This is the Pre-Published Version.

Reza Khoshfetrat, Hadi Sarvari, Daniel W. M. Chan & Mansooreh Rakhshanifar (2022) Critical risk factors for implementing building information modelling (BIM): a Delphi-based survey, International Journal of Construction Management, 22:12, 2375-2384.

This is an Accepted Manuscript of an article published by Taylor & Francis in International journal of construction management on 6 Jul 2020 (Published online), available online: http://www.tandfonline.com/10.1080/15623599.2020.1788759.

Critical Risk Factors for Implementing Building Information Modelling (BIM): A Delphi-based Survey

Abstract

Building information modelling (BIM) is one of the new technologies that, despite its perceived benefits and positive impacts towards the project objectives, has a very low level of adoption. The main problem with this issue may be attributed to several potential risk factors that disrupt the implementation of this technology. Previous research studies have identified various significant risk factors for implementing BIM technology, however, the relationships between these risk factors have not been evaluated and analyzed. This paper aims to identify and evaluate the critical risk factors (CRFs) for BIM adoption via several rounds of Delphi surveys. A total of 52 potential risk factors were identified and classified by an extensive desktop literature review. The analysis of Delphi questionnaires, which were distributed and responded by a panel of BIM experts in three rounds, identified 36 major factors as CRFs of BIM. Then the relationships between these 36 CRFs were determined and assessed by using the decision-making trial and evaluation laboratory method (DEMATEL). The results showed that the CRFs such as: lack of knowledge of BIM and need for software training, resistance to change, and lack of skilled BIM architects/engineers have the most profound impact and interaction with other risk factors. The identification and prioritization of the CRFs can enable BIM users to conduct a systematic risk management and analysis and develop appropriate effective strategies for mitigating the potential risks associated with BIM implementation in a proactive manner.

Keywords: Building Information Modeling (BIM), Implementation, Risk Evaluation, Risk Identification, Critical Risk Factors (CRFs).

1. Introduction

The building industry has been one of the most extensive industries in the world for the past few decades, accounting for a large percentage of each country's annual revenue. Some developing countries, spend more than 70% of their total revenue on development and infrastructure projects (Chan et al. 2019). According to global studies, the efficiency of the building industry has declined dramatically over the last 50 years. One of the most important reasons for the decline is the lack of communication and collaboration between individuals through information exchanges (Kymmell 2007). In addition, the growth of technology and increased stakeholder expectations have amplified the complexity of projects and have led to decreased efficiency. Increased complexity frequently results in lack of understanding and cohesiveness among the parties, which elevates the role of designers in the project design phase. Designers should be able to integrate stakeholder expectations, technical specifications, time constraints, cost optimization, implementation procedures, and more into their design, but they need powerful tools to do so.

Many researchers have considered making fundamental changes to the traditional processes by initiating and expanding the application of information technology in the building sector (Eastman et al. 2011). Building Information Modeling (BIM) technology, as a substantial part of the technological transformation in the construction sector (Preidel et al. 2015), could help resolve issues in the building industry by directing the way that project stakeholders share data, information, and models (Won et al. 2013). Although, BIM notion has been existing since the 1970s awareness about the improvements in the efficiency of all phases of buildings project life-cycle is recent (Ganah and John 2014). It leads to a growing interest toward using BIM during last decades (Volk et al. 2014). According to the definition provided by the US General Services, BIM is in fact the development and application of multidimensional computer software modeling, not only to document the design of structures, but also to simulate the process of construction and capital or facilities operating in the building project. It is also described as “the process of generating, storing, managing, exchanging, and sharing building information in an interoperable and reusable way” (Eadie et al. 2013).

BIM technology includes collecting comprehensive information about buildings from an integrated information repository (Mostafa et al. 2020). One of the main features of this stored information is that is parametric; therefore, many of its different aspects are interconnected, and a change to one object is reflected immediately in the entire project views and plans (Le et al. 2019). A BIM model contains all of the actual building components and connections, well beyond what is found in CAD-based maps (Christensen 2009). Such a dimension provides an opportunity for participants of a construction project to effectively visualize, analyze and communicate various aspects of construction progress over the entire life span of buildings (Najjar et al. 2019). Therefore, BIM acts as a common source of information for the design and construction teams, and results in integration of information, increased coordination, and reduction of errors and waste, ultimately increasing the quality of work (Kymmell 2007). The multidisciplinary nature of building projects requires clear communication and effective collaboration between project team members. BIM plays an important role in facilitating these actions. BIM improves communication and information management due to more efficient exchange and updates of project data (Sarvari et al. 2020). Benefits of BIM for consultants, designers, and engineers include:

- High speed and quality in the design, calculation, and preparation of maps;
- Speed and accuracy in structural calculations, energy, light, and environmental issues;
- Aggregate materials and accurate project cost estimation;
- Ability to update and apply changes at any time;
- Reduction or elimination of duplications in designs;
- Enhanced collaboration and interaction among project stakeholders (Eastman et al. 2011).

Stanford University conducted a study of 32 major projects that employed BIM, and identified the following as benefits of employing the technology:

- Increased accuracy of 3% in final cost estimation of project;
- Up to 40% reduction of cost of project changes;
- Up to 80% time reduction in construction projects;
- Up to 7% decrease in time required for project execution; and
- Up to 10% savings in contract value (Azhar et al. 2008).

BIM can effectively manage the responsibilities and authorities of construction parties and changes during the execution of the work (Preidel et al. 2015). It produces a parametric, intelligent, data-rich, object-oriented digital representation that allows users to extract and analyze various views, based upon their needs (Winberg and Dahlqvist 2010). It has the potential to reduce construction time, costs, risks, and project end claims, while increasing productivity (Ghaffarianhoseini et al. 2017 ; Ahuja et al. 2020). Like all new technologies and systems, however, it faces uncertainties and risks that need to be identified and assessed, as unmanaged risk is one of the reasons for the failure of projects (Raz and Michael 2001).(Ahuja et al. 2020)

The aim of this study is to identify and evaluate the critical risk factors for implementing BIM and to help industry users identify the potential risk factors and prepare contingency plans for responding to them before starting the project. To achieve this goal, the research literature has been reviewed comprehensively first to identify the potential risk factors of BIM. Then, Delphi questionnaires were distributed in three rounds to determine the critical risk factors (CRFs) of BIM. Moreover, the relationships between the CRFs were determined by using the decision-making trial and evaluation laboratory method (DEMATEL). Finally, the CRFs were classified according to their impacts and interactions with other CRFs. The results show that, lack of knowledge of BIM and need for software training, resistance to change, lack of skilled BIM architects/engineers, project phasing and design separation, and monitoring and execution phases are the most important CRFs during execution. The study's findings and recommendations can be served as a policy instrument and consultative toolkit for relevant project stakeholders for proper risk management in using BIM.

