International Journal of Business, Human and Social Sciences
ISSN: 2517-9411
Vol:14, No:1, 2020

Risk Assessment of Building Information Modelling Adoption in Construction Projects

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***Abstract*—**Building information modelling (BIM) is a new technology to enhance the efficiency of project management in the construction industry. In addition to the potential benefits of this useful technology, there are various risks and obstacles to applying it in construction projects. In this study, a decision making approach is presented for risk assessment in BIM adoption in construction projects. Various risk factors of exerting BIM during different phases of the project lifecycle are identified with the help of Delphi method, experts' opinions and related literature. Afterward, Shannon's entropy and Fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Situation) are applied to derive priorities of the identified risk factors. Results indicated that lack of knowledge between professional engineers about workflows in BIM and conflict of opinions between different stakeholders are the risk factors with the highest priority.

***Keywords*—**Risk, BIM, Shannon's entropy, Fuzzy TOPSIS, construction projects.

I. Introduction

BIM is a new construction management technology, which provides engineers to establish object-based multidimensional models for construction projects during their lifecycle [1]. Different projects from around the world, such as Shanghai Tower, Water Cube and Bird's Nest in Beijing Olympics Park, Washington National Park, Walt Disney Concert Hall, have been constructed by applying BIM technology [2].

The construction industry is known as very slow to adopt new information technologies in the integration of design, construction, and management [3], [4]. In recent years, BIM has been adopted in the construction industry and transformed it in different countries [5]. Construction projects obtain amazing profits in various aspects of BIM application. Center of Integrated Facility Engineering in Stanford University with studying 32 projects declared that applying BIM leads to numerous opportunity in project achievements, containing an up to 7% decrease in project time, an up to 4% increase in cost estimation precision, more than 80% decrease in duration of cost estimation process, and saving more than 10% of contract price by clash detection [2], [6].

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Although BIM is a useful technology to facilitate project management, adopting BIM is also associated with risks [7]. Projects are generally impressed by multiple risks. Thus, it is necessary to define a risk management plan through BIM adoption.

Risk management is a procedure to identify the source of risk, analyzing their influences, and define an appropriate solution to respond to risk items [8]. Fig. 1 indicates different phases of the risk management process. Risk assessment is the principal part of risk management, which can support project managers to identify and evaluate risk events [9], [10]. Besides, risk prioritization can be considered as a multi-criteria decision-making problem, and there are different methods to derive risk priorities [11].

Fig. 1 Risk management process [12]

This study aims to identify risks in BIM adoption in construction projects. Also, priorities of identified risks are defined with fuzzy TOPSIS. The project management team can present the appropriate risk management process to mitigate the effects of various risks on successful project implementation.

II. Research Method

According to the related literature and experts' opinions, with the help of the Delphi technique, various risks of BIM adoption in construction projects are identified. Then, experts determined the intensity of different risks using four different dimensions of time, cost, quality and scope of the project. Table I indicates the degree of intensity for various risks considering different dimensions of the project. Fuzzy Likert scale in Table II is used to establish pairwise comparisons for experts' judgments. Fuzzy concept is applied to consider uncertainties in linguist variables. Herein, Triangular fuzzy numbers (TFNs) linguistic scale are applied for pairwise comparisons.

A TFN is indicated as a triplet (l,m,u) and a membership function is defined as Fig. 2.

TABLE I
DEGREE OF INTENSITY ON PROJECT DIMENSIONS

Project dimensions	Degree of Intensity				
	Very Low	Low	Medium	High	Very High
Cost	Insignificant cost increase	Cost increase up to 20%	Cost increase between 20% to 30%	Cost increase between 30% to 50%	Cost increase more than 50%
Time	Insignificant time increase	Time increase up to 10%	Time increase between 10% to 20%	Time increase between 20% to 30%	Time increase more than 30%
Quality	Insignificant quality decrease	Quality decrease in some parts	Quality decrease need client approvement	Unacceptable quality decrease for client	Useless projects outcomes
Scope	Insignificant scope variation	Low variation in scope	High variation in scope	Unacceptable scope variation for client	Useless project outcomes

