BIM-based Risk Management: Challenges and Opportunities

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Abstract
In recent years, the awareness and concerns about risks have risen in the Architecture, Engineering and Construction (AEC) industry with possibility of occurrence of hazards gradually rising because of increase of structural complexity, growing project size and new and complex construction methods. However, the current experience and mathematics based risk management method has limited practical influence on improving systematic risk management of a project. To mitigate against these increasing problems, Building Information Modelling (BIM) is expected to play a significant role to integrate risk management with the design, construction and maintenance of a project. This paper explores challenges existing in the general risk management process and reviews the latest development and efforts in the area of BIM-based risk management. The findings show that one of the most significant problems observed in this study is the lack of a theory aligning BIM with risk management to support the development process of a project. This on-going research will take bridge examples as case studies to assist further development.

Keywords: BIM (Building Information Modelling), Risk Management, BIM-based Risk Management, Bridge Engineering

1 Introduction
The term "risk" was known in the English language from the 17th century and was derived from an original meaning "to run into danger or to go against a rock" (McElwee 2013). Today the concept of "risk" is adopted in many different fields and with a variety of different words, such as "hazard", "threat", "challenge", or "uncertainty". In the Architecture, Engineering and Construction (AEC) industry, risks have a two-edged nature, e.g. 'the likelihood of unwanted hazards and the corresponding consequences' (Zou et al 2007). An AEC project starts with planning and design, it may then experience a construction stage that lasts for many months, and eventually will come into the period of operation that may last for many decades before demolition, and different risks are present in the different stages of the project and product lifecycle. This means that regardless of the activity, there is always a possibility that hazards will occur and the whole project may be affected to different extents depending on the type of risk and how severe the consequences are. The scope of a risk consists of several issues: damage or failure of structures, injury or loss of life, budget overruns, and delays to the construction schedule, etc. In recent years, with the rapid development and civilisation of society, risks are gradually growing because of the increase of structural complexity and project size, and the adoption of new and complex construction methods. Consequently, all project participants need to improve their ability, knowledge and experience to manage risks during the project lifecycle to ensure a safe, successful, and sustainable project. According to ISO 31010:2009, risk management is a logic and systematic method that involves a set of activities and processes for establishing the context, facilitating risk communication, identifying, analysing, evaluating, treating risks, and recording and reporting the corresponding results properly and timely (ISO 2009). The first and most important step in the risk management process is to

recognise those potential risks at an early stage (Zou et al 2007). Then, through risk analysis, people are expected to know the possibility of occurrence and the significance level of the identified risks. To avoid any serious accidents and assist managing risks effectively in real projects, many risk assessment techniques have been introduced in practice, such as fault tree analysis (FTA) (Suresh et al 1996), decision trees (Dey 2002), and neural networks (NN) (Khoshgoftaar & Lanning 1995). These methods can be divided into two main categories: qualitative analysis techniques and quantitative analysis techniques. However, it is necessary to point out that these are still static and traditional methods (Alaeddini & Dogan 2011) and both are heavily reliant on multi-disciplinary knowledge and experience (Shim et al 2012). As a result, many researchers (Zhang et al 2014, Hartmann et al 2012, Shim et al 2012) have pointed out that the traditional risk management method can only play a limited role in the real world.

In recent years, Building Information Modelling (BIM) one of the main interest areas in the AEC industry, and it is expected to play a significant role also in facilitating risk management in the design, construction, and maintenance of a project. BIM is defined as *'a modelling technology and associated set of processes to produce, communicate, and analyse building models'* and allows a three dimensional representation of non-redundant data (Eastman et al 2011). A number of computer applications have been developed to support the use of BIM in practice, and also a new trend to use BIM and BIM-related digital tools for improving safety and risk management has been emerging. For example, Liu et al (2014) summarised the benefits and requirements of replacing the traditional 2D design method with 3D information modelling through the use of BIM tools to assist the design and construction of a long-span steel-box arch bridge project. Zhang et al (2013) outlined an automated rule-based checking framework built on BIM for managing and preventing fall accidents on site. Wang et al (2014) developed a BIM-based virtual environment and a game engine to address several key issues for building emergency management. However, it has been observed that there is still a huge gap in applying these new initiatives into general use.