2. BIM Challenges

Resilient and technically supported management, data, and communication is vitally important to realizing the benefits of BIM (Preidel et al. 2015); however, the best performance of BIM is restricted by technical and organizational barriers including training, investments, intellectual property, liability, trust, etc (Mostafa et al. 2020). The conservative attitude of the building project participants, and thus their fear of risks, caused by technical and financial concerns, discourages them from using BIM (Won et al. 2013). An awareness of the financial benefits of implementing BIM could stimulate interest in using it, but there is currently a lack of studies on the positive economic impacts of BIM on the lifecycle of projects (Eadie et al. 2013). In this context, Ganah and John (2014) identified the following challenges and barriers to BIM implementation in the UK building sector: *(i)* Resistance to change, *(ii)* Lack of commitment to training, *(iii)* Technical facilitation, *(iv)* Lack of emphasis on the importance of integration, interoperability and collaboration between/among stakeholders, *(v)* Lack of delineation of responsibilities incurred by the new process, and *(vi)* Problems with data exchange due to the lack of a common language.

For BIM to perform at its optimum capacity, contractors need to be integrated into the design phase (Porwal and Hewage 2013). The challenges provided by the UK building industry and listed above highlight the importance of better and further integration of all executive participants in a building project. Knowledge of market potentials and competition, and awareness of the risks that a BIM project faces throughout its lifecycle is vital to ensuring successful implementation of BIM.

3. Research Development and Results

An intense literature review was conducted on successful practices to identify the risks affecting BIM project implementation. This research stored and summarized the data from global databases, and processed and filtered the sorted data, using a Delphi questionnaire that was distributed to a group of experts dealing with BIM projects. The list of critical risk factors (CRFs) affecting BIM implementation were established by analyzing the Delphi questionnaires. DEMATEL, the decision-making trial and evaluation laboratory method, is an impressive hazard evaluation approach that was used, in this research to determine the relationships between/among CRFs in projects implementing BIM. The identification, definition, and management of the CRFs aids in successful implementation of BIM in construction projects.

3.1. Risk Identification

Literature from 2012 to 2020, including global databases Web of Science, Science Direct, Scopus, Engineering Journals and Google Scholar, was reviewed, and Table 1 shows the 52 risk factors that were identified. Table 2 displays the risk factors that were identified by various researchers.

Table 1: Risk Factors for BIM Implementation Identified by Literature Review

Risk factors for BIM implementation	
-F1-	High initial investment cost
-F2-	Lack of knowledge and need for software training (new business process and how to use BIM)
-F3-	No motivation from the owners
-F4-	Resistance to change
-F5-	Managers' insufficient knowledge of BIM
-F6-	Stakeholders' lack of recognition and unrealistic and ambitious expectations of BIM
-F7-	Lack of consistent attitude among managers
-F8-	Unwilling to share project information
-F9-	Project phasing approach and separation between designing, monitoring, and execution
-F10-	Lack of common language and compatibility of different sections
-F11-	Intellectual property and legal information rights of BIM
-F12-	Problems with how to implement BIM
-F13-	The gap between design and manufacturing processes

Risk factors for BIM implementation	
-F14-	Work interaction and challenges related to coordination and teamwork
-F15-	Lack of clarity of scope and responsibility for the accuracy of input information by different individuals and groups
-F16-	BIM application restrictions
-F17-	Replacement of experienced employees with new, unexperienced employees
-F18-	Requires new project delivery system
-F19-	Lack of hardware infrastructure
-F20-	Software errors
-F21-	Non-return of capital if inefficient use of BIM
-F22-	The need for new information data in different phases of the project
-F23-	No application for BIM
-F24-	More experienced competitors
-F25-	Lack of support for the construction industry's policymakers
-F26-	Lack of awareness of BIM potential
-F27-	Cyber security
-F28-	Lack of skilled architects/engineers proficient at using BIM
-F29-	The inability of small and medium-sized companies to implement BIM
-F30-	No requirement for contracts to use BIM
-F31-	Non-use of BIM in the design process by consulting companies
-F32-	Not using BIM in contracting companies
-F33-	Inefficiency in data and information exchange
-F34-	Problem updating and managing models
-F35-	Insufficient commitment from senior management
-F36-	Workflow transfer problem
-F37-	Increased initial workload in the short term
-F38-	Increased additional costs for software updates, legal and contractual disputes
-F39-	Lack of clear policies and standards for BIM implementation
-F40	Lack of standard contracts and specific insurance
-F41-	Information scatter and lack of collaboration management tools
-F42-	Complex applications space
-F43-	Need to recruit new troops
-F44-	Increased project risk in the implementation phase, and decreased accurate decision making
-F45-	Reduced reporting speed and weakness in project status review
-F46-	Lack of a unique program for BIM use
-F47-	Lack of opportunity for companies to implement BIM
-F48-	Requires in-depth knowledge of construction methods
-F49-	Lack of common interests and competition among vendors
-F50-	Uncertain cost structure for added domains
-F51-	Changes in the responsibility of project partners
-F52-	Problems measuring the effects of BIM

Table 2: Similar Risks in BIM-related studies

Risk factors	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Total number
F_1	*			*		*			*	*	*				*	*	*	*		*		*	*	*		*	(15)
F_2	*	*		*	*	*		*	*					*	*	*	*	*	*	*		*	*	*		*	(18)
F_3	*																						*	*			(3)
F_4	*			*		*		*		*					*		*					*	*			*	(10)
F_5	*				*				*						*			*									(5)
F_6		*		*																							(2)
F_7		*																									(1)
F_8		*								*				*						*				*			(5)
F_9		*																*									(2)
F_{10}		*		*			*			*						*	*		*		*	*					(9)
F_{11}			*	*	*											*									*	*	(6)
F_{12}					*					*		*			*	*											(5)
F_{13}					*																*						(2)
F_{14}			*	*	*		*						*				*			*		*			*		(9)
F_{15}			*	*			*						*			*	*								*	*	(8)
F_{16}				*									*														(2)
F_{17}				*													*										(2)
F_{18}				*																			*				(2)
F_{19}				*																*						*	(3)
F_{20}				*															*								(2)
F_{21}	*			*							*						*										(4)
F_{22}				*										*						*							(3)
F_{23}				*				*												*		*					(4)
F_{24}				*																							(1)
F_{25}						*		*							*							*	*	*		*	(7)
F_{26}						*		*	*														*	*		*	(6)
F_{27}							*									*				*				*	*	*	(6)
F_{28}								*	*											*	*		*	*		*	(7)
F_{29}								*								*											(2)

