Evaluation of framed building types based on the combination of fuzzy AHP and fuzzy MOORA methods

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ABSTRACT

Mankind has been using different kind of materials to build shelters and after then more specific structures throughout the history. If the stone is accepted as a primitive construction material; wood, concrete and steel has spread to the construction history. However, from both of the supply and demand view, it is possible to say that defining the best solution to the construction necessities and constraints is vastly ambiguous. In other words, making decision with respect to infinite parameters is an important task. The level of uncertainty in the optimality based definition of framed building types is relatively high and need to be carefully analyzed. Therefore, in order to select a proper construction technique, combination of fuzzy AHP (analytic hierarchy process) and evaluation based on fuzzy MOORA (multi objective optimization by ratio analysis) has proposed a new useful method, in which FAHP is used for calculating priority weight of criteria and the MOORA is implemented for obtaining the final ranking of construction techniques. In addition, for expressing the applicability of the offered model, it is supported by a case study. In the rating of framed building types; cost, performance, time, fire, corrosion, esthetics and recycling is considered as important factors. As a result, this model is easy to understand and simple to implement in various areas. Also, this method is applicable for the choosing of proper alternatives in different selection problems.

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1. Introduction

Lots of parameters should be considered in the comparison of framed building types such as reinforced concrete, steel or wooden constructions. Common failure titles in this comparison may be summed as calculation of cost and determination of seismic performance with regards to discrete structural elements. However, evaluation of any kind of structure should be positioned on a holistic way.

Reinforced concrete is a combination of concrete and steel bars that work together against dead/live loads and seismic forces. It has been the most common construction technique with respect to its many assumed advantages. Low construction cost based on its material puts reinforced concrete forward beyond the others. Another technique is steel construction that is preferred mostly for tall buildings and industrial structures. Steel has the highest strength through reinforced concrete and wood. Similarly to the steel construction technique, wooden construction has a significant tensile and flexural behavior in addition to its weight advantage and fire resistance disadvantage. Wood is the oldest construction material and has still a wide application field which evolved on modern approaches.

As it is seen in the above brief, all these construction techniques have some advantages and disadvantages. It is the main problem to determine which one of them is the most preferable technique. Strictly speaking, there is no absolute answer to this question. Because necessities and constraints can only point the most appropriate construction technique. Furthermore, commercial purposes

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could mislead the demanders. However, a rough survey on the main construction parameters could lead a general preference feasibility for both of the supply and demand sides.

Decision making has become one of the most important activities in the modern world today despite being attacked by diverse sophisticated technology decision tools. Technology alone sometimes cannot to deliver a decision without assuming human understood ability. Human capabilities with a good insight are considered to extend effective decision making to access a decision. One of the important decision making tools that was introduced in early seventies is multi criteria decision making theory.

The theory of decision making has formed a basis for more reasonable decision making especially in the situation where multiple criteria need to be calculated. The combination of multi criteria decision making (MCDM) with fuzzy logic can be efficiently implemented for solving decision problems with diverse criteria (Sánchez-Lozano et al., 2015).

Framed building types are compared with each other and our view was based on seven criteria. These are the three common construction types which we can select for this study:

- Reinforced concrete construction
- Steel construction
- Wooden construction

In this study, framed building type selection is defined as fuzzy integrated model. In order to, relevant criteria are determined as follows:

- Construction cost
- Structural performance
- Construction time
- Fire resistance
- Corrosion resistance
- Architectural esthetics
- Recycling

The purpose of this study is determination of the best framed building type for any supply and demand sides. For this reason, practical information was obtained from a sufficient number of civil engineer scholars. Many preference parameters were presented and also their new suggestions were asked. After the review of collected responses, these seven titles were determined and the study has been performed on them. First of all, the weights of criteria are calculated by using fuzzy AHP. After that, the ERP systems are ranked according to three different parts of fuzzy MOORA method.

2. Fuzzy Set Theory

Zadeh (1975) proposed fuzzy theory as a mathematical theory for first time. It is possible to create relationship between uncertainty and vagueness in real life world problems by using fuzzy theory. If X be the universe of discourse $X = \{x_1, x_2, \dots, x_n\}$, a fuzzy set ã of X is characterized by a membership function $\mu_{ã}(X)$, which maps each element x in X to real number within the interval [0,1]. The function values $\mu_{ã}(x)$, the stronger degree of membership for x in ã (Kaufman and Gupta, 1991).

