IMPROVING INFORMATION/KNOWLEDGE MANAGEMENT THROUGH THE USE OF BIM: A LITERATURE REVIEW

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With the rapid development of the construction industry, its projects are becoming more complex. Information management plays an important role in this scenario. Various information technology (IT) systems have been developed to support project information management. As a 3D object-oriented system containing geometric and non-geometric information of a project, building information modelling (BIM) has become widely used to manage the project's information. On the other hand, knowledge is the most competitive resource in any organisation. In construction, knowledge management has gained increasing attention. Some IT-based systems have been established to aid knowledge management during a construction project. Although BIM is widely used in information management, BIM-based knowledge management is rarely studied. This paper presents a comprehensive literature review on BIM-based information/knowledge management. The literature on BIM-based information management is first reviewed in a systematic way. BIM-based knowledge management is the focus of the second part of the literature review. This paper concludes with a critical discussion to indicate the knowledge gap in current research and to identify future research questions and directions in this area.

Keywords: BIM, information management, knowledge management, literature review

INTRODUCTION

Information management and knowledge management have been part of the construction industry for years. The fragmentary and temporary nature of construction projects makes it difficult for information to be communicated among project participants (Lindner and Wald 2011). Therefore, construction researchers have explored a variety of tools, methods and systems in order to improve information management in construction projects. Knowledge is at the higher hierarchy when compared to information and it is perceived to be the most competitive resource in most construction organisations (Rowley 2007). Several researchers have applied tools or strategies to assist knowledge management in the construction industry, such as ontology, knowledge maps and communities of practice (Carrillo *et al*., 2000; Rezgui 2006; Lin and Lee 2012).

BIM is an information-integrated tool, which is different from other traditional computer-aided design (CAD) tools (Singh *et al*., 2011). Information stored in BIM can be used to estimate schedule (4D) and cost (5D). In addition to 4D and 5D estimations, the design and construction information contained in the BIM model can be used by facility managers to evaluate energy consumption and generate better maintenance strategies.

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Moreover, researchers have recognised that BIM should be used in a collaborative way throughout the lifecycle of a project (Singh *et al*., 2011).

Although knowledge is rated higher than information, at this stage, only a small number of studies have recognised the potential of BIM in improving knowledge management practice. According to these studies, some characteristics of BIM can certainly make specific knowledge management processes much easier. For example, 3D model representation and simulation can facilitate knowledge visualisation (Meadati and Irizarry 2010; Lin 2014). The parametric nature of objects contained in the BIM model can be seen as a tool to capture and store knowledge (Meadati and Irizarry 2010; Deshpande *et al*., 2014). In addition, various knowledge management techniques integrated with BIM facilitate effective knowledge management, which include ontologies (Kim and Grobler 2009; Park *et al*., 2013; Charlesraj 2014), case-based reasoning (CBR) (Motawa and Almarshad 2013), fault tree (Motamedi *et al*., 2014), knowledge map (Lin 2014) and criteria measurement (Nguyen and Toroghi 2013).

Although several studies have recognised the capability of BIM to improve knowledge management processes, as a new research area, further research is required to explore how BIM can be used to achieve better knowledge management. Therefore, this paper aims to explore the shift from BIM-based information management to BIM-based knowledge management through a comprehensive literature review. Extant studies on BIM-based information management are first reviewed. The main focus of the first part will be on 4D, 5D, collaborative information management, and information management in facility management (FM). A review of the literature on BIM-based knowledge management will follow. After the literature review, a discussion will be made to identify the knowledge gap in current research and the future research questions and directions in this area.

METHOD

This paper is based on a literature review. The sources for the literature on BIM-based information management are chosen from peer-reviewed English language journals. For the literature sources of BIM-based knowledge management, both peer-reviewed English language journal papers and conference proceeding papers are included. Two search engines were used to source the literature, namely, Web of Sciences and Scopus. They contain different databases which ensure that no omissions are made while searching for relevant literature.

In order to search for the literature on BIM-based information management, keywords used include “BIM + information management”, and “Building information modelling + information management”. 217 results were obtained from Web of Science and 318 from Scopus respectively. However, a large number of results were repeated. After sorting them out, a total of 336 results remained. Although some articles contain the word “BIM”, they do not contain the concept of information management. Similarly, some articles contain the word “information management” but they have nothing to do with “BIM”. There were, however, some articles that included both “information management” and “BIM”. Unfortunately, they do not discuss BIM-based information management in depth. Therefore, such literature should be excluded. Finally, 86 publications were reviewed, which can be classified into 5 categories. These are 4D, 5D, energy analysis, collaborative information management, and information management in FM (see Table 1).

Similar to 108 publications on BIM-based information management, 23 journal papers and 30 conference papers about BIM-based knowledge management were identified. Since BIM-based knowledge management is a new research area, it is difficult to classify this area in detail.

