The Application of Fuzzy TOPSIS to the selection of Building Information Modeling Software

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***Abstract*—The evaluation and selection of Building Information Modeling (BIM) software are significantly important before purchasing decision is done by construction companies. This is due to the purchasing BIM software is not only required high investment, yet also affects project outcomes. The decision process is more complex with the emerging of numerous BIM software available in the market with different features, function and cost. This trend leads toward difficulty among companies to select BIM software. The decision might affect the company's investment and also project needs. Thus, this article demonstrates the application of a BIM software selection decision model using fuzzy TOPSIS. This approach is applied to a real case project for BIM in Malaysia. The case study involves ten criteria and five alternatives. This result indicates a better solution to support decision-making process in BIM software selection. The method has the potential to be applied in another related area by using Multi-Criteria Decision Making (MCDM).**

***Index Terms*—Building Information Modeling (BIM); MCDM; Fuzzy TOPSIS; Software Selection.**

I. Introduction

Nowadays, the issues such as the quality, effectiveness of the design, sustainability of the building, reducing time and cost of the project have frequently been raised in the construction management literature. However, the current practice in the construction industry is still based on fragmented process and still depending on outdated ICT tools such as 2D AutoCAD which has been considered inadequate to cope with the current situation in construction industry [1]. For example, design process through 2D AutoCAD always led to the design error, omission and automatically effect construction process such as project delay, cost overrun and so forth [1],[2].

Thus, due to this aforementioned issue, a new ICT technology in construction has been introduced in Malaysia which called Building Information Modeling (BIM). Based on the concept of BIM, it shows that BIM system mainly has shifted the way of construction design process from 2D drawing to 3D virtual model development which is more accurate and precise. Yet, the advantages of BIM is not only limited to the design phase, but BIM also been used for scheduling, building analysis (such as clash detection), database and others purpose [3], [4].

Currently, the emerging of numerous of BIM packages is growing rapidly in the market with different function, features and cost. In addition, purchasing the wrong software is not only influence the project performance but also negatively affect the company investment [5]. Therefore, the need of decision aid in software selection has been discussed in the literature [6], [7] In contrast, literature revealed most of the company tend to purchase BIM software based on a recommendation from software vendors and other construction company [4]. Since the selection of BIM software required a long investment and could affect the project outcomes, the selection of proper BIM software is significantly important. However, the study to develop a decision model for BIM software selection is largely neglected. BIM software selection is significantly considered as a multiple criteria decision making (MCDM) problem which is involved numerous criteria and alternative. Considering the current situation, this paper aims at showing the development of fuzzy TOPSIS decision model for BIM software selection in the industry based on a real construction project in Malaysia. This paper is organised as followed. Fuzzy TOPSIS literature review is briefly presented, the development of fuzzy TOPSIS decision model based on case study is developed and finally result and conclusion are given.

II. Fuzzy TOPSIS

MCDM is a decision technique that has gained much attention among researchers around the globe to deal with multi-criteria decision problem. MCDM has proven effective as a decision support tools to help decision makers in order to determine the best alternative to their preferences [7]. There are several MCDM method that widely been discusses in literature such as Weight Product Method (WPM), Elimination Et Choice Translating Reality (ELECTRE I, II, III and IV), Analytical Hierarchy Process (AHP), Analytical Network Process (ANP) and The Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS).

Each of these techniques has their advantages based on problem nature. Thus, in this paper TOPSIS has been chosen as analytical decision analysis in the selection of BIM software due to its promising concept advantages toward problem nature. TOPSIS has been proposed to determine the alternative that is closest to the ideal solution [8][9]. The basic concept of TOPSIS is to choose the alternative that has the shortest distance from positive ideal solution (PIS) and the farthest from the negative ideal solution (NIS) [9]. MCDM method such as TOPSIS has been considered as an effective method in solving selection problem. However, in order to represent a real-world problem, the MCDM method has been widely criticised due to the involvement of crisp data. Under many chances, crisp data are inadequate to the real-life model situation [10]. Human judgment in the decision process is always vagueness and uncertainty. Through the TOPSIS process, it caused a difficulty for the decision makers to give exact numerical values for weighting and rating assessment. Thus, to deal with this problem and providing more convincing and effective evaluation process, fuzzy set through linguistics language has been introduced by Zadeh [11]. Thus, in development of decision model in this paper was based on the extension of TOPSIS method with a fuzzy number that proposed by Chen [9].