Risk factors	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Total number
F_{30}									*									*									(2)
F_{31}									*														*				(2)
F_{32}									*											*							(2)
F_{33}										*														*			(2)
F_{34}										*																	(1)
F_{35}										*											*						(2)
F_{36}										*											*						(2)
F_{37}										*											*						(2)
F_{38}										*					*						*						(3)
F_{39}										*				*						*	*	*		*		*	(7)
F_{40}										*						*	*				*			*	*	*	(7)
F_{41}							*				*									*							(3)
F_{42}											*																(1)
F_{43}											*																(1)
F_{44}											*																(1)
F_{45}											*																(1)
F_{46}												*															(1)
F_{47}															*												(1)
F_{48}																*											(1)
F_{49}																	*										(1)
F_{50}																	*										(1)
F_{51}																				*							(1)
F_{52}																				*							(1)

A=(Hematianpour 2014); B=(Forqani 2014); C=(Bodaqi MT, Katayoun; Rostami, Azam 2015); D=(Fani 2015); E=(Bodaqi MKh, Azam; Haji yakhchali, Siyamak 2015); F=(Shakeri 2016); G=(Zand 2017); H=(Mesbah rad 2017); I=(Mousavian 2017); J=(Rezaei 2017); K=(Hajian nasab 2018); L=(Tse et al. 2005); M=(Holzer 2007); N=(Howard and Björk 2008); O=(Arayici et al. 2009); P=(Lu and Korman 2010); Q=(Becerik-Gerber et al. 2011); R=(Newton and Chileshe 2012); S=(Bryde et al. 2013); T=(Won et al. 2013); U=(Chien et al. 2014); V=(Hosseini et al. 2015); W=(Kiani et al. 2015); X=(Aladag et al. 2016); Y=(Ghaffarianhoseini et al. 2017); Z=(Ya’acob et al. 2018).

3.2. Delphi Survey Method

3.2.1. Team Formulation

Prior to initiating the 3-round Delphi method used in this research, a team had to be put together. The formation of a team is the most important stage of a Delphi study because the results are directly associated with expert opinions (Skulmoski et al. 2007). There were no definitive rules for selecting and recruiting experts for the team, but the expertise of each team member was given more priority than the number of participants recruited (Minghat et al. 2012). The number of experts needed is dependent upon multiple factors, including sample homogeneity or heterogeneity. The Delphi goal or difficulty range of quality of decision, ability of the research team to study, internal and external validity, time of data collection and available resources, the scope of the problem, and the acceptance of the response is usually less than 50, and often 15 to 20. Although the literature reported teams of 10 to 20, 10 individuals were sufficient in homogeneous groups. This research employed a team of 12, due to the difficulty of accessing access to experts in the field of BIM. Table 3 reflects details of the experts for this research.

Table 3: Respondents' Demographic Data

Basic information	Number of respondents	Percentage
Specialty field		
▪ Construction	4	33.3%
▪ Architecture	9	75%
▪ Electrical	1	8.3%
▪ Mechanical	1	8.3%
Level of education		
▪ Bachelor	2	16.7%
▪ Master	8	66.7%
▪ Ph.D.	2	16.7%
Responsibility		
▪ Client	0	0%
▪ Consultant	9	75%
▪ Contractor	2	16.7%
▪ Academic	1	8.3%
▪ Others	2	16.7%
Activity Field		
▪ Governmental	1	8.3%
▪ Private	6	50%
▪ Both	5	41.7%
Construction industry Experience (in years)		
▪ ≤ 5	1	5%
▪ 6-10	5	41.7%
▪ 11-15	4	33.3%
▪ > 15	2	10%
BIM experience (in years)		
▪ BIM research background	1	8.3%
▪ ≤ 5	3	25%
▪ 6-10	5	41.7%

Basic information		Number of respondents	Percentage
▪	11-15	3	25%

3.2.2. Round 1 (Brainstorming)

The Delphi questionnaire for this research consisted of two parts. Part 1 focused on grouping the risk factors incurred by adopting BIM, and Part 2 ranked them, to determine the extent that each impacted the implementation of BIM. Immediately following the literature review, a pilot study was conducted to verify and enhance the list of risk factors that directed the questionnaire. For this purpose, two experts were asked to define the risk factors determined by the literature review, and revise them, when necessary. This step culminated in the list of risk factors that was incorporated into the first round of the Delphi questionnaire.

In the first round, the experts were asked to group the risk factors into different categories including financial, technical, legal, personnel, and management. In Part 2 of the questionnaire, the experts were given a ranking sheet on which they were asked to rank the importance of each risk factor on a scale of 1 to 5, and to justify the ranking, either by an explanation or by citing academic references. A consensus among the experts was expected at the conclusion of this round.

This research used a common phrase for each risk factor as the consensus for Part 1, and the median value of the responses as the consensus for Part 2. The median value represented the groups' opinions. To measure the round's consensus, the average of all absolute deviations must be lesser than 1 unit (Sarvari et al. 2019). Equation 1 was used in this research to calculate the absolute deviation:

Absolute Deviation (AD) = (Median xj –Xj) (1)

If the consensus was in the acceptable range in the first round, the research could be continued to the second round.

3.2.3. Round 2 (Feedbacks)

The second round provided the experts an opportunity to modify or confirm their earlier judgments if there was more than two unit's difference in their original answer and the median value determined by the results of the first round. They were asked to justify their responses, whether or not they modified them. The analysis used for the first round was applied to the second round to calculate the median and average of every absolute deviation. If the consensus fell into the acceptable range in the second round, the research could be continued to the final round.

3.2.4. Round 3 (Final)

The median of the responses and the feedback obtained in the second round were given to the experts in the final round. They were asked to carefully read the feedback before answering the questions, which helped to reduce judgment bias by providing insight into how other think. The medians of the responses and the averages of all of the absolute deviations were calculated, as in the previous rounds. The average of all of the absolute deviations in the third round was then calculated, to determine whether a consensus had been reached in this round. Figure1 illustrates the overview of the Delphi survey method used in this research.

