Knowledge Management and BIM Practices: Towards a Conceptual BIM-Knowledge Framework

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Abstract

The construction industry is a knowledge-intensive and knowledge-generating industry. However, challenges exist in terms of capturing and sharing knowledge of best practices and lessons learned within projects, and from one project to another. This is mainly due to the multi-disciplinary, multiorganizational and temporary nature of construction projects, which causes valuable knowledge to remain with individuals and/or get lost with time. Therefore, it is critically important to effectively capture and share the experience-based knowledge that is generated in construction projects in order to enable improvements in decision-making based on continuous learning. Building information modelling (BIM) has emerged as a solution that could possibly help in this endeavour through effective collaboration and learning processes. However, currently, BIM practices mainly focus on digitalising traditional information exchanges among project stakeholders. Hence, there is little consideration of how experience-based knowledge can be effectively captured in BIM-enabled projects and used for continuous improvement. This paper presents insights into this issue by drawing on the literatures on knowledge management (KM) and BIM implementation. It proposes a conceptual BIM-Knowledge framework, the main contribution of the paper, which consists of a KM approach and five critical factors: individual psychosocial factors, organisational factors, economic factors, technological factors and client factors.

Keywords: Building Information Modelling, conceptual framework, construction industry, knowledge management, tools and techniques

1 Introduction

The construction industry is a knowledge intensive industry where abundant knowledge is generated. As a result, knowledge has been identified as a major asset and most competitive resource within the construction industry (Rowley, 2007). However, knowledge in the construction industry is fragmented in the sense that it is spread among a variety of stakeholders. This fragmentation, combined with the temporary nature of construction projects, make communication of information and knowledge difficult among project participants; thus, significantly reducing the chance of reusing the vast amount of knowledge generated in projects (Liu et al., 2013).

The current use of Building Information Modelling (BIM) is focused on digital data management and information exchanges with little consideration and exploitation of experience-based knowledge generated in projects, which is arguably more valuable for enabling positive improvement in the construction industry (Boyes, 2016). Therefore, the current approach to BIM is not mature enough to contribute to knowledge accumulation through continuous learning; and knowledge management (KM) is a stand-alone process separate from BIM implementation (Liu et al., 2013). Several researchers have identified the need for capturing and integrating experience-based knowledge into BIM practices in order to enable continuous improvement in BIM-enabled projects (e.g. Boyes, 2016; Deshpande et al., 2014). Boyes (2016) reviewed the studies on BIM-based knowledge management that were conducted between the years 2011 and 2016, and he revealed that most of them are limited in their scope and very few of them considered managing knowledge throughout project lifecycle. He concluded that there are significant potential benefits in integrating experience-based knowledge, which is continuously generated along projects, into BIM practices in order to attain a sustainable built environment. Similarly, Wang and Meng (2016) argued that there is a need for focusing on how to integrate the knowledge generated at each stage of BIM-enabled construction projects, so that BIM can improve decision-making in the subsequent stages of the project as well as in subsequent projects. Therefore, there are significant potential benefits of capturing and integrating experience-based knowledge into BIM practices effectively because this would enable continuous learning, thus enabling continuous improvement in decision-making in BIM-enabled projects.

2 Methodology

The present paper is based on a literature review that is undertaken as part of the ongoing Ph.D. research of the first author. Review of relevant literature has been accepted as one of the methodologies for advancing knowledge within the construction management field (Olubunmi et al., 2016). Using the document type "Article and conference paper" with date range from "2004 to 2017", under the "Article Title, Abstract, Keywords" section of Scopus, the search for relevant papers on knowledge management and BIM practice was conducted. Scopus search engine was used to retrieve the relevant papers due to its effectiveness (Tober, 2011) and popularity on previous similar studies (Darko et al., 2017). The year 2004 was chosen as the starting year for the search being the year the AVANTI programme (regarded as the impetus behind BIM in the UK) was published (https://www.stroma.com/certification/bim/history). Year 2017 was set as the upper limit because the search was conducted in that year.

