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Involving Knowledge of Construction and Facilities Management in Design through the BIM Approach

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Abstract

The construction industry has increasingly realised the importance of knowledge. Accordingly, various strategies and tools have been applied over the years to support knowledge management (KM). In particular, building information modelling (BIM) is a technology that has recently emerged in the construction industry. BIM is an object-oriented and parametric-based tool with the features of digital visualisation, life cycle simulation, coordination and collaborative environment. Consequently, many studies have been conducted to explore these four aspects. However, existing studies on BIM-based management mainly focus on the information level. By contrast, only a few studies have explored KM under the BIM environment. Therefore, this study explores the potential and expectations of BIM-based KM for the early application of knowledge of construction and facilities management (FM) into the design stage. A total of 30 semi-structured interviews are conducted to collect qualitative information from the AEC industry. The existing KM practice is explored based on the analysis of the collected qualitative information. Thereafter, a discussion is presented on how the BIM-based KM can be used to mitigate the current KM challenges. Lastly, this study presents the expectations on BIM-based KM for involving the knowledge of construction and FM into the design phase. Overall, this study provides new insights into the transformation of research focus from BIM-based information management to BIM-based KM.

Keywords: Building information modelling (BIM); knowledge management; construction project management; collaboration

1. Introduction

Many industries have realised the importance of knowledge and the architecture, engineering and construction (AEC) industry is no exception. Knowledge is applied within this industry to address a variety of difficulties and improve project performance, such as control of time [1] and cost and avoidance of health and safety accidents [2]. Consequently, knowledge management (KM) has become an important task for construction-related organisations and has received extensive attention in the academic circle. However, KM in construction projects is challenging because of the its temporary nature and the variety of disciplines involved in it [3, 4].

To enable KM to meet the additional requirements caused by the increasing complexity of a project, information technology (IT) tools and IT-based techniques are developed for knowledge capture and retention, knowledge sharing and knowledge reuse. Meanwhile, IT-supported KM is also used in each of the project stages, such as design [5], construction [6] and operation and maintenance (O&M) [7]. In addition, the focus of research began to shift to KM throughout the projects' life cycle because of the emphasis placed recently on the improvement of the project life cycle performance [8].

Building information modelling (BIM) is an emerging technology and is extensively used in the AEC industry. The National Institute of Building Sciences (NIBS) [9] explained that BIM is a digital representation of the physical and functional characteristics of facilities. The geometric and non-geometric information included in BIM models can digitally describe a building and its elements. Existing studies on BIM can be classified into two main aspects, namely

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technical- (e.g. clash detections, energy simulations, time and cost evaluations, data compatibility) and BIM process-related (e.g. collaboration, information sharing, BIM adoption and BIM-based procurements).

However, existing studies have only focused on the information rather than the knowledge level within projects. Accordingly, only a few studies have applied BIM to facilitate KM, although such research does not consider the BIM-based KM under a collaborative environment. In addition, no studies have yet to systematically explore BIM's potential for KM and the expectations and needs of BIM-based KM for collaboration. Therefore, the current study aims to fill in this knowledge gap by exploring methods to involve knowledge of contraction and FM into the design stage under a BIM environment.

This study firstly explores the existing early involvement of contractor and FM teams and identifies BIM's potential for KM thereafter. Lastly, the expectations of BIM-based KM for early contractor involvement (ECI) and early FM involvement (EFMI) are investigated.

2. Theoretical framework and literature review

2.1. Existing IT-supported KM in construction

Many KM related techniques have been used in construction projects. In addition, some ITs are also used to support KM techniques. The most common KM techniques used in current projects include brainstorming, communities of practice, face-to-face interactions, training and post-project review. Since construction projects are becoming increasingly complex, the involvement of various disciplines in projects is required. As a result, relying solely on people to manage knowledge is challenging. Existing studies show that IT has been applied to every process of KM in construction projects.

IT-based knowledge capture has developed from audio diaries [10] to Web 2.0 applications [6, 11]. For example, Soibelman et al. [5] developed a web-based design review checking system to obtain personal knowledge from projects and transfer such knowledge into the organisational level. Woo et al. [12] explained that knowledge of construction projects is mainly tacit and difficult to capture. Therefore, a few IT-based KM methods are developed to aid the capture of tacit knowledge, such as the ontologies used by Ugwu et al. [13] and network-based knowledge map used by Lin et al. [14]. Although the existing studies have begun to focus on the capture of tacit knowledge, only a few previous studies have explored the retention and storage of tacit knowledge. Consequently, the reusability of tacit knowledge is also inefficient. In addition, the use of post-project reviews as the main knowledge capture technique indicate that staff turnover and reassignment often suffer from missing knowledge during project implementation because of time lapse. To mitigate this issue, a web system was developed to achieve the proposed concept of "live" capture and reuse of knowledge [11].