3. Methods

3.1. Fuzzy AHP

AHP is one of the most important MCDM methods for modeling erratic problems in diverse areas. Fuzzy AHP was introduced to eliminate the defects of traditional AHP and to facilitate adoption to real life problems (Buckley et al., 2001). Chang (1992) proposed a fuzzy AHP based on the extent analysis method which is widely used in supplier selection problems (Kilincci and Onal, 2011; Ertuğrul and Karakaşoğlu, 2007) by using of triangular fuzzy numbers for pairwise comparison scale of fuzzy AHP. The steps of FAHP are as follows (Buckley et al., 2001) :

i. Build fuzzy triangular judgment matrix

The fuzzy triangular matrix $A = (a_{ij})_{nk*nk}$ is a closed interval, where pairwise comparison judgments express by $a_{ij} = (l_{ij}, m_{ij}, u_{ij})$ fuzzy numbers.

$u_{ij} = upper\ bound, m_{ij} = median,\ l_{ij} = lower\ bound,$ $i, j = 1,2, \dots, n_k$
n_k = the number of klevel indicator system

ii. Calculate comprehensive judgment matrix

The $a_{ij}^t = (u_{ij}^t, m_{ij}^t, l_{ij}^t)$ elements, express the fuzzy number which determined by decision makers $t = 1,2, \dots, T$ with comparing the indicators i and j.

$$M_{ij} = \frac{1}{T} \otimes \left(a_{ij}^1 + a_{ij}^2 + \cdots + a_{ij}^T\right). \quad (1)$$

$\otimes$ = multiplication principle of triangular fuzzy number.

iii. Calculate comprehensive fuzzy degree

The comprehensive fuzzy degree S_i calculates as follows:

$$S_i = \sum_{j=1}^{n_k} M_{ij} \otimes \left(\sum_{i=1}^{n_k} \sum_{j=1}^{n_k} M_{ij}\right)^{-1}. \quad (2)$$

iv. Calculation of indicator weight

The best scalar measure of indicator C_i is as follows:

$$d'(C_i) = min\, V(S_i \geq S_j), \quad (3)$$

where $0 \leq V(S_i \geq S_j) \leq 1, i, j = 1,2, .., n_k$. $V(S_i \geq S_j)$ shows the possibility degree of $S_i \geq S_j$.

$$V(S_i \geq S_j) = \mu(d) = \begin{cases} \frac{l_j - u_i}{(m_i - u_i) - (m_j - l_j)} & , \quad l_j \leq u_j \\ 0 & , \quad others \end{cases}. \quad (4)$$

The single level indicator weight:

$$W' = (d'(C_1), d'(C_2), \dots, d'(C_n)). \quad (5)$$

The normalized indicator weight:

$$W = \left(d(C_1), d(C_2), \dots, d(C_n)\right), \quad (6)$$

3.2. Fuzzy MOORA

The using of multi objective optimization by ratio analysis (MOORA) was commenced by (Brauers and Zavadskas, 2006) based on recent research. This multi criteria decision making method start with matrix X which it's elements x_{ij} express *i*th alternative of *j*th criterion ($i = 1,2,\ldots,m$ and $j = 1,2,\ldots,n$); in addition, the fuzzy MOORA method consists of three parts such as fuzzy ratio method, fuzzy reference point and fuzzy multiplicative form.

i. Fuzzy ratio method

Step1: Decision matrix is acquired according to the Tables 4 and 5:

$$\tilde{X} = \begin{bmatrix} [x_{11}^l, x_{11}^m, x_{11}^u] & \cdots & [x_{1n}^l, x_{1n}^m, x_{1n}^u] \\ \vdots & \ddots & \vdots \\ [x_{m1}^l, x_{m1}^m, x_{ml}^u] & \cdots & [x_{mn}^l, x_{mn}^m, x_{mn}^u] \end{bmatrix}. \quad (7)$$

Step2: In this part, we normalize decision matrix since it enables us to compare alternatives with each other more accurately (Liu and Liu, 2010).