The following suited search terms were used: "knowledge management" OR "KM" OR "knowledge management approach" OR "experience-based knowledge" AND "building information modelling" OR "BIM" OR "BIM Approaches" OR "BIM implementation". While acknowledging that these terms are not exhaustive, it important to state that they were chosen only to obtain a workable number of relevant publications for this study. Given the fact that it is practically impossible to include all the potential search terms in a single search (Darko et al., 2017), other possible keywords that could be included in future search include: "experiential knowledge", "Building information modeling" "BIM-based knowledge management", among others. In addition, only papers published in English language were included while all papers in other languages were excluded.

The first search identified 127 papers comprising of 58 journal articles and 69 conference proceedings in both AEC and non-AEC subjects (e.g. Mathematics, Chemistry, Business, Management and Accounting, etc.). Since the focus of the paper is AEC industry, all papers published on non-AEC subjects were consequently excluded first, leaving a total number of 51 papers in AEC subjects published in 30 different journals and conferences. A quick review of the titles and abstracts of the papers was conducted to filter out any repetition and unrelated papers. After the filtering, only 17 of the papers were found be directly related to the study. However, in other to ensure that important papers were not excluded, especially in the area of knowledge management approaches, which seems to have been a subject of research long before the advent of BIM, the references in most of the papers were also reviewed for relevance and possible inclusion. Consequently, additional 16 papers were found from the references to be relevant for inclusion in the review. After the whole exercise, a total number of 33 papers were found valid for review.

Drawing on the reviewed literature, this paper identifies a KM approach as well as five factors considered critical for effective integration of experience-based knowledge and BIM practices. These are then used to develop a conceptual framework that presents how experience-based knowledge could be integrated into BIM practices to enable continuous improvement in decision-making in BIM-enabled projects.

3 knowledge management and the construction industry

Throughout the different stages of construction projects, the stakeholders exchange information to achieve the required outcome by bringing to fore their different expertise and knowledge. Unfortunately, the teams are usually disbanded after each project without adequate capturing and storage of the abundant knowledge generated during the project for future use. The unique nature of every design and construction process requires creativity and innovation on the part of the designers and constructors to ensure success (Deshpande et al., 2014). Creativity, ingenuity and experiential knowledge play a vital role in decision-making regarding construction means and methods, identification and implementation of solutions to the problems encountered in the process of project delivery (Ferrada & Serpell, 2014). The knowledge generated throughout the life-cycle of a project is one of the greatest assets of a construction organisation and it provides competitive advantage. Effective capturing, storage and sharing of this knowledge for future use is critical to successful execution of subsequent construction projects and vital for competitiveness and survival of the organisation (Ping & Yu-Cheng, 2004; Deshpande et al., 2014). Knowledge management (KM) can help organisations focus on generating, capturing, storing and utilising knowledge for problem solving, dynamic learning, strategic planning and decision-making (Charlesraj, 2014). A major goal of KM is to improve productivity and team-work through a knowledge sharing platform (Ribino et al., 2009).

As a result, over the last decades, knowledge management has received a significant attention from construction scholars (Egbu, 2004; Deshpande et al. 2014). Knowledge management is a developing area of research and practice that aims to improve business processes by relying on various knowledge resources while incorporating innovation at the same time (Wickramasinghe, et al. 2009). The importance of knowledge management within the construction industry has been acknowledged by several researchers (e.g. Elgobbi, 2010; Tan et al., 2010). A framework (IMPaKT) that enables AEC organisations to understand the business impact of their knowledge management was developed by Carrillo et al (2004). Other studies were focused on structured approach to KM problem definition and strategy formulation for an AEC organisation (Cheng et al. 2003), activity based KM system for capturing the knowledge generated in the construction phase (Tsreng & Lin, 2004), development of web-based KM system which allows for knowledge capturing for subsequent use in the same project as well as other project (Tan et al., 2007).

