

INTEGRATION OF BIM AND RISK MANAGEMENT:A REVIEW OF LITERATURE

Dr. Debasis Sarkar¹ and Harsh Shah²

^{1,2} *Infrastructure Engineering and Management,*

Department of Civil Engineering Pandit Deendayal Petroleum University (India)

ABSTRACT

This paper is an attempt to explore the available literature pertaining to Building Information Modeling (BIM) and risk management. BIM is a tool which along with Integrated Project Delivery (IPD) can enhance the coordination, collaboration and communication of a multidisciplinary complex mega infrastructure project. Building information modelling (BIM) implementation involves various risks, which prevent users from assuring the potential benefits. The objectives of this study are to identify the risks associated with BIM implementation in architectural, engineering and construction projects and model the paths of these risks. Infrastructure projects are subjected to risks throughout all stages of the project starting from feasibility, design, development, implementation and operation. These risks lead to time and cost overrun which drastically reduces the probability of successful completion of the project within stipulated time and cost frame. The project authorities need to adopt mitigation measures to reduce the risk components in the activities of the infrastructure projects.

Key Words : *Building Information Modeling(BIM) , Risk , Risk Management*

Introduction to BIM

Building information modeling (BIM) has been transforming the architecture, engineering and construction (AEC) industry in many countries (Azhar, 2011)¹ and thus received increasing attention from both researchers and practitioners. Application areas of BIM include, but are not limited to site analysis, design option analysis, 3D presentation, design coordination, cost estimating, energy simulation, clash detection, construction system design, schedule simulation, quantity takeoff, site resource management, building performance prediction and offsite fabrication. Previous studies have identified a number of benefits that may be produced by BIM adoption. Number of benefits have been reported in previous studies, such as cost and time saving, reduction in design errors and omissions, reduction in rework and conflicts in construction, better occupant value, enhanced construction productivity, better information exchange and better stakeholders' relationships (Azhar 2011; Bryde, Broquetas, and Volm 2013)^[2]. The different dimensions of BIM are presented below:

BIM 3D = 3 DIMENTION

4D = 3D+SCHEDULING

2nd International Conference on Multidisciplinary Research (ICMR-2018)

Mahratta Chamber of Commerce, Industries and Agriculture, Pune (India)



08th - 09th September 2018

www.conferenceworld.in

ISBN :978-93-87793-45-3

5D= 4D+COST

6D= 5D+ENERGY

7D= 6D+FACILITY MANAGEMENT

8D= 7D+ACCIDENT PREVENTION (RISK MANAGEMENT)

Risk Management

In a risk management process, risk identification is usually the first step (Low, Liu, and He 2009)^[3], and risk categorization, which structures the diverse risks, has been widely accepted as an integral part of risk identification (Zou, Zhang, and Wang 2007)^[4]. In this study, the identification of risks associated with BIM implementation depends on a review of literature using the Scopus database, which has been one of the largest database for multidisciplinary scientific literature (Ameyaw et al. 2016; Le et al. 2014a; Moya-Anegón et al. 2007)^[5]. There are mainly 2 types of risk (i) external risk (ii) internal risk. External risks (Fang *et al.*, 2004, El-Sayegh, 2008, Tah and Carr, 2001)^[6] mean those risks that are outside the project and beyond the control of the project team. The external risks include political, economic, social and cultural risks. For example, the political risk may refer to the changes or variation of local laws and the economic risk could be the fluctuation of local currency. As external risks are at a macro level such as company or country level and are not under the control of the project team, there is a need for a continuous scanning and forecasting through all phases of the project and drawing up company strategies to manage their effects (Tah and Carr, 2001)^[7]. Internal risks (Fang *et al.*, 2004, El-Sayegh, 2008, Tah and Carr, 2001)^{[6]*} refer to those that are within the project and are more controllable by the project team. The scope of internal risks is much broader than external risks and there is a greater opportunity for the project team to manage them. The number of internal risks in the knowledge-based risk database is much larger than the number of external risks and the relation between different internal risks are inter-related and much more complex. Therefore, the internal risks were further divided into two groups like local and global, because some internal risks are related to the whole project whereas the others may cause effects local to the bridge or individual work packages (Tah and Carr, 2001)^{[7]*}. First of all, project risk analysis, including the steps of risk identification, risk classification and defining risk remediation strategies, should always be followed up by executing the risk remediation strategies, evaluating whether these measures work as expected, and modify them where required. Often, these risk remediation actions, of a preventive or corrective type, need to be executed by different persons, at different positions, at different moments in time, within the project. Second, the risk management process needs to become a lot more than a tick-boxing exercise, in which particularly a lot of paper is produced and processes are monitored with hindsight. Therefore risk management needs to be transformed from a should do activity to a want to do activity. This requires full and dedicated management commitment, as well as true risk management motivation by all persons involved in the project, including the external stakeholders.