TABLE II
TFNS FOR FUZZY LIKERT SCALE

Linguistic variable	Very low	Low	Medium	High	Very High
Fuzzy number	(1,1,3)	(1,3,5)	(3,5,7)	(5,7,9)	(7,9,9)

$\tilde{A}=(l,m,u)$ on X is a TFN if its membership function $\mu_{\tilde{A}}(x): X \rightarrow [0,1]$ conforms (1):

$$\mu_{\tilde{A}}(x)=\begin{cases}(x-l)/(m-l) & , l \le x \le m \\ (u-x)/(u-m) & , m \le x \le u \\ 0 & , otherwise\end{cases} \quad (1)$$

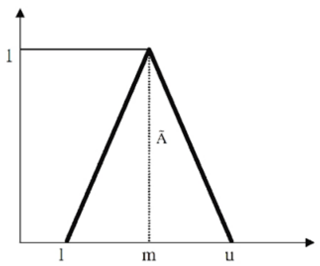

Fig. 2 A triangle fuzzy number $\tilde{A}$

Questionnaire survey is conducted anonymously in three rounds and feedback of experts' answers is shared with participants from second round onward. Experts' opinions are influenced by answers from other colleagues until consensus is obtained. Facilitator coordinates panel of experts to conduct Delphi survey [13]. Risk assessment framework in this study is illustrated in Fig. 3.

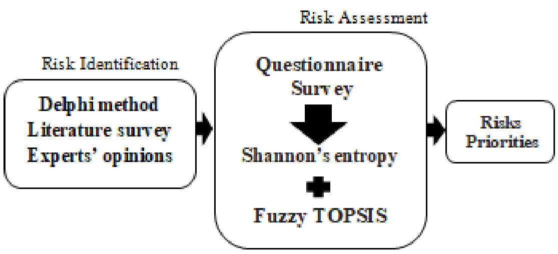

Fig. 3 Schematically risk assessment framework for BIM adoption

Risks are identified with Delphi method and classified into three different dimensions (see Table III). Then, fuzzy TOPSIS method is applied to define the risk priorities.

With respect to experts' opinions, the fuzzy average values of risk factors for degree of intensity in different project dimensions are calculated and indicated in Table IV. Shannon's entropy is used to determine the weights of technical, management and legal risk dimensions. In the sequel, the Shannon's Entropy and fuzzy TOPSIS methods are described.

A. Shannon's Entropy Method

The Shannon's entropy initially is applied in thermodynamics and then spread to information systems [14]. The Shannon's entropy is an evaluation of uncertainty in information using probability theory. Scholars used it to a wide range of applications such as economics, spectral analysis, and decision analysis [15]. Shannon's entropy method can be described as follows: Assume that there are *n* selection criteria as C_i $(j=1,2\ldots,n)$ and *m* alternatives A_i $(i=1,2,\ldots,m)$ to evaluate. Then, D is the decision matrix and can be established as:

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m1} & \cdots & x_{mn} \end{bmatrix} \end{array} \quad (2)$$

D matrix indicates criteria value of each alternative. Next, the normalize values for criteria weights can be calculated by (3):

$$P_{ij}=\frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (3)$$

By normalizing the decision matrix, the entropy values are calculated with (4):

$$e_j = -k\sum_{i=1}^{m} P_{ij} Ln(P_{ij}) \quad i = 1,2,...,m \tag{4}$$

TABLE III
RISK FACTORS FOR BIM ADOPTION IN CONSTRUCTION PROJECTS

Dimensions	Factor	Description
Technical	R-T1	Decrease the willingness to use BIM due to Insufficient experience in BIM project process
	R-T2	Unfamiliarity of project engineers with BIM workflow process
	R-T3	Impose additional unnecessary costs in BIM adoption process
	R-T4	Need a new appropriate project delivery system with BIM workflow process
	R-T5	Difficulties in model management (accuracy in data entry is necessary)
	R-T6	Incompetent data transmission during BIM-IFC file transfer
	R-T7	Conflict of opinions between different stakeholders
	R-T8	Time consuming process in learning related software
	R-T9	Inherent unsolved drawbacks of BIM
Management	R-M1	Need to new databases for different phases of project lifecycle
	R-M2	Elimination of professional staffs and engineers
	R-M3	Objection of different parties in project due to changes
	R-M4	Ambitious expectations of stakeholders from BIM
	R-M5	Increase in short-term costs
Legal	R-L1	Additional expenditures
	R-L2	Lack of BIM standard and no specified criteria for modelling
	R-L3	Uncertain legal liability and standard contract
	R-L4	Need to establish a new contractual condition considering BIM workflows
	R-L5	Conflict and inconsistence in legal ownership of models

