RISK ASSESSMENT TOOL FOR IMPLEMENTING BUILDING INFORMTION MODELLING IN INDUSTRIALISED BUILDING SYSTEM PROJECT

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ABSTRACT

Building Information Modelling (BIM) as an intelligent model-based process, provides significant enhancements in detailing and visualisation and improves project performance in terms of coordination and communication. The number of Industrialised Building System (IBS) construction projects that derive benefit from BIM implementation has extensively increased in recent years. IBS, as a standard construction technique in Malaysia, needs to adopt BIM. However, implementing new technologies in complex IBS environment involves several risks such as insufficient information about BIM, the risks associated with BIM adoption, and unclear BIM-related risk relations. This study aims to develop a prototype risk assessment tool (PRAT) for analysing and evaluating the risk factors associated with implementing BIM in IBS construction projects. "Fuzzy Delphi Method" was used to identify the critical risk factors, while "DEMATEL" and "Cybernetic Fuzzy Analytic network process" were employed for data analyses. PRAT consists of six main parts: instruction and opening window; modifiable database for inner-relation values; the ranking module for ranking the importance of risk factors, the ranking module of inter-dependencies of risk factors, calculation parts, and the result windows. In PRAT, five risk factors comprising thirty-two risk subfactors associated with BIM adoption in IBS projects have been considered as critical risk factors. PRAT enables the users to prioritise the most significant risks for any IBS project based on the relations of risk factors, their importance, and their influence on each other. Afterwards, to evaluate the PRAT, three case studies were implemented. After obtaining the results of PRAT implementation, multiple criteria approach was conducted to recognise its level of effectiveness and efficiency. Experts with an average of ten to fifteen years of experience in the fields of IBS and BIM have undertaken the process of PRAT evaluation. Finally, the experts' feedback indicated that the developed PRAT is effective and efficient using accurate and adequate data. Moreover, the users were satisfied with the performance of the developed tool in terms of reliability and flexibility. Through using PRAT at the primary phases of the projects, stakeholders can be aware of the significant risk factors for BIM adoption and able to execute early responses to the identified risks. Hence, the possibility of successful BIM implementation for IBS construction companies will increase.

ABSTRAK

Permodelan Maklumat Bangunan (BIM) sebagai proses berasaskan model cerdas, memberikan penambahbaikan penting dalam perincian dan visualisasi serta meningkatkan prestasi projek dari segi koordinasi dan komunikasi. Bilangan projek pembinaan Sistem Pembinaan Berindustri (IBS) yang mendapat faedah daripada pelaksanaan BIM telah meningkat secara mendadak pada tahun-tahun kebelakangan ini. IBS, sebagai teknik piawaian pembinaan di Malaysia, perlu menggunakan BIM. Walau bagaimanapun, pelaksanaan teknologi baru dalam persekitaran IBS yang kompleks melibatkan beberapa risiko seperti maklumat yang tidak mencukupi mengenai BIM, risiko yang berkaitan dengan penggunaan BIM, dan hubungan risiko yang berkaitan dengan BIM yang tidak jelas. Kajian ini bertujuan untuk membangunkan alat penilaian risiko prototaip (PRAT) untuk menganalisa dan menilai faktor-faktor risiko yang berkaitan dengan perlaksanaan BIM dalam projek pembinaan IBS. "Fuzzy Delphi Method" digunakan untuk mengenal pasti faktor risiko kritikal, sementara "DEMATEL" dan proses rangkaian “Cybernetic Fuzzy Analytic" digunakan untuk menganalisis data. PRAT terdiri daripada enam bahagian utama: arahan dan tetingkap pembukaan; pangkalan data yang boleh diubah suai untuk nilai hubungan dalaman; modul kedudukan untuk menentukan kepentingan faktor risiko, modul kedudukan antara kebergantungan faktor risiko, bahagian pengiraan, dan tetingkap keputusan. Dalam PRAT, lima faktor risiko yang merangkumi tiga puluh dua sub faktor risiko yang dikaitkan dengan perlaksanaan BIM dalam projek IBS telah dianggap sebagai faktor risiko yang kritikal. PRAT membolehkan pengguna memberi keutamaan kepada risiko yang paling ketara bagi setiap projek IBS berdasarkan hubungan faktor risiko, kepentingan mereka, dan pengaruh mereka terhadap satu sama lain. Selepas itu, untuk menilai PRAT, tiga kajian kes telah dilaksanakan. Selepas memperoleh keputusan pelaksanaan PRAT, beberapa kriteria pendekatan telah dijalankan untuk mengiktiraf tahap keberkesanan dan kecekapannya. Golongan pakar dengan purata sepuluh hingga lima belas tahun pengalaman dalam bidang IBS dan BIM telah melalui proses penilaian PRAT. Akhir sekali, maklum balas pakar menunjukkan bahawa PRAT yang dibangunkan adalah berkesan dan cekap dengan menggunakan data yang tepat dan mencukupi. Selain itu, para pengguna berpuas hati dengan prestasi alat yang dibangunkan dari segi kebolehpercayaan dan fleksibiliti. Melalui penggunaan PRAT pada fasa utama projek, pihak berkepentingan boleh menyedari akan faktor risiko yang signifikan bagi penggunaan BIM dan dapat melaksanakan respon awal terhadap risiko yang telah dikenal pasti tersebut. Dengan itu, kebarangkalian pelaksanaan BIM yang berjaya untuk syarikat pembinaan IBS akan meningkat.