Table 1: Paper classification of BIM-based information management

Categories	Numbers	%
4D and 5D	19	22
Energy analysis	13	15
Collaborative information management	28	33
FM	26	30
Total	86	100

The number of papers published in each year is analysed. Figure 1 shows the paper distribution of BIM-based information and BIM-based knowledge management separately according to the year of publication. Prior to 2010, there are few relevant studies. Figure 1 shows that research interest in BIM-based information management and BIM-based knowledge management has dramatically increased since 2011. This trend may result from government encouragement. For example, the UK government proposed a strategy on 31 May 2011, which mandated that all centrally funded projects are to be undertaken using BIM by 2016 (Cabinet Office 2011). When compared to BIM-based information management, very little literature can be found for BIM-based knowledge management.

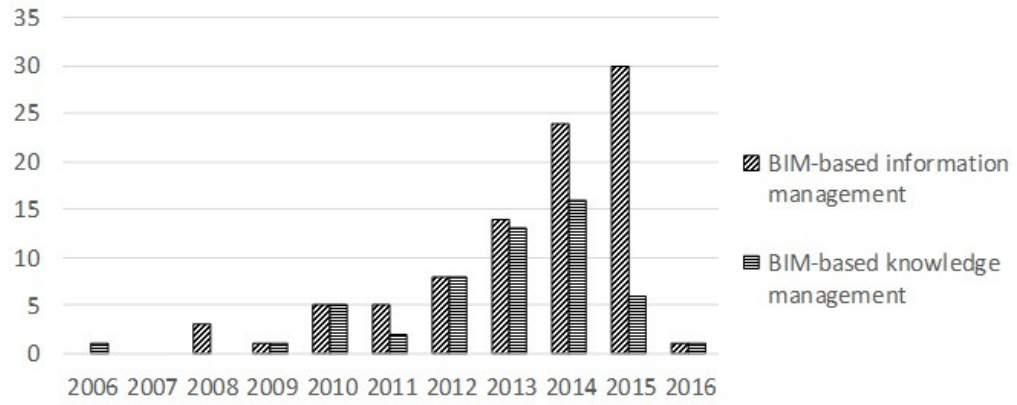

Figure 1: Paper distribution of BIM-based information management and BIM-based knowledge management according to year of publication

BIM-Based Information Management

BIM is an information-integrated tool, which is different from other traditional computer-aided design (CAD) tools (Singh *et al*., 2011). Information stored in BIM can be used to improve schedule (4D) and cost (5D) estimation. For the 4D visualisation and simulation, BIM integrates the scheduled plan and 3D model in order to simulate the construction progress. Structural problems and conflicts among different disciplines and sequencing conflicts of construction activities would be identified proactively as BIM achieves 4D visualisation and simulation (Zhang and Hu 2011). Hu and Zhang (2011) developed an integrated 4D BIM to analyse and manage conflict and structural safety

issues during construction. Additionally, BIM is also used for the visualisation of construction scheduling and site planning (Chau *et al*., 2004). As far as 5D is concerned, it integrates the 3D model with cost information such as quantities, schedules and prices. For example, Cheung *et al*., (2012) developed a prototype to conduct cost estimation in the early design stage. Kehily *et al*., (2013) linked BIM with cost estimate software containing lifecycle data such as time and interest rates to conduct a quicker and more accurate lifecycle cost analysis.

Since BIM contains both geometric and no-geometric information, it has been widely applied in the area of energy analysis. Most existing studies focus on how to make sure that information is exchanged effectively between BIM and energy analysis tools. For example, Gökçe and Gökçe (2014) applied Industry Foundation Classes (IFC) specification to facilitate the exchange of BIM model between design and energy simulation tools and information management platform. Cheng and Das (2014) developed a BIM-based web framework which can support automatic code checking and energy simulation.

BIM has been widely accepted and used in the design phase (Eastman *et al*., 2008) and construction phase (Goedert and Meadati 2008). However, according to Bryde *et al*., (2013), BIM has the potential to be used at all stages of the project's lifecycle. A number of studies have explored how to capture and store the information generated from design, construction, and operational phases to achieve better FM. Goedert and Meadati (2008) proposed a method to attach construction process information to the BIM, from which 3D and 4D as-built models are created for the owners to apply during the operation phase. Additionally, Liu and Issa (2012) proposed to integrate the BIM database and FM system in order to hand over full design information to the operation and maintenance phases, through which information management throughout the project lifecycle has been realised.