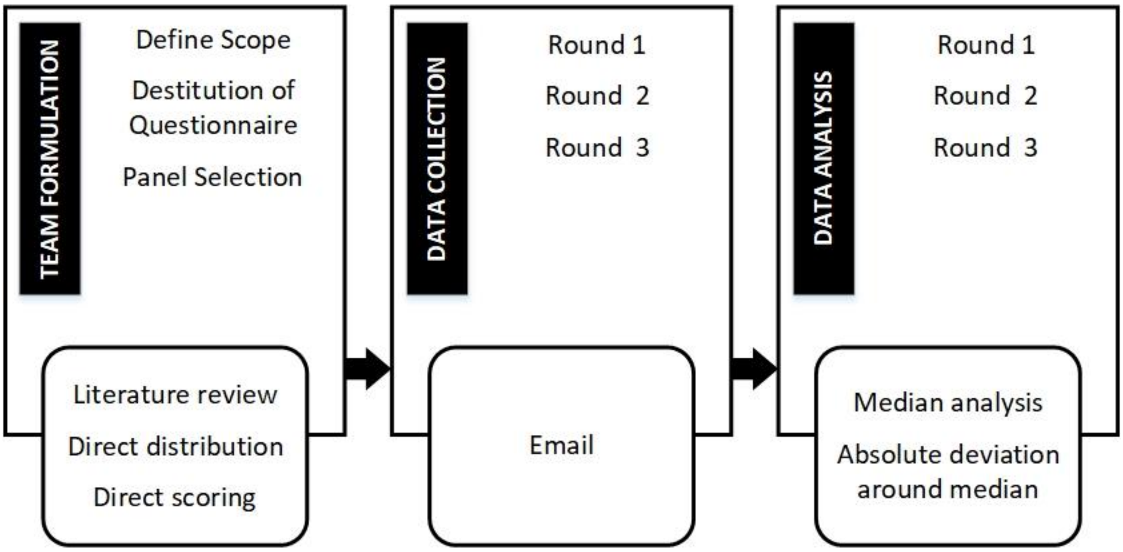

Figure 1: Overview of the Delphi survey method

3.2.5. Delphi Survey Results

The risks identified with all five aspects of BIM adoption were ranked by the experts in the 3-round Delphi process to confirm the critical risks and remove those deemed irrelevant. At the end of round 1, experts were asked to suggest another risk factor. In the first round of the Delphi questionnaire, 13 risk factors were omitted, and those that were not in the appropriate group were transferred to another group. A new risk was added to the technical risks: No responsibility for the delivery, operation and maintenance of the project by the main contractor. Table 4 depicts the results of the first round for Part 2. The highlighted factors are those that were removed by the experts in the first round.

Four other risk factors were eliminated, based upon the results of the second round. These included F16 (BIM application restrictions), F22 (the need for new information data in different phases of the project), F45 (reduce reporting speed and weakness in project status review), and F51 (change the responsibility of project partners). After these eliminations, 36 risk factors remained. The third round of the questionnaire confirmed the number of remaining risk factors, and classified them according to their rankings. These critical risk factors (CRFs) of BIM implementation are shown in Table 5.

Table 4: Critical Risk Factors for BIM Implementation Derived from Analysis of the First Round of Delphi Survey

Risk Factor		Median
F1.	High initial investment cost	5
F2.	Lack of knowledge and need for software training, new business process & how to use BIM	5
F3.	No motivation from the owners	4
F4.	Resistance to change	5
F5.	Managers' insufficient knowledge of BIM	5
F6.	Stakeholders' lack of recognition and unrealistic and ambitious expectations of BIM	3
F7.	Lack of consistent attitude among managers	3
F8.	Unwillingness to share project information	4
F9.	Project phasing approach and separation between designing, monitoring, and execution	3
F10.	Lack of common language definition and incompatibility between different sections	5
F11.	Intellectual property and legal information rights of BIM	5
F12.	Problems with how to implement BIM	4
F13.	The gap between design and manufacturing processes	1
F14.	Work interaction and challenges related to coordination and teamwork	4
F15.	Lack of clarity of scope and responsibility for the accuracy of input information by different individuals and groups	5
F16.	BIM application restrictions	3
F17.	Replacement of experienced employees with new, inexperienced ones	4
F18.	Requirement of new project delivery system	4
F19.	Lack of hardware infrastructure	5
F20.	Software errors	1
F21.	Non-return of capital if inefficient use of BIM	4
F22.	The need for new information data in different phases of the project	3
F23.	No application for BIM	2
F24.	Competition from those with more experience	1
F25.	Lack of support for the construction industry's policy makers	4
F26.	Lack of awareness of BIM potentials	4
F27.	Cyber security	1
F28.	Lack of skilled architects/engineers proficient in using BIM	5
F29.	The inability of small and medium-sized companies to implement BIM	5
F30.	No requirement for contracts to use BIM	5

Risk Factor		Median
F31.	Non-use of BIM in the design process by consulting companies	5
F32.	Dearth of contracting companies who use BIM	4
F33.	Inefficiency in data and information exchange	4
F34.	Problem updating and managing models	2
F35.	Insufficient commitment from senior management	5
F36.	Workflow transfer problems	2
F37.	Increased initial workload in the short term	4
F38.	Increased additional costs for software updates, legal and contractual disputes	4
F39.	Lack of clear policies and standards for BIM implementation	4
F40.	Lack of standard contracts and specific insurance	5
F41.	Information scatter and lack of collaboration management tools	2
F42.	Complex applications space	2
F43.	Need for recruitment of new troops	4
F44.	Increased project risk in the implementation phase, and decreased decision making accuracy	2
F45.	Reduced reporting speed and weakness in project status review	4
F46.	Lack of a unique program for BIM use	4
F47.	Lack of opportunity for companies to implement BIM	1
F48.	Requires in-depth knowledge of construction methods	1
F49.	Lack of common interests and competition among vendors	4
F50.	Uncertain cost structure for added domains	5
F51.	Changes in the responsibilities of project partners	3
F52.	Problems measuring the effects of BIM	2

Table 5: Critical Risk Factors for BIM Implementation

Dimension	Code	Risk factors
Technical Risks	CRF_1	Lack of knowledge and need for software training, new process and how to use BIM
	CRF_2	Project phasing approach and design separation, monitoring, and execution
	CRF_3	Lack of common language definition and incompatibility between different sections
	CRF_4	Problems with how to implement BIM
	CRF_5	Lack of hardware infrastructure
	CRF_6	Non-use of BIM in the design process by consulting companies
	CRF_7	Non- use of BIM by contracting companies
	CRF_8	Inefficiency in data and information exchange
	CRF_9	Increased initial workload in the short term
	CRF_{10}	Lack of a unique program for BIM use
	CRF_{11}	Lack of the main contractor’s responsibility in the project delivery phases, operation, and maintenance

Dimension	Code	Risk factors
Management Risks	CRF_{12}	Managers' insufficient knowledge of BIM
	CRF_{13}	Lack of awareness of BIM potentials
	CRF_{14}	Lack of consistent attitude among managers
	CRF_{15}	Stakeholder' lack of understanding and unrealistic expectations of BIM
	CRF_{16}	No motivation from the owners
	CRF_{17}	Insufficient commitment from senior management
Personnel Risks	CRF_{18}	Resistance to change
	CRF_{19}	Unwillingness to share project information
	CRF_{20}	Work interaction and challenges related to coordination and teamwork
	CRF_{21}	Replacement of experienced employees with new, inexperienced ones.
	CRF_{22}	Lack of skilled architects/engineers who use BIM
	CRF_{23}	Need to recruit new troops
	CRF_{24}	Lack of common interests and competition among vendors
Financial Risks	CRF_{25}	High initial investment cost
	CRF_{26}	Increased additional costs for software updates
	CRF_{27}	Increased additional costs for legal and contractual disputes
	CRF_{28}	Financial constraints for small and medium-sized enterprises to implementing BIM
	CRF_{29}	Non-return of capital if inefficient use of BIM
	CRF_{30}	Uncertain cost structure for added domains
Legal Risks	CRF_{31}	Intellectual property and legal information rights of BIM
	CRF_{32}	Lack of clarity on the scope and responsibility of the accuracy of input information by different individuals and groups
	CRF_{33}	Lack of clear policies and standards for BIM implementation
	CRF_{34}	No requirement for contracts to use BIM
	CRF_{35}	Lack of support and need for use by construction industry policymakers
	CRF_{36}	Lack of standard contracts and specific insurance

3.3. DEMATEL Method

This research used the analysis of the results of the Delphi questionnaires and DEMATEL to identify the effect of each of the critical risk factors on other critical risk factors.