Some other researches were focused on issues of ontologies and taxonomies for construction organisation and knowledge retrieval (El-Gohary et al., 2010; Wang et al., 2011; El-Dirabi, 2013) while other studies were directed at the people, state of the practice, and implementation aspects of KM (Javernick-Will, 2012; Xi et al., 2013). While the work of Tsreng and Lin (2004) is activity based and limited only to the construction stage, the study carried out by Deshpande et al., (2014) encompasses both the design and construction stages. However, a review of this body of literature reveals that there is still a lack of understanding of how experience-based knowledge, which continuously develops during the life-cycle of projects, can be effectively captured and used for continuous improvement. Given this shortcoming, the present paper next turns to the literature on BIM to make a case for integrating experience-based knowledge into BIM practices in order to enable meaningful and continuous improvement in decision-making in BIM-enabled projects.

4 a case for integrating experience-based knowledge into BIM practices

Building information modelling (BIM) is fast replacing the traditional ways of designing, building and operating facilities by more streamlined and collaborative work process, heavily supported by data-rich, parametric software applications (Niemeijer, 2015). HM Government (2015) document of Digital Built Britain defines Building Information Modelling as "a collaborative way of working, underpinned by the digital technologies which unlock more efficient methods of designing, creating and maintaining built assets". BIM is defined by the National BIM Standard as "a digital representation of physical and functional characteristics of a facility", and it is a "shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition" (BSA, 2012).

BIM is characterised by its ability to create, and operate on shared digital database for information exchange. It enables capturing and preserving information for reuse as well as managing changes effectively, such that a change to a part of the database is automatically reflected to all other parts. However, as stated by Boyles (2016), the current focus of BIM practices is on digital data management and information exchanges with little consideration and exploitation of experience-based knowledge. The clients' demand for quality jobs that are sustainable at a reduced price within the shortest possible time has become a serious challenge for professionals in the construction industry. This challenge may best be addressed if they can effectively and collaboratively make prompt informed decisions based on their expert knowledge developed through experience. The paradigm shift towards seeing knowledge as central to organisational performance and survival further justifies the need for effective integration of experience-based knowledge into BIM practices for impactful decision-making in the construction industry. Therefore, while BIM facilitates digital information exchange, there is still a need to better integrate experience-based knowledge into BIM practices to enable continuous improvement in decision-making. Hence, a KM approach that captures and integrates experience-based knowledge into BIM practices can help improving the decision making processes in the construction industry, including the decisions about BIM implementation.

5 towards a conceptual 'BIM-knowledge' framework

Knowledge management is about planning, organizing, motivating and controlling individuals and organisational information systems to improve their knowledge assets and productivity (King 2007). This suggests that knowledge management processes are complex and multifaceted. Therefore, a conceptual basis needs to be established when knowledge management is being considered. The complex and multi-faceted nature of knowledge management processes also suggest that there are several dimensions of critical factors that need to be identified and addressed for successful integration. Consequently, this section first sets the conceptual basis for a framework to effectively integrate experience-based knowledge into BIM practices. It then introduces the critical factors that need to be considered for achieving such integration. It finally uses these to develop a conceptual framework for effective integration of experience-based knowledge into BIM practices to enable continuous improvement in decision-making.

5.1 The Conceptual Basis

The distinction between explicit and tacit knowledge (Malone 2013) provides a useful vocabulary for thinking about the interface between experience-based knowledge and BIM practices. While explicit knowledge refers to knowledge which can easily be written down, captured in a database, and codified, tacit knowledge is more difficult to write down and codify. It is the knowledge which usually exists in the mind of the 'knower' and can often be learned through experience or informal training and education (Nonaka 1997). Hence, experiencebased knowledge (an example of tacit knowledge), which remains vital to the successful delivery of projects, is difficult to be effectively captured by the current BIM approach (Malone 2013).

