BIM and Knowledge Based Risk Management System: A Conceptual Model

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Abstract − Risk management is becoming increasingly important in the Architecture, Engineering, Construction (AEC) industry for minimising the possibility of occurrence of hazards, improving safety and quality, and achieving project goals within planned budget and cost targets. Though some techniques have been developed to assist this work, it is reported that currently risk management is still an experience based manual undertaking which is reliant on multidisciplinary knowledge, and capturing fragmented information from various participants correctly for solving risk problems in time is challenging. In this process, Knowledge Management (KM) could play an essential role to facilitate risk information stored in a proper structure, and communicated and reused effectively. As an emerging tool within the AEC industry, Building Information Modelling (BIM) not only is a digital representation of physical and functional characteristics of a building but can also establish a repository of shared knowledge forming a reliable basis for decision making. Therefore, there is a pressing need to integrate KM and BIM to support risk management throughout the lifecycle of a project; however, only limited research has been carried out in this area. This paper firstly explores the feasibility and potential of developing a BIM and Knowledge Based Risk Management System (BKRMS). It then presents a conceptual model of the BKRMS and discusses the related technical solutions. Finally, recommendations for future research directions in this area are formulated.

Keywords − BIM (Building Information Modelling), KM (Knowledge Management), Risk Management.

I Introduction

Over the last few decades, the AEC industry has experienced globally fast growth to keep pace with development of human society: large projects are being invested and built, new materials and construction methods are being adopted, and new design and project delivery approaches are being introduced. Though sharing some common features, each construction project has its unique characteristics and different environment and weather conditions. Project participants from different disciplines need to collaborate with each other and deploy their experience and knowledge to build a successful project. Failure to manage risks in the project and product life cycle may cause effects such as time and cost overruns, injuries or deaths, and structural damage or collapse. For example, because of design deficiency and inexperienced construction management, Quebec Bridge collapsed during construction in 1907 resulting in deaths of 75 workers [1].

It is becoming increasingly important to manage both foreseeable and unforeseeable risks at an early stage before any hazards actually occur. However, traditional risk management methods are confined to be static and only play a limited role in the real workplace [2]. To overcome this gap, some technologies such as Knowledge Management (KM) and Building Information Modelling (BIM) have been developed as solutions for managing risks. Conceptually, KM could improve the access to, communication and the reuse of risk information by managing data in a proper structure [3], and BIM can help early identification of both foreseeable and unforeseeable risks and facilitate risk communication by quickly establishing 3D information models of a project and accurately forecasting and visualising its construction, management, and maintenance in the computer based virtual environment [4]. It has been observed that nowadays there are some efforts to integrate KM and BIM for risk management.

This paper firstly explores the feasibility and potential to integrate KM and BIM for managing risks by reviewing the current challenges in general risk management methods, and development of KM and BIM for risk management. Then a new approach for combining BIM and Knowledge Based Risk Management System (BKRMS) to support project lifecycle risk management is presented. Both conceptual models and technical solutions for developing this system are discussed. Finally practical implications of implementing BKRMS and recommendations for future research are highlighted.

II DEVELOPMENT OF RISK MANAGEMENT

a) Challenges in general risk management

Risks are widely present during the lifecycle of a project and failure to manage them may lead to some unacceptable or even catastrophic results such as cost and time overrun, injuries or death, and structural damage or collapse. Risk management includes a series of processes applying logical and systematic approaches for mitigating against risks and facilitating improved communication [5]. Although there are many differences among different standards and specifications of risk management, e.g. PMI [6] and ISO [5], they describe that a general risk management process should at least contain the following sub-processes: risk communication and consultation, risk identification, risk analysis, risk evaluation, risk treatment, and risk monitor and review. The logical sequence of the general risk management process is shown in Fig. 1.

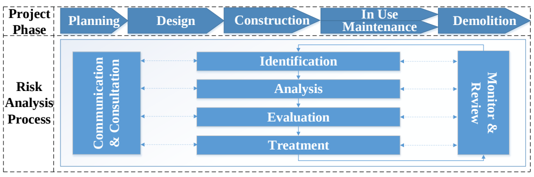

Fig. 1: General process of risk management

However, the actual work is complex and in most cases cannot be simply represented by the ideal process. People need to make a quick decision within a limited time on what the specific work is needed for managing a risk and the different sub-processes that may be applied in parallel [7]. Some techniques have been developed to help to identify, analyse, and treat risks, such as checklists [8], decision trees [9] and neural networks (NN) [10]. However, these methods are still static and traditional techniques [11], are heavily reliant on multi-disciplinary knowledge and experience, and only play limited roles in real workplaces [2]. A significant problem is that the communication of risk information tends to be poor, incomplete and inconsistent and capturing fragmented information and knowledge from various experts correctly for solving risk problems in time is challenging [12].

