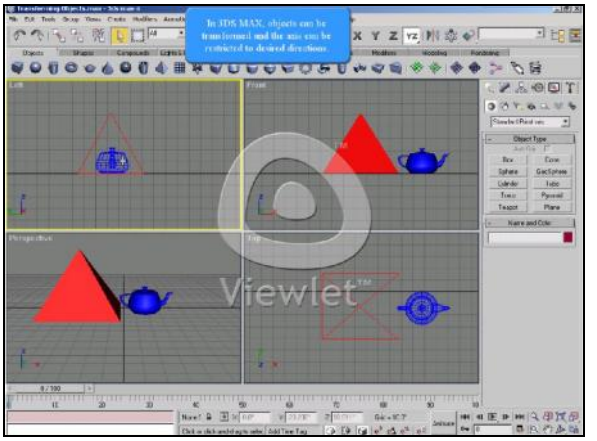

Figure 5: Sample 3D Learning Object

The metadata associated with the above 3D learning object are given in Table 2.

Table 2 Metadata for 3D object

Metadata elements	***Example***
Title (M)	Transforming Objects
Language (M)	English
Description (M)	Transforming objects including moving, rotating and scaling as well as creating object clones in geometric arrangements
Object Type (M)	Demonstration
Keywords (O)	Transforming Objects, Axis, Rotating, Scaling, Cloning
Version (O)	1.0
Contributor Role (M)	Educator
Creator (M)	Vian Ahmed
Date (M)	02/02/2006
Format (M)	Flash
Location (M)	http://elearning.scpm.salford.ac.uk/learningobjects/3d4a.swf
Construction Domain	Construction Information Technology

The programme structure is developed using ontology where the complex relations and concepts are modelled. It gives users freedom of choice in navigating and selecting required components by hiding the complex relations. Figure 6 shows the navigation structure of the programmes where users able to choose multiple modules and topics which are related to their learning object.

Figure 6: Programme Structure

For the example 3D object, Construction Information Technology is selected as Programme and Digital Modelling is chosen as Module. From the list of available topics, 3D Modelling is selected as appropriate one.

After choosing the pedagogical and structure details of the learning object, system will take users to the next step where learning object is labelled using the proposed metadata.

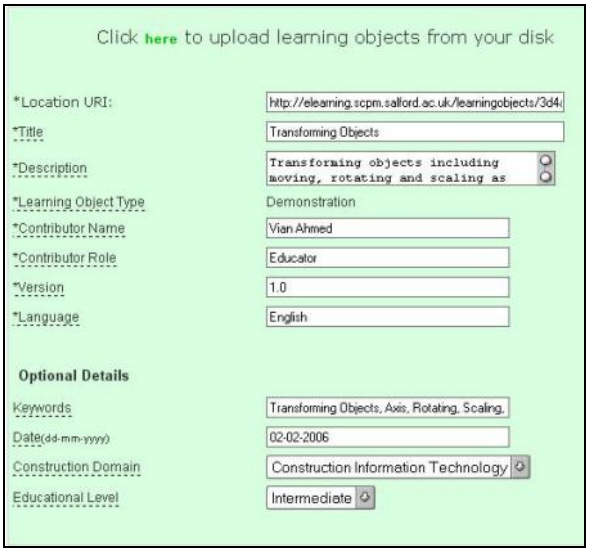

Figure 7: Metadata Input Form

The labelling of the above metadata onto a learning object is done using a form template as shown in Figure 7.

Searching Learning Objects

The submitted learning object can be searched by keywords. Figure 8 shows the screenshot of the search form. The search queries the Semantic Web based database and will provide logical results.

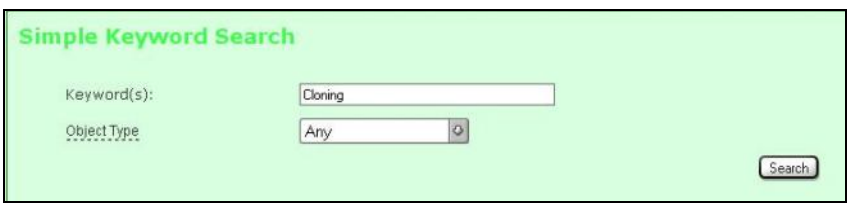

Figure 8: Keyword Search Form

Keyword "Cloning" is used to search the submitted object and is added in the metadata under "keywords" element. However search will look into all the provided metadata to look for search term. The search result is provided in the Figure 9. Search engine returned one object based on the keyword search.

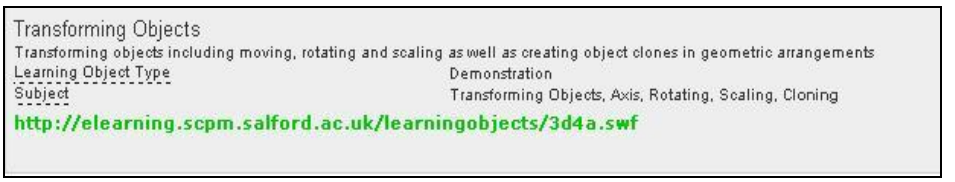

Figure 9: Search Results

From the link given in the search result, we can launch the object. Since it is a flash file, it will open in the internet browser.

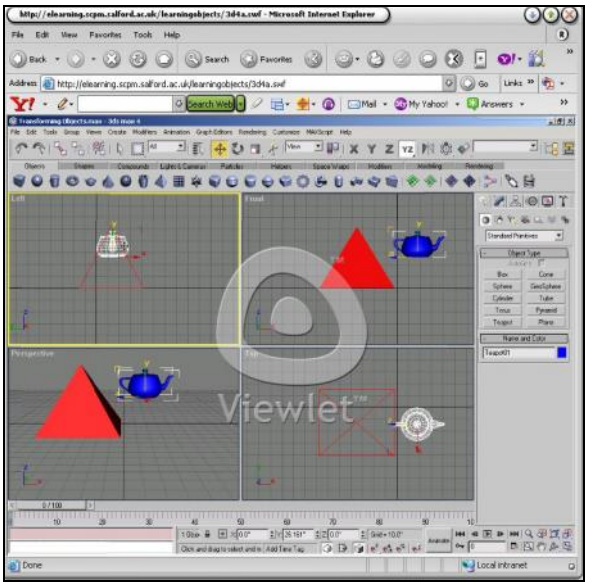

Figure 10: Launching the 3D Object

This paper covers the approach adopted to select the metadata standard for 3D learning objects. It demonstrated how the proposed metadata framework for construction education is integrated within the online environment for 3D learning objects.

CONCLUSION

This paper covers the approach adopted to develop the learning objects repository. It outlines the framework, architecture and enabling technologies that enabled the development of intelligent, dynamic learning objects repository. It also proposed the integration of learning objects with individual's learning styles and preferences as the object-oriented concept. We demonstrated how the proposed metadata framework for construction education is integrated within the online environment and how the learning objects can be packaged using the SCORM content package standard. Future works include the development of ontology with more educational concepts and relationships that will make the repository and learning objects more intelligent and dynamic.

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IDENTIFICATION AND DEVELOPMENT OF KEY PERFORMANCE INDICATORS TO ESTABLISH THE VALUE OF 4D PLANNING

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Performance measurement has received considerable attention by both academic researchers and industry over a past number of years. Researchers have considered time, cost and quality as the predominant criteria for measuring project performance. In response to the Latham and Egan reports to improve the performance of construction processes, the UK construction industry has identified a set of non-financial Key Performance Indicators (KPIs). A literature review reveals that a systematic measurement framework to evaluate the value of such systems at both quantitative and qualitative levels does not exist. Following an increased utilisation of IT based technology in the construction industry and in particular 4D (3D+time) planning. The aim of this ongoing research is to develop a suitable measurement framework to identify and analyse key performance indicators for 4D applications. Two major issues have been addressed in this research: an absence of a standardised set of 4D based KPIs and lack of existing data for performance evaluation. This paper reports on the first stage of the research study for the identification of key performance indicators and to evaluate the benefits of 4D planning at project level. The ultimate objective of this research is to deliver project based 4D key performance indicators and to identify how project performance can be improved by the utilisation of 4D planning.

Keywords: 4D planning, Information technology, Performance measurement, Key performance indicators, Visualisation.

INTRODUCTION

Applications of Information Technologies (IT) are progressing at a pace and their influence on working practice can be noticed in almost every aspect of the industry. The potential of IT applications is significant in terms of improving organisation performance, management practices, communication and overall productivity. The thrust for improved planning efficiency and visualisation methodology has resulted into the development of 4D planning.

Visual 4D planning is a technique that combines 3D CAD models with construction activities (time) has demonstrated advantages when compared with traditional approaches. In current practice, planners develop a sequential relationship between various construction activities on the basis of available 2D drawings and information. The traditional planning approach does not assist planners to consider the constructability issues during the advanced development of schedules. As a result such issues are left for later decisions on the site. In 4D planning project participants can

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effectively visualise, analyse, and communicate problems regarding sequential, spatial and temporal aspects of construction schedules and thereby rehearse construction progress in 3D at any time during the construction process. The whole basis of using 4D planning is to identify logical sequencing of the construction activities in construction projects prior to its execution. A rehearsal of the construction processes over time will identify and assist in overcoming spatial and resource conflicts for example, workspace conflicts, constructability, workflow etc which cannot be represented by using conventional planning techniques. As a consequence, much more robust schedules can be generated to reduce rework and improve productivity. According to *Dawood et al. (2002)* 4D planning allows participants in the project to effectively visualise and analyse the problems since the sequencing of space and temporal aspects of the project are considered by visualising and communicating the project schedule.

The Construction Industry Institute (CII) conducted research into the use of three-dimensional computer models in the industrial process and commercial power sector of AEC (architectural, engineering and construction) from 1993 to 1995 (*Griffis et al., 1995*). The major conclusions of the CII research include a reduction in interference problems; improved visualisation; reduction in rework; enhancement in engineering accuracy and improved jobsite communications. *Songer (1998)* carried out a study to demonstrate the use of 3D CAD technology during the project planning phase. The study focuses on the impact of using 2D and 3D technologies in the project schedule review. Songer's experimental results demonstrated that the use of 3D-CAD technologies during the planning stage of a construction project can assist in enhancing the scheduling process by reducing the number of missing activities and relationships between various activities as well as invalid relationships in the schedule and resource fluctuations for complex construction processes.

The Centre for Integrated Facility Engineering (CIFE) research group at Stanford University has experienced and documented various applications and benefits of 3D and 4D modelling (*Koo & Fischer-1998, Haymaker & Fischer-2001 and Staub-French & Fischer-2001)*. The application of the Product Model and Fourth Dimension (PM4D) approach at Helsinki University of Technology Auditorium Hall 600 (HUT-600) project in Finland also demonstrated the benefits of 4D modelling approach by achieving higher efficiency; better design quality and the early generation of a reliable budget on the project *(Kam et al. 2003)*.

Many researcher *(Songer et al. 2001; Messner & Horman 2003; and Haymaker & Fischer 2001)* evaluated the effectiveness of computer visualisation (4D CAD) to demonstrate the potential of 4D CAD visualisation techniques compared to traditional planning approaches during the planning review process. There are numerous approaches to quantify the economic assessment of IT impacts in construction. The important approaches to analyse investment in IT are financial methodologies (return on investment, internal rate of return & net present value), cost/benefit analysis, economic value added & value chain analysis. The industry based Key Performance Indicators (KPIs) that have been developed by the Department of Trade and Industry (DTI) sponsored construction best practice program (CBPP) are too generic and do not reflect the value of deploying IT system for construction planning and in particularly 4D planning. The above studies lack well-established metrics that would allow the quantification of 4D planning at project level. The key objective of this research study is to overcome the presence of a generalised set of KPIs by developing a set of 4D based KPIs at project level.

Researchers (Andresen et al. 2000; Marsh & Flanagan 2000; Love & Irani 2001) have indicated that the absence of clearly defined and quantified benefits have contributed to impending investment in IT in construction organisations. As a consequence there is no standardised methodology in existence for the evaluation of the benefits of IT in the

construction industry. In the absence of well-defined measures at project level, the priority of this research project is to establish a set of key performance indicators that will reflect the influence of 4D applications in construction projects. This will assist in justification of investment in advanced technologies in the industry. The remainder of the paper discusses the research methodology adopted; identification & ranking of 4D KPIs and research findings.

Research Methodology

The methodology has following interrelated phases:

i. Identification of performance measures by reviewing literature dealing with the effectiveness of 4D planning.

ii. Conducting semi-structured interviews with industry professionals who have experience of implementing 4D planning.

iii. Analysis of interviews to establish and priorities the performance measures.

iv. Data collection to quantify the identified performance measures.

To achieve the objectives of the study two principal methodologies have been considered: 1. an extensive literature review on performance measurement to identify an initial set of performance measures. 2. Exploration of the industrial view to formulate the key performance measures from a 4D planning view point. Initially, forty industry decision-makers with experience in using 4D planning on construction projects were contacted and invited to take part in the research. To date we have conducted twenty interviews, resulting in a 50% response rate. Due consideration has been given in the selection of interviewee by selecting stakeholders (client, architects, engineer, project manager, construction manager, contractors & sub-contractors) with various roles and responsibilities on a construction project. They assisted in sharing information on how to collect the required data and in identifying the methods to measure construction processes in detail. The questionnaire was designed to collect the information regarding the current "state of understanding" within the industry regarding 4D performance measures. Three major construction projects in London (currently under construction with a combined value of £230 million) were selected for the research study and data collection. To minimise the risk of collecting irrelevant data, a snowball sampling method was devised. A semi-structured interviewing technique was used to elicit information from them to obtain their views about the performance measures at project level. The data and information obtained from semi-structured interviews was analysed using the Delphi technique. This technique was chosen since it is ideal for modelling real world phenomena that involve a range of viewpoints and for which there is little established quantitative evidence *(Hanks & McNay 1999).*

Identification & Selection of KPIs

The development of the performance measure list included due consideration of the performance measurement characterised by Rethinking Construction, the construction best practice program which launched industry wide KPIs for measuring the performance of construction companies *(CBPP-KPI-2004).* The Construction Best Practice Program identified a framework for establishing a comprehensive measurement system within both the organisation and at project level. Other literature includes *Kaplan & Norton (1992); Li. et.al (2000); Chan et.al (2002); Cox et.al (2003); Albert & Ada (2004); Bassioni et.al (2004)* were used for the identification of performance measures.

Project and construction managers working for major construction companies were invited to participate in interviews. First task for the interviewee were to identify and rank the

performance measures from viewpoint of 4D planning by using a four (4) point Likert Scale. The second task was to identify the information required to quantify each measure. Their input was considered to be critical in the success of this research. The concept behind conducting semi-structured interviews was to evaluate how project and construction managers perceive the importance of performance measures, which will assist in the identification of project based performance measures that can be used to quantify the value of 4D planning. The interview included both open and closed questions to gain a broad perspective on actual and perceived benefits of 4D planning. Due consideration has been given to the sources from where data has to be collected in a quantitative or qualitative way. The research team intends to continue the interviewing process with senior project & construction managers. This will assist in gathering more substantial evidence about KPIs. The analysis of semi-structured interviews resulted in the development of following 4D-based KPIs as represented in table 1.

Ranking of KPIs

The ranking of the KPIs was done by using a four (4) point Likert Scale. For the prioritisation process, each KPI was graded on a Likert scale of 1 to 4 (where 1= Not important, 2 = fairly important, 3 = Important and 4 = Very important) to measure the importance of each performance measure. The benefits of 4D planning will be quantified on the basis of prioritised KPIs. The performance measures will be further classified in qualitative terms (rating on a scale) and quantitative terms (measurement units). Using responses from a four (4) point Likert Scale, the average weighted percentage value for each performance measure was calculated. Figure 1 represents the weighted (%) ranking of the performance measures on the basis of the views of the respondents. The performance measures perceived as being highly important by the respondents are: *time, safety, client satisfaction, planning efficiency and communication efficiency.* As shown in figure 1, time and safety scored the top ranking when compared to other performance measures.