Nevertheless, Abdullah et al. (2002) argued that both explicit and tacit knowledge can be represented as models to be managed. While explicit knowledge can be managed more easily because of its tangible nature; tacit knowledge will need to be converted to explicit knowledge for it to be managed. Knowledge conversion, according to Nonaka and Takeuchi (1995), can be achieved through the process of: socialisation, externalisation, combination and internalisation as shown in figure 1. *Socialisation* is the process of sharing tacit knowledge, while *combination* is about the dissemination of explicit knowledge. *Externalisation* is the process of making tacit knowledge explicit, while *internalisation* is the process of taking explicit knowledge and using it to develop tacit knowledge (Nonaka & Takeuchi, 1995).

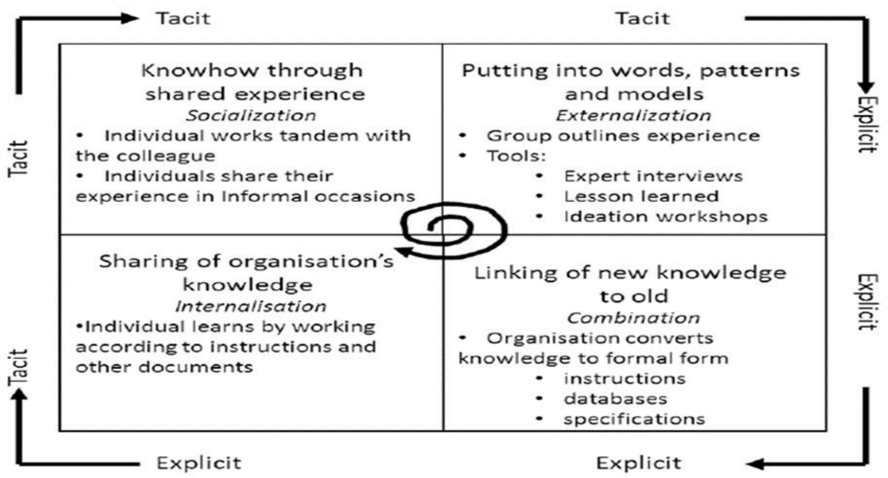

Figure 1: Organisational Knowledge Conversion Cycle. Source: (Nonaka & Takeuchi, 1995)

5.2 Knowledge management processes and tools

For effective knowledge integration, it is important to consider an appropriate knowledge management process (KMP) that can facilitate the generation, capturing and sharing of the knowledge. However, depending on the author's discipline and interest, different taxonomies and categorisations have been suggested for the processes of managing knowledge in the literature. For example, Fong and Choi (2009) proposed five KMPs (knowledge acquisition, creation, storage, distribution, use and maintenance) to study KM in professional service firm. On the other hand, Darroch (2005) suggested three processes: knowledge acquisition, dissemination, and responsiveness; while Andrea and Kianto (2011) adopted knowledge creation, intra-organisational knowledge sharing and application, external knowledge acquisition, and knowledge storage and documentation as their own KMP taxonomy. However, Bigliardi's (2014) KMP model is adopted as the conceptual basis of the framework proposed in this paper. This is because the four processes of knowledge management in Bigliardi's (2014) model are well-suited to operationalise Nonaka and Takeuchi's (1995) four mechanisms of knowledge conversion between tacit and explicit knowledge. According to Bigliardi (2014), the four processes of knowledge management are: 1. Knowledge creation, search and capture; 2. Knowledge organisation, storage and preservation; 3. Knowledge distribution, transfer and sharing; 4. Knowledge use, reuse and feedback. Therefore, Bigliardi's (2014) model provides a suitable conceptual basis for thinking about when and how knowledge conversion can be achieved in BIM-enabled projects for the experience-based knowledge to be captured and integrated into BIM practices.

