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Applications of Building Information Modeling (BIM) in Knowledge Sharing and Management in Construction

Shu-Hui Jan, Shih-Ping Ho, Hui-Ping Tserng

***Abstract*—**Construction knowledge can be referred to and reused among involved project managers and jobsite engineers to alleviate problems on a construction jobsite and reduce the time and cost of solving problems related to constructability. This paper proposes a new methodology to provide sharing of construction knowledge by using the Building Information Modeling (BIM) approach. The main characteristics of BIM include illustrating 3D CAD-based presentations and keeping information in a digital format, and facilitation of easy updating and transfer of information in the 3D BIM environment. Using the BIM approach, project managers and engineers can gain knowledge related to 3D BIM and obtain feedback provided by jobsite engineers for future reference. This study addresses the application of knowledge sharing management in the construction phase of construction projects and proposes a BIM-based Knowledge Sharing Management (BIMKSM) system for project managers and engineers. The BIMKSM system is then applied in a selected case study of a construction project in Taiwan to verify the proposed methodology and demonstrate the effectiveness of sharing knowledge in the BIM environment. The combined results demonstrate that the BIMKSM system can be used as a visual BIM-based knowledge sharing management platform by utilizing the BIM approach and web technology.

***Keywords*—**Construction knowledge management, building information modeling, project management, web-based information system.

I. Introduction

USEFUL knowledge can not only remain in experts' memory but can be recorded by way of various media, such as documents, databases and intranets. Knowledge management (KM) is the collection of processes controlling the creation, storage, reuse, evaluation, and use of experience-based knowledge in a particular situation or problem-solving context. In construction, KM focuses on the acquisition and management of important experience-based knowledge provided by jobsite engineers. Furthermore, the traditional updated as-built schedule is maintained using text-based activities. Enhancing the as-built schedule integrated with graphic visualization during the construction phase is helpful and important for advanced schedule management. With the assistance of graphic visualization, graphic-based information management solutions have facilitated updates to the as-built schedule information for general contractors.

During the construction phase of projects, one effective means of improving construction management is sharing knowledge and feedback provided by jobsite engineers. Such sharing helps to prevent mistakes that have been made in previous projects. Drawing on knowledge and experience eliminates the need to solve problems from scratch. Most construction projects in Taiwan have recently applied the BIM system to improve construction management during the construction phase. However, most shared information from the construction phase in text-based illustrations, but focus less on virtual illustration and sharing. In construction projects, there are many important relationships between the presentation and retrieval of knowledge and CAD in terms of knowledge management. Furthermore, when knowledge is available for sharing, it is not easy for engineers to understand it directly without 2D or 3D CAD illustrations. The main characteristics of BIM include illustrating 3D CAD-based presentations, keeping information in a digital format, and facilitation of easy updating and transfer of information in the 3D BIM environment. Therefore, the primary purpose of this study is to provide the jobsite engineers with a way to acquire, manage, and reuse knowledge effectively gained from other jobsite engineers, and this knowledge is integrated with the BIM approach within the 3D CAD environment.

Effective KM work in construction projects requires support and communication tools among project managers and jobsite engineers. The 3D BIM-based knowledge model provides effective tools for KM in a digital and graphical form. Notably, the animation stores the scenario and all relevant information in the system so that all jobsite engineers can understand the setup/process information via their own professional perspective. Project managers and jobsite engineers can track and access the most recently shared knowledge regarding interesting topics during the construction phase. Knowledge on various topics can be updated quickly and made available to each participant in the 3D BIM environment. This research is a pilot study to apply the BIMKSM system for knowledge management to a building project in Taiwan, to analyze and discuss the whole process of construction knowledge sharing management, and to implement KM sharing during the construction phase. The processing and content of construction

Shu-Hui Jan is Ph.D. Candidate, Department of Civil Engineering, National Taiwan University, No. 1 Roosevelt Rd, Sec.4, Taipei, Taiwan, (corresponding author email: d94521007@ntu.edu.tw).

Shih-Ping Ho is Associate professor, Department of Civil Engineering, National Taiwan University, No. 1 Roosevelt Rd, Sec.4, Taipei, Taiwan.

Hui-Ping Tserng is Professor, Department of Civil Engineering, National Taiwan University, No. 1 Roosevelt Rd, Sec.4, Taipei, Taiwan.

shared experience-based knowledge can be modified according to a project's characteristics. The results of an evaluation that involved a building project in Taiwan have indicated that the BIMKSM system effectively supports the sharing of knowledge in the 3D BIM-based environment. The case studies have also emphasized that a BIMKSM system can provide a web-based visual 3D-based knowledge sharing management platform.