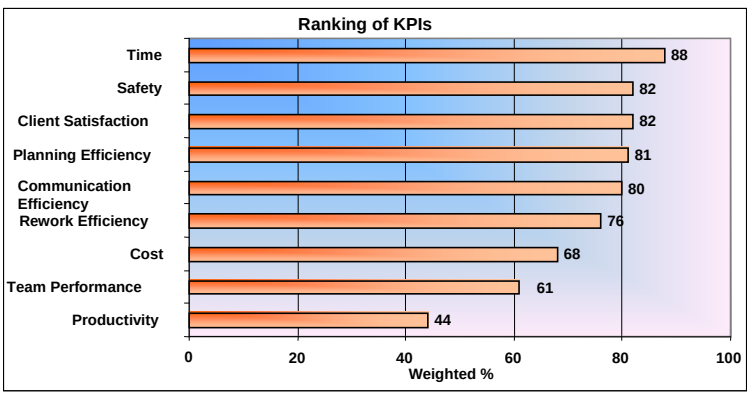

Fig. 1 Ranking of Performance Measures

Table 1: Definition of the Identified Performance Measures

Measure	Definition
Time	It can be defined as percentage number of times projects is delivered on / ahead of schedule. Completing a project on time is of prime importance for a construction manager. Implementation of 4D planning assists in development of an optimised construction sequence, analysis of various construction scenarios and to review planned vs. actual construction sequence performances to develop robustness in the project schedule. Schedule performance index (Earned value Approach) was identified to monitor the performance of schedule variance.
Safety	It can be defined as a measure of the effectiveness of safety policy and training of the personnel engaged in activities carried out on site. Safety is a major concern for every construction company, regardless of the type of work performed. Safety is normally measured quantitatively by time lost as a result of accidents per 1000 man hrs worked and number of accidents per 1000 man hrs worked.
Client satisfaction	Client satisfaction can be defined as how satisfied the client was with the product/facility. Usually measured weekly/monthly or shortly after completion and handover.
Planning Efficiency	Planning efficiency has been represented in terms of Hit Rate percentage (%).The critical success factor on a construction project is the reliability of the commencement date for each activity as per planning schedule. A late finish of an activity can inhibit the starting of another successive activity. This will ultimately results in an increase in the project duration time. Hit rate indicates the percentage (%) reliability of the commencement date for each activity in a package(s) by comparing the planned against actual programme i.e. percentage of activities started and completed on time. Hit rate percentage is a crucial indicator to represent the efficiency of planning on a construction project.
Communication	Information exchange between members using the prescribed manner and terminology. During pre-construction stage the use of 4D planning assists in communicating effectively the construction sequence and schedule to all stakeholders to reduce the amount of risk and delay associated within the schedule and to improve the work flow during construction stage. Communication can be quantified in terms of number of meetings per week and time spent on meetings (Hrs) per week.
Rework Efficiency	Rework efficiency can be defined as the activities that have to be done more than once in the project or activities which remove work previously done as a part of the project. By reducing the amount of rework in the pre-construction and construction stages, the profits associated with the specific task can be increased. Rework is responsible for 6-12% of the overall expenditure for a construction project. Presence of design and construction errors in the project escalates the rework cost both in terms of value of the rework and the time delays caused. The use of 4D must assist in decreasing the quantity of request for information generated, client change order requested, drawing approvals and similar documents in reducing the rework during the execution of the project. By reducing the amount of rework on the site, the profit associated with the particular task can increased remarkably. Rework can be represented in terms of number of client change orders, number of errors (construction/design), number of omissions (construction/design), number of requests for information to be generated, number of claims and number of clashes spotted.
Cost	Percentage number of times projects is delivered on/under budget. Cost performance index (Earned value Approach) has been identified to monitor the performance of cost variance.
Team Performance	Ability to direct and co-ordinate the activities of other team members in terms of their performance, tasks, motivation and the creation of a positive environment.
Productivity Performance	This method measures the number of completed units put in place on the basis of per individual man-hour of work done. Some of the identified productivity performance measures are; number of piles driven/day, number of piles caps fixed / day, tonnes of concrete poured / day/m^3 and pieces of steel erected per day or week.

Table 2 represent the ranking and ways to quantify the prioritise 4D performance measures at the different stages of a construction project. We have classified performance measures in three conceptual phases of a construction project (i.e. pre-construction, construction & post-construction phase) to evaluate the value generation by 4D planning at each level as project success criteria change with time in each phases. For example, 'Time' has been ranked as the top performance measure by the respondents and we propose to use 'Schedule Performance Index' to measure it. Schedule performance index (Schedule efficiency) can be defined as the ratio of the earned value created to the amount of value planned to be created at a point in time on the project. Similarly, we propose to measure 'Safety' in terms of number of accidents per 1000 man hrs worked and time lost in accidents per 1000 man hrs worked. Further, it is proposed that the identified KPIs will be represented in their respective indices form to easily capture the effect of any given change in the construction processes.

Table 2: Ranking of 4D-based KPIs in order of priority

Ranking	**KPIs**	**Indices**	**Performance Measures**	**Stages of Construction**
1	Time	Schedule Performance Index	(i) Schedule Performance	Pre-construction & Construction
2	Safety	Safety Index	(i) Number of accidents per 1000 man hrs worked (ii) Time lost in accidents per 1000 man hrs worked	Construction
3	Client Satisfaction	Satisfaction Index	(i) Number of client queries (ii) Satisfaction questionnaire (iii) Number of claims	Construction & Post-Construction
4	Planning Efficiency	Hit Rate Index	(i) Percentage of activities started & completed on time (Hit Rate %)	Construction
5	Communication Efficiency	Communication Index	(i) Number of meetings per week (ii) Time spent on meetings per week	Pre-construction & Construction
6	Rework Efficiency	Rework Index	(i) Number of errors (construction/design) (ii) Number of omissions (construction/design) (iii) Number of clashes (iv) Number of request for information generated (v) Number of change orders	Pre-construction & Construction
7	Cost	Cost Performance Index	(i) Cost Performance	Pre-construction & Construction
8	Team Performance	Team Performance Index	(i) Personnel turnover & productivity (ii) Timeliness of information from team	Pre-construction & Construction
9	Productivity	Productivity Index	(i) Tonnes of concrete poured per day / m^3 (ii) Pieces of steel erected /day or week (iii) Number of piles driven / day (iv) Number of pile caps fixed / day	Construction

Research Findings

Evaluation of the information gathered through interviews has assisted in understanding how stakeholders perceived the benefits of 4D planning, how it could be improved, how performance is measured and what are the barriers in the successful implementation of 4D planning within the industry. A majority of the project managers felt that the use of 4D planning has assisted them in risk reduction in schedule programme, decreasing the amount of rework and reduction in overall project duration. Evaluation of the information collected from the semi-structured interviews has revealed following potential benefits of using 4D planning:

- Risk reduction in a programme.
- Detecting clashes
- Improves visualisation.
- Assist in reducing overall project duration
- Enhanced client satisfaction
- Assists in reducing the amount of rework required to be done.

Construction industry is slow in adopting the potential benefits of 4D planning when compared to the other industries (E.g. manufacturing industry). Interviews with project managers revealed that there are varying views between the main contractors and trade contractors on the usage of 4D planning on a construction project. The main contractor's felt that 4D is unable to bring any confirmed value when compared to their own planning system. The concern at the moment is the availability of the information, time required to collect the information and cost factor attached in the implementation of the 4D technology. All the stakeholders were agreed that an early deployment of 4D brings about lot of transparency to resolve the conflicts among the various trades during the preconstruction phase.

The potential reasons cited for unable to explore the benefits of 4D planning are economical justification, financial risk and the reluctance of the organisation to learn new technology. The major impediments cited in the implementation of 4D planning in the construction industry are:

- Lack of sufficient IT skilled people with the required knowledge of 4D planning.
- Software incapability to represent the 4D model at detailed level.
- Time and money involved in training to upgrade the skills of work force.
- Resistance to change within the industry.
- Construction companies are not eager to invest in Research &Development.

Future Research Activities

The current and future research activities will include:

- Continuing the interview process to further confirm the 4D based KPIs.
- Establish a methodology for data collection and to quantify the identified performance measures (cost/benefit analysis) for the three identified construction projects.
- Benchmarking the performance measures with industry norms and identifying the improvements in construction processes resulted due to the application of 4D planning.

- Identifying the role of supply chain management in the development and updating of construction schedule for the 4D planning.

Conclusions

Research studies and industrial applications have highlighted the benefits of 4D planning in a subjective manner and it has been stipulated that 4D can improve the overall project performance by identifying clashes, improving communication and improved co-ordination. The evaluation of 4D planning in the construction management literature has not been addressed seriously from performance measurement viewpoint. This research study has developed five key performance measures consistently perceived as being highly significant at project level are: time, safety, client satisfaction, planning efficiency, and communication efficiency. A lack of system compatibility, standardisation, lack of sufficient IT skilled people and willingness of the user to adopt this technology were cited as main barriers for the implementation of 4D planning. The evaluation and justification of 4D planning is crucial to promote the value embedded in it.

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A problem-Based knowledge management approach to improved site management

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In the site management practices, site managers solve technical and complex problems by using their experience and intuition to find prompt solutions. The expertise and experience of site managers, both administrative and technical can be certainly utilised to manage knowledge on the construction site. Knowledge gains economic value when used to solve problems, explore opportunities and make decisions that improve production performance. This paper presents research results for improving site management practices based on the integration of applicable knowledge management processes. The paper starts with investigating previous Knowledge Management (KM) frameworks in construction and discusses the issues that need to be addressed to develop an effective KM framework. It then outlines case studies of site management practice on the construction sites and intended to investigate the possibilities to deploy KM initiatives at the operational level. The development of the problem-based KM framework that provides a structured KM approach at the construction site level is also presented. The paper then, discusses the process of encapsulating the framework into computer-based prototype system and system evaluation. It concludes that KM has the potential to significant improve construction site management practices if appropriately managed.

Keywords: construction, knowledge management, framework, site management practices.

INTRODUCTION

Knowledge management has become an important strategy for improving organisational competitiveness and performance (Wong and Aspinwall, 2006; Liao, 2003; and Gray, 2001). Over last five years, there has been significant growth in the adoption of Knowledge Management (KM) in construction organisations. The fundamental objectives are to deliver construction projects to the required quality more quickly (Egbu *et al.*, 2005; CIRIA, 2001), prevent the 're-invention of the wheel' (Holroyd, 1999) and improve project performance (Carrillo and Chinowsky, 2006; Robinson *et al.*, 2001).

Site management practices can benefit from knowledge management by implementing initiatives that enable the site management team to avoid repeating past errors. By capturing best practices, lessons learnt, and especially the solutions to problems that arise on site, similar situations in the future can be dealt with efficiently and effectively. This is because KM techniques are seen as a means of identifying and exploiting knowledge assets: individual experiences (Tserng and Lin, 2004; and Snider and Nissen, 2003), lessons learnt (Carrillo, 2004; and Liebowitz, 2001) and best practices (Gratton and Ghoshal, 2005). In the site management context, problems often arise on site and may lead to costly defects and delays if not resolved quickly and effectively. The greatest challenge facing construction

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managers are: to find the most efficient way of managing the construction site, to select the best method to resolve problems, and to make decisions in real time. An integration of KM into site management practices can act as a vehicle for connecting knowledge and performance as knowledge gains economic value when it is used to solve problems, explore opportunities and make decisions that improve production performance. Reducing problems on the construction site has the following advantages: (a) the cost of problem solving is reduced and (b) the probability of repeat problems is decreased (Tserng and Lin, 2004). In a construction site environment, KM can incorporate any or all of the following four components:

- *Business processes*: In written documents such as drawings, minutes of meetings, specifications or embedded in the construction methodology or setting-out procedures;
- *Information technologies*: IT tools used by site staff such as specialist management applications, word processing and CAD workstations;
- *Knowledge repositories*: Structured collections of documents, often written documents by internal company experts. These documents attempt to capture their author's expertise and insight on a subject; and
- *Individual Behaviours*: Construction knowledge in the mind of knowledge workers and trade workers, artisans and operatives.

An effective KM system is a complex combination of a series of organisational routines, themselves multi-faceted (and not necessarily IT-based). Dent and Montague (2004) argued that the components of KM systems in the construction organisation typically comprise:

- Standard procedures;
- Post-project reviews;
- Expert lists;
- Knowledge databases – e.g. best practice, lessons learned, customer relationship management (CRM);
- Intranets, including corporate portals;
- Knowledge networks and knowledge centres, both formal and informal (i.e. Communities of Practice);
- Collaborative technologies; and
- E-learning systems.

Figure 1 illustrates the typical components of KM systems in construction organisations. The corporate portal is an application that enables organisations to provide users with a single gateway to internal and external sources of information while the main function of the intranet is to store explicit and tacit knowledge (Dent and Montague, 2004). It is particularly important, in seeking to implement KM at site management level, to examine failed knowledge management initiatives in other organisations. Storey and Barnett (2000) have identified three main causes for the failure of knowledge management initiatives in an organisation. These are:

- Top management is 'committed' only up to a point;
- The KM initiative was undermined by divisions and differences in perspectives between diverse functional 'camps'; and
- A pilot for the KM initiative had been tried in one part of the company rather than planning for a total company-wide launch.

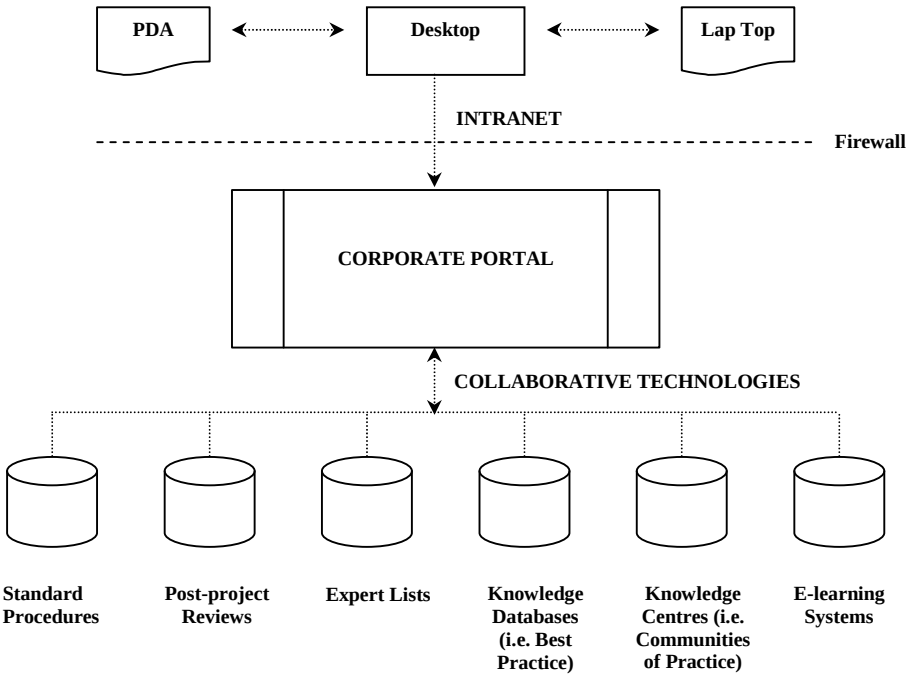

Figure 1: The Typical Components of KM Systems in the Construction Organisations (adapted from Dent and Montague, 2004).

Site managers can no longer depend totally on their past experience and intuition to find prompt solutions to technical and complex problems on the construction site because the nature of construction projects has become more complex during the past few years. Recent evidence has revealed that construction knowledge is more tacit than explicit (Egbu and Robinson, 2005). Tacit knowledge is difficult to communicate externally or to share while explicit knowledge can readily be captured and stored in project manuals, and procedures, and is, therefore, easily communicated and shared with others. The distinction between tacit and explicit knowledge is relevant because each must be managed differently. A workable and detailed framework that reflects the specific context of site management practices, and which makes provision for both explicit and tacit knowledge is therefore required. It is this need that this research has sought to address.

This paper presents a framework as a basis for integrating KM processes into site management practices. It starts with the research objectives and methodology. Knowledge management on the construction site management practices and its application is discussed. The stages of the integrated KM framework are described, and the findings from an evaluation workshop based on the application of the integrated KM prototype system are presented. It is concluded that the problem-based KM system can facilitate site managers to adopt knowledge management approach to addressing site management problem and minimise the negative impact of unpredictable problems.

RESEARCH OBJECTIVES AND METHODOLOGY

The rationale for undertaking this research was the need for well defined and systematic methods for managing knowledge on construction site. To fulfil this need, this study focuses on the development of a viable framework that reflects the specific contact of site management practices, and which makes provision for both explicit and tacit knowledge; underpinned by case study findings from constructions organisation that have implemented KM. The aim was achieved through several specific objectives of the research include:

- To review current site management practices, focusing on the key processes and actors involved and existing management procedures with a view to identifying current problems, and opportunities for improvement;
- To investigate knowledge management processes with a view to identifying those which are applicable at the construction site level;
- To develop a framework for improving site management practices based on an integration of KM processes;
- To encapsulate the framework in a computer-based prototype system; and
- To evaluate the prototype system and underlying model using industry practitioners and researchers.