In the first step, a matrix, with critical risk factors inputted into rows and columns, was formed, and experts were asked to determine the effect of each row's elements on the elements contained in each column. The comparison used five levels: 1= no influence, 2= extremely low influence, 3= low influence, 4= high influence, and 5= extremely high influence. These levels were represented by numbers between 0 and 4. Relationships between criteria were determined by the experts' pairwise comparisons. The numbers assigned by the experts were entered into the Microsoft Excel software program and then the calculations were done using the following steps in the software.

In the second step, a direct relation matrix was created by using equation 2 of the DEMATEL analysis to calculate the mean matrix A, where each element was the represented by the mean of the geometric points assigned by the experts. The scores by each expert will give us an *n* x *n* non-negative answer matrix $X^k = [x_{ij}^k]$, with $1 \leq k \leq H$. Thus, $X^1, X^2, \ldots, X^H$ are the answer matrices for each of the H experts, and each element of X^k is an integer denoted by x_{ij}^k. The diagonal elements of each answer matrix X^k are all set to zero. We can then compute the *n* x *n* average matrix A for all expert opinions by averaging the H experts' scores as follows: (Lin and Lin 2008):

$$a_{ij} = \frac{1}{H} \times \sum_{k=1}^{H} x_{ij}^{k} \quad (2)$$

To generate a direct relation matrix, Initial data can be gained, an n × n matrix A, in which A_{ij} is the degree to which criterion i affects criterion j.

$$A = \begin{bmatrix} 0 & a_{1,2} & \cdots & a_{1,n} \\ a_{2,1} & 0 & \cdots & a_{2,n} \\ \vdots & \vdots & 0 & \vdots \\ a_{n,1} & a_{n,2} & \cdots & 0 \end{bmatrix} \quad (3)$$

Step Three: Direct relation matrix normalization

According to the direct relation matrix A, matrix X gained, as normalized direct relation, by applying the following formula:

$$k = \frac{1}{\max\limits_{1 \leq i \leq n} \sum_{j=1}^{n} a_{i,j}}, i,j=1,2,\cdots,n. \quad (4)$$

$$X = k \cdot A \quad (5)$$

Step Four: Obtaining the total relation matrix

Matrix T (total relation matrix) will be obtained by the formula (6). Matrix T includes all influences consist of direct and indirect.

$$T = X + X^2 + \cdots + X^n \quad (6)$$

Based on Formula (4), we have

$$T = X \frac{I - X^{n-1}}{1 - X}$$

(7)

where I specifies the recognition matrix.

Normalized matrix X includes elements with numbers between 0 and 1. Therefore, when n tends to infinity, X^{n-1} tends to 0. So we have:

$$T = X\,(I - X^{n-1}) \qquad (8)$$

The fifth step ranked the effectiveness and interactivity of each factor. The sum results of the all elements of every row of the total relationship matrix (D) indicated the extent of effect, and the sum results of the all elements of every column of the total relationship matrix (R) indicated the extent to which they were affected. Therefore, the factor with the highest magnitude of (D-R) was shown to be the most effective factor, and the factor with the least magnitude of (D-R) was shown to be the factor with the least impact. Table 6 shows the ranking of risk factors, based on their level of impact (D-R).

Table 6: (D-R) Ranking for Critical Risk Factors for BIM Implementation

Critical Risk factors	D-R	Rank
F14. Lack of consistent attitude among managers	0.988212	1
F12. Managers' insufficient knowledge of BIM	0.704992	2
F26. Increased additional costs for software updates	0.407134	3
F19. Unwillingness to share project information	0.377128	4
F24. Lack of common interests and competition among vendors	0.363992	5
F10. Lack of a unique program for BIM use	0.36341	6
F17. Insufficient commitment from senior management	0.331843	7
F22. Lack of skilled architects/engineers who use BIM	0.306805	8
F15. Stakeholder' lack of understanding and unrealistic expectations of BIM	0.249856	9
F33. Lack of clear policies and standards for BIM implementation	0.242856	10
F31. Intellectual property and legal information rights in BIM	0.226868	11
F1. Lack of knowledge and need for software training for new process and how to use BIM	0.20724	12
F2. Project phasing approach and separation between designing, monitoring, and executing	0.205389	13
F13. Lack of awareness of BIM potentials	0.171325	14
F5. Lack of hardware infrastructure	0.143515	15
F21. Replacement of experienced employees with new, inexperienced ones	0.120799	16
F18. Resistance to change	0.099252	17
F32. Lack of clarity on the scope and responsibility of the accuracy of input information by different individuals and groups	0.084855	18
F11. Main contractor's lack of responsibility for the delivery, operation, and maintenance of the project	0.066883	19
F23. Need for recruiting new personnel	0.034613	20
F25. High initial investment cost	0.023506	21
F8. Inefficiency in data and information exchange	0.01289	22
F3. Lack of common language definition, and incompatibility between different sections	-0.0529	23
F35. Lack of support and need for use by construction industry policymakers	-0.05606	24
F30. Uncertain cost structure for added domains	-0.07349	25
F28. Financial constraints for small and medium-sized enterprises to implement BIM	-0.08149	26
F36. Lack of standard contracts and specific insurance	-0.10865	27

Critical Risk factors	D-R	Rank
F4. Problems with how to implement BIM	-0.28624	28
F20. Work interaction and challenges related to coordination and teamwork	-0.28913	29
F9. Increased initial workload in the short term	-0.36951	30
F27. Increased additional costs for legal and contractual disputes	-0.50662	31
F34. No requirement for contracts to use BIM	-0.60161	32
F29. Non-return of capital if inefficient use of BIM	-0.62348	33
F16. No motivation from the owners	-0.63413	34
F7. No use of BIM by contracting companies	-0.97683	35
F6. Non-use of BIM in the design process by consulting companies	-1.07323	36

The factor with the highest magnitude of (D + R) was the maximum interacting factor, and the factor with the least magnitude of (D + R) was the least interacting factor. Table 7 shows the ranking of risk factors, based on their degree of interactivity (D + R).