II. Background

Numerous research efforts have focused on applications of knowledge management in construction. Kivrak et al. [1] used a survey to find out how tacit and explicit knowledge are captured, stored, shared, and used in forthcoming projects, as well as to identify major drivers and barriers in knowledge management. A web-based prototype system, named CAPRI.NET, was developed to facilitate the live capture and reuse of project knowledge in construction [2]. A web-based collaborative knowledge management system was implemented to solve knowledge sharing problems within a construction company [3]. Furthermore, a web-based knowledge management system was implemented to support effective information search and analysis, by enhancing communication and collaboration among researchers in the underground construction field [4].

A great deal of previous research pertains to BIM issues in construction. Tse et al. [5] presented the core barriers and recommended using BIM technology for construction industries. Vanlande et al. [6] proposed an extension of BIM technology to manage information during the entire lifecycle of an AEC project. Goedert and Meadati [7] extended BIM technology into the construction process to create a single repository of facility data for the owner. Succar [8] explored publicly available international guidelines and introduced the BIM framework, a research and delivery foundation for industry stakeholders. Kaner et al. [9] illustrated how BIM can help managers of structural engineering firms to avoid some of the pitfalls of replacing 2D CAD practices. Isikdag and Underwood [10] proposed two design patterns as a foundation to formulate the design of information systems for BIM-based synchronous collaboration. Jeong et al. [11] tested data exchanges between BIM tools using a small but complex building model. Dossick and Neff [12] examined the use of BIM technologies for mechanical, electrical, plumbing, and life safety systems. Bynum et al. [13] investigated the perceptions of the use of BIM for sustainable design and construction among designers and constructors. Wang et al. [14] explored how BIM will beneficially support facility management in the design phase, such as space planning and energy analysis.

Although numerous information management systems have been developed for the application of construction knowledge management, such systems typically exist for knowledge sharing using only text-based illustrations. To enhance construction-related knowledge sharing using a BIM-based environment, this study proposes a novel management system for project managers and jobsite engineers.

III. System Design and Development

In this study, the proposed BIMKSM system facilitates visual knowledge sharing and management using the BIM approach during the construction phase. The BIM approach stores any problems, solutions, and comments, allowing project managers and jobsite engineers to access the most up-to-date knowledge. Furthermore, BIM can also be used to model basic characteristics, promoting the electronic sharing of detailed. The primary advantages of the proposed BIMKSM system are: (1) to provide a simple and clear representation of a scenario using 3D CAD illustration; (2) to effectively link knowledge using BIM-based graphic representations; (3) to promote relationships between areas of expertise via both vertical and horizontal graphic representations; and (4) to provide statuses of acquired knowledge of different situations using different colors.

Shared information from all jobsite engineers is divided and saved as “activity,” “object,” or “topic” for collection and management. The main advantage of BIM-based knowledge management is the ease with which information and knowledge can be understood and reapplied. Knowledge saved in the "topic" category includes both tacit and explicit knowledge. With respect to explicit knowledge, BIM-related information normally includes original comments, reports, drawings, documents, and comments submitted by jobsite engineers. Information that relates to the whole project and cannot be clearly classified into topic units is saved under the “project” category. In contrast, tacit knowledge may include process records, problems faced, problems solved, expert suggestions, know-how, innovations and notes on experience. Such information is better saved in topic-based units to facilitate classification and searching by users.

A 3D BIM-based knowledge model can be defined as a graphic representation of experiences linking relationships between 3D objects of the BIM model and aspects of experience-based knowledge. The BIM approach retains knowledge in a digital format, facilitating easy updating and transfer of knowledge into the 3D BIM environment. A 3D BIM-based knowledge model is designed to be easily integrated with experience-based information and 3D objects of the model (see Fig. 1). Information in the 3D BIM-based knowledge models can be identified, tracked, and managed, and problems encountered during construction projects can be solved. The most up-to-date knowledge and solutions can be acquired from participating engineers and then shared and saved as 3D objects of the BIM model for future reference. The model is constructed from variables that can be decomposed into 3D objects of a BIM model and can then store the identified knowledge. Information stored in 3D objects of BIM model includes both facing problems and solutions. Facing problems may be knowledge topics, knowledge attributes, descriptions of problems, or knowledge attachments (e.g., documents, reports, drawings, and photographs). The proposed

3D BIM-based knowledge models have eight components: event ID, event topic, event date, event description, event owner, event people, event attachments, and event history record.