$$\tilde{X}_{ij}^* = \left(x_{ij}^{l*}, x_{ij}^{m*}, x_{ij}^{u*}\right); i = 1,2,\ldots,m; j = 1,2,\ldots,n, \quad (8)$$

$$X_{ij}^{l*} = \frac{x_{ij}^l}{\sqrt{\sum_{i=1}^m [\left(x_{ij}^l\right)^2 + \left(x_{ij}^m\right)^2 + \left(x_{ij}^u\right)^2]}}, \quad (9)$$

$$X_{ij}^{m*} = \frac{x_{ij}^m}{\sqrt{\sum_{i=1}^m [\left(x_{ij}^l\right)^2 + \left(x_{ij}^m\right)^2 + \left(x_{ij}^u\right)^2]}}, \quad (10)$$

$$X_{ij}^{u*} = \frac{x_{ij}^u}{\sqrt{\sum_{i=1}^m [\left(x_{ij}^l\right)^2 + \left(x_{ij}^m\right)^2 + \left(x_{ij}^u\right)^2]}}. \quad (11)$$

Step3: In this step, calculated weights of criteria from AHP are used to form weighted and normalized fuzzy matrix (Vatansever, 2013).

$$\tilde{v}_{ij} = (v_{ij}^l, v_{ij}^m, v_{ij}^u)$$
$$v_{ij}^l = w_j x_{ij}^{l*}$$
$$v_{ij}^m = w_j x_{ij}^{m*}$$
$$v_{ij}^u = w_j x_{ij}^{u*}\,. \quad (12)$$

Step4. Summarizing ratio $\tilde{y}_i$ calculate for each *i*th alternative as follows (Baležentis et al., 2012):

$$\tilde{y}_i = \sum_{j=1}^{g} \tilde{v}_{ij} - \sum_{j=g+1}^{n} \tilde{v}_{ij}\,, \quad (13)$$

where $g = 1,2,\ldots,n$ denotes number of criteria to be maximized. On the other hand, $g+1,\ldots,n$ denotes number of criteria to be minimized.

Step5. In this step, fuzzy numbers change to non-fuzzy numbers by BNP equation and the amounts of BNP are calculated for each alternative. As a result, the alternatives with highest values are favorable for choosing.

$$\mathrm{BNP}_i(y_i) = \frac{\left(y_i^u - y_i^l\right) + \left(y_i^m - y_i^l\right)}{3} + y_i^l \quad (14)$$

ii. Fuzzy reference point

Fuzzy ratio system plays major role in the fuzzy reference point approach. The maximal objective reference point $\tilde{r}$ is obtained as well as second step of fuzzy ratio method. The fuzzy maximum or minimum of the *j*th criteria are calculated as follows:

$$\begin{cases} \tilde{x}_j^+ = \left(\max_i x_{ij}^{l*}, \max_i x_{ij}^{m*}, \max_i x_{ij}^{u*}\right),\ j \le g \\ \tilde{x}_j^+ = \left(\min_i x_{ij}^{l*}, \min_i x_{ij}^{m*}, \min_i x_{ij}^{u*}\right),\ j > g \end{cases}. \quad (15)$$

The every element of normalized matrix is calculated and final sort achieved based on deviation from the refere1nce point and the Min-Max metric of (Liu et al., 2014; Balezentiene and Streimikiene, 2013):

$$\min_i(\max_j(\tilde{r}_j, \tilde{x}_{ij}^*))\,, \quad (16)$$

iii. The fuzzy multiplicative form

Overall utility of *i*th alternative is obtained as follows:

$$\tilde{U}_i' = \frac{\tilde{A}_i}{\tilde{B}_i}, \quad (17)$$

where $\tilde{A}_i = (A_{i1}, A_{i2}, A_{i3}) = \prod_{j=1}^{g} \tilde{x}_{ij}$, $\mathrm{i} = 1,2,\ldots,m$ expresses the criteria of the *i*th alternative to be maximized $g = 1,2,\ldots,n$ being the number objectives to be maximized and where $\tilde{B}_i = (B_{i1}, B_{i2}, B_{i3}) = \prod_{j=g+1}^{n} \tilde{x}_{ij}$ expresses the criteria of the *i*th alternative to be minimized with $n - g$ being the number of objectives to be minimized. We need to eliminate fuzzy numbers of overall utility $\tilde{U}_i'$ to rank the alternatives. The alternative with higher BNP is favorable for choosing (Balezentiene and Streimikiene, 2013).

4. Framed Building Characteristics – Decision Criteria

Framed building types are evaluated through the following decision criteria as: Construction cost, structural performance, construction time, fire resistance, corrosion resistance, architectural esthetics, recycling.