Numerous studies have explored the use of ITs to support knowledge sharing. An intranet is often used to share knowledge within an organisation. The emergence of the World Wide Web enables such sharing of knowledge across organisations. However, the web integrated to KM can only support explicit knowledge sharing, whereas the contribution of tacit knowledge sharing is limited [15]. To promote tacit knowledge sharing, a few studies combine ITs with KM techniques, such as community of practice, which can enhance the interaction for this type of knowledge sharing [16].

Knowledge reuse comprises two aspects, namely, knowledge retrieval and knowledge adaptation. Many studies explored how ITs can facilitate knowledge retrieval and the retrieval scheme includes keywords [14], ontologies [17] and data/text mining [18, 19]. However, these studies fail to consider knowledge retrieval under collaboration. Existing studies lack IT-based knowledge adaptation.

Databases are extensively used in knowledge storage, requires a predefined classification structure, and is labour consuming and subjective. To mitigate this challenge, an automatic knowledge classifier is developed to be combined with the database developed by Chi et al. [20].

2.2. BIM-based KM

Presently, three methods are used to capture knowledge under the BIM environment. The first method is to capture and retain knowledge by using predefined customised parameters in the BIM model [21]. The second approach is using application programming interface to manipulate the data retained in the BIM model through external applications [22]. The last method combines BIM with a specialised knowledge capture tool [23, 24]. BIM enables users to create customised parameters to add the knowledge related to the building objects and project [25]. Deshpande et al. [21]

developed a KM system, in which different user-defined parameters, such as lessons learned and involved subject experts, are used to capture knowledge. Although existing studies utilise predefined parameters for knowledge capture, no studies explore how the structure of the parameters suits the collaboration among the different disciplines. Only a few studies focus on knowledge capture and reuse. In addition, research on BIM-based KM fails to consider the capture and reuse of tacit knowledge.

Knowledge sharing under the BIM environment is mainly based on the combination of BIM and knowledge-sharing tools, such as web application [26] and software [27]. BIM combined with web-based applications can use the accessibility, search capability and social interaction of web-based technologies and maximise the 3D description and parametric modelling features of BIM. Ho et al. [26] established a BIM-based web application to share knowledge in a text format. However, knowledge in text format is difficult to understand, thereby impeding collaboration. BIM as a 3D presentation tool can be used for visualised explanation of text-based knowledge.

Existing studies have yet to intensively explore knowledge retrieval under the BIM environment. Park et al. [28] and Ding et al. [29] applied ontology-based knowledge representation to aid knowledge retrieval under the BIM environment. To implicitly or imprecisely retrieve knowledge, Gómez-Romero et al. [30] combined fuzzy description logics with ontology in the BIM-based system to improve the knowledge retrieval results, in which the retrieval mechanism is not either "true or false" but relatively holds the truth. Additionally, case-based reasoning is introduced in the BIM environment for knowledge storage and retrieval [25].

2.3. Early involvement of knowledge of construction and FM into the design stage

ECI is proposed by the UK Highways Agency and aims to engage contractors earlier than normal to provide assistance with design [31]. ECI is a relationship between contractor and client or design team, thereby providing an opportunity for contractors to apply their knowledge into the design. During the design stage, contractors can provide suggestions to support the estimation of schedule and budget and the selection of materials and construction strategies.

Previous studies have stressed the benefits of ECI, such as improved constructability [1, 32–34], enhanced relationship [32, 35, 36], facilitation of innovation [32, 34, 37, 38], informed decision-making [1, 31, 34] and avoidance of potential risks and accidents [1, 31–34, 38–40]. Additionally, a few other aspects of a project, such as waste reduction, quality improvement, environment impact control, sustainability and defining the practical objectives, can be assisted through ECI [40]. ECI can also facilitate in easily meeting the requirements of clients [31].

The purpose of EFMI is to consider the potential problems that may occur in the operation stage during the design stage because FM teams are knowledgeable in the O&M of buildings and end users' special needs for business objectives [41]. Therefore, EFMI has obtained intensive attentions from the industries and academia.