Numerous studies [2, 13, 14] have pointed out that knowledge and experience management are fragmented and insufficient in traditional risk management. An important key to success for managing risks is to find out correct information from experienced personnel within a limited time. In addition, the person in charge must make sure the 'in mind' information is the correct solution to the potential risks, and can be understood clearly by others. However, all AEC projects start with planning and design followed by the construction stage lasting for months or years, and eventually the project will come into the operation phase that may last for decades before demolition. The whole process is dynamic and new problems and challenges appear every day. This may result in some risks cannot be identified and treated properly in time. For instance, construction progress meetings are crucial in the construction stage and provide an opportunity for architect, engineer, client, contractor, and other project participants to discuss and communicate any problems or risks that may influence the project goals. Senior experts are regularly invited to attend these meetings and discuss any potential risks related to the project with the construction team. The construction team hopes to obtain valuable experts' knowledge and experience through such meetings to manage potential risks. However, the challenges are: 1) the experts' 'in mind' thoughts are sometimes difficult to capture within a limited time; 2) the captured information might not be correct; 3) the information can be poorly communicated in the meeting and not well understood properly by others; and 4) the construction team may not change their schedules and execution if information provided by experts are regarded to be incorrect or unreasonable. In addition, the process of any AEC project is dynamic and new experience and lessons come out nearly every day. Consequently, successful risk management requires a quick evaluation of the right information through a 'brainstorm' session.

b) Knowledge management for risk management

Knowledge management (KM) is a process of capturing, developing, sharing and effectively using multi-disciplinary knowledge and experience [15]. In the AEC industry, valuable knowledge and experience gained from previous projects and academic studies could contribute significantly to managing risks for future projects. Effective management of such an enormous database of human knowledge and experience, and the flexible and accurate extraction of data become a precondition for success of risk management. It is crucially important to manage, use and communicate this data effectively during the life cycle of a project. In this process, KM can facilitate risk information stored in a proper structure, communicated and reused effectively. Some existing studies have recognized this idea and adopted KM for managing project risks. For example, the concept of KM was applied into development of a risk management framework by Tah and Carr [16] for describing projects using a common language based on hierarchical-risk breakdown structure and managing the risk repository based on database technology. Similarly, Sharmak, et al. [7] proposed a configurable knowledge based risk management process model and integrated it into the project lifecycle risk management process. To manage personnel safety risks at design stage, Cooke, et al. [17] implemented the theory of KM to develop a web based decision support program named ToolSHeD. The core principle behind ToolSHeD is to properly structure safety risk knowledge obtained from national guidelines, industry standards and other information sources, and employ the knowledge for assessing safety risks for complicated buildings.

c) Building Information Modelling (BIM) as a systematic solution

BIM has been highlighted in the AEC industry over the last years and can be used as a systematic risk management tool to support the development process of a project. It can not only provide new 3D computer-aided design (CAD) platforms and management methods [4], but also facilitate significantly communication and collaboration for both within and between organisations [18]. Besides, BIM has the potential to implement the concept of 'early risk identification and prevention' by visualising, analysing and managing building lifecycle information in computer based virtual environment before actual construction [19].

III The trend of integrating BIM and KM for risk management

In order to take full advantages of both BIM and KM, there is a pressing need to integrate the two techniques for risk management. However, very limited research has been found in this area. For example, Deshpande, et al. [20] presented a framework to classify and manage knowledge and proposed a new approach to capturing, extracting, and storing data and knowledge in building information models. To strengthen its practical application and facilitate the communication and reuse of construction knowledge, Ho, et al. [21] developed a BIM based Knowledge Sharing Management (BIMKSM) system to enable managers and engineers share and manage construction knowledge and experience in the BIM environment and obtain feedback provided by jobsite engineers for future reference. To mitigate against construction personnel safety risks at design stage, Qi, et al. [22] developed a dictionary and a constraint model to store construction worker suggestions and the formalised suggestions respectively. Then rule checking software can be implemented to check construction worker safety in BIM, which provides an approach to optimising the drawings and eliminating construction site hazards at an early stage. Similarly, Motamedi, et al. [23] integrated the use of KM and BIM to investigate an approach for detecting failure root-cause which could help facility management (FM) technicians identify and solve problems from their cognitive and perceptual reasoning. Integrated with BIM, a Computerised Maintenance Management System (CMMS) was developed to store inspection and maintenance data.