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 in a timely manner (ISO, 2009)^[9]. Architecture, Engineering and Construction (AEC) projects start with planning and design, followed by a

2nd International Conference on Multidisciplinary Research (ICMR-2018)

Mahratta Chamber of Commerce, Industries and Agriculture, Pune (India)



08th - 09th September 2018

www.conferenceworld.in

ISBN :978-93-87793-45-3

construction stage that may last for many months, and eventually will come into the operation stage that may last for many decades before demolition. Different risks are present in the different stages of the project and product lifecycle.

Integration of BIM and Risk Management

Building information modelling (BIM) implementation involves various risks, which prevent users from assessing the potential benefits. The objectives of this study are to identify the risks associated with BIM implementation in architectural, engineering and construction projects and model the paths of these risks. To achieve these objectives, 16 risks categorized into 9 groups were identified from a literature review, and a questionnaire survey was conducted with 38 professionals in Australia. The hypothetical risk paths were tested using partial least square-structural equation modelling. Eight risk paths were statistically significant, which further formed nine chains of risk paths. 'Inadequate relevant knowledge and expertise' was the primary root risk category, and 'technological issues', 'poor information sharing and collaboration' and 'data ownership issues' were the secondary root risk category. Additionally, the expense associated with BIM implementation can be offset by the cost savings brought by BIM.

The Current Status of Risk Management

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 in a timely manner (ISO, 2009)^[8]. Architecture, Engineering and Construction (AEC) projects start with planning and design, followed by a construction stage that may last for many months, and eventually will come into the operation stage that may last for many decades before demolition. 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 depending on the type of risk and how severe the consequences are. The scope of a risk consists of many issues: damage or failure of structures, injury or loss of life, budget overruns, delays to the construction schedule, etc. 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.

Challenges in Traditional Risk Management

Existing challenges in traditional risk management can be summarised as (1) Traditional risk management is still a knowledge and experience based manual undertaking, and numerous investigations (Shim et al., 2012, Hartmann et al., 2012, Zhang et al., 2014)^[9] have concluded it is time-consuming, error-prone and highly inefficient. In real projects many practitioners still work on two dimensional (2D) platforms and use 2D drawings and paper-based documents to convey the product information. In this process, though some simple

2nd International Conference on Multidisciplinary Research (ICMR-2018)

Mahratta Chamber of Commerce, Industries and Agriculture, Pune (India)



08th - 09th September 2018

www.conferenceworld.in

ISBN :978-93-87793-45-3

techniques, such as checklists, could assist risk identification and analysis (HSE, 2015)^[10], it is a significant challenge to combine and link 2D drawings, on-site observations and paper-based documents together for identification and consideration of risks. Decisions are to a large extent made through a “brainstorming” exercise based on existing knowledge and previous experience (2) Risk knowledge management is fragmented and insufficient, and risk knowledge transfer from project to project is difficult. Multi-disciplinary knowledge and experience play a key role in traditional risk management and the corresponding decision making. Project participants, e.g. clients, architects and engineers, gain valuable knowledge and experience from every project and can use them 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. However, 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)^[11]. In addition, the process of any AEC project is dynamic and new experience and new lessons come to light nearly every day. Consequently, another significant challenge is how to effectively manage the “database” of human knowledge and experience as well as extract the correct data flexibly and accurately (3) Communication and collaboration need to be improved in traditional risk management (Zou et al., 2017)^[12]. Since 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)^[13]. 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 tasks. Thus, large amounts of risk information may be lost if it is not recorded properly and communicated to other project participants.