This paper first summarises the current risk management process and outlines its main challenges followed by an investigation of why BIM has potential to improve risk management, and then reviews the current developments and efforts in this area, and points out the existing obstacles. To overcome these problems and facilitate the integration of BIM and risk management, the third part introduces the authors' future work which proposes a methodology for establishing an active relationship between BIM and the risk management system for bridge projects.

2 Challenges in current risk management process

Based on an extensive literature review and the authors' own experience, the general risk management framework currently used in the UK AEC industry is summarised in Figure 1. The method prescribes a long-term risk management strategy and a process that allows participants to work collaboratively to manage risks in a systematic way. The core philosophy of this method, defined in the Risk Mitigation Model, is that the greatest scope for identifying and mitigating risks should be carried out as early as possible, especially in the design and planning phases, which are controlled by the UK Construction Design and Management (CDM) regulations (HSE 2007). Therefore, ideally most of the foreseeable risks should be 'designed out' during the planning and design stages, and the residual risks should be managed during the construction and subsequent phases. Similarly, Gambatese et al (2008) stressed that as many risks as possible should be considered and treated at the design phase so that there is a strong link between designing for construction safety and construction site fatalities. The Risk Analysis Process presents a typical analysis loop adapted from ISO standard 31010:2009 which is broadly recognised in many industries. The model suggests that decision makers should establish the project context and an effective communication environment, make risks explicit, analyse them, take measures to control them, and review, record and report the results properly. Though the analysis loop looks the same in each project stage, the CDM coordinator legislated by the CDM rules has the responsibility to track, control and manage the whole process and guarantee that it is running well during the project lifecycle. However, leading roles for risk management are defined in each stage. Specifically, in the planning and design stage, the designer is responsible for risk management work and to cooperate with other project participants to identify all foreseeable risks that may occur during the whole lifecycle and try to mitigate them as far as possible. In the construction stage, the construction team takes the primary responsibility to work collaboratively with others to manage any risks on site to ensure a safe project to be constructed within budget and time. When the project is handed over for use, the client is then responsible for the daily use and maintenance as well as managing risks through hiring experts, technicians or others. Throughout the whole process, the CDM coordinator acts only as the coordinator to link different people, activities and processes on behalf of the decision makers.