Various research methodologies and strategies were adopted to achieve the defined objectives of the research. The initial strategies include extensive literature reviews; focusing on site management practices and knowledge management processes. The case study approach was undertaken after the initial stage to investigate the key problems of site management practices and to observe existing practice in managing knowledge on the construction site and opportunities for improvement. Several research tools were used include semi-structured interview, site observation and documents review. Drawing from literature on knowledge management, site management practices, together with the experiences and perceptions of the construction professionals interviewed, the study developed an integrated KM framework. Figure 2 summarises the research methodology adopted in this research project.

The case study findings and supported by literature review were used for development of integrated KM framework for construction site management. The integrated framework contains two main components. Firstly, a proactive approach - to take KM measures to avoid problems occurring. Secondly, a reactive approach - to tackle a specific problem that has arisen on site. Then, the integrated KM framework was encapsulated into computer based prototype system to simplify the format and use of the integrated KM framework. Finally, the evaluation of prototype system was undertaken during and after the development processes to validate the appropriateness and functionality of the developed prototype system.

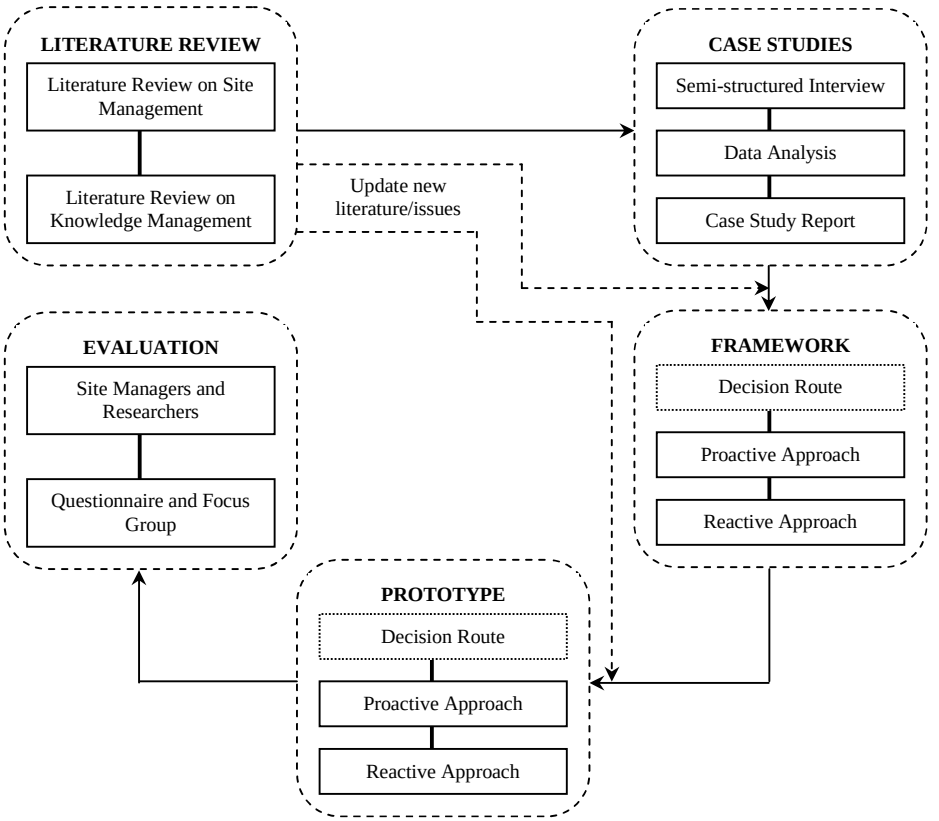

Figure 2: Research Methodology Adopted.

RELATED WORKS

Before developing a KM framework for construction site management practices, it is pertinent to analyse the ability of existing KM frameworks in construction with a view to compare their role, focus and level of detail. A study conducted by Rubenstein-Montano *et al.* (2001) revealed that the key limitations of existing KM frameworks are as follows:

- *Lack of overseeing framework*: The purpose of the framework is to direct work in a discipline. The frameworks can be classified as either prescriptive, descriptive, or a combination of the two. Prescriptive frameworks provide direction on the types of knowledge management procedures without providing specific details of how those procedures can be accomplished. In contrast, descriptive frameworks characterise or describe knowledge management. These frameworks identify attributes of knowledge management important for their influence on the success or failure of knowledge management initiatives;
- *Failure to address the entire KM process*: The KM frameworks should address the entire KM process. The KM process includes learning, organisational culture, strategy, tacit versus explicit knowledge, and KM tasks; and
- *Lack of details*: The KM framework must contain sufficient detail to be implemented. It should provide detailed steps of how to carry out KM expected outputs.

Table 1 shows the comparison of six existing KM frameworks developed in previous KM research in construction industry. The ratings are based on an analysis of the published information and verified additional information supplied by principle researcher on each of these. It is evident that research in knowledge management in construction has focused heavily on developing decision strategy, innovative techniques, and information technology tools for construction professionals to formulate and manage construction knowledge. Very little research has been done on understanding problem-based knowledge management as an

approach for managing knowledge at the construction site level. The KM-specific research projects presented in Table 1 adopts a broad view of the implementation of KM initiatives to improve project performance and have different levels of focus and maturity. It is observed that these research projects focused initially on the broad project management aspect of the construction process and do not address in adequate depth the underlying construction site processes which are rich with knowledge, best practices and lessons learnt.

Table 1: Comparison of KM Frameworks for Developing KM Strategies.

Element		**ConABKM (2004)**	**CLEVER (2005)**	**SELEKT (2005)**	**Project Histories (2004)**	**Audio Diary (2004)**	**C-Sand (2002)**
1. Problem based framework	Identify relevant site problem	✓	✓		✓✓	✓	
	Establish KM issues	✓	✓✓✓	✓	✓	✓✓	✓
	Develop KM initiatives	✓✓✓	✓✓	✓✓		✓	✓✓
	Evaluate the KM initiatives	✓					
2. Level of detail		✓✓✓	✓✓✓	✓✓	✓	✓	✓✓
3. Ease of use		✓	✓	✓	✓	✓✓	✓
4. Perspective		Project Level	Project Level	Project Level	Project Level	Site Level	Project Level

Key
✓ Good
✓✓ Fairly Good
✓✓✓ Very Good

Nevertheless, it is observed that some of the approach developed in the CLEVER (2005) framework can be fruitfully utilised for knowledge management at the construction site level. CLEVER (2005) framework is relevant because it enables the identification of the characteristics of the knowledge required and the key dimensions and transfer issues associated with it. The distinction between tacit and explicit knowledge is made and it is management differently. In the construction site context, although the Audio Diary research project concentrated on managing valuable experience on the construction site by developing an audio diary problem-solving event by Dictaphone, the developed framework only addresses the capture and dissemination of tacit knowledge and not contain sufficient details. Moreover, the approach of SELEKT framework can help site managers to explore the critical criteria (KM dimensions) of KM in order to select KM processes tailored to construction site management practices needs.

CASE STUDIES

To obtain more insight into the applicability of KM processes to improving existing site management practices, a five-step descriptive case studies approach (that incorporates qualitative comparators with observations made within five construction sites) was adopted. The main aim of case studies is to investigate the key problems of site management practices

and to observe existing practice in managing knowledge on the construction site. The case studies were based principally on semi-structured interviews with one site-based project manager in each of the companies. The interviewees under study were all experienced construction professionals which range from 16 years to 40 years experience in managing construction sites. The interviews were recorded, transcribed and returned to the construction organisation in order to ensure the validity of the transcript and also, in some cases, to gain additional information. This study was designed to seek variations in construction size and procurement method, which both play an important role in industry rivalry and profitability (Harris and McCaffer, 2001). These differences provide the opportunity for exploring variations in knowledge resources within and across construction site management contexts.

The case study findings revealed that 'management, supervision and administration' are the areas where problems occur most frequently on the construction site. They also identified services obstruction, poor site communication and information, incomplete design, local residents, and cooperation and motivation issues as major problems inhibiting construction site performance. Therefore, the site management team should be prepared to deal with on-site problems and risks in a systematic and efficient way. Knowledge management processes can be effectively used on the construction site to enable knowledge to be captured and reused in the future. Findings from the case study organisations also revealed that site management teams still do not have any systematic methods for the creation, capture, storage, sharing and reuse of a professional's domain knowledge of products, people and processes. Table 2 summarises aspects of KM in the case study organisations. The integration of KM into site management practices will address this and result in significant benefits to the construction project delivery process.

Table 2: Aspects of Knowledge Management in Case Study Organisations.

Unit of Analysis	Case A	Case B	Case C	Case D	Case E
Construction knowledge *	- 95% tacit - 5% explicit	- 50% tacit - 50% explicit	- 100% tacit	- 70% tacit - 30% explicit	- Depend on type of element
Approach to problem solving	- Informal discussion - Site meeting - Autonomous work package	- Quality control procedure - Refer to senior people and expert	- Previous team experience - Informal meeting with expert	- Discussion with sub-contractors - Consulting colleagues on-site and off-site - Refer to expert	- Draw from experience - Discussion with site management team - Refer to Technical division/expert
Approach taken when a mistake is made	- Meeting - Produce report (cause analysis) - Disseminate via intranet	- Problem identification - Lesson learned documented - Share via intranet	- Discussion internally - Circulate bulletin via intranet	- Register as non-compliance job - Document and record in project file	- Produce report (input for design team) - Share via KM system ' Tip Tops'
Knowledge sharing mechanisms	- Site meeting - Intranet	- Communities of practice - Intranet	- Monthly briefing talk - Seminar	- Informal meeting - Demonstrate example of the job	- Design meeting - Forum - Site meeting
IT tools and software used	- E-mail system - Central project file - Intranet system	- E-mail system - Intranet - BMS - Online PM system	- BMS - Online PM system - Intranet system - E-mail system	- E-mail system - BDMS - Intranet system	- E-mail system - Data store project file - online PM system - Intranet system
Role of Intranet	- Access information - Access project directory	- Managing construction knowledge - Access to company's BMS	• To support people • Access to BMS and company's information	- Access to process map - Access to BDMS and its content	- Communicate people - On-line training - Expertise information - KM system 'Tip Top'

***Respondent's personal perception rather than empirical study*

Key

BMS Business Management System
BDMS Building Division Management System

Framework development

The case study findings were revealed that construction site organisations have numerous mechanisms for managing their knowledge, although the label of KM is often not used. A problem-based KM framework was found essential for an effective and workable construction site KM framework. The framework developed as an integrated KM framework consists of proactive KM approach and reactive KM approach. The proactive KM approach is intended to support the institution of KM initiatives that will prevent the most common site management problems from occurring and to reduce the impact of those problems which do occur. These objectives form the basis of the five main stages of the proactive KM approach. The main element of this approach is a set of alternative solutions to resolve a specific site management problem. In contrast, the reactive KM approach is a nine-stage framework for identifying the knowledge gap that has led to a given site management problem and recommending measures to tackle the problem. The first decision point involves the site manager deciding, on whether to adopt a proactive or reactive approach to site management problems. The integrated KM framework can be used to solve site management problems for any construction site processes (planning, commercial management, material management etc.). Table 3 summarises the key stages of the KM framework. The framework can be used as a management tool to minimise the number of problems that occur on the construction site and reduce their impact (Mohamed and Anumba, 2005).

Table 3: Stages in the Proactive and Reactive KM Framework.

Stage - Proactive Approach	**Aim**	**Outcomes**
1. Specify SM process and problem to avoid	To specify construction site management process and potential problem that the site manager wishes to focus on.	Clarification of problem area (site management processes)
2. Identify relevant measures	To identify available measures for avoiding potential problems	Set of alternative measures to avoid problem
3. Implement measures	To take measures to avoid problems and to reduce the impact of problems if it does occur	Measures to avoid problem for each site management problem
4. Monitor and review	To assess the effectiveness of the measures taken	Monitor and review strategy for evaluating the impact of measures on construction site
5. Revise measures	To modify an existing measures so as to improve its effectiveness	Improvement plan with measurable indicators to identify ineffective action plan
Stage - Reactive Approach	**Aim**	**Outcomes**
1. Identify KM dimension	To identify whether problem is knowledge based or not	Clarification of the KM dimension in each specific problem
2. Determine if required knowledge is available	To discover if the knowledge to solve a given problem is available	Determination of the site manager's level of knowledge to solve a given problem
3. Identify the type(s) of knowledge required	To identify the type of knowledge required to solve the site management problem	Specific knowledge type(s) for typical site management problems
4. Identify the characteristics of knowledge	To identify the characteristics of the knowledge required. Use 'CLEVER' framework to support this stage (Anumba *et al.*, 2005)	Set of characteristics of the required knowledge
5. Select applicable KM processes	To facilitate the selection of the applicable KM processes	Appropriate KM processes for addressing a particular problem
6. Identify KM technologies and techniques	To identify KM technologies and techniques for the selected KM	Set of applicable KM technologies and techniques

	processes. Use 'SELEKT' framework to support this stage (Al-Ghassani *et al.*, 2005)	
7. Implement KM initiatives	To implement KM initiatives to assist the site manager in resolving site management problems	Implemented KM initiatives
8. Monitoring and review	To assess the effect of the KM initiatives in relation to what was meant to achieve	Report on effectiveness of implemented KM initiatives
9. Revise KM initiatives	To modify existing KM initiatives so as to improve their effectiveness	Revised KM initiatives and action plan

It may be useful for the site manager to view construction problem solving as a community activity: problem solvers do not operate within a vacuum but adopt and adapt solutions and methods practiced and learned in previous cases (Li and Love, 1998). The framework is appropriate to be a decision support for the experienced site manager. Alternatively, the framework can also be used collectively in a site management team, with the site manager acting as a facilitator. When using a framework, it is crucial to consider one site management problem at a time. This will provide a central focus for all stages in the framework. As such, this framework incorporates a part of the CLEVER (Cross Sectoral Learning in the Virtual Enterprise) framework, and thus has the capability to identify the characteristics of the knowledge required in an organisation. The CLEVER framework is a well-established KM framework developed at Loughborough University, which focuses on the definition and analysis of a knowledge problem in order to facilitate the selection of an appropriate KM strategy within an organisation (Anumba *et al.*, 2005). The framework also adopts a part of the SeLEKT (Searching and Locating Effective Knowledge Tools) framework which facilitates the selection of KM techniques and technologies in any given situation.

PROTOTYPE SYSTEM DEVELOPMENT

The integrated KM framework was encapsulated into computer-base prototype system using Microsoft Visual Basic, Version 6, program. The primary objective of KM-based construction site management system (also known as 'site-KM') is to facilitate site managers to adopt knowledge management approach to addressing site management problem. Abdullah *et al.* (2006) argue that there are several key benefits of knowledge management systems for the business organisation. These include:

- *Time saving*: The amount of time spent of doing the work manually is reduced;
- *Quality improvement*: The quality of decisions made increases because there are fewer errors than if decision were performed manually;
- *Practical knowledge made applicable*: Systems can assist managers in decision making even if they have that knowledge in hand; this improves the accuracy and timeliness of the decision made;
- *Reporting facilities*: Knowledge management systems can have built in reporting facilities that provide a written record of the rationale for a decision;
- *Learning tools*: Knowledge management systems can be used to disseminate manager knowledge in a structured manner; and
- *Productivity*: As manual processes are automated and the results of the decision-making process become error-free, so enterprise productivity improves.

To ensure that the desired features and objectives of the prototype are accomplished, system architecture for the prototype, illustrated in Figure 3 was developed. There are four main components provide a mean for developing a KM strategy in construction site management

practices. These components are ‘Site Management Problem’, ‘Establish KM Issues’, ‘Develop Initiatives’, and ‘Evaluation’. The solid arrows linking the four components indicate that entry and viewing on information is done forwards. However, the dash arrows at the bottom of the components show that the user can backwards to edit previous input for any component or part of element. For example, if user he/she think that the KM tools is not appropriate to implement KM initiatives, he/she can backwards to re-select the alternative KM tools that available in ‘Establish KM Issues’ component. In the last stage, the user will be allowed to evaluate the measures/KM initiatives implemented by monitor and review the selected measures/KM initiatives. If the users not fully satisfied with the current measures/KM initiatives, he/she can revise the measures/KM initiatives accordingly as illustrated in Figure 3.