Risk Breakdown Structure

To learn from and use past project knowledge and experience for managing risks, an effective way is to work out a comprehensive risk database containing all possible risks that may affect the project. The database could facilitate a systematic understanding of all project risks, and help the project team link risk information to real projects and make decisions quickly, e.g. (Kartam and Kartam, 2001, Wang and Chou, 2003)^[14]. As construction is by nature a dynamic process with unexpected changes and risks and new information is added into the project every day, it is crucial to use a logical and rapid approach for classifying and structuring the large amount of information. Currently a variety of tools have been developed for risk classification, e.g. risk list (PMI, 2004)^[15], risk matrix (Markowski and Mannan, 2008)^[16], risk maps (Dey, 2010)^[17] and RBS (Holzmann and Spiegler, 2011)^[18]. RBS in concept is a hierarchical structure that allows all types of risk factors and events to be well organised by groups and categories (Holzmann and Spiegler, 2011)^{[18]*}. It is an open, flexible and easily updatable tool and could offer a global view on risk exposure (Mehdizadeh et al., 2013)^[19]. The main advantages of RBS include: (1) to increase overall understanding of risks and facilitate risk communication; (2) to help locate identified risks into relevant places and make special strategies to treat them easily; (3) to provide an

architecture for managing risk database and developing risk management software. So far the main approach to develop a RBS is mining risk data from academic publications, project reports, and past project experience and classifying risk factors into a number of logical groups according to the sources of risk (El-Sayegh and Mansour, 2015)^[20].

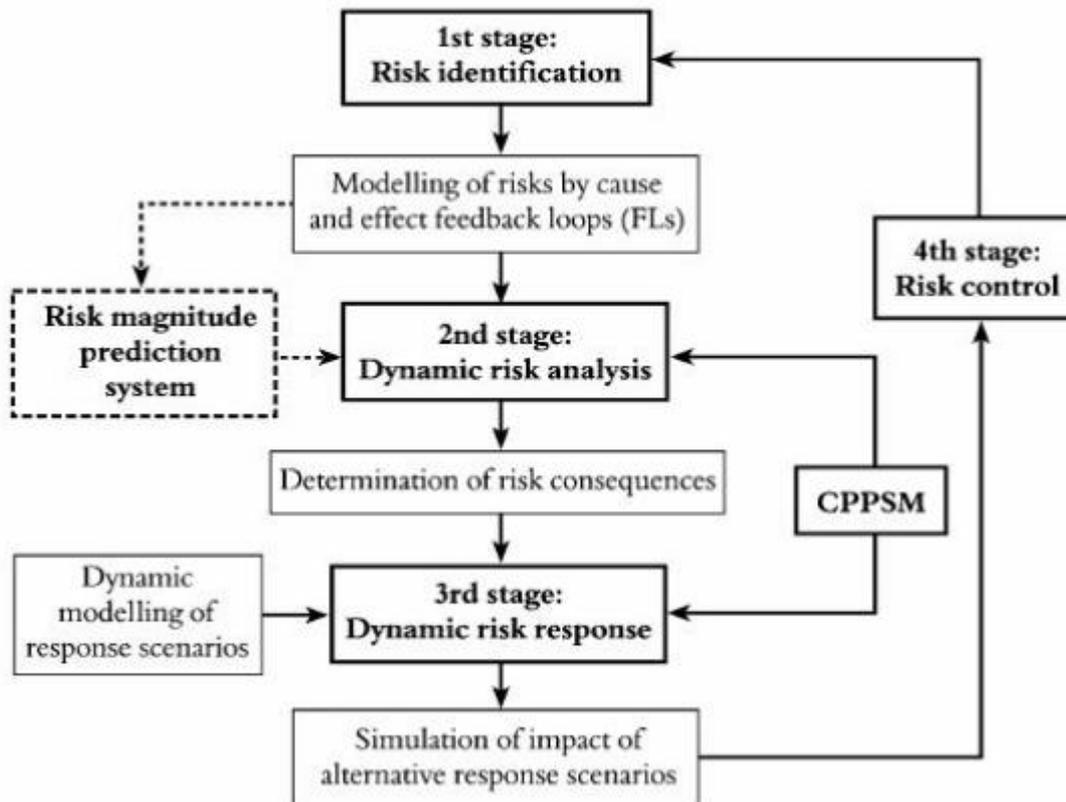
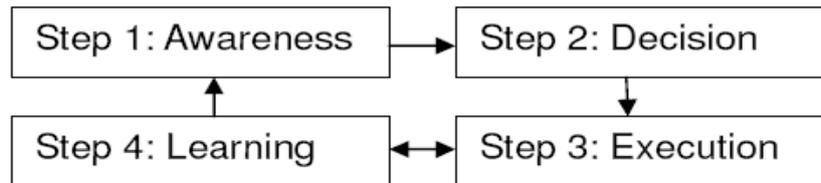