BIM is a central platform to integrate multi-disciplinary teams working on the same project. As a result, a lot of researches focus on collaborative working through the use of BIM. Singh *et al*., (2011) developed a theoretical framework based on the BIM-server to support multi-disciplinary collaboration. Wang *et al*., (2013) stressed that considering FM during early design stage contributes to the significant improvement of operation and maintenance during the FM phase. For this reason, they developed a BIM-based framework to involve FM information into the design decision making at an early stage. However, at this stage, interoperability is still a key barrier hindering collaboration practices (Patacas *et al*., 2015). In order to address this issue, a few studies have started to explore how to use open and neutral data formats such as IFC and Construction Operations Building Information Exchange (COBie) to enable the exchange of digital information in a structural and efficient way between different systems (Gökçe *et al*., 2013; Patacas *et al*., 2015; Wetzel and Thabet 2015).

BIM-Based Knowledge Management

Only a small number of recent studies have recognised the potential of BIM tools that can be used to improve knowledge management practice. Recent research on knowledge management under the BIM environment continues to mainly focus on one phase of the construction project lifecycle. For the design phase, Fruchter *et al*., (2009) integrated two knowledge management applications, RECALL and TalkingPaper, with BIM software. This was done to bridge the digital document, paper document and speech, in order to facilitate the knowledge capture process. Wang and Leite (2015) designed a system that can be used to capture the knowledge generated during the MEP design coordination

meeting. In this system, a customised tag tool was established to facilitate the knowledge recording process. Kim and Grobler (2009) applied the ontological technique under the BIM environment to aid the design coordination process. Kivits and Furneaux (2013) indicated that BIM has the potential to enable collaborative knowledge management in the design and construction phase, which in turn will facilitate sustainability and asset management. Nguyen and Toroghi (2013) proposed a BIM-based framework to represent the knowledge contained in the Leadership in Energy and Environmental Design (LEED) to ease the sustainability assessment for a building design.

For the construction phase, Park *et al*., (2013) combined BIM, augmented reality (AR) and ontology techniques to help collection and retrieval of defect information and knowledge, and AR-based inspection system to enable proactive field defect management. In addition, some researchers established a 3D CAD-based knowledge management system to integrate the 3D CAD object with relevant knowledge. Their purpose was to facilitate the knowledge sharing process during the construction phase (Jan *et al*., 2013; Ho *et al*., 2013; Lin 2014).

A number of studies also explored how to enhance knowledge management during the post-construction phase by using BIM. Charlesraj (2014) pointed out that as-built information stored in BIM model is valuable for FM. He further proposed a framework which links BIM with ontologies of FM to aid in knowledge management during the FM phase. Motawa and Almarshad (2013) also developed a knowledge-based BIM system for the maintenance phase, which helps solve current problems based on previous cases. Motamedi *et al*., (2014) applied the visualisation function of BIM with various types of building knowledge to explore the possible root causes of failures in FM.

At this stage, very few studies have focused on managing knowledge throughout the project lifecycle by using BIM. Kivits and Furneaux (2013) explored the potential to integrate BIM with knowledge management to facilitate sustainability and asset management throughout the project lifecycle. Konukcu and Koseoglu (2012) pointed out the possibility of combining BIM and the supply chain to realise knowledge management throughout the project lifecycle. Due to the fact that BIM can provide a single platform for multi-disciplinary participants to work in a collaborative environment, Kim and Grobler (2009) improved the design coordination process by integrating BIM with ontological checking techniques. In addition, Wang and Leite (2015) developed a BIM-based prototype system in which a tag function was introduced to live-capture and represent coordination information and knowledge during the BIM-based design coordination process. However, current studies did not lay emphasis on how to manage knowledge throughout the project lifecycle and in a collaborative way.

Among these BIM-based knowledge management strategies and systems, we find that various knowledge management techniques were utilised with BIM technologies, such as ontology (Kim and Grobler 2009; Park *et al*., 2013; Charlesraj 2014), case-based reasoning (CBR) (Motawa and Almarshad 2013); fault tree (Motamedi *et al*., 2014), knowledge map (Lin 2014) and criteria measurement and reporting (Nguyen and Toroghi 2013).

CONCLUSIONS AND FUTURE PERSPECTIVES

This paper mapped and investigated current research perspectives on BIM-based information and knowledge management through a comprehensive literature review. At this stage, many studies have exposed that information can be managed in an efficient way by using BIM. However, a limited number of studies have explored knowledge

management under a BIM environment. This paper reviewed relevant literature. Extant studies clearly show that future research in this area should lay more emphasis on collaborative knowledge management throughout the project lifecycle under a BIM environment. The following discussion analyses issues that were not considered in previous studies on BIM-based knowledge management and deliberates on new research directions and research questions.