A few existing studies discussed the benefits of EFMI. Firstly, EFMI assists the design team to identify potential design errors and ensure the operability, maintainability and serviceability of buildings, including material selection and space layout for equipment installation and accommodation [42, 43]. Mohammed and Hassanain [43] further indicated that feedback from the design team during the EFMI process can also improve O&M in the future. This scenario can be considered as a knowledge loop. Additionally, the FM team can recommend appropriate and efficient equipment and systems based on durability and reliability because this team has the experience in maintaining building systems [43, 44]. Clients/end users can also obtain benefits from EFMI, such as achievement of their expectations [43, 44], guarantee of particular systems or objects' performance [45], adaptability for their business needs [41], reduction of life cycle cost [43, 44] and flexibility and adaptability for future changing needs [41, 43].

Apart from the advantages of ECI and EFMI, barriers and challenges are also identified by existing studies (see summary in Table 1).

Table 1. Barriers to ECI and EFMI

Barriers to ECI	References	Barriers to EFMI	References
Responsibility allocation	[31, 46]	Lack of the understanding of benefits	[42, 45]
Reluctance to change	[1, 33, 46]	Lack of common knowledge	[42, 47, 48]
Lack of the understanding of benefits	[1, 40]	Lack of technical supports	[48, 49]
Lack of mutual trust and respect	[46]		
Loss of competitiveness	[32]		
Lack of technical supports	[34, 46, 50]		

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3. Methodology

To collect in-depth information from the industry, the current study opted for semi-structured interviews as the research method. A total of 30 experts from the construction industry were interviewed. All interview participants have extensive knowledge and experience in BIM and are working in different organisation types, including design, construction, FM, consulting company and client. The reason for the range of organisations is that the current study aims to explore the collaborative KM in the design stage. Thus, the interviewees' project functions included architect, consultant, contractor, facilities manager, structural engineer and client. Additionally, they were selected from 30 different companies with different sizes, tasks and locations in the UK and Ireland.

The pre-designed interview paradigm was developed and revised based on the literature review and four pilot interviews, respectively. The interview structure was divided into three main sections. The first section aimed to identify the interviewees' personal information and their organisation information. The second section explored the current KM practice in construction projects, which includes the existing KM tools and techniques, KM processes (i.e. knowledge capture and retention, knowledge sharing, knowledge reuse) and BIM's potential for KM. In the third section, interviewees were asked to explain how the contractor and FM team were involved in the design stage of the project. Thereafter, they provided their perspective on how BIM can aid this early engagement process. Furthermore, the interviewees were asked to specify their needs for and expectations of a BIM-based KM system.

Each interview was recorded using a voice recorder with permission from the interviewees. Furthermore, the interview audio will be transcribed into a Word document format for analysis.

4. Findings and discussion

4.1. ECI and EFMI in the current construction industry

The interview results indicate that the interviewees agree that the most efficient ECI should occur before the start of the design drawing rather than during the design process. Interviewees from the design disciplines explained that a client occasionally asks the design team to present their ongoing works and the contractor will be asked to conduct value engineering for the client. Consequently, a few design schemes should be changed, thereby increasing the design team's workloads. Hence, the design team is reluctant to show their design to the contractor to avoid the additional work caused by redesigning. Moreover, a few interviewees suggested that subcontractors should be considered during the ECI process because they have substantial knowledge of technical details and their knowledge is considerably targeted to such specific aspects. One of the interviewees also reiterated that several subcontractors had their own design teams. Hence, they will conduct the design work based on the project design team's general requirements and description. If they need to further discuss with the project design team, then they can ask the main contractor to hold a meeting for them. Furthermore, a few interviewees mentioned that the contractor is invited to participate in the design coordination meeting, which can also be considered as a form of ECI.

A few interviewees believed that when FM participated in the design meeting, the design drawings or models should be presented to facilitate an improved understanding of the design intentions. This situation may be caused by the lack of design knowledge and geometric thinking of the FM team compared with the contractor. The information collected from the interviews was used as basis to conclude that a few decision points in certain projects are set during the design stage. The FM team will be brought to these decision point meetings to comment on how the design should proceed. By contrast, a few interviewees believed that EFMI should not overly rely on the design drawings, because the FM team can lack the design knowledge and skills in geometry. Hence, they need additional time to understand the design drawing. Therefore, if the FM team overly relies on the design drawing, EFMI will become inefficient. These interviewees suggest involving FM in a creative manner, particularly when the drawing work has not started. Moreover, the FM team can be involved in the design as paid consultants to provide suggestions, although they may not be appointed as the final FM team of the project. Two interviewees from the design discipline mentioned that they occasionally use the data from the FM team to support their design, such as maintenance and replacement period cycles of materials or components. If the early involvement of the FM team is not approved by the end user, this team may fail to reflect the end user's needs during the design stage, such as the spatial layout requirements.