Fig.1 Stages of Risk

Risk Identification

Risk identification is a critical phase in a project risk management process (Low et al., 2009)^[21]. A simple but valid method is to develop a risk checklist (Fang et al., 2004)^[22]. Through a literature review, a checklist of the risks associated with BIM adoption in the AEC industry was developed. Content analysis has been widely adopted to determine the major facets of data, by counting the frequency that a topic is mentioned or an activity occurs (Fellows and Liu, 2008)^[23]. In this study, the risks identified in each literature were marked down and then similar risks were assembled. The frequency of each risk in the literature was also counted. Table I shows that the 16 risks identified from 22 previous studies, with their frequency of appearance in the literature. A total of 16 risks were grouped into nine risk categories, some of which comprise only one risk. Previous studies on risks associated with BIM adoption overlooked the interactions between risks. For example, Azhar (2011)^{[1]*} and Azhar et al. (2012)^{[2]*} identified several risks associated with BIM adoption, but overlooked the relationships between risks; Ghaffarianhoseini et al. (2017)^[24] introduced the risks and challenges of BIM adoption, but did not explain how the risks interact with each other; and Chien et al. (2014)^[25] identified 13 risk factors and but failed to explore the cause-and-effect relationships among risks. Simply ranking risks is not adequate to address these risks because it overlooks the effects of top risks on others. It is more reasonable to employ a networking of various risk paths, representing the interactions among the risks, than to apply risk checklists only (Eyboosh et al., 2011)^[26]. Thus, this study aims to model the risk paths in BIM adoption using the empirical data from China, which will help locate the root risks and explore the mechanism of interactions among risks.

Some of the common risk sources are (1) Machinery breakdown (2) Inflation (3) Adverse weather conditions (4) Contribution to local community (5) Increased payment in replying with changed labour standard law (6) Discrepancy in geology or topographic conditions (7) Change orders (8) Underestimation of construction costs due to lack of information (9) Inefficiency of owner supervisors (10) Material overuse by subcontractor with poor technique or working habits (11) Changed labour safety laws or regulations (12) Schedule delay caused by rejection of unqualified material (13) Construction accidents resulting from operating errors or carelessness (14) Reworking or delay of work due to poor workmanship of subcontractor (15) Pressure to crash project duration (16) Faulty design not detected by contractor in tendering process (17) Construction errors due to faulty design but not checked in time by contractor (18) Deficit in financial resources and (19) Construction errors due to faulty design but not checked in time by contractor

Risk Data Mining

The next step is to search for valuable risk information from the data collected in risk data collection step by adopting a manual text mining approach. Specifically, a manual analysis through careful reading of each document and interpreting and understanding the text in its relevant context was conducted to identify and record the risk information. As the collected documents use different methods and standards to describe risks, e.g. 'cost increase' and 'budget overrun', it was then important to classify similar risks and put them into different risk groups individually according to the source of risk. Currently there is no consensus on how to

develop the RBS (Mehdizadeh et al., 2013)^[19], thus a list of key words (e.g. project risk, external risk, global risk, design risk) were identified from previous studies (Tah and Carr, 2001)^{[7]*}, (Choi and Mahadevan, 2008)^[27], Mehdizadehet al., 2013)^{[19]*} to be an initial hierarchy for allocating and managing the collated risk information. After this, all identified risk factors and corresponding information were organised into groups and stored in an initial database which is defined as a ‘risk pool’ in this paper.