Basically "selection" problem in MCDM consist of p alternatives $A_1, A_2, A_3, \dots A_P$ and q criteria $CR_1, CR_2, CR_3, \dots CR_q$. Each of alternatives will take a consideration with respect to criterion q. The rating of criteria and weight with respect to each criterion can be accurately represented in the form of matrices such as

Fuzzy Decision Matrix, $D = \left(x_{ij}\right)_{p\times q}$ (1)

Fuzzy weight Matrix, $W = \left(w_1, w_2, \dots w_q\right)$ (2)

where $x_{ij}(i = 1, \dots, p; j = 1, \dots., q)$ and $w_{j=}(j = 1, \dots., q)$. Fuzzy TOPSIS is executed by using the following steps:

Step 1:

Construct a fuzzy weight matrix, W and fuzzy decision matrix, D where x_{ij} and w_j are linguistic variables that can be shown by triangular fuzzy number as the followings:

$$X_{ij} = \left(a_{ij}, b_{ij}, c_{ij}\right) \quad (3)$$

$$w_j = \left(w_{j1}, w_{j2}, w_{j3}\right) \quad (4)$$

Step 2:

Perform normalised fuzzy decision matrix. Linear scale transformation is used to transform into comparable scale. The normalisation approach preserves the property that ranges from [0,1] in normalised triangular fuzzy numbers. It is noted by

$$\widetilde{R} = \left[\tilde{r}_{p\times q}\right] \quad (5)$$

where B and C are the set of benefit attributes and cost attributes, respectively and

$$\tilde{r}_{ij} = \left[\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+},\right], j \in B; \quad (6)$$

$$\tilde{r}_{ij} = \left[\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a}\right], j \in C; \quad (7)$$

$$c_j^+ = \max_i c_{ij}, j \in B; \quad (8)$$

$$a_j^- = \min_i a_{ij}, \text{if } j \in C; \quad (9)$$

Step 3:

Construct weight normalised fuzzy decision matrix, $\tilde{V}$

$$\tilde{V} = \left[\widetilde{V_{ij}}\right]_{p\times q} \quad (10)$$

where $\tilde{v}_{ij} = \tilde{r}_{ij}(.)w_j$

Step 4:

This step attempts to determined distance measurement between the Fuzzy Positive Ideal Solution (FPIS), A^+ and Fuzzy Negative Ideal Solution (FNIS), A^-. Having $\tilde{V}$ as a normalized positive triangular fuzzy that ranges from 0 to 1, we can easily group the member as follows;

$$A^+ = \left(\tilde{v}_1^+, \tilde{v}_2^+, \dots \tilde{v}_q^+\right) \quad (11)$$

$$A^- = \left(\tilde{v}_1^-, \tilde{v}_2^-, \dots \tilde{v}_q^-\right) \quad (12)$$

where $\tilde{v}_j^+$= (1.0, 1.0, 1.0) and $\tilde{v}_j^-$= (0.0, 0.0, 0.0). Thus, the distance measurement can be obtained by using the following equations.

$$d_i^+ = \sum_{j=1}^{q} d\left(\tilde{v}_{ij}, \tilde{v}_j^+\right), \forall i = 1,2, \dots\dots, p \quad (13)$$

$$d_i^- = \sum_{j=1}^{q} d\left(\tilde{v}_{ij}, \tilde{v}_j^-\right), \forall i = 1,2, \dots\dots, p \quad (14)$$