4.2. BIM's potentials for KM

The interview results indicate that the three potentials of BIM related to KM are knowledge capture and retention, proactive KM and visualisation-supported KM.

Within the BIM model, description data can be added to the related building objects, such as materials, size and colour. The BIM applications also enable users to create customised parameters, which can be used to capture and retain knowledge. For example, customised parameters can be used to record the knowledge in the BIM model to instruct the contractor how to install or construct a specific part of a building. Such customised parameters can also retain knowledge to guide the FM team on how to operate/maintain the facilities during the O&M stage. Interviewees even suggested that the client/end user should be encouraged to request the knowledge that they need. Accordingly, the design team and contractor will input the required knowledge in the BIM model during the design and construction process. This knowledge-rich model will be forwarded to the FM team for O&M.

Interviewees also believe that the visualisation of BIM can aid KM, particularly for the collaborative KM. A possible motivation for this is that a few collaborators, such as the FM team and client/end user, may lack geometric thinking and design knowledge. If 3D visualisation provides support, then the FM experts and client/end user can easily understand the design intention. They can also intuitively see if the design meets the O&M requirements, building functions and business objectives. Thus, they can provide their suggestions to improve the design. For example, doctors and nurses can use 3D visualisation as basis to suggest to the design team what the layout of the operation room should be and the space needed to transport equipment.

The interviewees explained that BIM has the potential to facilitate proactive KM. They proposed this idea mainly based on the detection, simulation and analysis features of BIM. BIM enables a proactive clash detection. Consequently, design teams can proactively solve these potential problems using their experience and knowledge. BIM can also provide the simulation results for the design, such as energy consumption and sun path movement, thereby assisting project teams to optimise their design. This simulation feature prompts life cycle issues to be considered in the design stage. Additionally, interviewees mentioned that BIM can provide early analysis, such as construction cost, construction program and lead time of suppliers, thereby providing early scenarios to project teams. Accordingly, they can make an informed decision based on their knowledge and experience.

4.3. Expectations of BIM-based KM for ECI and EFMI

The interview results indicate that the interviewees proposed the expectations of the KM processes, namely, knowledge sharing, knowledge capture and retention and knowledge reuse, as well as provided a few other expectations of the proposed BIM-based KM for ECI and EFMI.

Section 4.2 reiterates that the interviewees did not point out that BIM has the potential to share knowledge directly. However, they believe that combining BIM with knowledge-sharing platform can substantially facilitate the efficiency and effectiveness of knowledge sharing. Therefore, the interviewees suggested that the BIM-based knowledge-sharing platform should enable people to comment on the related building objects of BIM. Additionally, they also believe that a discussion module should be included in BIM-based KM, thereby facilitating the interaction during knowledge sharing. The interviewees even think that embedding a common data environment (CDE) to BIM-based KM is necessary. The likely reason for this opinion is that CDE as a central repository includes project-related documentation and graphical and non-graphical data. Although CDE is currently applied exclusively to the information level, such an environment can also be theoretically applied to the knowledge level. Consequently, project parties can share and acquire knowledge on a central platform and avoid errors and conflicts caused by the inconsistency and dispersion of knowledge. Moreover, storing knowledge in the central repository provided by CDE can alleviate the problem of knowledge redundancy in the BIM-based KM system. The expectations of knowledge-sharing mentioned in the interviews are all about explicit knowledge. Although the interviewees understand the importance of tacit knowledge, they did not propose any relevant strategies to manage tacit knowledge in this system.

The interviewees also expect that the BIM-based KM can be used to capture and retain knowledge. The possible reason is that the customised parameters of BIM enable users to add a descriptive natural language. Thus, the customised parameters of BIM enable people to add knowledge related to building objects or even projects. Although BIM can be regarded as a single central repository to capture and retain knowledge, interviewees believe that reliability of importing knowledge from the BIM model into the external database for improved management. The interviewees also reiterated that during the process of knowledge retention, A common "language" should be used for the knowledge index because this BIM-based KM system is for the collaboration of different disciplines in the design stage. The interviewees also explained that with the increasing knowledge in the proposed system, the problem of redundancy should be avoided. The interviewees suggested two solutions. One solution is to generalise knowledge, while the other is to update the previous knowledge based on the latest problems. One interviewee explained that he expected that this system can enable knowledge transfer from project to organisational level.