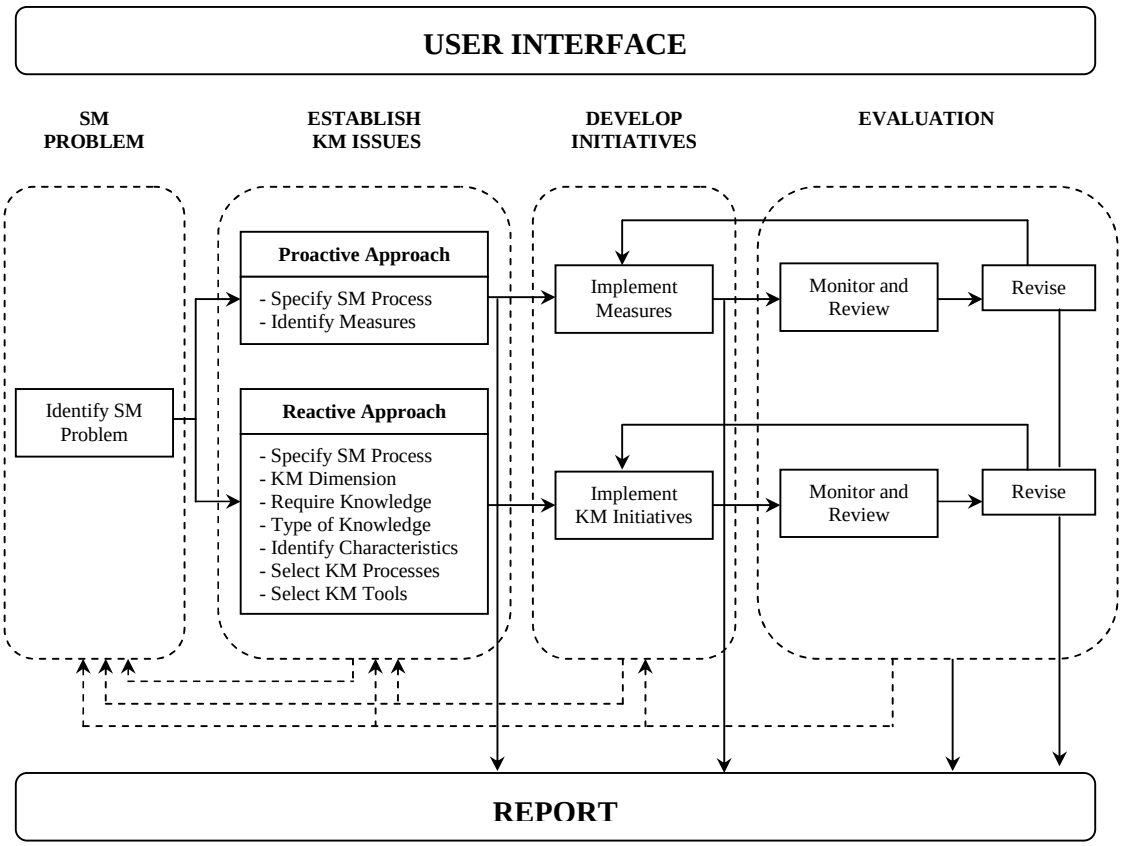

Figure 3: System Architecture of the ‘site-KM’ Prototype.

The arrow linking the elements to the report show that the input, once entered, is immediately sent to the report and instantly modified if input is edited during the process. The report for reactive and proactive KM is generated separately and presented as summary of output as created by the users. This report can also be used as a reference document for the site managers when developing problem based knowledge management strategy on the construction site.

The prototype system was evaluated with a view to determine the appropriateness and functionality of the developed system in improving site management practices. The focus group approach was adopted to evaluate the prototype system, which involved four site

managers and 10 university-based researchers. The evaluation workshops were undertaken consists of three main elements: presentation on the background to the prototype system, demonstration, completed an evaluation questionnaire and discussed key issues relating to the system. The relevant comments and suggestions were used to refine and improve the prototype system. Majority of the participants made at least one comment in the evaluation questionnaire and discussion session. The main suggestion was to develop more generic KM system on construction site, which allows the site manager to customise the construction site management processes. Majority of the site managers also suggested that site management team need a proper training before implementation on construction site. The other suggestions for research area include:

- Need to improve the system by the input of further data as more projects are included;
- Link and integrated the prototype system into existing intranet/extranet on the construction site; and
- Dynamically updated fields and information stored in the system database (e.g. tools in the KM techniques and KM technologies database) to ensure the prototype system remain effect

The 'site-KM' prototype system is essentially a problem based knowledge management framework on construction site. The relevancy and capability of these tools for addressing site management problems has been confirmed and verified through evaluation workshop. Moreover, through the evaluation workshop the participants identified several benefits of the prototype system, which include:

- The systems provide a new and innovative approach for avoiding problem and minimising its impact and for solving problems or finding help to solve new problems;
- The systems can be used by site manager as a problem solving methodology usable on any construction site and scalable to any type of project;
- The systems can be used as learning tools. The main function is a training aid for junior site manager, where in current site management practices there is a very little information available;
- The systems provide site manager a well defined and systematic approach to identifying characteristics of knowledge, 'sources' and 'destination' of knowledge, applicable KM processes and KM techniques and technologies;
- The systems provide details required when developing KM initiatives/measures (e.g. action plan, tools required, etc.);
- The systems provide a structured and workable approach of documenting and presenting the processes that site managers should follow to addressing problems on site; and
- The systems provide a simple and relevant tool for evaluating a KM initiatives or measures so as to improve their effectiveness in a given situation.

CONCLUSION

This paper has described an attempt for improving site management practices based on the integration of applicable KM processes. This has involved an analysis of site management problems and improvement opportunities through five detailed case studies. The case studies highlighted the key problem areas as well as the opportunities for using KM to improve site management practices. The research has demonstrated the potential of KM to significantly

improve construction site management practices if appropriately managed. An integrated KM framework for the enhancement of construction site management practices through an integration of knowledge management processes was introduced. The integrated framework provides a structured KM approach at an operational level that is simple to use and easily deployable as a problem-solving methodology usable on any construction site. The framework was encapsulated into prototype systems, which aimed to simplify the format and use of the integrated KM framework. The construction site managers should take advantage of the prototype system developed in the research as it provides many benefits particularly in facilitating site managers to reduce the number of problems that occur on construction site and minimise the negative impact of unpredictable problems

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A Conceptual CBR Model for Health and Safety Competence Assessment

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Abstract
Employing Health and Safety (H&S) competent duty-holders in the inception of a project is an important provision stipulated by UK construction H&S legislations. However, evidence demonstrates that the current practice of H&S competence assessment is full of unnecessary bureaucracy, procedure and paperwork and adds little value to the project. In order to improve the performance of H&S competence assessment, Health and Safety Executive (HSE) initiated to apply standardised evaluation criteria at corporate/organizational level and the individual level to replace the ubiquitous competence questionnaire. Since H&S competence assessment is a multiple criteria binary classification problem with non-linear, qualitative and semantic assessment features, it is difficult for practitioners to make proper decisions on selecting H&S competent duty-holders. Such a decision-making process requires a large amount of knowledge, experience and heuristics. However, present Artificial Intelligent (AI) technologies have been identified as an effective means of dealing with knowledge-intensive problems. It is thus hereby proposed to investigate usable features of different AI technologies and find an appropriate tool assisting the application of standardised H&S competence assessment criteria. A literature review of standardised criteria and AI technologies is presented, while a qualitative screening process is carried out to envision a conceptual model and development framework of a Case-Based Reasoning (CBR) Knowledge-Based System (KBS) for H&S competence assessment.

Key Words: Construction Health and Safety Management, Construction (Design and Management) (CDM) Regulations, Health and Safety Competence Assessment, Artificial Intelligent (AI) Technologies, Case-based Reasoning

Introduction

Health and safety (H&S) issues have been significantly taken into account in the construction industry in recent years. Concerted efforts, such as

- setting 'revitalising targets' to cut fatalities as well as minor and major injuries,
- holding construction H&S summit to review and resolve H&S problems, and
- modifying H&S legislations to fit the new circumstances,

have been made to achieving a sustained improvement in health and safety performance. However, the construction is still notorious for its poor safety record when compared with other industries.

Evidence suggested that knowledge and experience of construction processes and H&S issues were vital for appropriate design and for the production of risk assessments and method statements (HSE 2005). The lack of certain skills or knowledge would lead to errors that contributed to the incident (Wright, et al, 2003; HSE, 2003). It is hereby self-evident that competent duty-holders with sufficient knowledge and experience could ensure the well being of those who work in the industry and those who subsequently operate, maintain and eventually decommission the facility (Carpenter, 2006). An incompetent duty-holder, whereas, could bring about prosecution as a result of an accident on site.

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Construction legislations stipulate that employing H&S competent duty-holder is an important responsibility of relevant practitioners. For example, the Construction (Design and Management) (CDM) Regulations 1994 requires all duty-holders to take on the responsibility of appointing competent sub-duty-holders when necessary. Furthermore, the draft of new CDM regulations imposed strict requirements on Clients to nominate competent duty-holders. However, legal provisions and corresponding Approved Code of Performance (ACoP) only provide duty-holders with a general guideline that is too brief to help them carry out H&S competence assessment.

A Standardised Approach for Construction Health and Safety Competence Assessment

In order to establish good practice in the selection of duty-holders (Designers, Planning Supervisors and Contractors) according to the CDM Regulations and set out reasonable techniques for such a selection, from August 2004 to September 2005, HSE launched a research to investigate the current practice and view of health and safety competence assessment in the industry. As a result of this research, a standardised approach for H&S competence assessment was proposed to setup reasonable yardstick assisting efficient and effect judgment.

The standardised approach categorises competence into two levels: the corporate/organisation level and the individual level. Corporate competence was defined as '*a culture within an organization that actively considers the health, safety and welfare of its own people, and of those that its work activities affect, with this being achieved through active management and participation of employee*'(Carpenter, 2006). A group of standardised 'Core Criteria' is presented to fit organisations of any size and cut off unnecessary and bureaucratic standard pre-qualification competency questionnaire. The Core Criteria digested from relevant legislation requirements and competence accreditation schemes are consistent standards of evaluating duty-holders' H&S competency in construction. A two-stage assessing process is recommended to implement the Core Criteria check. Stage 1 refers to general assessment of an organisation's H&S culture and management. 14 Core Criteria are introduced as a systematical means by which the duty-holders can demonstrate their capabilities in the following aspects:

1. Health and Safety Policy and Organisation for Health and Safety
2. Arrangements
3. Competence Advice – Corporate and Construction related
4. Training and Information
5. Individual Qualifications and Experience
6. Monitoring, Audit and Review
7. Workforce Involvement
8. Accident Reporting and Enforcement Action; Fellow up Investigation
9. Sub-contracting/consulting procedures (if applicable)
10. Design and Hazard Management (Designers)
11. Risk Assessment Leading to a Safe Method of Work (Contractors)
12. Managing Interfaces between yourself (Contractor or Designer) and other Contractors
13. Co-ordinator (Planning Supervisor in CDM 1994) Functions
14. Health and Welfare (Contractors and Designers)

Due to the diversity of construction project, specific work experience is an element no less important than the generic criteria. Stage 2 therefore focuses on checking the former working experience in the field of work which duty-holders are suppose to apply.

On the individual level, the standardised criteria include

1. Task Knowledge: appropriate for the tasks to be undertaken. May be technical or managerial;

2. Health and Safety Knowledge: sufficient to perform the task safely, by identifying hazard and evaluating the risk in order to protect self and others, and to appreciate general background; and
3. Experience and Ability: sufficient to perform the task (including where appropriate an appreciation of constructability), to recognise personal limitations, task related faults and errors and to identify appropriate actions.
The membership or certificate of relative professional institutes is usually treated as the evidence of individual competence, although some criticisms have been shed on the institutions in respect of the lack of knowledge and ability of some of their members, and their membership procedures (ibid).

Establishing consistent H&S competence assessment criteria in the industry could improve the efficiency and reduce bureaucracy. However, as stipulated in regulation 8 of the CDM Regulations, to be 'reasonably satisfied' the duty-holders' competence implies that the appointers should know how to appropriately evaluate those criteria. Since competence is not demonstrated simply by academic qualification (Joyce, 2001), Carpenter (2006) put forward a judgment approach clarifying key assessment evidence of competence criteria. In terms of the assessment process, the competence criteria could be categorised into four types:

- Procedure-related criteria: Documented procedure of arranging a specific H&S issue, such as H&S arrangement, should be provided as the evidence of a systematic problem-solving process and well-developed health and safety culture;
- Example-related criteria: The past examples of dealing with certain health and safety issues, such as Design hazard management, are required as the evidence of practical abilities;
- Data-related criteria: Relevant data of important documents, action plan, and performance/qualification record should be in place to demonstrate the consistency of ability in relation to the health and safety issues, such as Training and Information; and
- Numberic-related criteria: The percentage rate of holding appropriate professional qualifications among employees could show the level of competence in an organisation. Only is one criterion, Individual Qualification and Experience, in this group. However, this criterion would be expunged when all practitioners were expected to have appropriate qualifications by 2010.

Overall, assessing duty-holders' H&S competence is a kind of regulation-compliance checking process in which the assessor compares the documents and specific cases provided by candidates with the bespoken standards, and then make a judgment according to his personal knowledge, experience and rule of thumb. Therefore, it is self-evident that the H&S competence assessment is a knowledge-intensive decision-making process requiring specialised knowledge in construction H&S management, affluent working experience and accumulated heuristics.

At present, the state-of-art artificial intelligent (AI) technologies have been extensively used to provide an efficient and effective means of which the computer can do things that would require intelligence if done by humans (Negnevistsky, 2002). Many AI research efforts on boosting productivity or efficiency have been carried out in different construction disciplines. However, AI technologies have seldom been applied in H&S competent assessment to date. It is hereby take into granted that AI technologies could be used to facilitate the selection of H&S eligible duty-holders.

Selecting Appropriate AI Technologies for H&S Competence Assessment
Human's intelligence is their ability to learn and understand, to solve problems and to make decisions (ibid). The simplest and most popular definition of AI is "making computers think like people" (Giarratano & Riley, 2005). After around 60 year's development, AI technologies have become a full-fledged science enabling a computer to achieve the human-level

performance in cognitive tasks. A large number of expert knowledge-based systems (KBS) have been developed by using AI technologies to solve problems that are difficult enough to require significant human expertise for their solution (ibid). In a KBS, AI technologies are usually applied in the reasoning process to emulate the thought process of an expert while dealing with a certain domain problem.

'Knowledge acquisition bottleneck' has been identified as a significant obstruction in the knowledge transferring process from human expert to the KBS (Negnevistsky, 2002). The possible effective way to overcome this problem is to clarify the characteristics of related expert knowledge, and then select appropriate AI technologies to build up the reasoning process. In the light of the characteristics of four types of standardised evaluation criteria, the expert knowledge of H&S competence assessment is cognitively complex and tacitly pragmatic. The decision-making process could be attributed as:

- Qualitative in nature: Decision-making is largely related to the regulation-compliance documents checking.
- Subjective judgment: Decision could vary according to personal knowledge and experience; and
- Linguistic format: Most of judgment is expressed or justified through descriptive natural language.

In accordance with the requirement of 'eliminating the incompetent' not necessarily 'identifying the most competent' by HSE (Carpenter, 2006), the outcome of this competence assessment can be simplified into a two category – competent or incompetent. Therefore, H&S competence assessment is a multiple criteria binary classification problem. The selection of AI technologies dealing with such a problem should take the following considerations into account:

- Linguistic evaluation: Transfer vague and ambiguous evaluation terms such as good, fair or poor into the reasoning process.
- Non-linear knowledge representation: Create non-linear relationship between multiple input criteria (standardised criteria) and binary output variables (competent or incompetent). This is the key point while selecting an appropriate AI reasoning technology.
- Intelligent explanation: Provide clear semantic explanation for knowledge learning. This was strongly recommended by HSE in order to give SMEs an web based facility providing an indication of readiness (ibid)

Table 1 presents the proposed AI technologies capable of satisfying the above three requirements.

Required Functions	**AI Technologies**
Linguistic evaluation	Case-based Reasoning, Fuzzy Logic
Non-linear knowledge representation	Case-based Reasoning, Fuzzy Logic, Neural Networks, Genetic Algorithm
Intelligent explanation	Rule-based Reasoning, Case-based Reasoning

Table 1: AI Solutions for Required Functions

In the light of Table 1, Case-Based Reasoning (CBR) has the preference over other alternatives tackling the current problem. In addition, former research focusing on contractor pre-qualification decision-making, a similar non-linear two-group classification problem, have applied CBR (Ng, 2001), Fuzzy Logic Reasoning (FL) (Juang et al, 1987) and Artificial Neural Networks (ANNs) (Lam et al, 2000) to establish non-linearity, uncertainty and imprecision models for competence evaluation. Although each alternative has its own pros and cons in the practical application, CBR has more advantages in solving such a multi-criteria binary classification problem.