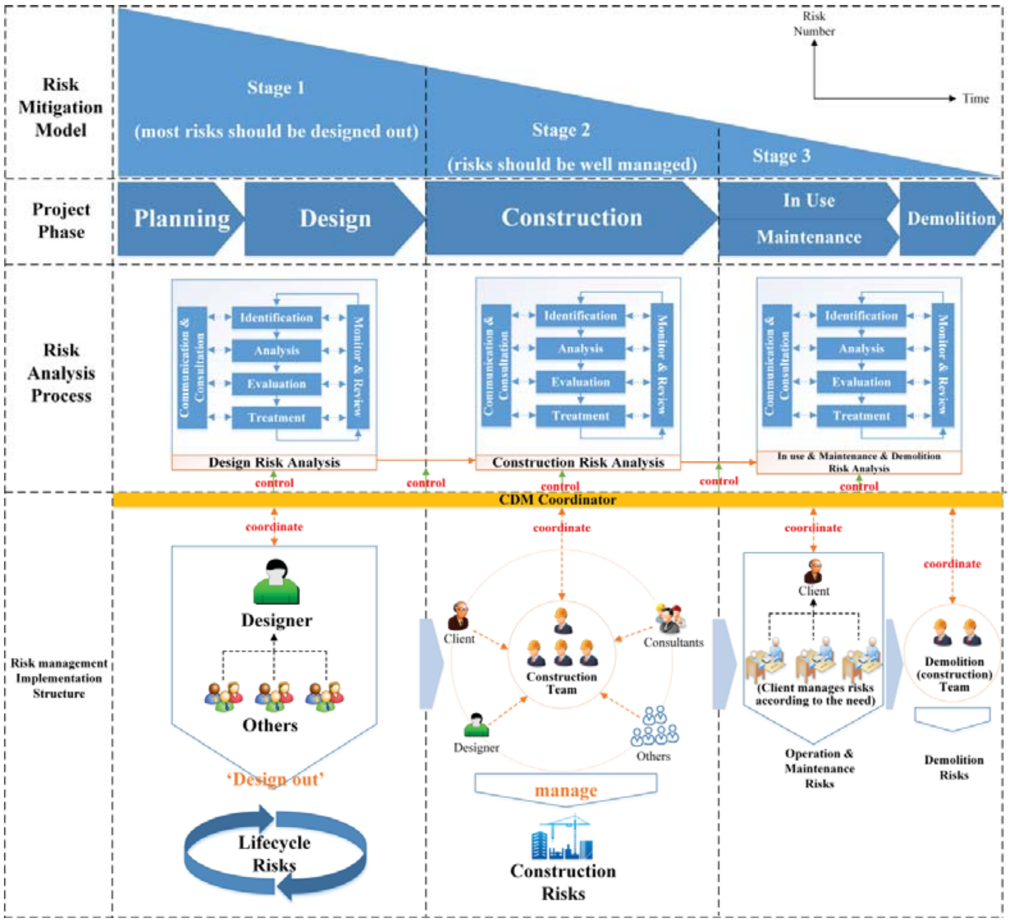

Figure 1 General Risk Management Framework

However, numerous investigations (Shim et al 2012, Hartmann et al 2012, Zhang et al 2014) have pointed out that some outstanding challenges exist in the current risk management method that is heavily reliant on experience and multi-disciplinary knowledge, which decreases its effectiveness and makes it highly dependent on the individual skills in real projects.

The first step of the risk management process is identifying risks, where potential risks associated with an AEC project are identified (Zou et al 2007). Failure to do so may lead to further risks. As a project normally experiences many different phases and most of the participants may leave the process after completing their work, the unidentified risks may lead to a superimposed effect and the possibility of hazards will therefore increase.

According to Shim et al (2012), multi-disciplinary knowledge, experience, and mathematical analysis still play a key role in risk analysis and the corresponding decision making. Participants, e.g. clients, architects and engineers, gain valuable knowledge and experience from successful projects and can use this to contribute to future work. In this case, the effective management of this large database of human knowledge and experience as well as flexible and accurate data extraction become a precondition for the success of risk management. Unlike some manufactured products that can be made automatically, every AEC project has its unique characteristics that are distinguished from others (Clough et al 2000). In addition, the process of any AEC project is dynamic and new experience and new lessons come to light nearly every day. Consequently, successful risk management requires a quick identification of the right information through a "brainstorming" exercise. However, this is only the first step. This crucial information is needed to be understood by others in charge and implemented correctly.

Besides, the implementation of risk management in industry is still a knowledge and experience based manual undertaking (Forsythe 2014). As projects are completed by a team cooperatively, any common risks will be identified and treated individually, and the corresponding information will be documented and sometimes this work will be ignored or forgotten (Kazi 2005). This may lead to the risk that information cannot be presented, shared, recorded, and updated effectively during the development process of a project. As the project is handed over from designer to contractor, and then from contractor to the client, people will normally leave the project after completing their task. Thus, large amounts of risk information may be lost if it is not properly recorded and communicated to other project participants.