Risk Data Analysis

An interpretative approach was used to inform the data analysis and aimed to build understanding of the empirical data. The analysis process resulted in three interconnected components. Firstly, a narrative of the cases were developed to provide an in-depth account of the implementation process, describing key events and their impact on project success, secondly, the empirical data was categorized into the six constructs of the DeLone and McLean IS Success Model to provide a thematic map of the constituent parts of implementation and thirdly, dependencies between each construct were then established to capture the relation between the conditions of implementation and project success. A detailed risk management framework is given in figure 2.

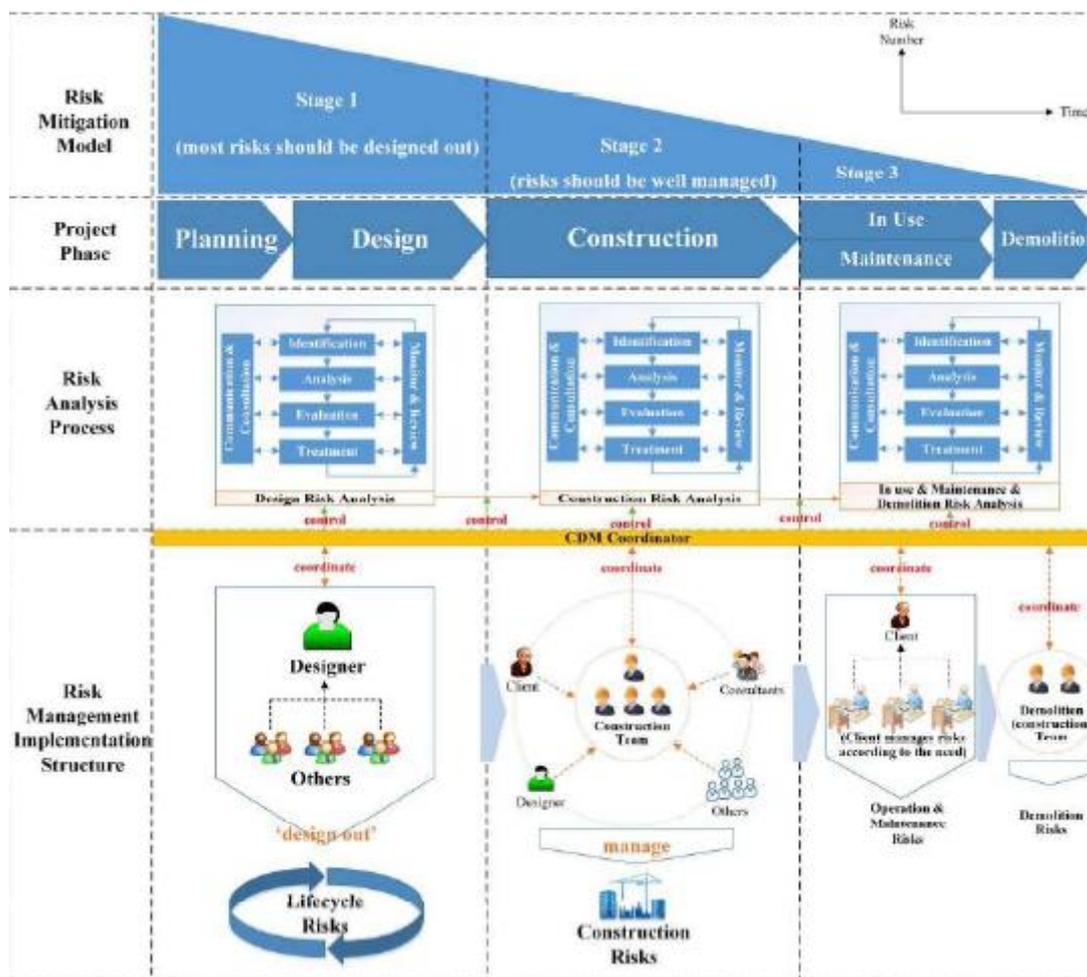


Fig. 2 . A Detailed Risk Management Framework(Zou et al. 2016)^[28]