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LIST OF ABBREVIATIONS

BIM	-	Building Information Modelling
IBS	-	Industrialised Building System
PRAT	-	Prototype Risk Assessment Tool
DEMATEL	-	Decision Making Trial and Evaluation Laboratory
CFANP	-	Cybernetic Fuzzy Analytic Network Process
FMEA	-	Failure Modes and Effects Analysis
FTA	-	Fault Tree Analysis
FDM	-	Fuzzy Delphi Method
TFNs	-	Triangular Fuzzy Numbers
SD	-	System Dynamics
SWOT	-	Strength, Weakness, Opportunity, and Treat
AHP	-	Analytic Hierarchy Process
ANP	-	Analytic Network Process
MCDA	-	Multi Criteria Decision Analysis
ETA	-	Event Tree Analysis
RBS	-	Risk Breakdown Structure
PMI	-	Project Management Institute
PMBOK	-	Project Management Body of Knowledge
AEC	-	Architecture Engineering Construction
CITP	-	Construction Industry Transformation Programme
PWD	-	Public Work Department
CIDB	-	Construction Industry Development Board
CIC	-	Construction Industry Council
IT	-	Information Technology
RFID	-	Radio-Frequency Identification
AR	-	Augmented Reality
GIS	-	Geographic Information System
BBB	-	Bridging BIM and Building
IFC	-	Industry Foundation Classes
LOD	-	Level of Detail

CI	-	Consistency Index
CR	-	Consistency Ratio
LW	-	Local Weight
GW	-	Global Weight

LIST OF SYMBOLS

$\mu A(x)$	-	Membership function
a_L	-	Triangular number for left
a_R	-	Triangular number for right
$(a_m, 1)$	-	Peak point of Fuzzy triangular
CI	-	Consistency Index
RI	-	Randon Index
λ_{max}	-	Maximum wavelength
PJ	-	Pairwise Judgment
PJ *(i:j)*	-	Pairwise judgment for indicator *i* to indicator *j*
A	-	Direct relation matrix
X	-	Normalised direct relation matrix
T	-	Total relation matrix
T^s	-	θ-cut total relation matrix
θ	-	Threshold value
T *(i:j)*	-	Total influence for factor *i* to factor *j*
GM	-	Geometric Mean
S_i	-	fuzzy synthetic extent
LW*i*	-	Local weight for factor *i*
LW*si*	-	Local eeight for subfactor *i*
GWs*i*	-	Global weight for subfactor *i*

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CHAPTER 1

INTRODUCTION

1.1 Overview

The construction industry, as the second-largest industry in a world, has been transformed into a systematic and professional way in recent decades. Currently, Industrialised Building System (IBS) is a mechanised-based process as the direct result of the industrial revolution. IBS technology assists the construction industry to be more productive and efficient. Numerous benefits of adopting IBS had been reported such as reducing material and time waste, diminishing labour usages, decreasing completion time and costs by prefabrication of components, and making systematic mechanised building as a modular coordination (Kamar *et al.*, 2009; Jabar *et al.*, 2013; Nawi *et al.*, 2015). Accordingly, using IBS as an integrated system has resulted in the driven of local construction towards producing and using the prefabricated and mass production of the buildings.