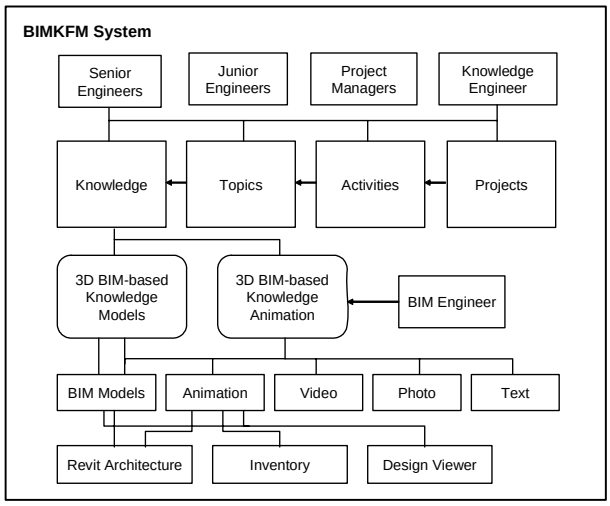

Fig. 1 The Concept and Framework of the 3D BIM-based Knowledge Models

The BIMKSM system provides a user-friendly portal for all project participants. It also serves as a real-time online communication channel for knowledge management. All data are stored and classified using 3D BIM-based knowledge models. The BIMKSM system is a solution that uses a single unified database linked to BIM files with different levels of access granted to users based on their roles. Only authorized participants can access the 3D BIM-based knowledge models to update information on content relevant to each user's responsibilities in the project. When information is updated in the BIMKSM system, the server automatically sends e-mails and RSS to the project managers and jobsite engineers involved in the project.

The developed BIMKSM system runs on Microsoft Windows 2008 software with an Internet Information Server (IIS) as the web server. The BIMKSM system has been developed using Java Server Pages (JSPs), which are easily incorporated with HTML and JavaScript technologies. The BIMKSM system server supports four distinct layers: interface, access, application and database layers. Each layer has its own responsibilities. The interface layer defines administrative and end-user interfaces. Users can access information via web browsers such as Microsoft Internet Explorer or Google Chrome. Administrators control and manage information via the web browser or a separate server interface. The access layer provides system security, restricted access, firewall services, and system administration functions. The application layer defines various applications for analyzing and managing information. The database layer consists of a primary Microsoft SQL Server 2003 database. A firewall and virus scan can be used to protect the system database against intrusion. Users can utilize the BIM models in the BIMKSM system to request assistance or send word of a problem directly to the BIMKSM system to ask for further support.

In this study, the BIM model is interpreted as an information model in the BIMKSM system. The application of BIM models to acquire and store information regarding a 3D object includes the description of the problem being faced, knowledge, comments, and attaching documents in the BIMKSM system. Autodesk Revit Architecture and Revit MEP were used to create the BIM model and files. Autodesk Design Review was used to read the files for 3D BIM-based knowledge models. Autodesk Inventor was used to create BIM-based animations to illustrate the information. Integration of the information with the BIM models was achieved using the Autodesk Revit application programming interface (API) and the Microsoft Visual Basic.Net (VB.Net) programming language. A 3D BIM-based knowledge models was developed in Autodesk Revit Architecture and Revit MEP by programming in VB.Net and using Revit API. All information in the BIM files could be exported to an ODBC database for connection with BIMKSM system.

IV. Case Study

In the following case, the general contractor has had sixteen years of experience specifically in construction building projects. Currently, the general contractor has construction projects mainly in Taiwan. Furthermore, the general contractor hoped to take full advantage of the 3D BIM-based knowledge management system to facilitate knowledge exchange and management between the design phase and construction phase and reuse it in other similar projects. Therefore, the general contractor announced that all jobsite and project managers would be encouraged to use the BIMKSM system to apply knowledge management to effectively manage acquired information during the construction phase in the 3D BIM environment. The BIMKSM system was utilized in the construction project, which was in Taiwan, to verify the proposed methodology and demonstrate the effectiveness of sharing previous experience in the construction phase. The case study was undertaken during a 4-month construction project. Moreover, all jobsite and project managers were encouraged to explore and edit their own recorded experiences in the BIMKSM system.