As mentioned earlier, information can be managed efficiently by using BIM, and various aspects of information management in BIM environment have been explored. For example, project information stored in BIM can facilitate 4D and 5D, and energy estimation, which will reduce the time consumption significantly. Information management throughout a project's lifecycle has also been explored in previous studies. Additionally, as a centre platform, BIM enables multi-disciplinary participants to share their information in a collaborative way. However, interoperability is also one of the main barriers to BIM-based information management. Therefore, future research into BIM-based information management should pay more attention to interoperability issues. Research should not only work towards solving the interoperability among different BIM tools, but should also explore the interoperability between BIM tools and other information management systems such as the documentation system and expert system.

Since BIM only contains geometric and non-geometric information of a project rather than knowledge, BIM-based knowledge management is much more complex than BIM-based information management. Therefore, there are various aspects of knowledge management under a BIM environment that need to be explored.

Since BIM has the capability to contain multi-disciplinary information, the introduction of BIM eases collaborative information management, makes coordination processes more efficient, and reduces conflicts among project teams. However, existing studies on BIM-based knowledge management do not lay emphasis on collaborative knowledge management. In a construction project, designers have the intent and rationale that aid the construction phase (McCarthy *et al*., 2000). Facility managers are in the best position to know the functionality and practicability of a building and the requirements of clients (Meng 2013). Contractors, have a higher level of construction knowledge and experience because of their specialist training, their in-depth knowledge of construction materials, methods and local practices (Song *et al*., 2009).

Therefore, future research must make full use of the central platform provided by BIM to realise BIM-based collaborative knowledge management. Some knowledge management techniques and tools could be integrated with BIM to facilitate collaborative knowledge management. For example, web-based technologies have been widely used for collaborative knowledge management (Lin *et al*., 2006). In addition, some knowledge strategies could be added to the BIM-based knowledge management system to enhance the aspect of collaborative knowledge management, such as communities of practice (Lin and Lee 2012). Therefore, integrating collaborative knowledge management technologies and strategies with BIM to facilitate the shift from BIM-based information to BIM-based knowledge management would be a novel research direction.

In addition, as an information-intensive 3D objects model, BIM can be used as a visual representation to facilitate knowledge management practices. According to Ewenstein and Whyte (2009), visual representations can be used to manipulate epistemic objects that enable different epistemic communities to work in a shared way. In this manner, the problem can be solved based on a shared understanding of problems. Luck (2007) also emphasised that the level of clients' understanding of the design can be improved in the

conversations with the support of artefacts such as drawings and models, and sometimes, the knowledge is embedded in the artefacts themselves. Therefore, future research can focus on using the BIM model as a visual representation to facilitate collaborative knowledge management.

Compared to the use of BIM for managing information throughout the lifecycle of a project, few studies have focused on managing knowledge throughout the project's lifecycle. Konukcu and Koseoglu (2012) proposed the possibility of combining BIM and the supply chain to realise knowledge management throughout project lifecycle. Kivits and Furneaux (2013) explored the potential of BIM to enable sustainability and asset management issues to be concerned at all stages of the project lifecycle through knowledge management. Although these studies have found the possibility of BIM to be used to assist knowledge management throughout the project lifecycle, more research is still needed. Future research should focus on how to integrate the knowledge from each phase of the construction project through the use of BIM. Due to the fragmentary nature of the construction project, and different project participants involved with different experience and knowledge (Dave and Koskela 2009), various knowledge management tools would be used by these project teams. Consequently, knowledge is difficult to be transferred and shared among project participants. Future research direction could turn the focus on how to connect knowledge management tools of each project team with BIM to facilitate knowledge management throughout the project lifecycle. Figure 2 shows the integrated framework in which BIM is used as a knowledge carrier to support knowledge management throughout the project lifecycle. However, to apply BIM as a carrier to transfer the knowledge contained in different knowledge management tools, interoperability would be a main barrier that should be addressed.

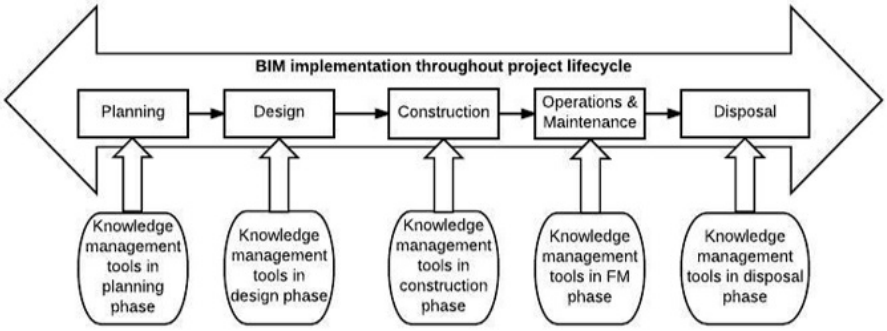

Figure 2: Proposed BIM-based knowledge management framework throughout project lifecycle

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