3 Trends of applying BIM and BIM-related technologies to manage risk

In recent years, BIM has seen a rapid increase in use and development in the AEC industry and offers the potential to enhance collaboration and communication, increase productivity and quality, and reduce project cost and delivery time (Azhar 2011). In order to overcome the existing obstacles in traditional risk management method, numerous attempts of the use of BIM and BIM-related technologies for risk management have been conducted globally. For instance, BIM itself has been proven as an effective way to assist early identification and assessment of risks for design and construction through 3D visualisation (Grilo & Jardim-Goncalves 2010), 4D scheduling (Zhang & Hu 2011), and 5D cost estimating (Mitchell 2012). With the growing development of BIM in the AEC industry, some efforts that could further integrate BIM with risk management have been observed, e.g. automatic rule checking (Eastman et al 2009, Zhang et al 2013, Sulankivi et al 2013), proactive IT (Information Technology)-based safety systems (Forsythe 2014), and safety training in a virtual gaming environment (Guo et al 2012). There are a number of marked reasons behind the increasing interest and adoption of BIM for risk management.

Firstly, a strong thrust of policies is facilitating the adoption of BIM in the AEC industry. For example, Bew & Richards (2008) developed a BIM maturity diagram defining the maturity levels from 0 through 3 as shown in Figure 2, and set the deadline of 2016 for all UK public projects to achieve significant benefits of BIM at Level 2 (BIS 2011). In addition, to improve the safety of AEC projects, the CDM regulations was introduced in the UK initially in 1996, and '*the beneficial application of BIM to administration of the CDM regulations 2007 will still be relevant when the new CDM regulations are made in 2015 after the current consultation period*' (Joyce & Houghton 2014).

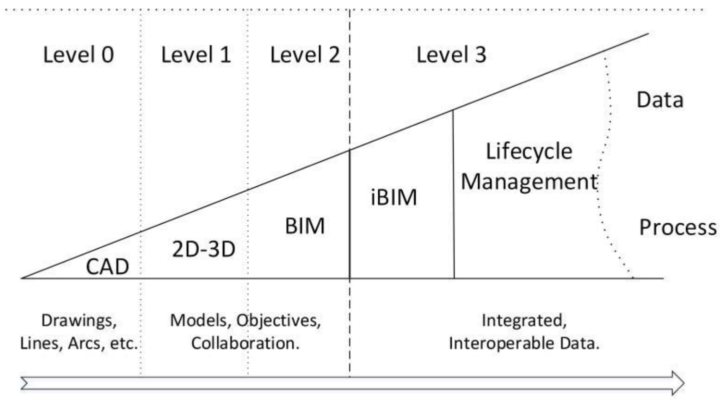

Figure 2 BIM Maturity Diagram (Bew & Richards 2008)

The second driver for BIM-based risk management is that the industry has benefited from the technical advantages of the BIM technology itself. In addition, it has been realised that all risk management methods become ineffective if any risks could not be detected before they happen (Carter & Smith 2006), and BIM could assist significantly in the early identification of risks. For instance, BIM has converted the 2D design method into an information-supported and parametric spatial design that is distinguished from the typically so-called '3D design'. It is significantly easier to check any mistakes and the rationality of a design in an information rich 3D environment, and BIM where parametric information is linked to the objects is convenient for any optimisation and changes (Eastman et al 2011). Moreover, common BIM applications include physical clash detection (Leite et al 2011), 4D construction scheduling (Chau et al 2004) and 5D cost estimating (Popov et al 2010). These applications can help build the virtual project in the computer and simulate the construction process, scheduling, and cash flow. In this case, clients, designers, contractors and risk specialists have a much better chance of identifying risks at an early stage and putting forward any needed mitigation measures in advance.