The case study was implemented in the middle of the construction phase. All BIM models were created and developed for the purpose of construction management. Finally, the BIM models were reused and applied for knowledge management. The invited engineers explained their experiences and comments based on the topic and presented relevant information and documents. The initial engineer created topics regarding the selected activity and 3D objects of the BIM model in the initial phase. All related documents for this topic were collected and digitized by the senior engineers and knowledge assistants. After the topic was identified, the senior

engineers were invited to share their knowledge and comments related to the topic via the system. The posted files included digital documents, photos, and films. The knowledge assistants helped the senior engineers to digitize the content, and they then created the 3D BIM objects related to the topic. The other topics were communicated in the same manner. All engineers were required to submit experience-based information and discussions regarding the topic via the BIMKSM system. The engineers read previous comments provided by others, learned from these records, and submitted their own discussions and comments via the BIMKSM system, which allowed the other engineers to discuss their work. The comments provided by the senior engineers included notes, actual problems/solutions, and suggestions. Finally, the engineers communicated their problems and answers to the senior engineers, posted their comments in the system and shared their case discussions with others. Additionally, the engineers had to submit their knowledge pertaining to the3D BIM objects of the BIM model via the BIMKSM system. The senior engineers reviewed all questions and solutions and posted comments for all interested individuals. Furthermore, all information was stored in the central database to prevent the collection of redundant data. Finally, the information was automatically backed up from the system database to another database. Fig. 2 illustrates knowledge sharing in the 3D environment of the BIMKSM system.

Fig. 2 Application of 3D BIM-based Knowledge Models and Animations in the Case

The questionnaire results from the case study evaluation reveal that the BIMKSM system effectively shares knowledge for construction projects. The verification test was performed by checking whether the BIMKSM system could perform tasks as specified in the system analysis and design. The validation test was undertaken by requesting selected case project practitioners to use the system, and the provide feedback by answering the questionnaire developed herein. The validation test was undertaken by requesting selected case project practitioners to use the system, and the provide feedback by answering the questionnaire developed herein. There were 13 respondents.

Questionnaire results indicate that the primary advantages of using the BIMKSM system are as follows: (1) it easily provides automatic corrections and notices when knowledge is updated on a current project (80% agreed); (2) it integrates with 3D BIM-based knowledge models and animation easily and effectively (89% agreed); and (3) it clearly identifies available knowledge when such information requested for a current project (86% agreed).

User feedback indicated that the primary barriers to using the BIMKSM system were as follows: (1) insufficient updated information related to different types of knowledge; (2) substantial amounts of time and assistance needed for engineers and managers to use BIM software to edit and update knowledge feedback; (2) further effort is required to update information related to various 3D objects of a BIM model or the activities in a project. (3) the senior and jobsite engineers require substantial time and assistance to edit knowledge feedback in 3D environment; (4) most senior engineers cannot edit their contributions of information without assistance in typing; and, (5) unwillingness of participants to share their own knowledge and experiences without enough incentives.

V. Conclusion

To enhance management of construction knowledge sharing in building projects, this work presented and developed the BIMKSM system as a visual platform. The BIMKSM system illustrates knowledge with problem descriptions and solutions in the 3D BIM environment. BIM is a highly promising means of enhancing knowledge management during the design phase of a project. Collecting problem descriptions and solutions using the BIM approach allows project managers and jobsite engineers to contribute and share the most up-to-date knowledge and experience regarding problems and solutions in construction. The BIM approach generates 3D drawings, thus identifying valued experience-based knowledge relevant to topics and activities. Additionally, BIM provides 3D objects and illustrations when knowledge is available. The BIMKSM system collects specific problem solutions, and supports all information across projects. Overall, field test results indicate that the BIMKSM system is an effective and simple platform for knowledge management in construction projects. Case study results demonstrate the effectiveness of a BIMKSM-like system for KM due to its incorporation of BIM and web technologies during the construction phase.

In summary, the engineers were able to increase their understanding of previous captured knowledge and experience from all participants located in different projects. Notably, BIM integrates the 3D objects comprising knowledge management work by incorporating external factors, such as problem and solution descriptions, comments, and suggestions, into the sole source for all construction 3D-BIM KM information. Effectively utilizing web technologies and BIM during the design phase allows project participants to identify, monitor, coordinate and access information for future A/E/C projects.

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Shu-Hui Jan: Ph.D. candidate of the Department of Civil Engineering of National Taiwan University. She's research deals with development and application of building information modeling (BIM) in AEC industry. Her research interests also include project management, construction management, information management, schedule management and property management.

Shih-Ping Ho: Associate Professor of Construction Management at National Taiwan University. He taught at Stanford University in 2010 as endowed Shimizu Visiting Associate Professor. He is on the Editorial Board of Engineering Project Organization Journal. His research focuses on game theory modeling and analysis, the internationalization of A/E/C firms, the governance of Public-Private Partnerships (PPPs), strategic management, and knowledge sharing.

Hui Ping Tserng: Full professor at the Department of Civil Engineering of National Taiwan University. He also is corresponding member of Russian Academy of Engineering. He has a PhD in Construction Engineering and Management and he is official reviewer or editorial of board member of several international journals. His research interests include advanced techniques for knowledge management, construction project management, management information system, GPS/Wireless Sensor Network, and automation in construction.