The interviewees listed three expected methods of knowledge presentation. The first method is to present knowledge in case studies, in which the background information of previous knowledge can be considered when people reuse the knowledge for a current problem. The second method is to link knowledge with related building objects in the BIM model, by which the visualisation of BIM can be used to obtain an improved understanding of the knowledge. The third method is to use conversation as a knowledge presentation method during the knowledge exchange because this technique can facilitate the evaluation of the reliability of knowledge and inspire new ideas.

The expectation of knowledge reuse is mainly about knowledge retrieval. The interviewees proposed three available methods of knowledge retrieval, namely, keywords, condition-based filter and category-based retrieval. However, no matter what retrieval method the expected BIM-based KM system adopts, such techniques should enable adaptation to the collaboration of different disciplines because of the lack of common knowledge among the different disciplines.

The interviewees also expect the system to consider using visualisation, simulation, clash detection and early analysis of BIM to support a proactive KM.

The interviewees also believe that the BIM-based KM should be combined with a few project management strategies, including asset information requirement (AIR), employer's information requirement (EIR) and soft landing (SL). AIR proposes the information to be captured and fed into the asset information model (AIM) for the O&M phase. In addition, AIR indicates the information needed by an organisation in relation to an asset. EIR will be developed based on AIR, in which the information required by a client for project development and operation will be specified. Additionally, the information provided in EIR will facilitate decision-making at each employer's decision point. SL is a strategy that emphasises the collaboration amongst design, construction and O&M. This strategy also emphasises post-project evaluation that can provide feedback for future projects, thereby facilitating knowledge reuse. Although AIR, EIR and SL are currently used only in the management of information level, if KM is combined with these project management strategies, or use AIR, EIR and SL as carriers of knowledge, then collaborative KM will be improved.

5. KM framework under the BIM environment for ECI and EFMI

The improvement of ECI and EFMI requires three aspects of support, namely, technical, cultural and process, based on the expectations of ECI and EFMI in the literature review and the results obtained from the interviews. The three aspects of the BIM-based KM for ECI and EFMI are not independent but complementary. Table 2 shows the details of the BIM-based KM framework for ECI and EFMI. Technical aspect includes knowledge sharing, capture, retention and reuse. Moreover, the six other technical requirements specifically aimed to aid early collaboration in design are management of tacit knowledge, proactive KM, knowledge adaptation, facilitation of common knowledge, responsibility allocation and knowledge presentation.

Table 2. The details of the BIM-based KM framework for ECI and EFMI

Elements of BIM-based KM framework	Mentioned by # of 30 interviewees	Number of quotes
Technical		
Knowledge sharing	21	66
Knowledge capture and retain	7	10
Knowledge reuse (retrieval and adaptation)	15	43
Tacit knowledge	5	12
Proactive KM	21	57
Common knowledge	7	9
Responsibility allocation	5	8
Knowledge presentation	22	44
Process		
AIR	9	10
EIR	16	29
SL	5	14
Knowledge transfer from project to organisation	1	1
Strategies for lack of participation	2	3
Cultural		
Relief of conflicts	3	3
Adaptation to change	12	12
Understanding of benefits of ECI and EFMI	10	14

The process aspect mainly considers the integration of AIR, EIR and SL into the environment of the BIM-based ECI and EFMI. The improvement of the process should also consider improving the traditional capture procedures to solve the lack of participation in post-project reviews or lessons-learned meetings. Moreover, the process aspect should consider how to transfer the knowledge of the project to the permanent part of the organisation.

Without a suitable cultural context, the expected BIM-based KM for collaboration in design will not have a good performance. The results of the literature review and interview analysis indicate that the cultural aspect of this BIM-based KM includes relief of conflicts, development of 'win-win' environment, adaptation to change and understanding of the benefits of ECI and EFMI.

6. Conclusion

This study mainly aims to explore the role of BIM in ECI and EFMI, as well as systematically summarise the existing KM status and challenges of ECI and EFMI through literature review. Thereafter, this research collected information through semi-structured interviews to explore the application of ECI and EFMI in real projects and the experts' views on BIM to improve KM. The interview also revealed the expectations of BIM-based KM for ECI and EFMI. In combination with the results of literature review and interviews, a KM framework under a BIM environment has been proposed and comprised three aspects, namely, technical, cultural and process. Overall, this study provides BIM-related research an idea that transforms BIM into building knowledge modelling (BKM).

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