Nevertheless, in practice the conversion requires the selection and use of adequate knowledge management tools. Several authors in the field of knowledge management emphasised that knowledge management is not done merely by using some information technology (IT)-based tools but also non-IT-based practices are crucial for successful knowledge management (Ruggles 1997; Al-Ghassani 2002; Egbu et al. 2003). In a similar line of thought, Bigliardi et al. (2014) identified two different strategies for KM implementation, namely: an IT-centric strategy and a people-centric strategy. The IT-centric strategy focuses on the use of IT tools such as electronic databases, ERP, internet and intranet to facilitate the main KM processes. On the other hand, the people-centric strategy makes use of activities such as brainstorming, meetings, and direct observation etc., to motivate and facilitate knowledge workers to develop, enhance and use their knowledge to achieve organisational goals. Therefore, a framework to effectively capture and integrate experience-based knowledge into BIM practices must consider both IT-based and non-IT-based tools in a complementary manner because the interface that is being addressed involves both people-centric experience-based knowledge and IT-centric BIM software applications.

5.3 The critical factors

There are several factors from the reviewed literature that can influence the effective integration of continuously generated, experience-based knowledge into BIM practices for enabling continuous improvement in decision-making. According to some of the authors (e.g. Carrillo et al. 2004; Egbu 2004), the barriers for effective KM are compounded by the lack of standard work processes, time and money constraints, poor information technology infrastructure, limitations to oral and paper communication modes, complicated information flows among the increasingly diversified stakeholders, and lack of common language to communicate information and knowledge. Other scholars (e.g. Saini et al. 2017; Arif et al. 2015; Wong 2005; Robinson et al. 2001) have also identified lack of standard work processes within organisation, lack of management support, poor organisation culture, poorly articulated strategy and difficulty in evaluating benefits. The factors were summarised and categorised under five critical factors, which can impact on successful integration of experienced-based knowledge into BIM practice as summarised below:

1. *Individual's Psycho-social Factors (IF):* These are the individuals' psycho-social factors which are part of a KM system as well as those who are responsible for the development and implementation of the system. These factors include personal culture (values and behaviours), willingness to accept solution from others, perception of knowledge as flow or stock, psychology of the people, social settings, level of trust among members, motivation, incentives and support, level of skills and knowledge, and experience in IT (Bambang 2017; Saini et al. 2017; Arif 2015; Egbu 2004).
2. *Organisational Factors (OF):* These factors include management support, commitment and awareness, level of competition with other organisations, process problems, type of ownership, organisational structure and policy, and organisational culture (Saini et al. 2017; Arif 2015; Wong 2005; Robinson et al. 2001).
3. *Economic Factors (EF):* Among these factors are high cost of software procurement, high cost of hardware, desktops and networks, cost of training and operations, and financial ability of the organisation (Robinson et al. 2001; Carrillo et al. 2004).
4. *Technological Factors (TF):* Technological factors include IT infrastructure and support systems, hardware specifications (i.e. availability and usability of software packages, data capturing and analysis tools, and data integration tools), availability and specification of information and communication technology (ICT), continuous change and advances in the industry; and methods and tools available for KM (Egbu 2004; Wong 2005; Arif et al. 2015).
5. *Client/Customer Related Factors (CF):* These actors are about clients' demands for, for example, value for money, decreased time and cost of project; improved quality of products, improved supply chain management, and improved customers relationship management (Bambang 2017; Saini et al. 2017; Arif et al. 2015).