The third reason is that BIM could facilitate collaboration and communication in risk management. Large-size construction projects, in which a series of activities and processes are conducted and a large number of people from different disciplines are involved to complete the one-off endeavour successfully, are complicated to manage. Different views and misunderstandings can create significant risks. Effective communication and collaboration are always required for successful risk management (Renn 1998). This is potentially where BIM could be of help. For instance, BIM could be utilised across organisational boundaries, which include interdisciplinary coordination, and for the vertical integration of information exchange within one design and construction discipline such as concrete design, fabrication and construction (Dossick & Neff 2011). Specifically, BIM can facilitate a collaborative and communicative environment to enable: *'1) the owner to develop an accurate understanding of the nature and needs of the purpose for the project; 2) the design, development, and analysis of the project; 3) the management of the construction of the project; and 4) the management of the operations of the completed project during its operation and decommissioning'* (Grilo & Jardim-Goncalves 2010).

4 Development and challenges of BIM-based risk management

To summarise the state-of-the-art and challenges of BIM-based risk management, an extensive review of published literature concerning the use of BIM and BIM-related tools for risk management was conducted. The findings show that BIM could be used as a systematic tool to manage risk during a project's lifecycle. For example, the spatial visualisation and dynamic modelling of a project in a computer system could effectively facilitate early risk identification and communication(Liu et al 2014), and assist strategy and decision making to improve safety, time and cost management in construction (Hardin 2011). Meanwhile, neutral data formats such as Industry Foundation Classes (IFC) that store standard and customised data for all project elements and provides an interoperable digital representation of all project elements enabling interoperability between BIM software and applications (Laakso & Kiviniemi 2012), which can increase the repeated use of data and reduce the possibility of errors. Besides, BIM can also perform as a core data generator and platform to allow other BIM-related technologies, e.g. automatic rule checking, knowledge based systems, reactive and proactive IT-based safety systems, for further risk analysis, where most of these technologies could be used interactively in related investigations. For example, Sulankivi et al (2013) presented a theory that safety issues that are unknowingly built into the construction schedule can be automatically identified early in the design stage and developed an automated safety rule-checking prototype for BIM. Aiming at fall prevention, Zhang et al (2013) outlined a framework for a rule-based checking system for safety planning and simulation by integrating BIM and safety. Motamedi et al (2014) integrated the use of knowledge management (KM) and BIM to investigate an approach for detecting failure root-cause which could aid facility management (FM) engineers to identify and solve problems from their cognitive and perceptual reasoning. Guo et al (2012) resolved major construction activities with potential safety issues and developed a game technology-based safety training platform through BIM and a 3D game engine for training site operatives in the use of construction plant and equipment to prevent problems. To effectively manage conflicts, structural safety problems, people's health and safety, and property, Hu and Zhang proposed in their two papers (Hu & Zhang 2011, Zhang & Hu 2011) a 4D structural information model based on BIM, 4D technology, time-dependent structural analysis, collision detection, and so on. They implemented this theoretical solution by developing an integrated archetypal system named 4D-GCPSU 2009 and validated it using 3 case studies.

Despite these considerable achievements of BIM-based risk management, most of the current efforts relate to the design and construction stages of a project. In addition, it is very important to point out that because of technical limitations and the lack of "human factor" testing most of these emerging technologies are still at a conceptual or prototyping stage and have not been broadly used in the real work environment (Forsythe 2014). Similarly, Zhou et al (2012) indicated that these considerations to manage safety risk are 'mindful' actions that challenge assumptions. Most of these efforts focus mainly on using or developing new digital technologies to manage some particular risks in an ideally assumed scenario, e.g. prediction and prevention of fall accidents (Zhang et al 2013), and thereby there is a high demand for research on how new technologies for risk management can be implemented to achieve high-level value. Furthermore, currently traditional risk management methods and processes still play a significant role in real projects. Future research is expected to align BIM and BIM-related technologies with traditional methods to manage risk in real projects (Hartmann et al 2012). In general, a huge gap in implementing BIM and BIM-related tools for risk management on construction sites still exists.