In current construction practices, there is an increase in the use of tools, software, and decision support systems, while Building Information Modelling (BIM) has been adopted as a popular approach. BIM has been recognised as a revolutionary change in the process of design, construction and maintenance. Moreover, BIM was introduced based on the concept of storing and managing various data produced throughout the building lifecycle in an integrated manner (Oh *et al.*, 2015). BIM is an exact representation from the information revolution so that associates composition of processes to make, communicate, virtualises, scrutinise, collaborate, coordinate, and integrate building models.

Notably, the number of construction projects using BIM is increasing all around the world, as it capable of simulating the projects in the visible virtual environment (Azhar, 2011). Accurate BIM implementation results in increasing total project quality, providing precise quantity take-offs, improving scheduling, and consequently, reducing total project contingencies and costs. BIM needs to be implemented in an efficient way to achieve the stated benefits and improve the overall performance construction of companies.

BIM offers all the stakeholders the opportunity to utilise an integrated shared model to achieve the project goals at an optimum level. The data sharing provided by BIM among different team members allows for constant evaluation and information control. Visual verification of design intent and knowledge sharing through virtual design and construction increase the clients' satisfaction levels. Exchange of visual information among designers and clients mitigates the time needed for communicating complex ideas. BIM enables simplified knowledge management. Continuously collected, stored and maintained project data throughout the building lifecycle streamlines tracking and evaluation of project details. BIM enables immediate and accurate comparison of different design options, which enables the development of more efficient, cost-effective and sustainable solutions. BIM can also facilitate the analysis and comparison of various energy performance alternatives to help facility managers dramatically reduce environmental impacts and operating costs.

1.2 Background of Research

Since the first project of Industrialised Building System (IBS) in the year 1964 till today, IBS in Malaysia is not widely adopted because of failure to meet the project's targets adequately (Liu *et al.*, 2017). High initial capital investment and lack of coordinated IBS modular components are other reasons that IBS not implemented with the maximum efficacy. Lack of cooperation among stakeholders at the preliminary stage in IBS construction projects produces errors that have severe impacts on subsequent phases towards an overall project.

Additionally, it is observed that problems such as changing orders, delays in production or construction and over budgets may be encountered due to defective decisions in implementing IBS (Yunus and Yang, 2011). Wrong decision and consideration on the IBS matter will ultimately alter the performance, outcomes and quality of the projects. Numerous information which comes from various phases of the project's lifecycle by different IBS vendors is commonly fragmented and stored in different information systems. Omissions or errors in design which are discovered late or during construction are responsible for approximately one-third of the contract's value (Zahrizan *et al.*, 2014). They may also lead to schedule delays due to rework and changes required to mitigate the errors. More importantly, serious errors committed during design that are not resolved during the course of a project can result in catastrophic construction failures (Al Hattab and Hamzeh, 2015).

Notably, Building Information Modelling (BIM) benefits pre-construction cost estimating and improve planning and scheduling that related to time and cost as well as reducing errors associated with inconsistent and uncoordinated project documents, improving the communication on a single system for exchanging digital information (Zahrizan *et al.*, 2013). However, while BIM provides excellent opportunities, it also raises challenges. Since most of the construction companies are familiar with conventional construction approaches, adopting BIM as a new application poses new risks which need to be handled. The process of risk assessment would be more complex while the risks are different from the ones that have been implemented by the managers for conventional construction projects.