Table 7: (D+R) Ranking of Critical Risk Factors for BIM Implementation

Critical Risk factors	D+R	Rank
F1. Lack of knowledge and need for software training for new process and how to use BIM	4.21834	1
F10. Lack of a unique program for BIM use	4.020134	2
F7. No use of BIM by contracting companies	3.919191	3
F22. Lack of skilled architects/engineers who use BIM	3.72115	4
F6. Non-use of BIM in the design process by consulting companies	3.689508	5
F33. Lack of clear policies and standards for BIM implementation	3.68517	6
F35. Lack of support and need for use by construction industry policymakers	3.676151	7
F12. Managers’ insufficient knowledge of BIM	3.494468	8
F4. Problems with how to implement BIM	3.452566	9
F18. Resistance to change	3.403258	10
F36. Lack of standard contracts and specific insurance	3.367544	11
F20. Work interaction and challenges related to coordination and teamwork	3.311647	12
F13. Lack of awareness of BIM potentials	3.264029	13
F34. No requirement for contracts to use BIM	3.247071	14
F32. Lack of clarity on the scope and responsibility of the accuracy of input information by different individuals and groups	3.154535	15
F14. Lack of consistent attitude among managers	3.132831	16
F3. Lack of common language definition, and incompatibility between different sections	3.131179	17
F16. No motivation from the owners	3.068961	18
F2. Project phasing approach and separation between designing, monitoring, and executing	3.049469	19
F8. Inefficiency in data and information exchange	2.954109	20
F25. High initial investment cost	2.839703	21
F29. Non-return of capital if inefficient use of BIM	2.636744	22
F9. Increased initial workload in the short term	2.56865	23
F23. Need for recruitment of new personnel	2.543978	24
F17. Insufficient commitment from senior management	2.514444	25
F19. Unwillingness to share project information	2.387308	26
F5. Lack of hardware infrastructure	2.334747	27

Critical Risk factors	D+R	Rank
F11. Main contractor's lack of responsibility for the delivery, operation, and maintenance of the project	2.248685	28
F27. Increased additional costs for legal and contractual disputes	2.22545	29
F15. Stakeholders' lack of understanding and unrealistic expectations of BIM	2.223453	30
F31. Intellectual property and legal information rights of BIM	2.185184	31
F28. Financial constraints for small and medium-sized enterprises who want to implement BIM	2.078687	32
F30. Uncertain cost structure for added domains	1.981904	33
F21. Replacement of experienced employees with new, inexperienced ones	1.625934	34
F24. Lack of common interests and competition among vendors	1.585745	35
F26. Increased additional costs for software updates	1.404167	36

Figure 2 depicts a causal diagram that was created by using the values in Tables 6 and 7. The vertical line (average value) and horizontal line (value 0) divide the diagram into four quadrants. Every quadrant of this diagram shows certain characteristics. Factors in the first and fourth quadrants have high prominence, and factors in the second and third quadrants have low prominence. Factors in the first and second quadrants have high relation, and factors in the third and fourth quadrants have low relation.

3.4. Discussions and Practical Implications of Research Findings

To succeed in BIM implementation, it is important to carry out systematic risk management of how risks are mitigated and the challenges are overcome. It would be difficult, if not impossible, to provide a holistic effective plan for dealing with every possible risk in every step of the project. Therefore, important risk factors should be identified and prioritized to improve the quality and efficiency of risk management in construction projects. A preliminary roadmap for developing contingency plans only for the risk factors that have the highest priority has been drawn up for reference.

The rate of prominence and relation can be used to prioritize the critical risk factors. For example, the risk factors that have high prominence and high relation are more important than the risk factors that have low prominence and low relation, because they can affect the likelihood of occurrence of other risk factors. Therefore, according to the causal diagram shown in Figure 2, various critical risk factors for BIM adoption can be determined and prioritized as follows.

The first quadrant (core factor) includes factors that have high prominence and high relation. These factors are the most important factors and should be the first priority for risk management. The second quadrant (driving factor) includes factors that have low prominence and high relation. These factors affect few of the other factors, and should be the second priority for risk management. The third quadrant (independent factor) includes factors that have low prominence and low relation. These factors are independent and can be controlled separately. The fourth quadrant (impact factor) includes factors that have low relation and high prominence. These risk factors are result factors and do not get managed directly, so should be the fourth priority for risk management. Therefore, the risk management priorities are as follows.

- 1^{th} quadrant: Core factors;
- 2^{th} quadrant: Driving factors;
- 3^{th} quadrant: Independent factors;
- 4^{th} quadrant: Impact factors.