Step 5:

Calculated relative closeness coefficient. Choose an alternative with the maximum CC_i or rank alternatives to CC_i in descending order based on the following expression;

$$CC_i = \frac{d_i^-}{(d_i^+ + d_i^-)}, \forall i = 1,2, \dots., p \quad (15)$$

III. CASE STUDY A

In order to develop and present a decision model for BIM software selection, a real case project in Malaysia has been selected as a case study. It is the first government project through BIM [12]. According to Construction Research Institute of Malaysia CREAM [13], the project was considered as a fast track BIM with Design Built. Face to face semi-structured interview has been organised with the decision makers who directly involved in the selection of BIM software for the specified project. There are three decision makers namely DM1, DM2 and DM3 involved in this study. They possess vast experience (at least involved in four or more BIM project in Malaysia) in development of BIM project. Each of them is a different background in construction such as DM 1 (Consultant), DM 2 (Architect) and DM 3 (BIM coordinator).

Table 1
Decision Makers Profile

Decision Makers (DM)	Position	Experiences (Years)	Number of BIM project involved
DM 1	Consultant	12 years	8
DM 2	BIM Coordinator	16 years	12
DM 3	Architect	25 years	5

Instead of criteria of BIM software selection, decision-makers were also asked about the current trend of BIM software selection among the construction companies in Malaysia. According to them, most of the companies tend to select BIM software based on CIDB and others company recommendation or based on software vendor's recommendation and advertisement. A brief profile of decision makers is shown in Table 1. Decision makers were asked to fill the questionnaire that related to with the criteria in BIM software selection. After determining all related criteria and alternative from decision makers, a hierarchical fuzzy TOPSIS for BIM software selection was developed. The determined criteria and alternatives are label as shown in Figure 1.

Then, decision makers were required to fill the weight and rating assessment in fuzzy TOPSIS through linguistic scale that proposed in [9] as shown in Table 2. Weighting and rating results are shown in Table 3 and 4.