First of all, CBR can represent cases by a number of fields in various readable forms such as numerical, logical, alphabetical, and strings (Arditi and Tokdemir, 1999). ANNs and FL need to transfer data from text format into numerical format for the reasoning calculation.

Secondly, CBR applies simple computable algorithm in its case indexing, retrieving and adapting process (Kolodner, 1993). ANNs need to rely on a complicated training process such as Back Propagation (BP) learning law to assign synaptic weights of all neurons. The extensive calculations even could result in slow training process (Negnevitsky, 2002). Although the fuzzy inference is not as complex as ANNs, it is difficult to determine the term membership function for the competence criteria (Lam et al, 2001).

Thirdly, CBR can provide an intelligent explanation mechanism that can adapt former similar phenomenon to fit the current situation (Kolodner, 1993). For ANNs, It is difficult to combine with explanation facility because of its 'black-box' reasoning process. Although, FL can use fuzzy rules to express the reasoning process, the work of configuring a large number of rules is quite cumbersome for a multiple input criteria problem.

Last but not least, CBR is capable of automatically adding new cases in the cases' library and using them in future. Such an iteration of solving problems and recording corresponding solutions in CBR can extensively expand its knowledge base and enhance the ability of solving future problems. ANNs and FL are limited by their reasoning algorithm and can't expand their expert knowledge in practice. Apart from the above points, CBR is also characterized by the following advantages (ibid):

- Fast resolution achieving;
- Effectiveness in interpreting open-ended and ill-defined concepts;
- Usefulness in warning of the potential for problems that have occurred in the past and alerting a reasoner to take actions to avoid repeating past mistakes; and
- Help in highlighting the important parts of a problem in the reasoning.

Of course, no technique is completely perfect. CBR has its own limitations such as:

- Knowledge may be misapplied
- Sometimes the requirement of a large case base
- Difficulty to determine good criteria for indexing and matching cases.

However, in the light of the above analysis, it is envisaged that CBR could be applied to create a web-based KBS for construction H&S competence assessment.

The Conceptual Architecture of CBR for H&S Competence Assessment

According to the basic working theory of CBR, Figure 1 illustrates the conceptual architecture of CBR for H&S Competence Assessment.

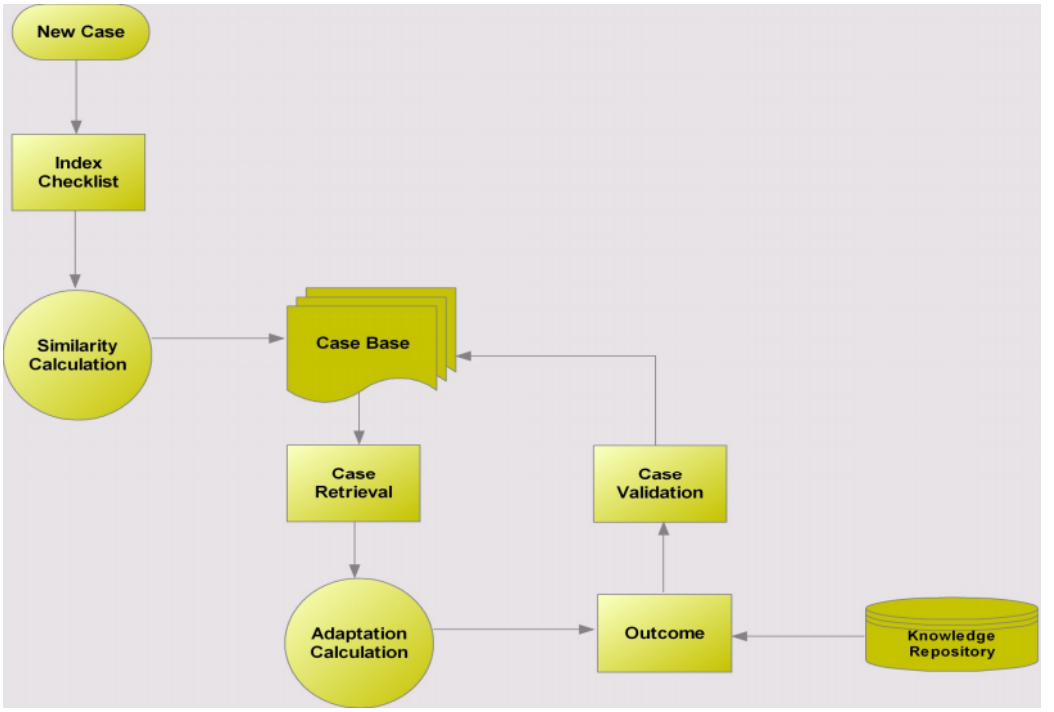

Figure 1: Conceptual Architecture of CBR for H&S Competence Assessment

The core component of this CBR system is the Case Base containing sufficient historical competence assessment cases that have been evaluated by experts according to standardised criteria. When a new case (candidate duty-holder) needs to be assessed by this system, an Index Checklist extracted from former cases should be filled in to supply relative parameters for the Similarity Calculation. As the result of Similarity Calculation, the ballpark case is retrieved from the Case Base. Afterwards, Adaptation Calculation is activated to adapt the result of former case to fit the current case. Outcome is a straightforward result telling whether the duty-holder is competent for the present project. If incompetent case occurs, the Knowledge Repository provides candidates with suggestion for further improvement. Meanwhile, the Knowledge Repository could be used as an e-learning facility providing relative knowledge for construction H&S management. All new cases is stored in a temporary database for further Validation by experts, and then added into the Case Base.

The Conceptual Development Methodology

Since case representation, indexing, retrieval and adaptation are four important techniques making up CBR (Watson, 1997), the development of this CBR system will take them into account in three main phases (Figure 2).

Phase One: In order to clearly represent competence assessment case, standardised criteria need to be broken down into sub-criteria depicting key features of the case. Index checklist also should be selected to support quick case searching. Relative documents and domain experts might be used as two resources for data collection, classification and validation.

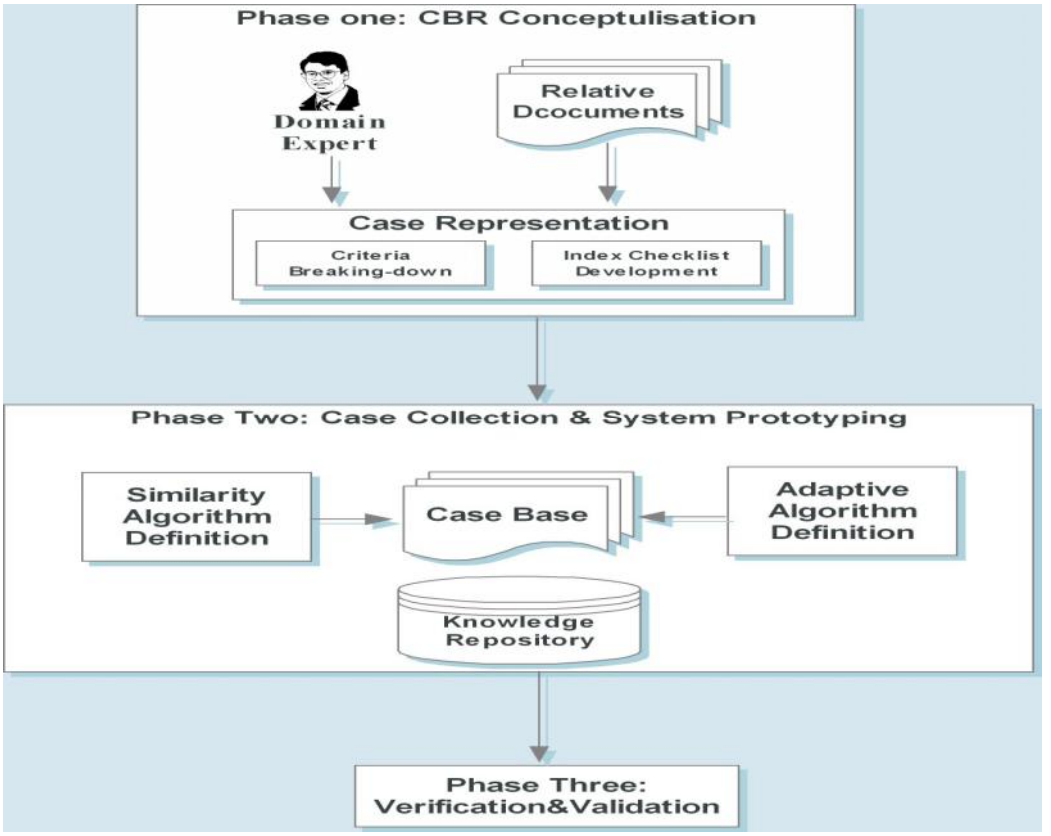

Figure 2: General CBR Development Process

Phase Two: The retrieval of cases is related to select the most similar stored case with the current case and decide whether or how to adapt former solution to match the target case. Similarity and adaptive algorithms should thereby be carefully designed for the success of the CBR. Sufficient cases could be collected from the reality or hypothesized by experts to establish a sound case base, while a knowledge repository of construction H&S knowledge, including legal requirements, technique explanations and practical heuristics, is developed.

Phase Three: Verifying is a white-box process that analyzes the rules for sequence, structure, and specifications (Awad, 1996). After the CBR system is prototyped, testing cases will be fed in to verify the correctness of each working component. In sequence, the CBR system should be applied in practice to validate whether it can generate practicable and robust recommendations regarding H&S competence to different duty-holders.

Conclusion

Duty-holder's competence assessment is the first and crucial link in the whole chain of construction project H&S management. H&S qualified duty-holders can minimise the possibility of accidents in the construction process and maximise the project value for the client. Due to the increasing legal burden of selecting H&S competent duty-holders, there has been an emergent requirement of clarifying the relevant responsibilities and practicable code of performance from the industry. After an extensive research, Carpenter (2006) recommended duty-holders standardised criteria for a systematic H&S competence assessment. However, it is quite difficult to handle such a knowledge and experience intensive task without an appropriate tool for most practitioners, especially a lot of one-off clients. Brief guideline is not effective and efficient enough to facilitate duty-holders to make correct appointment decisions in various projects. Standardised H&S competence criteria were recommend by HSE as a consistent evaluation standard for H&S competence assessment. Presently, with the fast development of Information Communication

Technologies (ICTs), AI technologies have been widely used as decision support tools to improve the effectiveness of many complicated knowledge-intensive works through emulating the thought process of human experts. CBR was envisaged as an appropriate tool to help duty-holders deal with this multi-criteria binary classification problem according to the analysis of knowledge characteristics of current problem and the comparison of available AI technologies. A conceptual architecture of CBR was illustrated to develop a web-based KBS as an intelligent decision-making device and e-learning facility to aid the correct duty-holders appointment and relative knowledge sharing. The development methodology was finally conceptualised as a guideline for the future research. Other than the considerations in three important development phases, several issues for a practicable system also need to taken into account as followings:

- Efficient web programming language for fast case retrieval
- Appropriate case validation process convenient for the case-base expanding
- User-friendly Graphical User Interface (GUI) development
- Useful knowledge representation in the knowledge repository for different levels of practitioners

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COLLABORATIVE BENCHMARKING PROCESS BETWEEN CONSTRUCTION COMPANIES FOR FACILITATING KNOWLEDGE PROCESS AND ORGANISATIONAL LEARNING

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Abstract

The link between benchmarking, inter-organisational collaboration and organisational learning has received some attention in the literature. Benchmarking has been viewed recently as a process for assisting organisational learning, and also has been considered a strategy for knowledge acquisition. However, the understanding of how knowledge is transferred and the ways of this knowledge is created in the organisations has not been properly investigated in collaborative benchmarking process. The main aim of this ongoing thesis is to develop a framework for inter-organisational collaborative process between construction companies for facilitating knowledge creation and organisational learning. The action research was used as the main research strategy aiming to understand the inter-organisational collaborative process and also the changes achieved by the companies. The initial findings indicated that, the collaborative benchmarking processes had the role of inductor of the learning process, encouraging the transfer and adaptation of knowledge to the companies' context.

KEY WORDS

Benchmarking, collaborative process, knowledge creation, knowledge transfer organisational learning, performance measurement

INTRODUCTION

In recent years, the organisations everywhere have been investigating about the opportunities and difficulties associated to the sharing and transfer of best practices both inside and outside of the organisations. The literature in areas of knowledge management and organisational learning points out that the benchmarking process may be considered as a strategy for knowledge sharing, acquisition and transfer (Garvin, 1993; Dibella et al., 1996; Probst et al., 2002 and Davenport and Prusak, 2003).

The traditional concept of benchmarking refers to a continuous, systematic process of evaluation the products, services and work procedures of organisations that are recognized as representing best practices for the purpose of organisational improvement (Spendolini, 1992). This concept emphasises a competitive type of benchmarking, which is conceived as a measure to assist the gaining of superiority over others (Wolfram Cox et al., 1997).

By contrast, collaborative benchmarking refers to a group of firms, which share knowledge in a particular activity, all hoping to improve based upon what they learn (Boxwell, 1994). The aim of collaborative benchmarking is learning with others rather than gaining position over them. The dominant relationship is joint collaboration and partnership rather than competition, and there is discussion among members, considering the factors, which affect the group as a whole (Wolfram Cox et al., 1997).

The openness and richness of inter-organisational collaborative processes are believed to foster a fertile environment for the creation of new knowledge, while also accelerating the

innovation rate (Seufert et al, 1999). One advantage is the opportunity to encourage product and process innovation and the development of new skills in more controlled and lower risk way (Barlow and Jashapara, 1998).

In the construction industry there have been several initiatives in different countries, such as USA, UK and Chile, which aim to develop collaborative benchmarking processes through Benchmarking Clubs (Constructing Excellence, 2004; Construction Industry Institute, 2002; Grillo and Garcia, 2003). Those clubs can be defined as forums for individuals to learn from best practices, while creating a local support network for continuous improvement (Constructing Excellence, 2004). In general, those initiatives involve a set of similar companies that compare results and share practices.

However there is a knowledge gap in these initiatives, which refers to the understanding of how the knowledge shared in this environment is transferred to the companies and what are the impacts inside the companies due to the sharing of knowledge in terms of knowledge creation and organisational learning.

CONTEXT OF THE STUDY

In Brazil, an ongoing initiative, called SISIND-NET Project, has been developed since April 2004 by the Building Innovation Research Unit (NORIE) of the Federal University of Rio Grande do Sul (UFRGS) and the Association of Construction Companies from the State of Rio Grande do Sul (SINDUSCON/RS), with the support of the National Council for Scientific and Technological Development. It involves the design and implementation of a Performance Measurement System (PMS) for Benchmarking in the construction companies through a collaborative process.

During the development of this project, the objective of the study was broadened, thus also focusing on how to develop collaborative processes among construction companies aiming knowledge creation and organisational learning. Thus, some concepts of benchmarking process have been used as a strategy to conduct this club aiming to encourage knowledge acquisition, sharing and transfer. And also, some concepts of knowledge creation and organisational learning have been used as a theoretical basis to analyse the changes achieved by the companies due to the collaborative process.

aiM OF THE research

The main aim of this thesis is to develop a framework for inter-organisational collaborative process between construction companies for facilitating knowledge process and organisational learning.

The objectives are:

- **To establish a set of factors, which influence the transfer of knowledge from collaborative groups to the companies;**
- **To identify facilitating conditions and barriers for facilitating knowledge process and the organisational learning in the companies;**
- **To evaluate the effect of the collaborative process in knowledge and learning processes.**
- **To establish guidelines for the formation of benchmarking collaborative group aiming knowledge creation and organisational learning.**

Research Method

The action research methodology is used as the main strategy aiming to understand the collaborative process which has taken place between the set of construction companies and also the changes achieved by the companies related to the measurement process and

performance comparison. The action research has been developed through cycles, which includes: Diagnosing (D), Action Planning (AP), Action Taking (AT), Evaluating (E) and Specifying Learning (SL) (Eden and Huxman, 1996). Moreover, the author of this paper has been acted as the facilitator of action research.

The research also includes the review of the literature, the preparatory stage, *two ex post facto case study* (Chilean PMS benchmarking program and UK KPI Program), the action research data analysis stage, as well as the development of a framework for inter-organisational collaborative process between construction companies aiming to knowledge creation and organisational learning (see Figure 1).