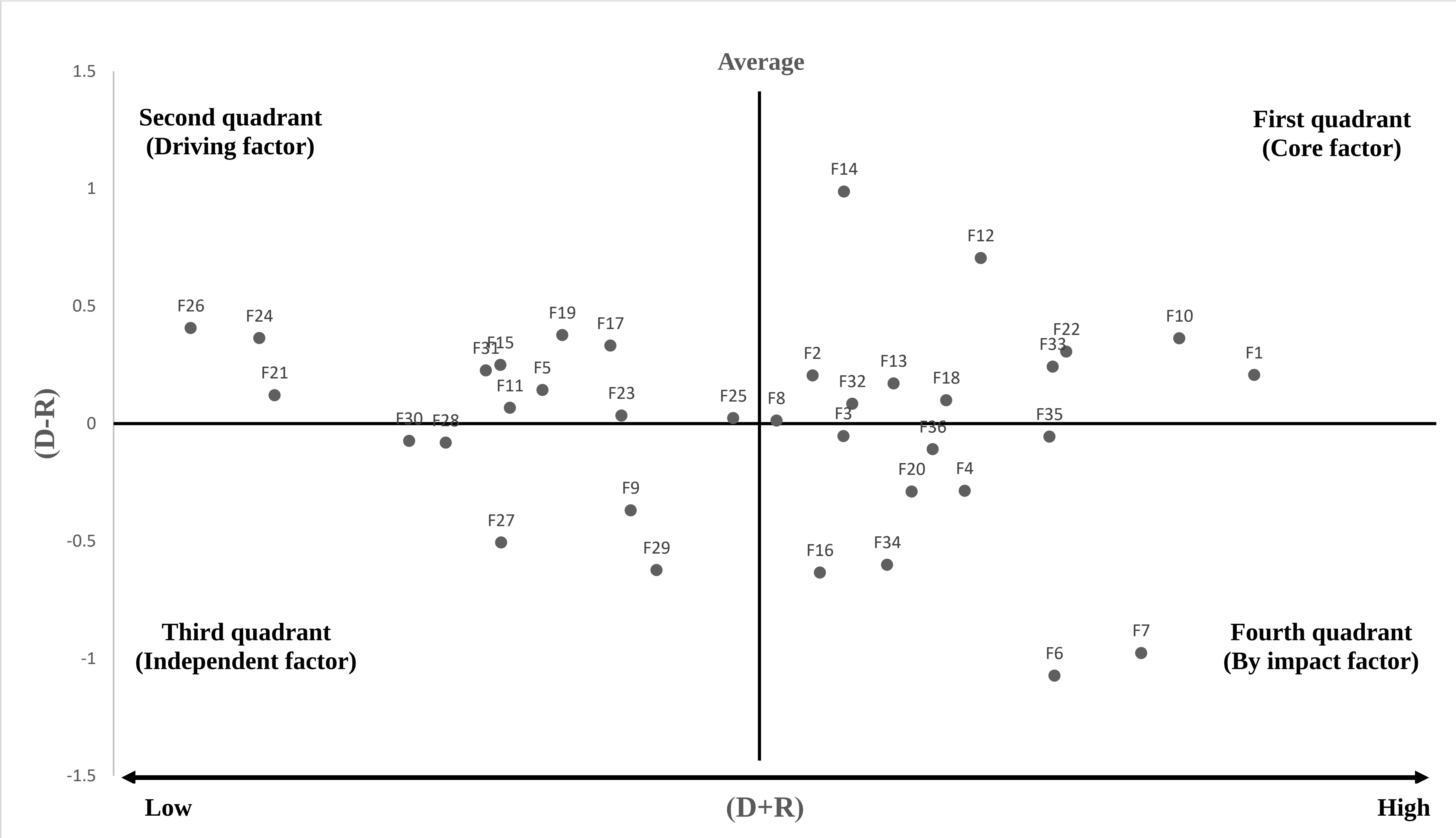

Figure 2. Casual diagram of BIM critical risk factors

4. Conclusions

Due to its many benefits, the implementation of Building Information Modeling (BIM) technology has expanded rapidly in developed countries over the past several years. In some developing countries, however, the application of this technology is still rare because of potential users' lack of knowledge of the technology. For instance, many countries are not aware that an understanding of the critical risk factors (CRFs) incurred by using BIM may enable managers to respond to possible hazards at the earliest time and to promote successful implementation. Risk management requires that the characteristics of CRFs are understood so that the risks can be prioritized and responded to appropriately. The results of this research provide technology experts and other developing countries with an understanding and relevance of the risks. According to the casual diagram (Figure 2), the following factors have the most impact and interaction with other CRFs: *(i)* lack of knowledge and need for software training, *(ii)* including the new process and how to use BIM, *(iii)* project phasing and design separation, *(iv)* monitoring and execution of the construction process; *(v)* inefficiency in data and information exchanges, *(vi)* lack of unique program for BIM use, *(vii)* managers' lack of knowledge of the technology, *(viii)* lack of knowledge of BIM potentials, *(xi)* lack of consistent attitude among managers, *(x)* resistance to change, *(xi)* lack of skilled BIM architectures/engineers, *(xii)* lack of clarity of scope and defined responsibility for accuracy, *(xiii)* information that is inputted information by different individuals and groups, and *(xiv)* lack of clear policies and standards. The results of this research will enhance the chances of the BIM implementation being successful, thereby contributing to the industrial and academic sectors.

According to the differences in perceptions between the identified BIM risk factors in different countries (especially in developing and developed countries), it would be difficult to determine how the findings of this study are generalized to all countries, which may be attributed to the disparities in the various pace of development and execution of BIM technology between these two types of countries. Another limitation of the study lies in the number of experts participating in the three rounds of Delphi surveys (currently 12 only). In addition, the Delphi experts were heavily biased towards the consultant group (9 out of 12), it would be more representative and balanced to solicit more experts from both client group and contractor group in future studies.

Therefore, future researchers can examine the effects of the above critical risk factors of BIM across different countries. In order to overcome the limitations of the study, another future research direction is to broaden the spectrum of factors that are critical for BIM implementation – so as to guarantee the generalizability of the research results for execution. It is also recommended that future research studies may be launched to compare the level of severity and probability of occurrence of CRFs between developing countries and developed countries where the evolution and application of BIM are more mature and popular. With the identified critical risk factors of BIM in mind, industry leaders and decision makers can come up with the corresponding effective risk mitigation strategies or measures for BIM implementation advocated in other western countries where BIM is more maturely developed and applied such as the United States and Europe.

References:

Ahuja R, Sawhney A, Jain M, Arif M, Rakshit S. 2020. Factors influencing BIM adoption in emerging markets–the case of India. *International Journal of Construction Management*. 20(1):65-76.

Aladag H, Demirdögen G, Isık Z. 2016. Building information modeling (BIM) use in Turkish construction industry. *Procedia Engineering*. 161:174-179.

Arayici, Y., Khosrowshahi, F., Ponting, A.M. and Mihindu, S.A., 2009, May. Towards implementation of building information modelling in the construction industry. In *Proceedings of the fifth international conference on construction in the 21st century: Collaboration and integration in engineering, management and technology* (pp. 1342-1351).

Azhar, S., Nadeem, A., Mok, J.Y. and Leung, B.H., 2008, August. Building Information Modeling (BIM): A new paradigm for visual interactive modeling and simulation for construction projects. In *Proc., First International Conference on Construction in Developing Countries* (Vol. 1, pp. 435-46).

Becerik-Gerber B, Jazizadeh F, Li N, Calis G. 2011. Application areas and data requirements for BIM-enabled facilities management. *Journal of Construction Engineering and Management.* 138(3):431-442.

Bodaqi MKh, A., Haji yakhchali, S. 2015. The benefits and problems of implementing Building Information Modeling in the construction industry. *Proceedings of the First International Conference and the Third National Conference on Project Management 2015.*

Bodaqi MT and Rostami, A. 2015. Identify opportunities and challenges of BIM application in the construction industry. *Proceedings of the International Conference on Management, Economics and Humanities 2015.*

Bryde D, Broquetas M, Volm JM. 2013. The project benefits of building information modelling (BIM). *International Journal of Project Management*. 31(7):971-980.

Chan DWM, Olawumi TO, Ho AML. 2019. Perceived benefits of and barriers to Building Information Modelling (BIM) implementation in construction: The case of Hong Kong. *Journal of Building Engineering*. 25:100764.

Chien K-F, Wu Z-H, Huang S-C. 2014. Identifying and assessing critical risk factors for BIM projects: Empirical study. *Automation in Construction*. 45:1-15.