Let $k = (\frac{1}{Ln(m)})$ and the degree of divergence d_j for each criteria can be obtained as (5):

$$d_j = 1 - e_j \quad , \quad C_j\,(j = 1,2,...,n) \tag{5}$$

The value of d_j indicates intrinsic contrast intensity for C_j. Therefore, the higher value for d_j means that C_j is the more important criteria for problem.

Finally, the objective weight can be calculated for each criterion using (6):

$$W_j = (\frac{d_j}{\sum_{j=1}^{n} d_j}) \tag{6}$$

To combine the subjective weights of decision makers for criteria (δ), formula in (7) is used to integrate judgments of decision makers for related criteria:

$$W_j = (\frac{\delta_j d_j}{\sum_{j=1}^{n} \delta_j d_j}) \tag{7}$$

B. Fuzzy TOPSIS Method

TOPSIS is one the multi criteria decision making (MCDM) techniques for ranking and selecting a number of appropriate alternatives by evaluating Euclidean distances. This technique is a popular and widely used to solve MCDM problems in various research fields [16]. In this method, the ideal alternative should have the shortest distance with the positive ideal solution (PIS) and the farthermost distance with the negative ideal solution (NIS) [17]. The lingual variables to declare judgments are always subjective and uncertain [18]. Fuzzy theory is introduced by Zadeh to consider vagueness and uncertainties in imprecise experts' judgments [19]. The superiority of fuzzy approach is to assign fuzzy numbers instead of crisp values and reflect reality more rigorously in calculations.

According to [20] fuzzy TOPSIS is conducted by the following steps:

Step1. Establish the fuzzy decision matrix and select a competent fuzzy Likert scale for pairwise comparisons.

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m1} & \cdots & \tilde{x}_{mn} \end{bmatrix} ; \quad i = 1,2,...,m;\ j = 1,2,...,n$$

where $\tilde{x}_{ij}$ is the rating for alternative A_i with respect to C_j criteria and generated with k^{th} expert, p is the number of experts:

$$\tilde{x}_{ij}^{(k)} = (l_{ij}^{(k)}, m_{ij}^{(k)}, u_{ij}^{(k)}) , \qquad \tilde{x}_{ij} = \frac{1}{p}(\tilde{x}_{ij}^{(1)} \oplus \tilde{x}_{ij}^{(2)} \oplus ... \oplus \tilde{x}_{ij}^{(p)}) \tag{8}$$

Step2. Fuzzy decision matrix normalization: the normalized fuzzy matrix $\tilde{R}$, for benefit and cost criteria are shown as:

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n} \ , \ i = 1,2,...,m \ ; \quad j = 1,2,...,n \tag{9}$$

$$\tilde{r}_{ij} = (\frac{l_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^+}) \ ; \ u_j^+ = \max_i \{u_{ij} : i = 1,2,...,m\} \tag{10}$$

$$\tilde{r}_{ij} = (\frac{l_j^-}{u_{ij}}, \frac{l_j^-}{m_{ij}}, \frac{l_j^-}{l_{ij}}) \ ; \ l_j^- = \min_i \{l_{ij} : i = 1,2,...,m\} \tag{11}$$

Step3. The weighted normalized fuzzy decision matrix $\tilde{V}$ is calculated with:

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n} \ , \ i = 1,2,...,m \ ; \quad j = 1,2,...,n \tag{12}$$

$$\tilde{v} = \tilde{r} \otimes \tilde{w}_j \tag{13}$$

where $\tilde{w}_j$ shows the significance weight of criterion C_j.