Adopting BIM for Risk Management

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)^[1]. 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 a systematic way to assist early identification and assessment of risks for design and construction through 3D visualisation (Grilo and Jardim-Goncalves, 2010)^[29], 4D scheduling (Zhang and Hu, 2011)^[30], and 5D cost estimating (Mitchell, 2012)^[31]. 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)^[32], and assist strategy and decision making to improve safety, time and cost management in construction (Hardin, 2011)^[33]. Meanwhile, neutral data formats such as IFC that store standard and customised data for all project elements provide an interoperable digital representation of all project elements enabling interoperability between BIM software and applications (Laakso and Kiviniemi, 2012)^[34], which can increase the repeated use of data and reduce the possibility of errors. 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)^[35], proactive IT (Information Technology)-based safety systems (Forsythe, 2014)^[36], and safety training in a virtual gaming environment (Guo *et al.*, 2012)^[37]. A critical review by Zou *et al.* (2016)^{[28]*} summarised the latest developments of using BIM and BIM-related technologies for risk management. Despite these considerable achievements, literature shows that BIM-based risk management has not been widely used in practice because of the following obstacles like (1) Most of the current efforts relate to the design and construction stages and fail to support the development process of a project (Zou *et al.*, 2016)^{[28]*} (2) Because of technical limitations and the lack of “human factor” testing, most of these emerging technologies are still at a conceptual or prototyping stage (Forsythe, 2014)^[36] (3) Most of these efforts focus on using or developing new digital technologies to manage particular risks in an ideally assumed scenario, e.g. prediction and prevention of fall accidents (Zhang *et al.*, 2013)^[35], and there is still a lack of methods to use new technologies for risk management systematically. In addition, Zhou *et al.* (2012)^[40] indicated that these considerations to manage safety risk on site are assumption-based actions. Therefore, further investigations are needed to deepen the practical applicability of BIM-based risk management. To strengthen the practical applicability of BIM-based risk management, an important solution is to align traditional methods with BIM and take advantages of both for managing risks (Zou *et al.*, 2016)^{[28]*}. A number of studies (Ding *et al.*, 2016)^[38] have proved the feasibility and demonstrated the benefits including (1) Through visualising the project and simulating the construction scheduling virtually in a 3D computer environment, BIM could facilitate project team linking existing knowledge and experience with visualisation for identifying risks and making corresponding mitigation strategies (2) Knowledge and experience based traditional methods are still playing an important role in practice and could be further strengthened by combining with BIM (3) Risk data could be effectively stored, managed and reused through the project life cycle through merging traditional methods with BIM. It is observed that there

2nd International Conference on Multidisciplinary Research (ICMR-2018)

Mahratta Chamber of Commerce, Industries and Agriculture, Pune (India)



08th - 09th September 2018

www.conferenceworld.in

ISBN :978-93-87793-45-3

are two different development directions of aligning traditional method with BIM for risk management, i.e. (1) product-oriented; and (2) process-oriented. For example, some studies, e.g. (Shim et al., 2012, Zou et al., 2015)^[9], demonstrated the feasibility and overall framework of developing a computer tool to visualise and link risk information to BIM while other researchers, e.g. (Hartmann et al., 2012)^[39], investigated the possibility of integrating BIM into the traditional workflow for risk management or develop a new implementation framework for BIM-based risk management. However, only limited research has been found in this area and new investigation is still needed.

CONCLUSIONS

Reviewing the available literature it has been observed that researchers have worked on BIM and also on risk management. Adequate literature is available on applications of BIM in building projects. But applications of BIM in infrastructure projects have lesser literature. Adequate literature is available on risk management process like risk identification, risk analysis and risk response planning. Adequate literature is also available on applications of risk management in infrastructure projects. But adequate literature is not available on integrated BIM and risk management model. The present study aims at exploring the possibility of developing an integrated BIM and risk management model for infrastructure projects.