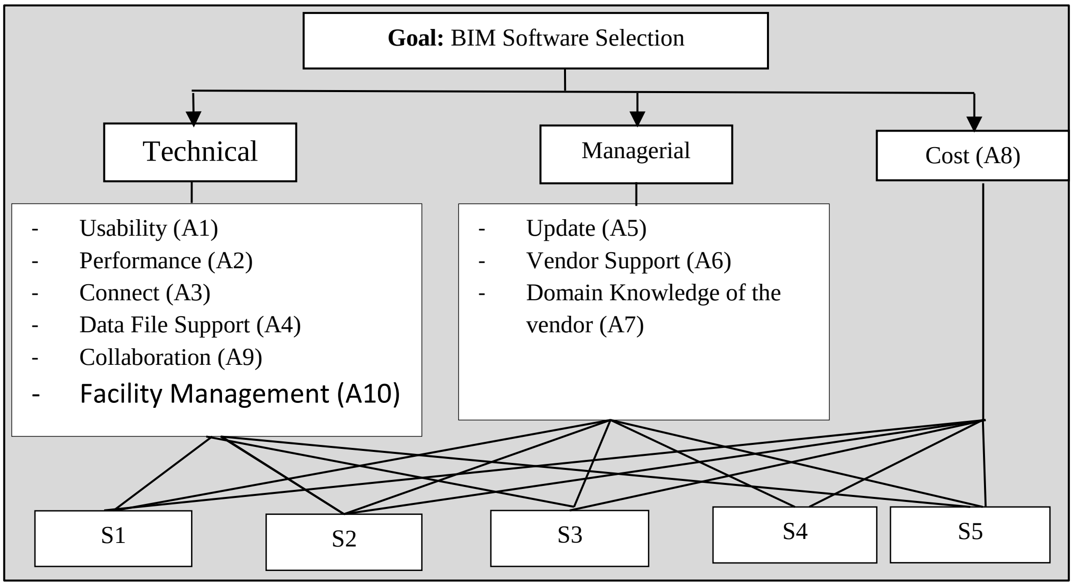

Figure 1: Decision hierarchy for BIM software selection

Table 2
Weight and Rating Scale

Weight		Rating	
Linguistic variables	Fuzzy Number	Linguistic variables	Fuzzy Number
Very Low	(0,0,0.1)	Very Poor	(0, 0, 1)
Low	(0,0.1,03)	Poor	(0, 1, 3)
Medium Low	(0.1, 0.3, 0.5)	Medium Poor	(1, 3, 5)
Medium	(0.3, 0.5, 0.7)	Fair	(3, 5, 7)
Medium High	(0.5, 0.7, 0.9)	Medium Good	(5, 7, 9)
High	(0.7, 0.9, 1.0)	Good	(7, 9, 10)
Very High	(0.9, 1.0, 1.0)	Very Good	(9, 10, 10)

Table 3
Weight of Criteria

Criteria	Linguistic Variables		
	DM1	DM2	DM3
A1	VH	H	MG
A2	H	H	VH
A3	H	-	VH
A4	H	VH	VH
A5	-	-	MH
A6	MH	M	MH
A7	M	-	-
A8	MH	VH	M
A9	VH	H	VH
A10	M	M	M

These differences resulted due to the differences of decision maker background and differences objective of using BIM software. However, there was a similarity in the result of decision makers, with the S2 score the least. This is due to the fact that S2 is still new in the market leading to less implementation evident from industry. Next, the group aggregation result is presented in Table 5.

This group aggregation result shows that; Software S1> Software S5> Software S3> Software S4> Software S5. The group ranked result yield software S1 as the best software for this case study. Software 1 is the same software that has been used in the case study A project. Based on decision maker preference, result in Table 6 indicated that Software (S1) ranked the highest closeness coefficient valued and followed by Software (S5), Software (S3), Software (S4), and was Software (S2) at the last rank.

Thus, fuzzy TOPIS has yield software S1 as the best to fits the decision maker needs. This is exactly the same software that has been utilised in Case Study A. Decision maker has highlighted that each of software has their advantages and disadvantages, it depends on the decision makers' background (BIM coordinator, constructor or architect, consultant) and project needs.

IV. Decision Model Validation

The development of topsis4BIM is not for predicting value or recommending actions. Its main purpose is assisting the decision makers in organising the decision-making problem and doing the required calculation. Although some of the DMs are using the same criteria, it is may still yield a different result when using different weighting for each attribute and rating assessment. For these reasons, this decision model has been validated by comparing the result from decision model with current practice result (without decision model). The decision makers were asked to rank BIM software based on their intuition and experience (without using decision model). Thus, in order to determined weight from DMs, Rank Order Centroid (ROC) has been utilised.

Table 7 shows the comparison of the pattern of decision making output among the decision makers without DSS and with DSS. The comparison table shows that topsis4BIM yield almost similar result compare to current.

V. Discussion and Conclusion

Since there are numerous of BIM software available in the market with different functions, features and cost have caused difficulty for the construction company to select the best software that fulfils the company's and project needs. It worsens due to the purchasing of BIM software is not only require high investment for hardware and software, but also training expenses from the company. Thus, there is a need for an appropriate technique for evaluating BIM software through detailed evaluation. The objective of this paper is to analyse the potential of software and choose the best software based on decision maker preferences by using Multi-criteria decision making (MCDM) techniques. Thus, this paper has developed fuzzy TOPSIS decision model based on Chen [9] model for BIM software selection.