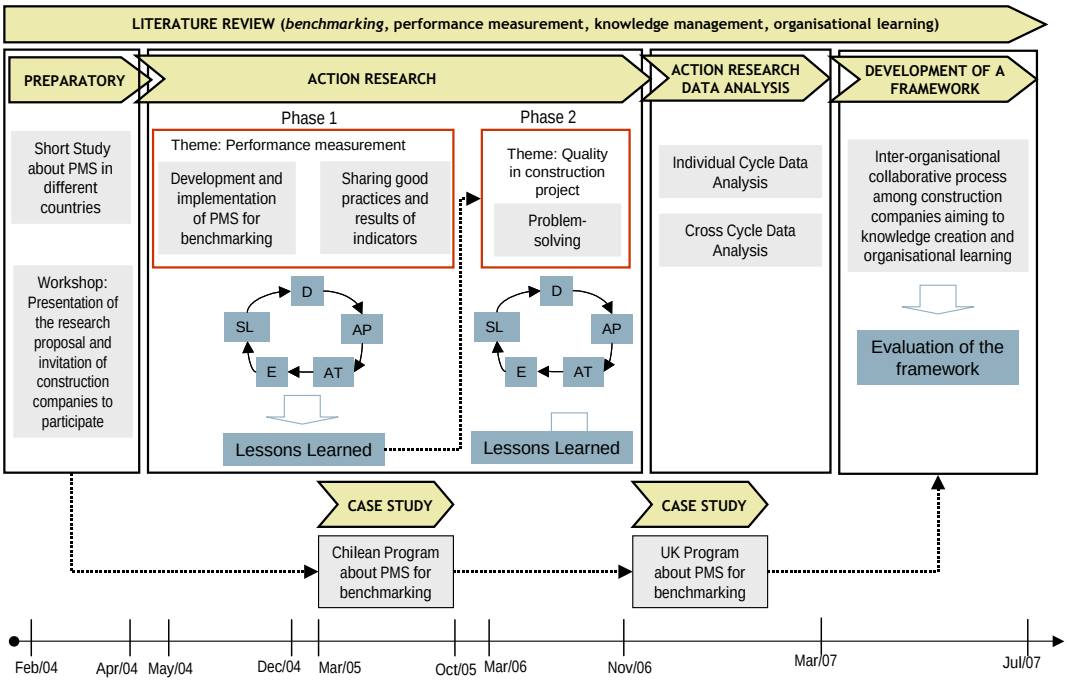

Figure 1 - Research Design

In the preparatory stage, a short case study was carried out on international initiatives in three different countries: USA, UK and Chile aiming to identify the scope of the performance measurement system for benchmarking developed in each programme, and also to learn lessons concerning the conceiving and implementation of these measurement systems. Besides this, a workshop was organised aiming to present the research proposal to the local construction companies and also to encourage some of them to participate of the research project.

The action research occurred in the benchmarking club, which has been operating since May 2004. The action research had two different phases. The first phase aimed to experiment how to develop the benchmarking collaborative process and identify the impacts of the actions promoted inside the companies. The theme discussed in this phase was performance measurement, and operated from May 2004 until October 2005. This phase included two cycles: (1) the development and implementation of the PMS for benchmarking and (2) sharing good practices and results of indicators. The second phase aimed to consolidate the benchmarking collaborative process, using the lessons learned from the first phase aiming to improve the strategies to conduct the process as well as to enhance the potential of knowledge creation and organisational learning inside the companies. The theme, which was chosen by the companies, was quality in construction projects. Table 1 presents the main characteristics of each phase and cycle of the action research.

Table 1 – Characteristics of the Action Research

Characteristics	**First Phase**		**Second Phase**
	Cycle 1	**Cycle 2**	**Cycle 3**
Aim	• Define the set of measures for benchmarking and to motivate the companies to implement this system. • Promote an environment for sharing.	• Allow the companies to share practices and results of the indicators. • Establish a sharing learning environment, thus motivating the knowledge transfer.	• Create an environment in which the companies would share their problems with other, understand them and find their own solution.
Operating since-to	May 2004-Dec 2004	March 2005-Oct 2005	March 2006-Nov 2006
No construction companies	18	14 (12 of them participated in the first cycle)	7 (all participated in the first and second cycles)
No of meetings and visits	Nine meetings	Six meetings and Three visits to construction sites of member companies	Nine meetings (until Oct.). One more meeting and two visits will happen until Nov.
Facilitator	Author	Author	Author (until Sep.)
Main actions	• Definition of each measure of the system (objectives, formulae, data collection and analysis procedures). • Training of the PMS • Discussion of the first steps of the implementation	• Sharing of good practices (health and safety, layout and logistic of construction sites, cost management and good measurement practices) • Establishment of data validation routine • Development and implementation of the Online Measurement System (project website) • Seminar for disseminating the findings	• Definition of the process to be investigated • Understanding and sharing the problem • Planning actions to solve the problem • Implementing the actions planned • Reflecting about the results
Strategies used to conduct the club	• Elaboration of the first draft of the measure procedure before the meeting and based on the criteria adopted in each company. • During the meeting, the discussion followed the measure procedure previous developed. • The review of this procedure was carried out based on the discussion. • Sharing of the implementation process	• Establishment of three rules to conduct the club: (a) regular participation of the members in the meetings and site visits; (b) sharing of equivalent information among member companies; and (c) making stimulating questions to encourage the real understanding of the practices presented. • Handouts with questions provided at the beginning of the meeting. • The good practices were presented by the members of the club • Visits to construction sites of members companies.	• Application of three rules to conduct the club: (a) regular participation of the members in the meetings and site visits; (b) sharing of equivalent information among member companies; and (c) making stimulating questions to encourage the real understanding of the practices presented. • Invitation of expertise to present good practices • Visits to construction site of member companies as well as other company from automotive industry.
Data Collected in the Club	• Minutes of the meetings • Presence of the members • Notes of the researcher during the meetings.	• Minutes of the meetings • Presence of the members • Notes of the researcher during the meetings. • Answers of the members concerning the handouts with questions provided at the	• Minutes of the meetings • Presence of the members • Notes of the researcher during the meetings.

		beginning of the meeting.	
Data Collected in the companies	• Two semi-structure interviews with 18 participants companies, one to characterise the company and its PMS and other to identify the implementation process. • Analysis of documents.	• Meetings for data validation • Meetings for data analysis supporting in some companies • Semi-structure interview and questionnaire to evaluate the impact in the 10 companies highly involved. • Analysis of documents. • Results of the measures provided.	• Two meetings to help the understanding of the problem. • Semi-structure interview to evaluate the progress of the collaborative process in the 5 companies highly involved.

Simultaneously to the development of the action research, two specifics *ex post facto* case studies were proposed aiming to complement the results about the initiatives of PMS for benchmarking in Chile and UK, which were obtained in the preparatory stage. The study case about the Chilean initiative was carried out in March of 2005 and the KPI UK initiative will start in October 2006. These studies will contribute to a better understanding about the best practices in these countries and how these practices can be transfer to different contexts.

The action research has been analysed according to two units of analysis: the benchmarking club and the companies, and it was divided in two parts: individual cycle data analysis and cross cycle data analysis. Five main constructs were established, being two of them related to the benchmarking club: (a) collaborative process among companies and (b) strategies to lead the collaborative process; and three of them related to the companies: (c) degree of implementation, (d) degree of knowledge transfer and knowledge creation and (e) degree of changes promoted in the companies. Figure 2 presents the scheme of data analysis and the main sources of evidence.

a) **Collaborative process among companies** means identify the nature of the problem discussed, the interest of the members concerning the theme, the sharing knowledge as well as the involvement of the members in order to solve the problem.

b) **Strategies to lead the collaborative process** means identify the influence of the strategies and assumptions adopted in the study in order to promote the collaborative process, and also the acting of the Facilitator in this process.

c) **Degree of the Implementation of the PMS** evaluates in which extent the categories established by Costa (2004) were implemented: measure definition; alignment of measures to strategies; insertion of measures into the company routine; use of benchmarking, and learning achievement through measurement.

d) **Degree of knowledge transfer and knowledge creation** means identify to which extent the knowledge acquired by the individual in the collaborative process was socialised, externalised, combined and internalised in the companies (Nonaka; Takeuchi, 1995).

e) **Changes Inside the Companies** evaluates in which extent the companies learned concerning two aspects: learning focus, which refers to the learning was concentrated on improvements in work procedures (incremental changes), the identification of new insights or knowledge (adaptive changes) or changes in existing principles (innovative changes) (Sweringa and Wierdsma, 1995, Argyris and Schön, 1995; DiBella et al., 1996); and the skill development focus, which assess the learning was achieved by the individual, a group of people or included the organisational as a whole (Nonaka; Takeuchi, 1995; DiBella et al., 1996).

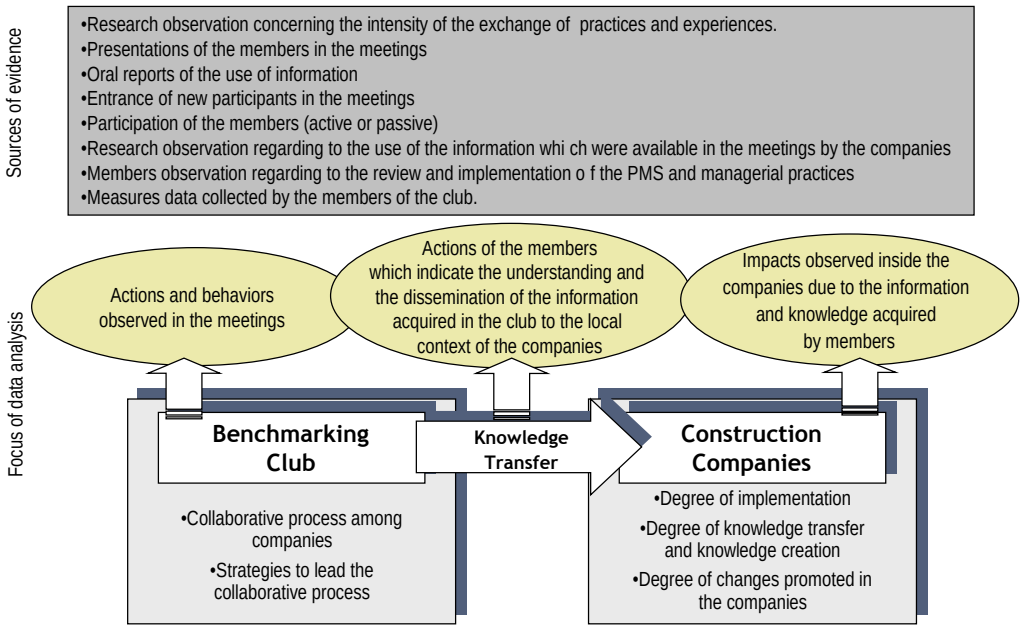

Figure 2 – Scheme of data analysis and the main sources of evidence

CORE ELEMENTS OF THE INTER-ORGANISATIONAL COLLABORATIVE PROCESS

The identification of the core element in the inter-organisational collaborative process among the construction companies was based on the findings of the first phase of the action research. The second phase has been analysed aiming to confirm or not the elements proposed.

The learning process of the benchmarking club occurred through discussion, sharing of ideas, and experimentation. The findings indicated that due to the negotiation of the meaning for the definition of data collection criteria and the discussion provoked, the representatives of the companies involved understood well the set of measures and they were aware of the relevance of each measure. Thus, the companies started a sharing process of ideas and practices, because the representatives manifested their experiences and opinions during the definition of the measures. Consequently, the members realized that they built together a set of measures, and they identified themselves with the result achieved.

Moreover, aiming for the consolidation of the collaborative environment some strategies were used aiming to stimulate the sharing of knowledge and the acquisition of knowledge related to the measurement process, such as discussion of implementation cases, practices related to the measures, and also direct observation through visits to construction sites. As a result, the representatives exchange information and explicit knowledge, which motivated them to promote changes inside the companies. However, each company achieved different levels of PMS implementation as well as different levels of learning.

Therefore, this analysis indicated that the benchmarking club encouraged a collaborative benchmarking process aiming the mutual learning. It had the role of inductor of this learning process with others, motivating the transfer and the adaptation of the knowledge acquired in the club to the companies' context. Through the formation of the Benchmarking Club as well as the exchange of practices, the companies found a favourable environment to incorporate and internalise the use of performance measures, focusing in the use of the measures in their routine.

Three important elements were identified in the Collaborative Environment: (a) the common problem; (b) the collaborative process; and (c) the member. Also, three other elements were identified as critical in the Companies' Environment: (a) the extent to which the problem is meaningful for the company; (b) the extent to which the company is willing to promote changes; and (c) the extent to which people are involved (see Figure 3).

The existence of a common problem is the core aspect of the collaborative environment because the interest for the problem and the search for solution will be promote the attention and the maintenance of the group. The common interest creates common ground or sense making (Wenger et al., 2002; Weick, 1990), promoting a sense of identity in the group. The common problem inspires the members to contribute and to participate actively in the group, and also it can guide the learning process, giving meaning for the actions (Wenger et al., 2002).

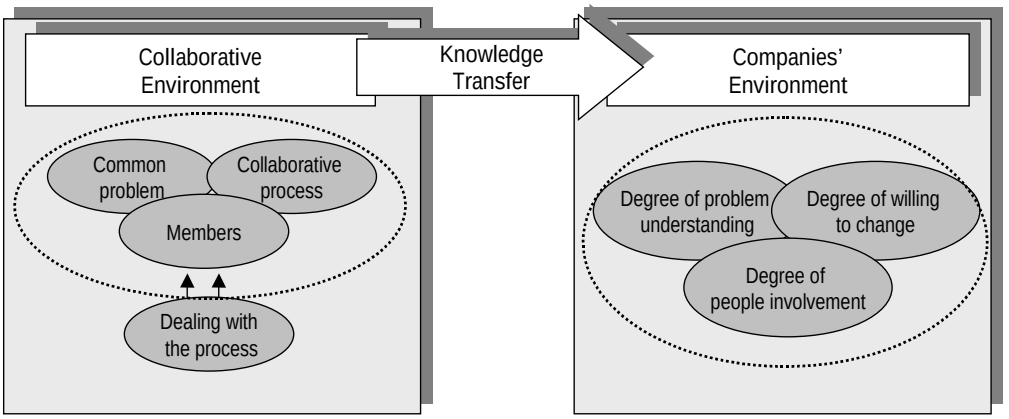

Figure 3 – Core elements of the inter-organisational collaborative framework

The collaborative process is developed when the participants realised that they are getting mutual learning. According Wenger et al. (2002), mutual learning happens when there is interaction between members and the relationship is based on mutual respect and trust, thus encouraging a willingness to share ideas, ask difficult questions, and listen carefully. Moreover, there is a need of a common language between the participants. It influenced positively the interaction of the group and confirms the idea of Trompenaars (1995) that communication of knowledge is only possible among people who, to some extent at least share a system of meaning.

The members have the role to lead the implementation of changes, taking action and promoting an effective communication of ideas to other managers within the collaborative environment and within the company. Therefore, the low and middle managerial leadership involves the personal capability to absorb the knowledge available in the club and transfer it to the organisation. Absorptive capacity is the ability of a firm to recognise the value of new, external information, assimilate it and apply it to commercial ends (Cohen and Levinthal, 1990). Cohen and Levinthal (1990) state that the individual's absorptive capacity includes, in particular, prior related knowledge and diversity of background. Prior related knowledge enhances learning because the memory establishes linkages with pre-existing concepts, while the diversity of background increases the prospect that incoming information will relate what is already known (Cohen and Levinthal, 1990).

An important characteristic of the member of the collaborative process is that the individual should already posses the appropriate contextual knowledge necessary to make new knowledge fully intelligible (Cohen and Levinthal, 1990). Kogut and Zander (1992) call this characteristic as "common stock of knowledge" among members, which means that the recipient has sufficient context within which the received knowledge can be interpreted and

reconstructed sufficiently close to the structure and meaning intend by the originator (Shariq, 1999). Consequently, it should facilitate both the sharing knowledge and the knowledge transfer from the member to the organisation.

From the point of view of the company's environment, the following factors influence the success of the implementation. The first factor is the extent to which the company understands that the problem discussed in the collaborative environment is a critical process, and it is important to solve the barriers related to that. The problem needs to be meaningful, making sense for the company to invest resources in the search of the solution. The second factor is the extent to which the company is willing to promote changes. The changes can be analysed from the point of view of the skill development focus (individual, a group of people or included the organisational as a whole) (Nonaka and Takeuchi, 1995) or the learning focus (incremental changes, adaptive changes, innovative changes) (Sweringa and Wierdsma, 1995 and Argyris and Schön, 1995). These changes are dependent on the organisational structure, the managerial system and the environment for learning.