Risk assessment a systematic process of evaluating the potential risks that may be involved in a projected activity or tasks. risk assessment is the combined effort of identifying and analysing potential events that may negatively impact individuals, assets, or the environment; and making judgments on the tolerability of the risk-based on risk analysis while considering influencing factors. Identifying and analysing the risks at the primary stage of the project is essential because the process of risk management will be performing on only the identified risk factors. As a result, to systematically manage complex BIM projects, the potential risks must be identified during the risk management process as insufficient risk assessment knowledge and techniques are the primary barriers to risk management.

A review of the BIM implementation in construction projects revealed that these projects involve risks due to the fragmented nature of the Architecture, Engineering and Construction (AEC) industry, complicated technology, large investment, industry's reluctance to change existing work practice and hesitation to learn new concepts and techniques (Chien *et al.*, 2014; Zahrizan *et al.*, 2014; Tan *et al.*, 2019). Lack of awareness and training, inadequate clarity on roles and responsibilities and distribution of benefits are other factors that hinder the BIM implementation (Zahrizan *et al.*, 2013; Tulenheimo, 2015; Liu *et al.*, 2016).

1.3 Research Problem

Building Information Modelling (BIM) is thought to provide significant enhancements in detailing, visualisation and simulation, clash detection, and improved project efficiency in terms of coordination and communication. However, the process of adopting new technologies and systems involves numerous risks and challenges (Chien *et al.*, 2014). Based on CIDB report, 41 per cent of organisations lack clear policies that support the implementation of BIM, 72 per cent lack allocation for any financial incentive for using BIM, 64 per cent failed to invest in BIM training and 67 per cent failed to invest in BIM hardware and software (CIDB, 2016). In order to reduce the adverse effect of these risks and challenges on the performance of technologies, the risk factors must be identified and assessed before the adoption and during the implementation phases.

Risks in BIM-based projects are divided into two categories: the risks that are influenced by the BIM implementation, and the risks inherent in BIM as the risk source. Insufficient information about BIM and how they affect risks and unclear BIM-related risk relations are the issues that need to be considered (Tomek and Matějka, 2014). Risk is inherent in all project activities, and it can never be eliminated; however, it can be effectively assessed and managed to mitigate the impacts on the achievement of the project’s targets. Each construction project is unique and comes with its own set of challenges (Chien *et al.*, 2014); thus, risks must be appropriately identified, characterised, understood, and evaluated by all project stakeholders exclusively.

Several researchers have investigated different theories, tools and techniques for assisting risk assessment. Nonetheless, there is a clear gap between the theory and practice of risk assessment. Hence, it is vital to understand the actual practice of risk analysis and review the development of construction risk assessment in an attempt to develop a risk assessment model or tool that may contribute to closing this gap (Taroun, 2014).

Moreover, to the best of researcher's knowledge, there is no risk assessment model for BIM implementation in the Malaysian construction industry. Consequently, there is a need to develop a tool to investigate and evaluate the risk factors of adopting and implementing BIM in IBS projects in Malaysia.

1.4 Research Questions

Reviewing the literature highlights various issues regarding the risks of Industrialised Building System construction projects and BIM-based construction projects. It is vital to organise the issues into questions to formulate and design the study aim and objectives accordingly. The research questions that are needed to be addressed are:

- What are the risk factors associated with BIM implementation in IBS construction projects?
- How do the identified risk factors correlate amongst each other?
- How can assess the risk factors of implementing BIM in IBS construction organisations through a model or tool?
- How to make sure that a proposed model/tool for risk assessment is practical?

1.5 Aim and Objectives

The study has presented the problem statements and research questions on lack of any model or tool for risk assessment of BIM-based construction projects. Therefore, this study aims to propose a tool to determine the significant risk factors for implementing BIM in each unique IBS construction projects. To achieve this aim, the following objectives have been defined:

(1) To identify the significant risk factors for implementing BIM in IBS projects.

(2) To investigate the available causal relationships among the identified risk factors.

(3) To develop a risk assessment tool for implementing BIM in construction projects that use IBS as the construction technique.

(4) To evaluate the developed risk assessment tool.