Table 4
Rating of alternative

Criteria	Software alternatives	Rating DM 1	DM 2	DM 3
A1	S1	F	G	MG
	S2	F	F	MP
	S3	G	F	G
	S4	G	G	MG
	S5	G	G	G
A2	S1	VG	VG	F
	S2	F	F	G
	S3	F	F	G
	S4	VG	VG	MG
	S5	G	VG	G
A3	S1	G	-	F
	S2	F	-	F
	S3	G	-	MP
	S4	G	-	G
	S5	MG	-	VG
A4	S1	G	G	G
	S2	F	F	F
	S3	G	F	F
	S4	G	G	G
	S5	G	G	G
A5	S1	-	-	MG
	S2	-	-	MG
	S3	-	-	F
	S4	-	-	MG
	S5	-	-	G
A6	S1	G	P	MG
	S2	F	P	F
	S3	G	P	F
	S4	G	P	F
	S5	G	P	F
A7	S1	G	-	-
	S2	F	-	-
	S3	G	-	-
	S4	G	-	-
	S5	F	-	-
A8	S1	G	F	F
	S2	P	F	F
	S3	P	MG	MG
	S4	G	G	G
	S5	G	VG	VG
A9	S1	G	VG	MG
	S2	F	F	F
	S3	G	VG	MG
	S4	F	VP	MG
	S5	G	G	F
A10	S1	G	F	F
	S2	F	P	MP
	S3	G	G	G
	S4	F	P	P
	S5	MG	F	F

Table 5
Result for Each Decision Makers

Alternatives	DM 1		DM 2		DM 3	
	cc	Rank	cc	Rank	cc	Rank
S1	0.69	2	0.68	1	0.63	2
S2	0.44	5	0.33	5	0.49	5
S3	0.76	1	0.46	3	0.58	4
S4	0.65	4	0.41	4	0.63	3
S5	0.66	3	0.57	2	0.69	1

Table 6
Group Aggregation Result

Alternatives	DM 1	DM 2	DM3	Group cc	Group Rank
	Cc for each DMs				
S1	0.69	0.68	0.63	0.666	1
S2	0.44	0.33	0.49	0.42	5
S3	0.76	0.46	0.58	0.6	3
S4	0.65	0.41	0.63	0.5633	4
S5	0.66	0.57	0.69	0.64	2

Table 7
Decision Pattern in Group Decision Approach

Decision Approach	Software	Group ROC	Group Rank
Without DSS	S1	0.33	1
	S2	0.056	5
	S3	0.12	4
	S4	0.24	3
	S5	0.27	2
	Software	Group cc	Group Rank
TOPSIS	S1	0.66	1
	S2	0.42	5
	S3	0.6	3
	S4	0.56	4
	S5	0.64	2

In order to present this methodology, a real construction project which is Case Study A has been deployed. Criteria and alternatives ware identified through face to face semi-structured interview project consultant who directly involved in the case study project. Based on the result, the decision model in this study capable of guiding the company to systematically choose the best software based on their own preferences and needs. As mentioned by Soni [14], a set of criteria in software selection is the most important element that affects the software acquisition decision Thus, this study has identified ten criteria and five alternatives software has that influence the selection of BIM software. Result also has highlighted that decision maker mostly interested in technical criteria in BIM software selection.

These criteria are significant in order to provide a guide for construction players in BIM software selection and enhance the adoption of BIM in Malaysia in future. Most of the construction company tend to select BIM software based on the recommendation from vendor software or the best software in the market without having a proper analysis technique [4]. This is parallel with this study, according to the decision maker, the selection of BIM software mostly based on recommendation from CIDB, other company or software vendors. Moreover, the deficiency of decision aid among the construction companies in BIM software selection also has been mentioned by Ruiz [4]. Thus, the development of fuzzy TOPSIS decision model in this study has provided a new approach to assist the decision maker in BIM software selection.

VI. LIMITATION AND FURTHER RESEARCH

In this paper, we only considered the development of Fuzzy TOPSIS methodology in solving BIM software selection. We do not interpret the result of BIM software selection in the context of others MCDM techniques. The utilisation of other MCDM method in solving BIM software selection might enrich the research findings.

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