The literature suggests that these factors must be considered for successful KM applications, and therefore, they are also considered critical for effectively integrating experience-based knowledge into BIM practices. Those who undertake KM practices are people. Hence, it is critical to first address the individual human psycho-social factors for successful integration of experience-based knowledge into BIM practices, especially the issues about individual cultural frictions. Besides, for people to share knowledge, it is important to build trust among various individuals through interactions. Additionally, those who are willing to share their knowledge must be kept motivated with incentives that encourage creating and taking opportunities for continuous learning and innovation. The organisational policy and culture must be enabling for individuals, and they must encourage members to learn and share their knowledge freely either through job rotation, meeting and face-to-face interaction. Though the technological means must be adequately selected and implemented in the service of higher goals of managing knowledge, the human related factors must also be given their pride of place while managing knowledge within the BIM practice. Earlier studies, especially on BIM implementation and practice, have always emphasise the importance of technological factors at the detriment of the human factors. A correct balance must be established between the prioritisation for technological and other critical factors especially in the case of integration of experience-based knowledge into BIM. Finally, all the efforts must be aligned according to the needs of clients in order to ensure that the efforts for KM add value in overall.

5.4 A conceptual BIM-knowledge framework

Current BIM practices in the construction industry are information-centric causing knowledge management to be handled separate from BIM practices to a large extent. Therefore, there is a growing need to effectively capture the experience-based knowledge that is generated in construction projects and integrate it into BIM practices, so that improved decision-making can be enabled through continuous learning. Addressing this challenge, Chen et al. (2009) conducted a research on visualisation process to develop a knowledge-based system. In Chen et al.'s (2009) work, expert knowledge stored in the system is inserted to facilitate the collaboration process by enabling domain knowledge sharing and reuse between different users. Liu et al. (2013) adopted the same principle to develop a building knowledge modelling framework, by expanding information exchange into knowledge sharing with the integration of a fully functional knowledge management system.

Inspired from Liu et al.'s (2013) work, and developed upon the conceptual basis and critical factors discussed above, this paper proposes a conceptual framework (named BIM-Knowledge framework) for effectively capturing and integrating experience-based knowledge into BIM practices in order to enable continuous improvement in decision-making in BIM-enabled projects (see Figure 2 below).

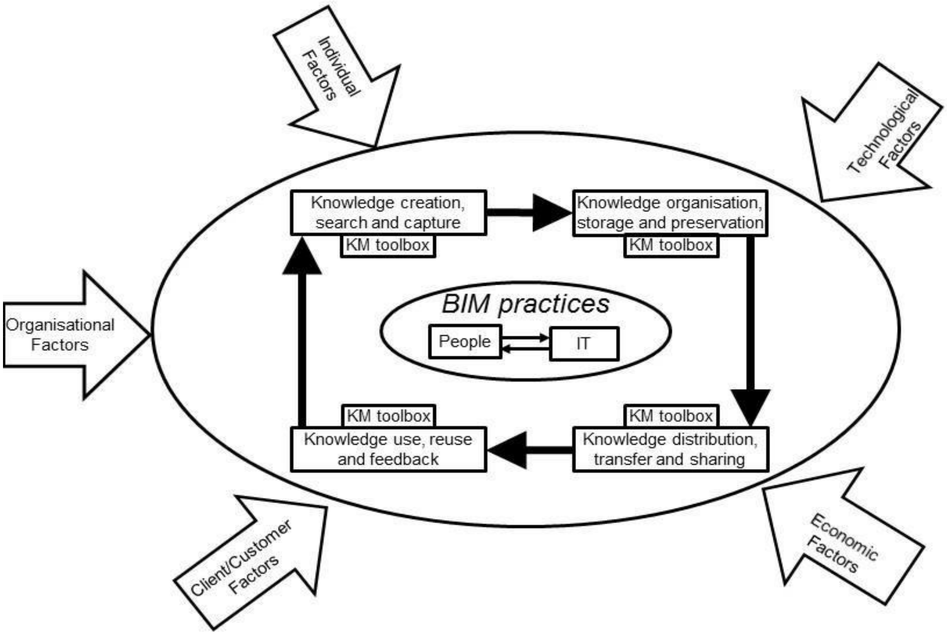

Figure 2: Conceptual BIM-knowledge framework for the integration of knowledge into BIM practices

The framework depicts a continuous process that involves continuously capturing and integrating experience-based knowledge into BIM practices based on Bigliardi's (2014) four KM processes and the identified critical factors. Therefore, according to the framework, the selection and use of adequate KM tools throughout the various stages of a project is crucially important.