Christensen, D.K., 2009. BIM (Building Information Modeling) and TCO (Total Cost of Ownership). *Facilities Manager*, *25*(3), pp.27-31.
Eadie R, Browne M, Odeyinka H, McKeown C, McNiff S. 2013. BIM implementation throughout the UK construction project lifecycle: An analysis. *Automation in Construction*. 36:145-151.
Eastman C, Teicholz P, Sacks R, Liston K. 2011. BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors. John Wiley & Sons.
Fani FT, Rouhollah; Sabze parvar, Majid. 2015. Assessing the risks of using BIM in construction projects. *Proceedings of the International Conference on Civil Engineering, Architecture and Urban Infrastructure 2015.*
Forqani MH. 2014. Barriers to the application of building information modeling in Iran. *Proceedings of 10th International Project Management Conference,* Ariana Institute.
Ganah A, John GA. 2014. Achieving Level 2 BIM by 2016 in the UK. *Journal of Computing in Civil and Building Engineering,* 143-150.
Ghaffarianhoseini A, Tookey J, Ghaffarianhoseini A, Naismith N, Azhar S, Efimova O, Raahemifar K. 2017. Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges. *Renewable and Sustainable Energy Reviews.* 75:1046-1053.
Hajian nasab MMj, Alireza; Seyed ebrahimi, Kazem. 2018. Evaluating the Most Important Challenges of Implementing Building Information Modeling System Using Analytical Hierarchical Multi-criteria Decision Making. *Proceedings of the 3rd Annual National Conference on New Solutions in Civil Engineering and Urban Planning 2018.*
Hematianpour RR, Mehdi; Hematianpour, Hamidreza. 2014. The Benefits, Costs, and Obstacles of Using BIM in Construction Management. *Proceeding of the First National Conference on Civil Engineering and Sustainable Development of Iran 2014.*
Holzer D. 2007. Are you talking to me? Why BIM alone is not the answer.
Hosseini, M.R., Azari, E., Tivendale, L. and Chileshe, N., 2015. Barriers to adoption of building information modeling (BIM) in Iran: Preliminary results. In *proceedings of the The 6th International Conference on Engineering, Project, and Production Management (EPPM2015)* (pp. 2-4).
Howard R, Björk B-C. 2008. Building information modelling – Experts' views on standardisation and industry deployment. *Advanced Engineering Informatics.* 22(2):271-280.
Kiani I, Sadeghifam AN, Ghomi SK, Marsono AKB. 2015. Barriers to implementation of Building Information Modeling in scheduling and planning phase in Iran. *Australian Journal of Basic and Applied Sciences.* 9(5):91-97.
Kymmell, W., 2007. *Building Information Modeling: Planning and Managing Construction Projects with 4D CAD and Simulations (McGraw-Hill Construction Series): Planning and Managing Construction Projects with 4D CAD and Simulations*. McGraw Hill Professional.
Le PL, Chaabane A, Dao T-M. 2019. BIM contributions to construction supply chain management trends: an exploratory study in Canada. *International Journal of Construction Management.*19(1):1-19.
Lin, K.M. and Lin, C.W., 2008, October. Cognition map of experiential marketing strategy for hot spring hotels in Taiwan using the DEMATEL method. In *2008 Fourth International Conference on Natural Computation* (Vol. 1, pp. 438-442). IEEE.
Lu, N. and Korman, T., 2010. Implementation of building information modeling (BIM) in modular construction: Benefits and challenges. In *Construction Research Congress 2010: Innovation for Reshaping Construction Practice* (pp. 1136-1145).
Mesbah rad, A. 2017. Identify and rank the advantages and disadvantages of using the BIM method in the construction industry. *Proceedings of the Second National Conference on Civil Engineering and Sustainable Development 2017.*
Minghat AD, Yasin RM, Udin A. 2012. The application of the Delphi technique in technical and vocational education in Malaysia. *International Proceedings of Economics Development and Research.* 30(1):259-264.

Mostafa S, Kim KP, Tam VW, Rahnamayiezekavat P. 2020. Exploring the status, benefits, barriers and opportunities of using BIM for advancing prefabrication practice. *International Journal of Construction Management*. 20(2):146-156.
Mousavian VS, Ebrahim. 2017. Reasons for not using BIM building information modeling in Iranian construction projects. *Proceedings of the 5th National Conference on Applied Research in Civil Engineering, Architecture and Urban Management.*
Najjar MK, Tam VW, Di Gregorio LT, Evangelista ACJ, Hammad AW, Haddad A. 2019. Integrating parametric analysis with building information modeling to improve energy performance of construction projects. *Energies*. 12(8):1515.
Newton K, Chileshe N. 2012. Awareness, usage and benefits of building information modelling (BIM) adoption–the case of the south Australian construction organisations. *Management*. 3:12.
Porwal A, Hewage KN. 2013. Building Information Modeling (BIM) partnering framework for public construction projects. *Automation in Construction*. 31:204-214.
Preidel C, Borrmann A, Oberender C, Tretheway M. 2015. *Seamless integration of common data environment access into BIM authoring applications: The BIM integration framework.*
Raz T, Michael E. 2001. Use and benefits of tools for project risk management. *International Journal of Project Management.* 19(1):9-17.
Rezaei SSf, Ehsan; Athari nikravan, Hamidreza. 2017. Needs Assessment Understanding Solutions to Improve Risk Management Implementation of Building Information Modeling (BIM) in the Construction Industry. *Proceedings of the International Conference on Contemporary Iranian Civil, Architecture and Urban Development.*
Sarvari H, Chan DWM, Rakhshanifar M, Banaitiene N, Banaitis A. 2020. Evaluating the Impact of Building Information Modeling (BIM) on Mass House Building Projects. *Buildings.* 10(2):35.
Sarvari H, Valipour A, Yahya N, Noor N, Beer M, Banaitiene N. 2019. Approaches to Risk Identification in Public–Private Partnership Projects: Malaysian Private Partners' Overview. *Administrative Sciences.* 9(1):17.
Shakeri EAb, Khashayar. 2016. Current Status of Building Information Modeling in Iran for Implementation and Acceptance in Construction Industry of Iran. *4th International Congress of Civil, Architecture and Urban Development.*
Skulmoski GJ, Hartman FT, Krahn J. 2007. The Delphi method for graduate research. *Journal of Information Technology Education Research.* 6(1):1-21.
Tse T-CK, Wong K-DA, Wong K-WF. 2005. The utilisation of building information models in nD modelling: a study of data interfacing and adoption barriers. *Journal of Information Technology in Construction (ITcon)*. 10(8):85-110.
Volk R, Stengel J, Schultmann F. 2014. Building Information Modeling (BIM) for existing buildings—Literature review and future needs. *Automation in Construction.* 38:109-127.
Winberg A, Dahlqvist E. 2010. *BIM-the next step in the construction of civil structures.*
Won J, Lee G, Dossick C, Messner J. 2013. Where to focus for successful adoption of building information modeling within organization. *Journal of Construction Engineering and Management*. 139(11), pp.04013014.
Ya'acob, I.A.M., Rahim, F.A.M. and Zainon, N., 2018. Risk in implementing building information modelling (BIM) in Malaysia construction industry: A review. In *E3S Web of Conferences* (Vol. 65, p. 03002). EDP Sciences.
Zand F. 2017. Introduction to the basic concepts of building information modeling system. *4th National Conference on Construction and Project Management.*