Finally, the last factor is the extent to which the people are really involved in solving the problem. The top managers also had a key role in the knowledge transfer, because they had the responsibility to approve the changes, and also because they should provide the adequate resources to allow the project run effectively, thus encouraging the involvement of people at different levels. The role of the manager as discussed above involves the ability to assimilate, transfer and use the outside knowledge, thus leading the changes of the process in which they are involved.

CONCLUSIONS

The benchmarking collaborative process motivated the members to transfer the explicit knowledge acquired in this environment to their local context. The data obtained in the action research as well as the data collected inside the companies allowed the identification of both quantitative and qualitative benefits inside the companies. One of the success factors of the collaborative environment is the existence of a common problem among the companies, which they desired to discuss and to solve it. Moreover, the companies realised a mutual gain in their participation, and the members realised that they had a role to lead the process of knowledge transfer in the companies.

From the point of view of company's environment, the explicit knowledge shared was adapted and internalised according to the companies needs. The findings showed that different types of learning and changes due to the collaborative process in the benchmarking club. This happened because the conversion of knowledge is both a technical and a social process. Consequently, the path and the scope in which this knowledge moves throughout the organisation depend on the importance and meaning of the process for the company, the involvement of the members, but mainly, the extent to which the company is willing to promote changes. Moreover, for the consolidation of the knowledge transfer, the companies still need to develop internal mechanisms to facilitate the communication of the new knowledge, motivating the understanding and further application. Also, the companies should identify the individual and organisational capabilities required to learn and to create knowledge, increasing their absorptive capacity.

This paper presented a preliminary analysis, being necessary further analysis aiming to have a real understanding about how the collaborative process contributed to facilitate knowledge and learning processes in the companies. Furthermore, the framework should be validated in order to provide results according to methodological criteria, such as credibility, reliability and also enabling transfer of the results for other context.

Acknowledgements

This research project was made possible due to the financial support of CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico). The twenty companies which participated in this research.

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Partnering - Strategic Tool of Integrating Supply Chain in the Construction Industry

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This research will explore an alternative approach to undertaking construction procurement between partners involved in the construction process. The research begins by examining the current circumstances of the construction industry. The research will then present and analyze the problems in the current partnering relationship. The construction industry will be compared with other industries (manufacturing and IT), to achieve some successful experiences of partnering relationship, and apply them to construction to explore the framework of next generation partnering relationships.

Keywords: fragmentation, partnering, SCM (Supply Chain Management), PR (partnering relationship).

INTRODUCTION AND BACKGROUND

The construction industry has suffered fragmentation for decades and still kept the high localization in comparison with other industries. A number of researchers have conducted a great deal of researches, for example, trusting the team (Bebbett and Jayes, 1995), the seven pillars of partnering (Bennett and Jayes, 1998) and rethinking construction (Egan, 1998) to analyze and improve the current position and provide a more cooperative manner to conduct project.

The construction industry has also played an important role in national economy. In particular, the boom of construction industry will create more employment opportunities for employees and employers. For example construction in the UK is one of the pillars of the domestic economy and employs around 1.4 million people, which produced output as £58 billions in 1998, accounting for 10% of GDP (Egan, 1998). The similar position in China, although its construction industry is still labour-intensive industry, output of which is likely to be ¥1249.8 billions in 2000, accounting for 13.98% (China, 2000). The construction industry has achieved huge success and development, however, can not still hide these facts: low and unreliable rate of profitability, conservative construction management and adverse atmosphere between partners.

In particular, due to development of construction techniques and skills, current construction management has obviously exposed its disadvantages which seriously restricted development of the construction industry. Furthermore, development of IT has made a heavy impact on almost every aspect in every industry except construction. The traditional construction procurement has fallen behind other industries. For example Green et al., (2005) identified that UK aerospace has achieved huge development as a result of the imperatives of global competitive pressures, however, construction industry still remains highly localized after experiment of decades of fragmentation.

Fragmentation, which is an inherent particularity of construction and poor co-ordination has damaged the construction industry heavily and brought out inefficiency, waste, and quality and safety problems (CIDB, 1989; Ofori, 2000;Green et al., 2005). The traditional construction procurement has several obvious disadvantages: win-lose contract, distrust between each party, uncertainty of risk and commitment, lack of exchange of information, a focus on negative issues, maintain the price competition through gaining each material from

many companies and an atmosphere of fear, dishonesty and frustration. Ofori, (2000) utilized these negative characteristics to describe the current relationship among construction firms and their partners. In addition, adverse relationship among partners and lengthy payment periods and delays in payments heavily damage construction businesses, in particular small and medium-sized firms. This is because most construction firms are small scale or self-employment, which seriously restricted development of construction industry.

In addition, current tender system, which is one of the greatest barriers to improvement in construction has evolved because of the desire for a competitive price (Egan, 1998). Egan report (1998) identified that too many clients still equate price with cost and select designers and constructors almost exclusively on the basis of tendered price. In order to make profits and enlarge the margin each firm has to squeeze their client (upstream) and supplier (downstream) continuously. The traditional approach to construction is like that: the client's major objective is to reduce cost and they will select the lowest price. The prime contractor knows this point and that some changes will be inevitable during the period of the construction contract. It is easy to raise the price during construction process because of some construction difficulty by making claims for some eventuality, whether true or not, which can make profit and make an initial loss-making tender become profitable. Then a great deal of suspicion comes out between client and prime contractor, consequently, distrust emerges, which results in a deteriorating loop. For example (Deter, 1999) Crown House has experienced this kind of suffering for many years. Their previous strategy was not working through claims to compensate the loss in the low price tender, which enforced them to adopt a new strategy to make major changes or go out of business. Alternatively, they can make a new strategy of considering clients and suppliers as long-term partners with whom to work towards a common aim and aspirations, in replacement for the traditional win-lose relationship of business 'partners' with different objectives (Ofori, 2000).

Based on the above, innovation and change are necessary, however, the question is: how to change and what should be changed? Through comparative study of aerospace and construction Green et al. (2005) identified that techniques and theories developed in other sectors can be adapted for implementation in the construction sector. Notably, other industries e.g. IT, retail and manufacturing have improved quality, delivery times and saved hundreds of millions of dollars while improving customer service via controlling their supply chain effectively and applying supply chain management techniques, only the construction industry has made a little progress (Egan, 1998; Deter, 1999; O'Brien, 1999; Latham, 1994). The huge achievements of other industries are enough to attract construction industry to learn some appropriate experiences although construction as an industry has its own peculiarities.

This research intends to supplement and explore an alternative approach to conducting the construction project in the construction industry, in particular, to formulate a series of KPIs to estimate the performance of partnering within the new generation partnering relationship.

SCM IN CONSTRUCTION INDUSTRY

Supply Chain Management (SCM) takes a systemic and holistic viewpoint to analyze and resolve the problems among participants and to optimize individual activities at best. In particular, SCM contrasts sharply with traditional methods of planning, controlling and contracting for projects. Early research identifies that SCM which is viewed as a strategic tool can provide an engineering basis to design, plan, and manage construction projects in a collaborative manner (O'Brien, 1999). As for current construction SCM, to some extent, there are some changes (e.g. more cooperative construction environment and improvement in

construction process). Construction SCM offers an alternative approach to reduce cost (material and labor) and increases the quality and speed of the construction process.

However, the construction project is not likely to be so continuous as the manufacture or a product, and its nature is one or temporary organization (Turner and Müler, 2003). One of the inherent characteristics in the traditional way of construction procurement is the one-off of project. Due to its one-off nature, some participants attending the project will probably be absent in the next project, which results in it faces that skills and knowledge of cooperation can not be transferred from one project to another. Consequently next time same situation will appear again. Functional fragmentation has worked against multidisciplinary team work. Particularly non-continuity, self-protective pressures and adversarial attitudes have impeded innovation and increasing complexity, altogether making the construction industry a slow adopter of supply chain from the manufacturing sector (Kumaraswamy and Dulaimi, 2001; Titus and Bröchner, 2005,). SCM is still not widely known and significantly applied in the construction industry in any country, there is still a long way needed to walk in applying supply chain management completely into construction (Ofori, 2000). Application of SCM in construction is in the first stage, however, partnering between participants along construction supply chain (client, prime contractor, subcontractor etc.) is researched by a great deal of researchers (Bebbett & Jayes, 1995; Egan, 1998; Bennett & Jayes, 1998). Furthermore, (Egan, 1998), identified that partnering which has great generality and flexibility and framework agreements were increasingly utilized to tackle fragmentation by the best firms in place of traditional procurement e.g. Tesco Store and Argent have used partnering arrangements to reduce a great deal of cost and time.

Bennett & Jayes (1995) built the first generation partnering framework: trusting the team. Furthermore Bennett & Jayes (1998) upgraded it as the second generation partnering, in particular proposing the third generation partnering. The framework identified that partnering is the core of the construction process. Each upgrade of framework of partnering made the construction supply chain relationship become tighter. The specific development process of the partnering framework is followed as Fig.1. This also showed that partnering is critical tool to integrate and optimize the holistic construction supply chain. Thus, in order to integrate construction supply chain further it is necessary to explore the next generation of partnering framework.

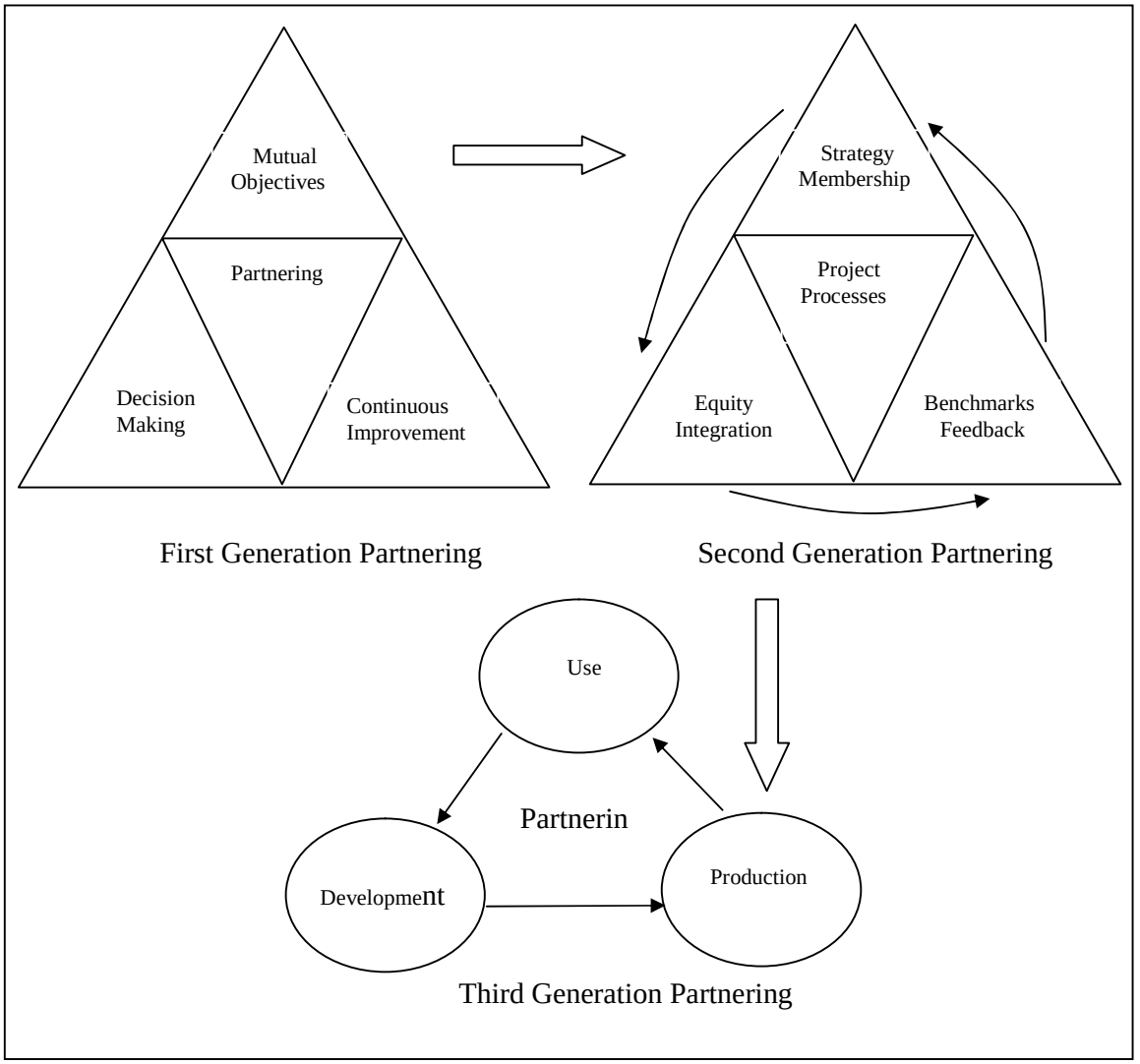

Fig.1 Development process of the construction partnering framework

From Bennett & Jayes (1995) "trusting the team" and Bennett & Jayes (1998) "the seven pillars of partnering"

AIM AND OBJECTIVES OF THE RESEARCH

The research will combine knowledge and experience between business management and construction and try to enlarge the application of theory from business into construction. In particular, in order to enlarge the application of SCM in construction industry further, continuously to explore more perfect framework of partnering to integrate the construction supply chain, based on this aim the following research objectives are expected to be achieved:

Φ Through stating and analyzing current practice, to display the disadvantages (e.g. fragmentation and distrust) of traditional construction procurement (e.g. tender-based) then explain why the current construction industry needs to change and innovate. Consequently there is a requirement, to explore new frameworks to resolve the problems in the current construction industry through literature review e.g. analyzing and summarizing finding of previous research.

. Based on current application of SCM in construction industry, the research will explore the linkage between partnering relationships and supply chain relationships, how to integrate the construction supply chain through enforcing partnering and arrive at that whether partnering is essential to integrate the construction supply chain. In particular, the construction industry can learn to resolve the related problems from the experience of other industries (e.g. manufacturing, IT and aerospace) through analyzing their development process. The premise of learning from other industries will be described and explored as well.

 To devise and develop an appropriate methodology to undertake the research, in particular, to provide a series of KPIs (key performance indicators) to estimate the performance within the partnering mode. Meanwhile the research will identify the key factors determining partnering success or not.

 To explore how to create more value for each other between parties involved in a partnering relationship through utilizing strategic tools (e.g. value management and value engineering) then identify the value adding activities among the partners.

RESEARCH METHODOLOGY

In order to achieve the above research objectives and aim, the research will be conducted using appropriate methodology.

Firstly, regarding the research paradigm, in terms of characteristics of the goals and objectives of this research, it is appropriate to choose **interpretivisim** because this research will emphasize description and exploration. In addition, the most objectives of the research are to answer "how" and "what". Such understanding puts an emphasis on the researcher's own frame of reference and the subjective aspects of researcher's activity via exploring the new partnering mode and estimating it rather than test the relationship among a series of measurable variables.

Secondly, regarding research approach, **inductive** will be chosen to conduct the research because it is useful to attach these approaches to the different research philosophies: the deductive approach owes more to positivism and the inductive approach to interpretivisim (Saunders et al., 2003). This research is to explore how the firm integrated and optimized its supply chain, how to create value for each other, In particular, to explore new partnering relationship in construction supply chain. In terms of the characters of the questions and the researcher's frame and reference, it is appropriate to adopt inductive approach to conduct this research.

Thirdly, this research will inevitably involve a number of cases and analysis. Through analyzing and comparing their success or failure, the author will identify the value-adding activities in the construction process and key factors determining the partnership is successful or not. Thus **case study** is appropriate for this research.

Finally, data will involve second data and primary data. Secondary data has been collected by other researchers for other purpose. However, such secondary data also can provide a useful source from which to answer the research questions. The primary data will directly answer the research questions. According to (Collis et al., 2003), there are various methods which the researcher can utilize them to collect primary data: **interview, observation, questionnaires etc**. This research will adopt interview and questionnaire and observation.

CONCLUSION

The research will bridge the construction and business via comparing construction and business then analyzing their commonness and speciality. This research will try to adapt more business models and apply them into construction and look for best practice to support the new partnering mode in construction industry. The research will summarize the characteristics of construction and identify current problems e.g. fragmentation is an inherent particularity which has restricted the development of construction industry and tender has resulted in competitive price in construction project. Based on the problems, the research states the necessity of change and innovation and will explore resolution for the current position.

This study will explore another direction for the future research. The research is to enlarge application of SCM through upgrading the mode of partnering in the construction industry. There is a great deal of research which needs to be carried out, to tackle the fragmentation of construction, to improve the traditional and adverse attitude and to achieve the "CI" (Continuous Improvement) of construction industry.