REFERENCES

- [1] Azhar, S. (2011), "Building Information Modeling (BIM): trends, benefits, risks, and challenges for the AEC industry", Leadership and Management in Engineering, Vol. 11 No. 3, pp. 241-252.
- [2] Azhar, S., Khalfan, M. and Maqsood, T. (2012), "Building Information Modeling (BIM): now and beyond", Australasian Journal of Construction Economics and Building, Vol. 12 No. 4, pp. 15-28.
- [3] Low, S.P., Liu, J.Y. and He, S.Q. (2009), "External risk management practices of Chinese construction firms in Singapore", KSCE Journal of Civil Engineering, Vol. 13 No. 2, pp. 85-95.
- [4] Zou, P. X. W., G. Zhang, and J. Wang. 2007. "Understanding the Key Risks in Construction Projects in china." International Journal of Project Management 25:601–614.
- [5] Ameyaw, E. E., Y. Hu, M. Shan, A. P. Chan, and Y. Le. 2016. "Application of Delphi Method in construction Engineering and Management Research: A Quantitative Perspective." Journal of Civil engineering and Management 22:991–1000.
- [6] Fang, D., Li, M., Fong, P. and Shen, L. (2004), "Risks in Chinese construction market-contractors' perspective", Journal of Construction Engineering and Management, Vol. 130 No. 6, pp. 853-861.
- [7] Tah, J. and Carr, V. (2001), "Knowledge-based approach to construction project risk management", Journal of Computing in Civil Engineering, Vol. 15 No. 3, pp. 170-77.
- [8] ISO (2009), Risk management - Risk assessment techniques, IEC/FDIS 31010:2009, International Organization for Standardization (ISO).

2nd International Conference on Multidisciplinary Research (ICMR-2018)

Mahratta Chamber of Commerce, Industries and Agriculture, Pune (India)



08th - 09th September 2018

www.conferenceworld.in

ISBN :978-93-87793-45-3

- [9] Shim, C.-S., Lee, K.-M., Kang, L.S., zang, J. and Kim, Y. (2012), "Three-Dimensional Information Model-Based Bridge Engineering in Korea", *Structural Engineering International*, Vol. 22 No. 1, pp. 8-13.
- [10] HSE (2015), *The Construction (Design and Management) Regulations*, Health and Safety Executive (HSE), London.
- [11] Clough, R.H., Sears, G.A. and Sears, S.K. (2000), *Construction project management*, John Wiley & Sons, Canada
- [12] Zou, Y., A. Kiviniemi, and S. W. Jones. 2017. "A Review of Risk Management through BIM and BIM- related Technologies." *Safety Science* 97: 88–98.
- [13] Kazi, A.S. (2005), *Knowledge management in the construction industry: A socio-technical perspective*, IGI Global, USA.
- [14] Kartam, N.A. and Kartam, S.A. (2001), "Risk and its management in the Kuwaiti construction industry: a contractors' perspective", *International Journal of Project Management*, Vol. 19 No. 6, pp.325-35.
- [15] PMI. (2004), *A guide to the project management body of knowledge (PMBOK Guide)*, Project Management Institute (PMI), USA.
- [16] Markowski, A.S. and Mannan, M.S. (2008), "Fuzzy risk matrix", *Journal of hazardous materials*, Vol. 159 No. 1, pp. 152-57.
- [17] Dey, P.K. (2010), "Managing project risk using combined analytic hierarchy process and risk map", *Applied Soft Computing*, Vol. 10 No. 4, pp. 990-1000.
- [18] Holzmann, V. and Spiegler, I. (2011), "Developing risk breakdown structure for information technology organizations", *International Journal of Project Management*, Vol. 29 No. 5, pp. 537-46.
- [19] Mehdizadeh, R., Breyse, D., Taillandier, F. and Niandou, H. (2013), "Dynamic and multi perspective risk management in construction with a special view to temporary structures", *Civil engineering and Environmental Systems*, Vol. 30 No. 2, pp. 115-29.
- [20] El-Sayegh, S. and Mansour, M. (2015), "Risk Assessment and Allocation in Highway Construction. Projects in the UAE", *Journal of Management in Engineering*, Vol. 31 No. 6, pp. 04015004.
- [21] Low, S.P., Liu, J.Y. and He, S.Q. (2009), "External risk management practices of Chinese construction firms in Singapore", *KSCE Journal of Civil Engineering*, Vol. 13 No. 2, pp. 85-95.
- [22] Fang, D.P., Li, M.G., Fong, P.S.W. and Shen, L.Y. (2004), "Risks in Chinese construction market Contractors' perspective", *Journal of Construction Engineering and Management-Asce*, Vol. 130 No. 6, pp. 853-61
- [23] Fellows, R. and Liu, A.M.M. (2008), *Research Methods for Construction*, Blackwell, Oxford.
- [24] Ghaffarianhoseini, A., Tookey, J.,, Naismith, N., Azhar, S., Efimova, O. and Raahemifar, K. (2017), "Building Information Modelling (BIM) uptake: clear benefits, understanding its implementation, risks and challenges", *Renewable and Sustainable Energy Reviews*, Vol. 75, pp. 1046-1053.
- [25] Chien, K.-F., Wu, Z.-H. and Huang, S.-C. (2014), "Identifying and assessing critical risk factors for BIM projects: empirical study", *Automation in Construction*, Vol. 45, pp. 1-15.