The main principles of the existing studies established that: 1) KM can effectively extract and manage fragmented expert based knowledge and experience, and facilitate data stored in a proper structure, communicated and reused; 2) BIM is considered as the primary data repository for shared knowledge forming a reliable basis for decision making; and 3) the visualisation capabilities of BIM could help technicians or decision makers to implement the concept of 'early risk identification and prevention' and refine the plan.

However, one or more of the following gaps are still existing in current efforts: 1) no theory to support the integration of KM and BIM for managing multi-disciplinary knowledge for risk management; 2) lack of a theory aligning BIM with general risk management methods to support the development process of a project; and 3) lack of a standard and colour scheme for supporting visualising risk in BIM.

IV Towards a BIM and Knowledge based Risk Management System (BKRMS)

a) Motivation and overall concept

To overcome these problems, this research is proposing to use a knowledge based approach for developing a BIM and Knowledge based Risk Management System (BKRMS). The system takes advantages of a structured dynamic risk database and an active link between the database and building information model to integrate KM and BIM.

This idea was motivated by previous research conducted by Kiviniemi [24] for managing user requirements during the life cycle of a project by establishing an active link between requirements models and building product models. Kiviniemi [24] successfully illustrated that user requirement information can be divided into different levels and linked with building information models. Similarly, for this research risk information can also be linked to building information models to support the development process of a project. However, there is currently no theory or software to support this solution. Therefore the objectives of this work are as follows: 1) Develop a knowledge based risk model that stores risk information and cases in a proper structure; 2) Develop a methodology that can establish the relation between a knowledge based risk model with BIM; and 3) Develop a tool based on existing BIM software to implement and validate the proposed methodology through a selected case study.

The overall solution is presented in Fig. 2. BIM not only is a digital representation of physical and functional characteristics of a building but can also establish a repository of shared knowledge forming a reliable basis for decision making. Through building and managing 3D/4D information models in a computer based virtual environment before real construction, BIM could improve risk information extraction and facilitate the performance of risk identification and communication. In this process, KM could play an essential role to facilitate risk information stored in a proper structure, communicated and reused effectively. In this research, risk information related to a construction project can be summarised through previous cases, knowledge and experience into a risk model. The risk model can be linked to a building information model (BIM) to generate a BIM and knowledge based system to support systematic risk management in the lifecycle of a project.

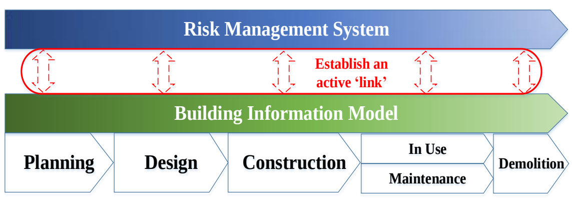

Fig. 2: Establishment of an 'active' link between BIM and Risk Management System

b) Framework and methodology

Risks are highly related to the specific type of projects. To limit the scope of this work, it has been focused on bridge engineering. As literature targeting at bridge risks is very limited but most construction projects share a large number of common risks [25], the collection of risk sources for this research can be extended to all types of construction projects.

The proposed framework of BKRMS is illustrated in Fig. 3 and consists of two main modules: the BIM Module and the Risk Module where the two modules are linked intelligently to each other. In the BIM Module, design, environmental and other general project information can be captured firstly to generate a 3D building information model (BIM). The second step is to collect and analyse the construction information, schedule and work breakdown tasks, which can be connected with the 3D BIM to generate a 4D BIM. The Risk Module provides a user interface for managing any updates and changes of identified risk in BIM and will help capture and retrieve from two databases the information of risk that may affect the project during its life cycle. An initial set of risk data can be generated from academic studies, industrial practices and existing documentation and hierarchies which are stored in the knowledge based risk database. Another database called the case based reasoning library (CBRL) is a collection of both successful and unsuccessful cases that can provide risk management knowledge about project cases for analysing the ongoing project and helping decision makers investigate possible solutions. The CBRL is able to retain and update new cases from the BIM Module. Risk information will be visualised in the 3D/4D BIM that enables identification, communication, and the management of risks at an early stage.