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Developing Spatial Visualisation Skills in a New Era

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Abstract

The development of Spatial Visualisation Skill (SVS) is a crucial module in engineering design training for decades. However, with the dominance of CAD and computer-based three-dimensional (3D) objects, traditional SVS trainings turn to be abandoned. Moreover, the lack of certain level of spatial awareness, students often encounter difficulties in learning 3D related CAD skills, which indicates the need to develop a systematic, structured approach to developing conceptual visualisation skills for the new era. This paper reports on an investigation into the impact of using VR in developing SVS, to stimulate the awareness and self-discipline in visual spatial thinking. The paper also describes the development of a dedicated – Virtual Spatial Training (VST) system, which is created and introduced to students at University of Wolverhampton in their engineering Computer Aided Design (CAD) courses.

Keywords: CAL, VR application, spatial visualisation skill

Introduction

For engineering design, the mental skills involving three-dimensional representations - spatial visualisation were recognised as the vital competency in relation to innovation and creativity. It has been established as a fundamental subject in engineering training for decades (Sorby & Baartmans 1996; McGee 1979; Miller 1996).

Nowadays, as the advent of IT, the use of CAD to produce computer generated graphics has entirely dominated modern-day design processes, and lead the training of CAD to become an integral part of the curricula within most universities and schools for teaching engineering design. However, the teaching of CAD which relies extensively on computer automation seem to disregard certain abilities of human's native aptitudes, such as Spatial Visualisation Ability (SVA). As the result, the topic of developing SVS is generally neglected in most of CAD related courses.

This study started with a series of investigation on the variation of SVA in current CAD students and its correlation with the performance of CAD learning. Based on these results, this paper argues that it is still radical to pursue the efforts on developing students' SVS for learning effectiveness. Meanwhile, unlike many traditional methods in teaching and developing spatial skills, a novel VST system with a unique virtual-model environment is devised to aid of spatial perception.

Spatial visualisation skill in definition

Classified as a subset of spatial ability, Spatial Visualisation Ability (SVA) is defined as the aptitude to mentally manipulate, rotate, twist, or invert pictorially presented stimuli (McGee 1979). SVS can be applied to manipulate an object in an imaginary 3D space or create a representation of the object from an alternative viewpoint.

Kali & Orion (1996) described SVS as the relevant ability of the visualisation process, that is, the skill for thinking in three dimensions, for visualising shapes in the mind's eye, rotating, translating and shearing them, and for imagining complex changes overtime in the form of a cinematographic visual image. It involves being able to recognise, retain, and recall a configuration in which the object has been manipulated in three-dimensional space.

Overall, SVS can be commonly regarded as an intellectual skill in dealing with three-dimensional representation of objects mentally, which connects to the competences in mental imagery, spatial memory, and mental transformation, etc.

The pre-required ability for learning

Spatial ability is an important factor in many engineering, technical, mathematical, and scientific professions (Miller & Bertoline 1991). Ursyn suggest that the ability to generate visual representations of scientific concepts constitutes a critical attribute for activities such as: learning, problem-solving, and even memorising (Ursyn 1997). Consequently, spatial ability is applicable to many disciplines. It has been shown to contribute significantly in the fields of: astronomy (Bishop 1978); chemistry (Baker & Talley 1972; Talley 1973; Carter, LaRussa & Bodner 1987; Coleman & Gotch 1998; Khoo & Koh 1998); biology (Lord 1985; Lord & Nicely 1997); physics (Anderson 1976; Pallrand & Seeber 1984); geology (Yakemankaya 1971); geometry (Battista, Wheatley & Talsma 1982); mathematics (Smith 1964; Sherman 1967; Macoby & Jacklin 1974; Kiser 1990); music (Hassler, Birbaumer & Feil 1985); science (Small & Morton 1985); engineering (Miller 1996); and technical graphics (Deno 1995) [Cited in (Bertoline 1988), (Strong & Smith 2001)] .

Clearly, spatial visualisation is an established element of Engineering Graphics and Engineering Design (Miller 1996) and is integral to applications in graphics and engineering in general (Sorby & Baartmans 1996). The ability to perform complex mental manipulation of objects has been established as an essential skill in other technology related disciplines, notably in civil engineering and architectural design. Multi-faceted spatial skills help civil engineers and architects to conceptualise links between reality and abstract models. As Alias describes, a Civil Engineer needs first to have an intuitive understanding of the interactive relationships of structural components before, for example, attempting to predict the resultant deflected shape of a structure; thereby leading to the identification of an abstract model (Alias 2000). This intuitive understanding is also essential to civil engineers in other aspects of the profession: it helps in visualising, predicting, designing and checking for the worst possible combination of loads on a given structure.

The link between visualisation and engineering drawing and design is also well established (Ferguson 1977), (Ferguson 1992). Bertoline and his co-workers, for example, suggest that visualisation ability is central to design, and that imagery provides a bridge between design ideas and their representation in sketching and drawing (Bertoline 1995).

SVA in modern-day CAD classes

To argue the necessity of developing SVS in modern-day CAD classes, a series of investigations towards the variation of SVA within students and the correlation between SVA and 3D CAD skills were conducted.

By using a pro-designed test program for measuring SVA, a student's survey was conducted within the students at University of Wolverhampton. The statistical analysis results shows that the students in the sample hold high diversity in regard to the SVA. In addition, significant differences are found in age groups and academic level groups, which infer that the younger students and early academic level possess a comparatively lower level of SVA. Overall, the analysis of the diversity suggests that significant variation exists in respect of SVA. In particular, attention should focus on the younger age groups, and/or on the groups at an early stage of academic studies.

The results of SVA test (shown in Figure 1) were also used in the correlation analysis with the 3D CAD learning performance. As shown in scatter-plot, the statistical correlation analyses suggest a highly positive relationship between SVA and performance in 3D CAD learning.

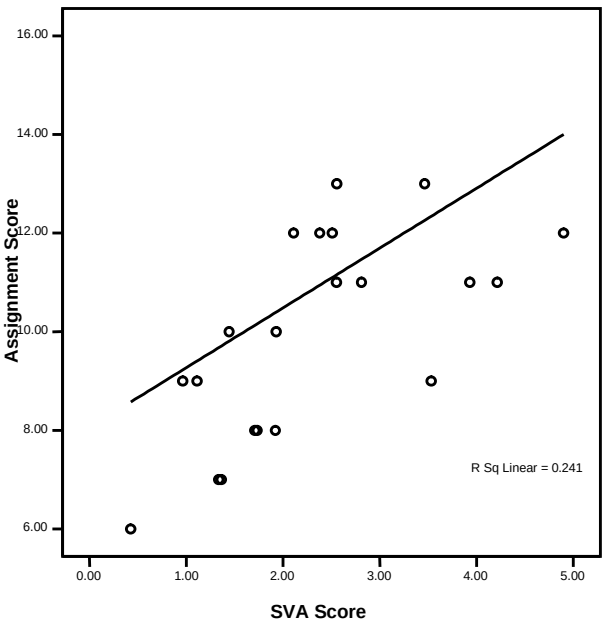

Figure 1 Scatter-plot of correlation

VR approach for developing SVS

Generally, the characteristic three-dimension modelling environment in CAD requires high spatial visualisation abilities to interact with. As Mohler (1997) indicated, the phenomenon he found within his research is that the students have significant problems in dealing with static 3-D environments, because they are generally used to dealing with "dynamic" environments in their daily lives. However, by presenting real sense of space, motion, time and spatial

relationship, the computer-generated simulation via VR technology can easily release those complications in perception.

In respect of developing the spatial visualisation skills, the key is to help students establishing the links between visual stimuli, formation of representations and perceptual concept. In general, it can be delivered intuitively by presenting of concrete physical models. Currently, the VR models, with dynamic demos and user-centred interactivity, provide another alternative. A new generation of VR technology also integrate capacities in presenting high quality realistic models, rich interactions between inside and outside of VR environment and flexibility for programming and multimedia applications.

The features of VST system

To determine the method, mode, and structure of training equipped in the VST system, some key features were set out in the construction of the program.

Problem-based learning

The problem-based tasks in the VST system are used to initiate critical and analytical learning through engaging the learner in challenge and curiosity. Along with such a situated environment, the students are encouraged to use and foster pre-defined skills for solving a particularly designed task.

Open-structured task

The open structure of tasks provides more flexibility in management, maintenance, as well as independent learning.

Interactive manipulation within the VR environment

Through active engaging with the intuitive virtual models, rather than passive watching, the VR environment is employed as an effective vehicle for interactive learning.

Clue & rectification

The VR models play the role in supplying clues and learning aids in solving the puzzle-like problem or task. The interactivities in observation of models through different angles also provide comprehensive rectification in seeking the right solution.

Mental model simulation

The dynamic demo that simulates spatial concept in a particular task helps developing mental model in problem solving. For example, by following the animated VR show, learner can soon be able to use similar tactics to perform the exercise mentally, such as mental rotation, mental cutting, or mental folding.

VST system

The VST system is developed to investigate the potential of VR application for developing SVS. It comprises four modules: Mental Rotating Task (MRT), Mental Cutting Task (MCT), Paper Folding Task (PFT), and Virtual Building Component (VBC). The MRT is designed to develop the mental skills to deal with object rotations around multiple-axes. MCT develops the skills in spatial imagination and visualisation of planes cutting through solid objects. By

rotating and manipulating different pieces of pattern mentally in three dimensions, PFT is used to develop skills in imaging and visualising the 3D structure of objects. VBC is designed to improve the understanding of building concepts in 3D modelling. Figure 2 show examples of MRT, MCT, PFT and VBC developed within the VST system:

Figure 2a - Mental Rotation Task

Figure 2b - Mental Cutting Task

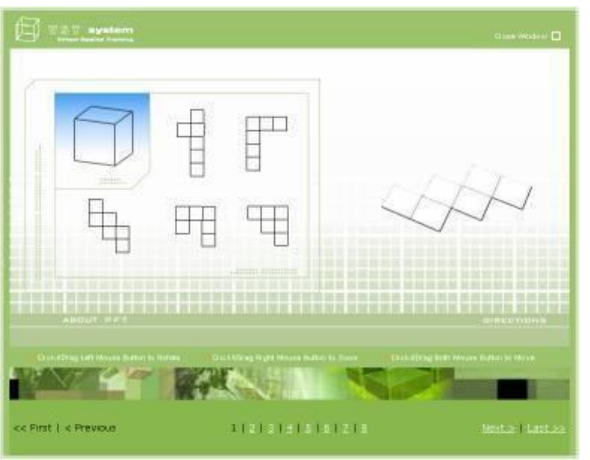

Figure 2c - Paper Folding Task

Figure 2d - Virtual Building Component

The first three modules of the VST system are designed as a question-based training programme in which the tasks are primarily based on corresponding mental testing criteria. In the MRT section, the student is required to identify the 3D object image that can be rotated to match the target figure. A corresponding VR model is also presented to provide clues for solving the problem. Once the correct answer is selected, an interactive animation illustrates a typical rotation process that could be imagined by the student. In MCT, the student is required to imagine the 2D pattern that will be generated by the target figure being cut by a prescribed plane. A VR solid model corresponding to the shape of the target figure is provided for reference. An animation illustrates the plane cutting through the solid model and subsequent formation of the 2D section. The VR model is linked to the correct answer, and can be controlled to rotate about various axes to aid the visualisation process. In a similar manner to the above, the PFT tasks require the student to identify the particular 2D pattern that can be folded into a specified 3D target figure. An interactive folding process is also associated with the correct answer.

The Virtual Building Component module provides a means of demonstrating the potential for learning the spatial concepts of building technology. In particular, this section is aimed at understanding the transformation between 2D plan and elevation views, and a 3D virtual model of a building. Within the building, several interactive animations demonstrate the relationships between 2D drawings and the 3D virtual model.

Effectiveness of VST system

A web-based questionnaire survey was carried out for the evaluation of the VST system. In result, after VST system was introduced, there are 34 respondents from the School of Engineering & the Built Environment, University of Wolverhampton. Within these respondents, 5 are lecturers of CAD related training courses, and 29 are students from different levels of CAD courses.

Questionnaire design

Generally, to demonstrate the effects of SVS development requires longer-term observations. Thereby, within short-term period of this study, the main objective of evaluation is set to investigate the effect of promoting awareness of developing SVS and stimulating self-discipline in corresponding learning process; and to justify the potential of VR technology in relevant training. Some criteria used in evaluating the effectiveness of Computer Aided Instruction (CAI) instruments, such as overall impression, user control, interactivity and motivation were also employed.

Referred to Baldwin (2000), a self-report method, that ask participants to look within themselves and disclose their own attitudes, feelings, perceptions, and beliefs, was adopted

within the questionnaire design for evaluation, by using a 5-rank Likert scale as rating system.

Results

The questionnaire was divided into two sections. 10 questions were designed for investigating the impact of VST system as a CAI instrument, and 8 for investigating the effects of SVS training via VR. The mean, mode (the most frequently occurring score), and standard deviation for each question are reported in Table 1.

Table 1. Result of questionnaire survey

	Questions	Mean	Mode	SD
1.	Do you feel comfortable with the interface of this programme?	4.03	4	0.627
2.	Did this programme provide a clear structure for access?	4.09	4	0.668
3.	Does this programme provide understandable information (such as introduction, on-screen message, directions and other instructions)?	3.76	4	0.890
4.	Is it easy to learn to use this programme?	4.24	5	0.855
5.	How do you think the interactivity of using the programme?	4.00	4	0.816
6.	Please indicate the attractiveness of using virtual model for learning.	4.09	4	0.793
7.	Overall, please indicate the experience of manipulating the VR model in this programme.	3.85	4	0.744
8.	Overall, please score the functions and learning materials that you expected to be included in this programme.	3.88	4	0.640
9.	Do you think this programme is worthwhile to have a go to through all the tasks?	3.97	4	0.674
10.	Do you think the way of presenting question-based tasks in visualisation training sections is helpful for developing visual-spatial thinking?	4.06	4	0.776
11.	In VBC section, does the virtual house provide helpful means to understand the relationship between 2D drawing and 3D model, and the basic structure of general buildings?	4.21	4	0.808
12.	Overall, please indicate how much confidence have you gained after going through all the programme for further dealing with this kinds of 3D spatial problems appeared in this programme?	3.38	4	1.045
13.	Do you agree that the VR model presented in this programme can significantly release the mental stress of spatial visualisation?	3.91	4	0.753
14.	Do you agree that this programme can be used as an assistant tool to help dealing with 3D visualisation problems?	3.91	4	0.621
15.	Do you agree that this programme can effectively encourage the learning of 3D abstract concepts in CAD training?	3.85	4	0.610
16.	Do you agree that the VR application in this programme is a good sample for developing spatial visualisation skill?	3.94	4	0.489
17.	How helpful do you think is the VST programme to develop spatial visualisation skills?	3.91	4	0.830
18.	Do you agree that this VST programme can fulfil the learning needs of developing spatial visualisation skills?	3.76	4	0.606

Through the evaluation of VST system, it shows high-level appreciation and satisfaction from the respondents. The result indicates that the VST system has a user-friend interface, a clear structure and useful guidance features; it is easy to use and interact with. The virtual models presented in the system are also reckoned as impressive and attractive by respondents. Most of respondents recognised the great value in using VST system. In terms of developing SVS, the survey also gained high scores from respondents, a significant release of mental stress in

spatial visualisation is reported by using VR model system, and the VST system as an assistance tool has show its value towards specific learning needs.

Conclusion

The VST system is designed as a CAI tool for developing specific spatial visualisation skill, in which the latest VR application on the Internet, Web3D, is employed as a novel approach for the learning of abstract and spatial concepts involved in engineering design training.

In conclusion, with advanced visualisation software and tools for drawing and making 3D models, learning can become an active, exciting and engaging 'hands-on' experience. However, sophisticated computer application also causes learning difficulties associated with traditional issues in engineering design education. The development of SVS again becomes the main topic discussed in this study, but based on the new environment that is fashioned by and new technology.

This study has shown its values through a series of research phases designed to tackle the emerging problems in current learning and teaching environment. An investigation of the current state of SVA in CAD training reveals that, even with the aid of the latest visualisation system in CAD application, some students are still suffering frustration in learning 3D and spatial concepts which implies that it is necessary to reignite traditional practice in developing spatial ability. The consequence reflected on existing CAD training that regardless of individual differences on the intellects for spatial visualisation has evoked growing awareness to rethink the issue more seriously and strategically. It also needs to be reconsidered the exact effect of CAD training with advanced visualisation properties towards the development of native intellects.

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