1.6 Scope of Study

This study intends to prioritise the risk factors of implementing Building Information Modelling (BIM) application in IBS construction projects through developing the risk assessment tool. Factors determined in this study are gathered from all references around the world; though, the experts for refining these factors are selected from BIM specialists, IBS construction companies, and academicians in Malaysia.

Currently, IBS is a common practice in Malaysia. Moreover, implementing BIM in construction projects can play a crucial role in enhancing the performance of projects. The proposed risk assessment tool supposed to work for all IBS companies that plan to adopt BIM in the future. Hence, this study focused on IBS projects that preparing for adopting BIM, and the case studies selected from IBS projects. In this study, three case studies have been chosen to cover different types of IBS.

It is worth mentioning that, due to the complexity of actions for risk management, this study focuses on the risk assessment that includes risk identification and analysis, as a primary part of risk management. Moreover, three different cases were selected to evaluate all aspects of the assessment for the developed risk assessment tool. Notably, the developed risk assessment tool is designed to assess only construction projects in the pre-planning stage.

1.7 Significance of Study

It is expected that the Industrialised Building System (IBS) stakeholders would have to select Building Information Modelling (BIM) applications rather than the conventional in their subsequent projects. Implementing BIM technology is new in Malaysia and adopting new technology involves numerous challenges. A comprehensive insight and understanding about the risks (such as lack of BIM knowledge, high cost of technology, and insufficient BIM training) affecting the performance of BIM adoption and implementation enable the managers to be prepared for applying appropriate risk response strategies. Employing effective risk response strategies definitely enhance the performance of implementing BIM in IBS projects.

The study has focused on assessing the risks connected with BIM implementation in construction companies, where BIM has not been adopted. This study shall explain how the questions mentioned above can be partly answered by looking at the risks during the BIM implementation process and use. Hence, this study is dedicated to developing a risk assessment tool for implementing BIM in IBS project, and this model will assist IBS construction companies and project managers to prioritise the potential risks and their associated impacts to each unique project.

The study highlights four important aspects that would be achieved in this study: 1) to give a new insight to BIM-based projects, 2) highlight the risk factors of implementing BIM in IBS projects, 3) consider the correlation between the risk factors, and 4) develop a risk assessment tool for BIM-based IBS projects to mitigate the probability of risk occurs during the life cycle of the project.

1.8 Thesis Outline

This thesis consists of seven chapters. The chapters were arranged according to the sequence of the objectives and rationale behind the study. Chapter 1 formulates the proposal for the study. Chapter 2 reviews all the related fields of studies have been conducted regarding risk assessment. All risk factors of BIM-based construction projects were presented throughout this section as well. At the end of this chapter, the methods that have been used for risk assessment in the construction industry were critically reviewed.

Chapter 3 presents all the methodologies that have been used for this study. It begins with the preliminary studies followed by application of Fuzzy Delphi study for factor identification. Then, decision-making trial and evaluation laboratory method (DEMATEL) was discussed for determining the available causal relationships. Cybernetic Fuzzy analytic network process (CFANP) also used for risk assessment model development. Then, the software used for the development of the prototype system was explained. In the end, a multi-criteria evaluation approach for the risk assessment tool evaluation was discussed.

Chapter 4 presents the results and analyses of the study. It starts with the identification of risk factors for BIM-based construction projects. Then, the causal relationship between risk factors was identified using DEMATEL. The results of this chapter were used as the material for developing the risk assessment tool.

Chapter 5 presents the process of risk assessment tool development. It starts with the architecture of the risk assessment tool, followed by the user requirements, and in the end, the functional tool was developed and discussed. Additionally, all the formulas that have been used for risk assessment tool development were discussed.

Chapter 6 evaluates the developed risk assessment tool through three case studies. The priorities of the risk factors were indicated based on the correlations among the risk factors and the users' responses. At the end of this chapter, the evaluation of the risk assessment tool was performed and discussed regarding the efficiency, effectiveness, satisfaction, and use of the risk assessment tool.

Finally, based on the objectives of the study, the conclusions derived from the study were presented in Chapter 7. The study contributions to the body of knowledge, including academic and practical implications, as well as the recommendations for future works, were highlighted throughout that chapter.

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