Step4. Define the fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS): TFNs are included in the interval [0,1] and then FPIS and FNIS can be calculated as:

$$A^+ = (\tilde{v}_1^+, \tilde{v}_2^+, ..., \tilde{v}_n^+) \tag{14}$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, ..., \tilde{v}_n^-) \tag{15}$$

where $\tilde{v}_j^+ = (1,1,1)$ and $\tilde{v}_j^- = (0,0,0)$, $j = 1,2,...,n$.

Step5. Compute the distance of each alternative from FPIS and FNIS. The area compensation method can derive the distances ($\tilde{d}_i^+$ and $\tilde{d}_i^-$) of each alternative from A^+ and A^- as follow:

$$d_i^+ = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^+) \ , \ i = 1,2,...,m \ ; \ j = 1,2,...,n \tag{16}$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-) \ , \ i = 1,2,...,m \ ; \ j = 1,2,...,n \tag{17}$$

Step6. Generate the closeness coefficient and define the priorities of alternatives using (18):

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-} \ , \quad i = 1,2,...,m \tag{18}$$

Alternatives with bigger value for closeness coefficient have superiority in prioritization.

III. Analysis and Results

Shannon's entropy is applied and criteria weights for project dimensions are derived. Cost, time, quality and scope of project assign following values respectively: 0.510, 0.290, 0.111 and 0.089.

According to the criteria weights for project dimensions, fuzzy TOPSIS method is used to generate risks priorities. In the sequel, due to huge amount of calculations process, results for fuzzy TOPSIS are expressed in Tables IV and V. The average value for decision matrix is calculated in Table IV and closeness coefficient is provided in Table V. Risk factors with higher closeness coefficient obtain higher priorities.

TABLE IV
AVERAGE DECISION MATRIX OF FUZZY NUMBERS FOR RISK FACTORS

Risk Factor	Scope	Quality	Time	Cost
R-T1	(0.05,0.23,0.56)	(0.08,0.28,0.61)	(0.04,0.14,0.44)	(0.07,0.28,0.66)
R-T2	(0.22,0.57,0.98)	(0.28,0.62,1.00)	(0.16,0.47,0.89)	(0.15,0.47,0.92)
R-T3	(0.05,0.21,0.57)	(0.05,0.21,0.53)	(0.07,0.24,0.64)	(0.10,0.39,0.87)
R-T4	(0.18,0.49,0.93)	(0.09,0.29,0.62)	(0.09,0.28,0.67)	(0.11,0.35,0.78)
R-T5	(0.11,0.30,0.69)	(0.09,0.30,0.64)	(0.06,0.30,0.72)	(0.07,0.31,0.75)
R-T6	(0.08,0.21,0.62)	(0.07,0.24,0.68)	(0.16,0.21,0.78)	(0.04,0.23,0.54)
R-T7	(0.13,0.34,0.74)	(0.14,0.38,0.78)	(0.06,0.20,0.57)	(0.06,0.30,0.72)
R-T8	(0.09,0.18,0.54)	(0.08,0.29,0.65)	(0.17,0.55,0.89)	(0.13,0.34,0.78)
R-T9	(0.04,0.22,0.47)	(0.06,0.31,0.54)	(0.08,0.25,0.74)	(0.11,0.49,0.77)
R-M1	(0.21,0.51,0.97)	(0.13,0.37,0.75)	(0.06,0.31,0.73)	(0.07,0.31,0.75)
R-M2	(0.11,0.33,0.71)	(0.12,0.38,0.76)	(0.07,0.30,0.69)	(0.09,0.31,0.74)
R-M3	(0.17,0.52,0.92)	(0.11,0.37,0.72)	(0.11,0.33,0.74)	(0.12,0.33,0.76)
R-M4	(0.15,0.44,0.87)	(0.11,0.35,0.71)	(0.07,0.30,0.70)	(0.07,0.31,0.75)
R-M5	(0.12,0.34,0.76)	(0.14,0.36,0.77)	(0.65,0.24,0.62)	(0.11,0.34,0.79)
R-L1	(0.11,0.30,0.68)	(0.08,0.28,0.64)	(0.06,0.31,0.72)	(0.06,0.31,0.75)
R-L2	(0.17,0.48,0.95)	(0.06,0.22,0.54)	(0.07,0.18,0.57)	(0.07,0.34,0.81)
R-L3	(0.16,0.46,0.91)	(0.07,0.27,0.61)	(0.07,0.26,0.64)	(0.09,0.28,0.68)
R-L4	(0.21,0.54,0.95)	(0.05,0.21,0.54)	(0.08,0.24,0.62)	(0.09,0.21,0.65)
R-L5	(0.12,0.35,0.77)	(0.16,0.42,0.83)	(0.07,0.18,0.55)	(0.08,0.26,0.67)