A use case of BIM-Knowledge framework is demonstrated in Table 1 below. Table 1 shows the four KM processes and the corresponding appropriate KM tools that can be used to capture and integrate experience-based knowledge into BIM practices for the design stage of a project. The specifics of the five critical factors will change from project to project, and therefore their effects are neglected in the presentation of this hypothetical use case. To create, search and capture knowledge at the design stage, members will rely on their personal and company experience, brainstorm together, discuss lessons learnt from the past and present projects, discuss best practices, and rotate jobs.

Table 1: KM Toolboxes for implementing BIM-Knowledge to the design stage of a project

Stage	KM Process	Example of KM Toolbox
DESIGN STAGE	Knowledge Creation, Search and Capture	Experience (personal & company), brainstorming, Coaching and mentoring, lessons learnt, best practices, job rotation, meetings, innovative practices
	Knowledge Organisation, Storage and Preservation	Minutes of meetings, computer files, knowledge bank (databases), internet, virtual libraries
	Knowledge Distribution, Transfer and Sharing	Mentoring, daily interaction, expert input, on-thejob training, chatting and storytelling, meetings, best practices
	Knowledge Use, Reuse and Feedback.	Knowledge/experience from previous jobs, feedback meetings, face-to-face interaction, intranet

The experts and the experienced project members will have to coach and mentor the new and younger ones. The emphasis will be on non-IT-based tools here to create, search and capture knowledge, especially the tacit knowledge through *socialization* and *externalization*. The captured knowledge will need to be adequately organized, stored and preserved, which will require systematic ways of recording. Minutes of meetings, knowledge banks (i.e. databases), computer files and online platforms can be used for these purposes, and these can also be digitally linked to the project's BIM technologies for more efficient knowledge organisation, storage and preservation.

In order to enable improved decision-making, the stored knowledge will need to be disseminated for *combination* and *internalisation* through activities such as daily interaction, on-the-job training etc. with the support of appropriate IT-based KM tools. The tacit knowledge that is acquired through internalisation will be used and reused, thus building a basis for constructive feedback to further enable the creation, search and capture of new knowledge. These four KM processes need to be performed as a cycle to enable continuous improvement in decision-making in BIM-enabled projects.

6 Conclusions

Knowledge is a major asset for all organisations in the construction industry because it is the basis of effective decision-making which enables competitive advantage. BIM is increasingly being adopted in the construction industry as a solution to this end. However, the current BIM practices give little consideration to capturing and exploiting the experience-based knowledge generated in BIM-enabled projects, thus delivering suboptimum value. This paper put forward a conceptual BIM-knowledge framework to effectively capture and integrate experience-based knowledge into BIM practices in order to enable continuous improvement in decision-making in BIM-enabled projects. The proposed framework suggests a cyclical KM process that needs to be operated considering five critical factors. Another major contribution of this paper is the identification and emphasis on the human factor (individual psycho-social and client/customer related factors) as critical factors to be considered while integrating experience-based knowledge into BIM practice.

There are limitations associated with the proposed framework. It is developed based on the initial insights into the KM and BIM implementation literatures. Therefore, further refinement may be needed based on a wider review of the literature in these areas and other relevant areas, such as the scholarship on decision-making. Also, the proposed framework is purely based on literature review. Therefore, it needs to be empirically tested and validated to be finalised. Nevertheless, the framework provides a useful starting point to consider how continuous improvement in decision-making could be enabled in BIM-enabled projects, thus enabling a useful basis to be built upon. Since this paper is based on an ongoing Ph.D. study, future research will focus on the refinement of BIM-K framework as well as its empirical testing and validation.

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