5 On-going research

There is no doubt that BIM will push the AEC industry to the next generation and thereby it is believed that risk management will be more powerful and effective than it is today. Since AEC projects are one-off endeavours with many unique features and risks exist during the whole dynamic process, risk management could play a valuable role when a project's core participants start to use these new technologies as part of their daily work. However, most of the current efforts of BIM-based risk management are technology-driven and few studies have focused on how new techniques and the traditional risk management methods, activities, and processes can be integrated systematically and effectively so that BIM-based risk management can become more applicable in the AEC industry.

To overcome this gap, this paper proposes a new method to create an active "link" between BIM and Risk Management System as shown in Figure 3. The paper is part of the on-going PhD research project of the first author to develop a BIM and Knowledge Based Risk Management System (BKRMS) in order to support the risk management in the design and construction stages of bridge projects. Though the research focuses on bridges, the method and system are expected to be also useful for other AEC projects. KM is defined as '*the process of capturing, developing, sharing, and effectively using organisational knowledge*' (Davenport 1994) and could play an essential role to facilitate risk information stored in a proper structure, communicated and reused effectively. Today some KM applications for improving the performance of the BIM process have been developed (Ali et al 2004, Fong & Wong 2009, Motamedi et al 2014). The core idea of the proposed method is to summarise and further analyse published academic papers, national standards, industrial practices and other documentations through a knowledge-based approach to formalise a knowledge-based risk database, case-based reasoning library, and a risk communication and documentation framework for bridge engineering. The next stage will build on the previous results to link risk models with BIM and investigate how risks can be visualised in 3D/4D BIM. The last step is to develop a prototype with a user interface to test and validate the proposed method.

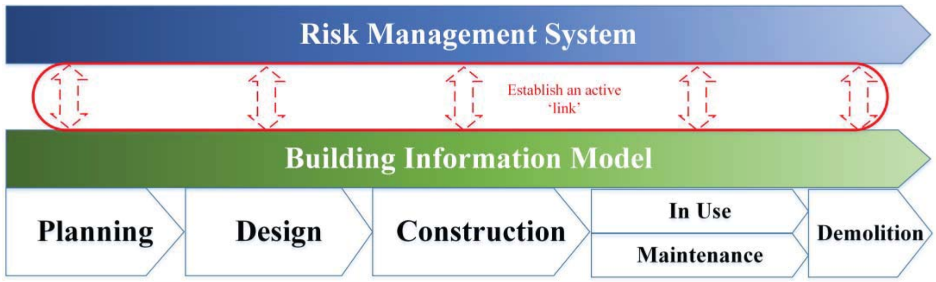

Figure 3 Establishment of an 'active' link between BIM and Risk Management System

6 Discussion and conclusion

The current risk management method is heavily reliant on experience and knowledge, based on human cognition and there are several known challenges waiting to be dealt with. It is also very important to identify and mitigate risks at an early stage, and failure to do so may lead to further risks. In recent years, it has been observed that there is a new trend to use BIM and BIM-related technologies to facilitate risk management.

This paper not only summarises the general risk management process and existing deficiencies, but also examines and explains the potential of BIM in the risk management implementation process. It documents a gap in implementing BIM-based risk management in the real world and how further research could help fill the gap by establishing an active 'link' so that the advantages of both a general risk management method and BIM could be combined. The literature review indicates that most of the current literature has focused on exploiting new technologies to treat one or two risks in a particular scenario, such as the prediction and prevention of falling accidents on site. Most of these emerging efforts in this area are still at a conceptual or prototyping stage and have not been broadly used in the real work environment. Therefore they cannot be considered as mature solutions at present. Some limitations like the results' reliability of the rule checking technology and deficiencies such as the tracking accuracy problems in proactive safety systems must still be solved or improved. Consequently, it can be seen that a complete BIM-based risk management solution is still some time away. However, aligning BIM and other BIM-based techniques with the general risk management method to systematically support the development process of a project would be a significant step towards such a solution.

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