2nd International Conference on Multidisciplinary Research (ICMR-2018)

Mahratta Chamber of Commerce, Industries and Agriculture, Pune (India)



08th - 09th September 2018

www.conferenceworld.in

ISBN :978-93-87793-45-3

- [26] Eyboosh, M., Dikmen, I. and Birgonul, M. T. (2011), "Identification of risk paths in international construction projects using structural equation modeling", *Journal of Construction Engineering and Management*, Vol. 137 No. 12, pp. 1164-1175.
- [27] Choi, H.-H. and Mahadevan, S. (2008), "Construction project risk assessment using existing database and project-specific information", *Journal of Construction Engineering and Management*, Vol.134 No. 11, pp. 894-903.
- [28] Zou, ArtoKiviniemi, Stephen W. Jones , (2016),"Developing a tailored RBS linking to BIM for risk management of bridge projects", *Engineering, Construction and Architectural Management* , Vol. 23 No. 6, pp. 1-17.
- [29] Grilo, A. and Jardim-Goncalves, R. (2010), "Value proposition on interoperability of BIM and collaborative working environments", *Automation in Construction*, Vol. 19 No. 5, pp. 522-30.
- [30] Zhang, J.P. and Hu, Z.Z. (2011), "BIM- and 4D-based integrated solution of analysis and management for conflicts and structural safety problems during construction: 1. Principles and methodologies", *Automation in Construction*, Vol. 20 No. 2, pp. 155-66.
- [31] Mitchell, D. (2012), "5D BIM: Creating cost certainty and better buildings", in proceedings of RICS COBRA 2012 (the annual RICS international research conference) in Las Vegas, USA, 2012, pp. 1-9.
- [32] Liu, W.P., Guo, H.L., Li, H. and Li, Y. (2014), "Using BIM to Improve the Design and Construction of Bridge Projects: A Case Study of a Long-span Steel-box Arch Bridge Project", *International Journal of Advanced Robotic Systems*, Vol. 11, pp. 125.
- [33] Hardin, B. (2011), *BIM and construction management: proven tools, methods, and workflows*, John Wiley & Sons, Indiana, USA.
- [34] Laakso, M. and Kiviniemi, A. (2012), "The IFC standard - A review of history, development, and standardization", *Journal of Information Technology in Construction*, Vol. 17, pp. 134-61.
- [35] Zhang, S.J., Teizer, J., Lee, J.K., Eastman, C.M. and Venugopal, M. (2013), "Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules", *Automation in Construction*, Vol. 29, pp. 183-95.
- [36] Forsythe, P. (2014), "Proactive construction safety systems and the human factor", *Proceedings of the Institution of Civil Engineers: Management, Procurement and Law*, Vol. 167 No. 5, pp. 242-52
- [37] Guo, H., Li, H., Chan, G. and Skitmore, M. (2012), "Using game technologies to improve the safety of construction plant operations", *Accident Analysis & Prevention*, Vol. 48, pp. 204-13.
- [38] Ding, L.Y., Zhong, B.T., Wu, S. and Luo, H.B. (2016), "Construction risk knowledge management in BIM using ontology and semantic web technology", *Safety Science*, Vol. 87, pp. 202-13.
- [39] Hartmann, T., Van Meerveld, H., Vossebeld, N. and Adriaanse, A. (2012), "Aligning building information model tools and construction management methods", *Automation in Construction*, Vol. 22, pp. 605-13.
- [40] Zhou, W., Whyte, J. and Sacks, R. (2012), "Construction safety and digital design: A review", *Automation in Construction*, Vol. 22, pp. 102-11.