TABLE V
RISKS PRIORITIES OF BIM ADOPTION

Risk Factor	Distance from FPIS	Distance from FNIS	Closeness Coefficient	Risks Priorities
R-T1	3.771	0.305	0.074	18
R-T2	3.429	0.668	0.163	1
R-T3	3.721	0.351	0.086	12
R-T4	3.477	0.477	0.119	6
R-T5	3.763	0.311	0.076	17
R-T6	3.759	0.322	0.078	16
R-T7	3.518	0.588	0.143	2
R-T8	3.712	0.365	0.087	10
R-T9	3.717	0.355	0.091	11
R-M1	3.659	0.423	0.104	9
R-M2	3.621	0.472	0.116	7
R-M3	3.565	0.533	0.130	4
R-M4	3.722	0.362	0.088	13
R-M5	3.752	0.325	0.079	15
R-L1	3.744	0.328	0.081	14
R-L2	3.538	0.551	0.134	3
R-L3	3.639	0.448	0.111	8
R-L4	3.603	0.481	0.118	5
R-L5	3.735	0.336	0.082	13

International Journal of Business, Human and Social Sciences
ISSN: 2517-9411
Vol:14, No:1, 2020

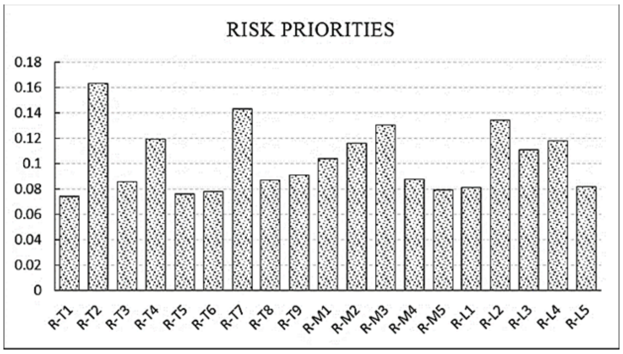

Fig. 4 Risk priorities of BIM adoption in construction projects

IV. Conclusion

BIM is a new technology in which digital information models are applied to facilitate construction management throughout the lifecycle of project. In this study, a decision making model is introduced for risk assessment of BIM adoption in construction projects. With respect to the experts' opinions 19 risk factors are identified. Then, Shannon's entropy is used to define the criteria weights for project dimensions. Finally, risk factors priorities are generated with fuzzy TOPSIS. Results indicate lack of knowledge and unfamiliarity of project engineers with BIM workflow process and conflict of opinions between different stakeholders are technical risk factors with high priority in BIM adoption. Also, objection of different parties in project due to changes and elimination of professional staffs and engineers are management risk factors with higher priorities. In legal risk factors, lack of BIM standard and no specified criteria for modelling and need to establish a new contractual condition considering BIM workflows are placed in higher attention. It is necessary to provide an appropriate strategy to mitigate effects of different risk factors in BIM adoption and application in construction projects and encourage project managers and other different involved parties in project to use its advantages in project management.

Acknowledgment

This work was supported in part by the Ministry of Science and Technology of China under Grant 2016YFC0503606, in part by the National Natural Science Foundation of China under Grant 71825007, in part by the Chinese Academy of Sciences Frontier Scientific Research Key Project under Grant QYZDB-SSW-SYS021, in part by the CAS Strategic Research and Decision Support System Development under Grant GHJ-ZLZX-2019-33-3, in part by the Marianne and Marcus Wallenberg Foundation under Grant MMW 2015.0007, and supported by the International Partnership Program of Chinese Academy of Sciences, Grant No.211211KYSB20180042.

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