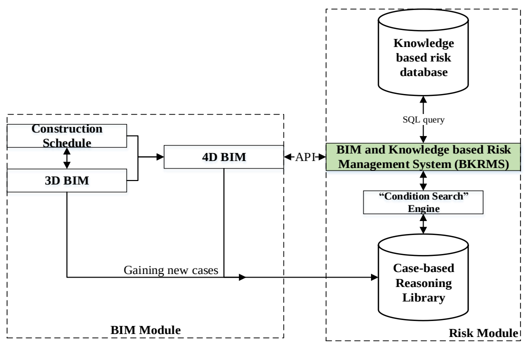

Fig. 3: Framework of BIM and Knowledge based Risk Management System

c) Technical solution

To validate this proposed methodology, a tool will be developed and tested through a selected case study. The technical application of BKRMS is based on Autodesk Revit, Autodesk Navisworks, Microsoft Visual Studio and Microsoft Access. Revit is BIM based design and modelling software which allows users to design a building and its components in a 3D environment and provides the access to building information from the building model's database. The Revit model can be further developed in Navisworks for achieving 4D functions such as construction planning and simulation, and real-time navigation. Access is a database management system and will be used to store, share and communicate risk information and risk cases. Taking advantage of the Application Program Interface (API) provided by Revit and Navisworks, a user interface of BKRMS can be developed in Microsoft Visual Studio and embedded into Revit and Navisworks as a plug-in to link the BIM module and the Risk Module to manage knowledge and cases stored in Access databases. By implementing the system, the Risk Module provides a data base to help risk identification. In addition, risks can also be visualised, displayed and managed in a 3D/4D BIM environment to support the project life cycle. An active 'link' between the BIM and Risk Modules would greatly benefit the efficiency and productivity of project risk management.

V CONCLUSION AND FUTURE RESEARCH

Successfully managing risks in AEC projects is crucial. However, the current methods which are heavily reliant on multi-disciplinary knowledge and experience only play a limited role in a real environment. A significant problem is that the communication of risk information tends to be poor, incomplete and inconsistent. Also capturing fragmented information and knowledge from various experts correctly and in a timely manner can be challenging. Knowledge and experience management are fragmented and insufficient in traditional methods. In recent years, KM and BIM have been developed as solutions for information management and demonstrated by some researchers to have the potential to overcome the observed problems in risk management. To take full advantages of both techniques, there are some efforts to integrate the KM with BIM to support life cycle project risk management.

This paper is part of an ongoing research project to develop a BIM and Knowledge based Risk Management System (BKRMS). A conceptual model of the BKRMS has been developed in this paper which takes advantage of structured dynamic risk databases and an active link between the databases and building information model to integrate KM and BIM. The core principle of the proposed method is that risk knowledge developed from existing documentation, published literature and industrial practices can be stored in knowledge based databases and linked to 3D/4D BIM to support the risk management during the dynamic process of a project's life cycle. Through visualising and managing risks in BIM, hazardous work can be identified, analysed, communicated and prevented at an early stage. The next stage of this research will focus on: 1) to establish the risk database by detailed analysis of the published literature, industrial documentation and accidental reports concerning construction risks; 2) to collect and analyse industrial risk management cases to develop the case based reasoning library; 3) to further analyse the information stored in the risk database and case based reasoning library and store the data in a proper structure, and 'link' risk data to different levels of BIM (i.e. project level, structural level, personnel level, site level, and object level); and 4) to develop a tool based on existing BIM software and validate the proposed methodology through a selected case study.

Interesting research topics in the near future may include: 1) to further develop the knowledge based risk database and expand the cased based reasoning library, especially for specific type of projects; and 2) to validate the BKRMS in both simple and complicated construction projects and investigate implementation approaches and experience. Long-term research topics may focus on improving the automation and intelligence of BKRMS, such as interpreting the risk knowledge to be automated or semi-automated machine readable rules; or integrating the proposed system with other digital techniques such as sensing and tracking technologies to establish a real-time risk management environment.

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