4.1. Construction cost

Construction cost of and type of structure actually depends of many other parameters. While the expense for structural material could be said that has the main portion, it is more complex than this evaluation. Because production, transport and installation stages totally specify the initial construction cost. Installation cost regarding qualified labor (especially for steel and wooden construction) should not be neglected. Reinforced concrete has a significant advantage on this parameter. It is also obvious that this parameter is generally assumed as one of the most important preference criteria.

4.2. Structural performance

Any type of building is expected to have a high structural performance against dead/live loads and seismic forces. Substantial properties of construction materials that affect their structural performance could be defined as compression/tensile/flexural strength, ductility and stiffness. However, especially for seismic performance, strength/weight proportion is the main factor. Repeated reversible forces are highly subjected to the structural elements' weight and reinforced concrete structures recede into background considering their excess weight.

4.3. Construction time

Steel and wooden construction types are ahead of reinforced concrete construction considering this parameter. Because steel and wooden structural elements are pre-fabricated, these techniques could be applied independent of climate conditions. However, reinforced concrete construction is executed totally on the field. Rain, snow, hot&cold weather conditions prevents the labor and also concrete casting while steel and wooden construction is based mostly on the mounting of prefabricated elements.

4.4. Fire resistance

Despite some possible precaution methods, fire is crucial for firstly wood and then steel. One can say that carbonization delay the collapse of wooden structures, it is obvious that wood gets affected and damaged faster than steel. Additionally, reinforced concrete should not be assumed in a similar way as steel construction. Owing to the concrete cover on the steel rebar, reinforced concrete has the highest fire and high temperature resistance in comparison to steel and wooden structures.

4.5. Corrosion resistance

Traditionally, corrosion has a significant negative effect on metal materials. Steel construction has the biggest disadvantage regarding to this parameter although many precaution methods against corrosion are available. However, similarly as the fire protection, they increase the construction cost and should be taken in consideration without these additional solutions. For reinforced concrete structures, concrete cover on the steel rebar decrease corrosion effect. Moreover, corrosion is an undesirable situation for wooden structures, lifetime of timber is affected more by other negative factors.

4.6. Architectural esthetics

This parameter has actually a subjective aspect and esthetical look ranking could be applied based on the common opinion. However, most important indicator of architectural esthetics should be the diversity level of architectural design. Especially regarding to the low weight and high tensile/flexural strength of steel and wood materials; much number of extraordinary designs are possible than reinforced concrete construction. Moreover, natural look of wooden construction brings an additional positive value than the other techniques.

4.7. Recycling

Nowadays, recycling has been one of the most important arguments in all mankind productions. Despite the long lifetime of buildings, recycling should be considered for material selection. Furthermore, exhaustion of natural sources is possible to be implemented in this evaluation. Hence, steel is the foremost material regarding to its recycling capability.

5. Illustrative Example

The useful data have been acquired from the survey throughout civil engineer scholars and it was seen that the level of uncertainty in the selection of framed building types is relatively high and need to be carefully analyzed. Therefore, in order to select a proper construction technique, combination of fuzzy AHP (FAHP) and evaluation based on fuzzy MOORA (multi objective optimization by ratio analysis) has proposed a new useful method, in which FAHP is used for calculating priority weight of criteria and the MOORA is implemented for obtaining the final ranking of framed building types. Fig. 1 shows the hierarchical structure of the model. Decision making group, which has a significant background in this field, selected 7 main criteria. This group also confirmed the convenience of three construction types as our alternatives. In this study, linguistic variables are used then they are converted into triangular fuzzy numbers (Table 1). Accordingly, a systematic approach based on combination of fuzzy AHP with fuzzy MOORA is proposed to determine the best construction technique. Table 2 shows the comparison of 7 decision criteria with each other. The abbreviations are; equally important: EI, moderately important: MI, important: I, very important: VI, much more important: MMI. The weights of criteria that were calculated by FAHP is presented in Table 3.

5.1. Determination of criteria weights

In this section, the fuzzy scale of Chang (1996) is used through fuzzy AHP for calculating the weights of criteria.

Table 1. The fuzzy scale of Chang (1996).

Linguistic variables	Fuzzy scale	Response scale
Equally Important	(1,1,1)	(1,1,1)
Moderately Important	(2/3,1,3/2)	(2/3,1,3/2)
Important	(3/2,2,5/2)	(2/5,1/2,2/3)
Very Important	(5/2,3,7/2)	(2/7,1/3,2/5)
Much More Important	(7/2,4,9/2)	(2/9,1/4,2/7)

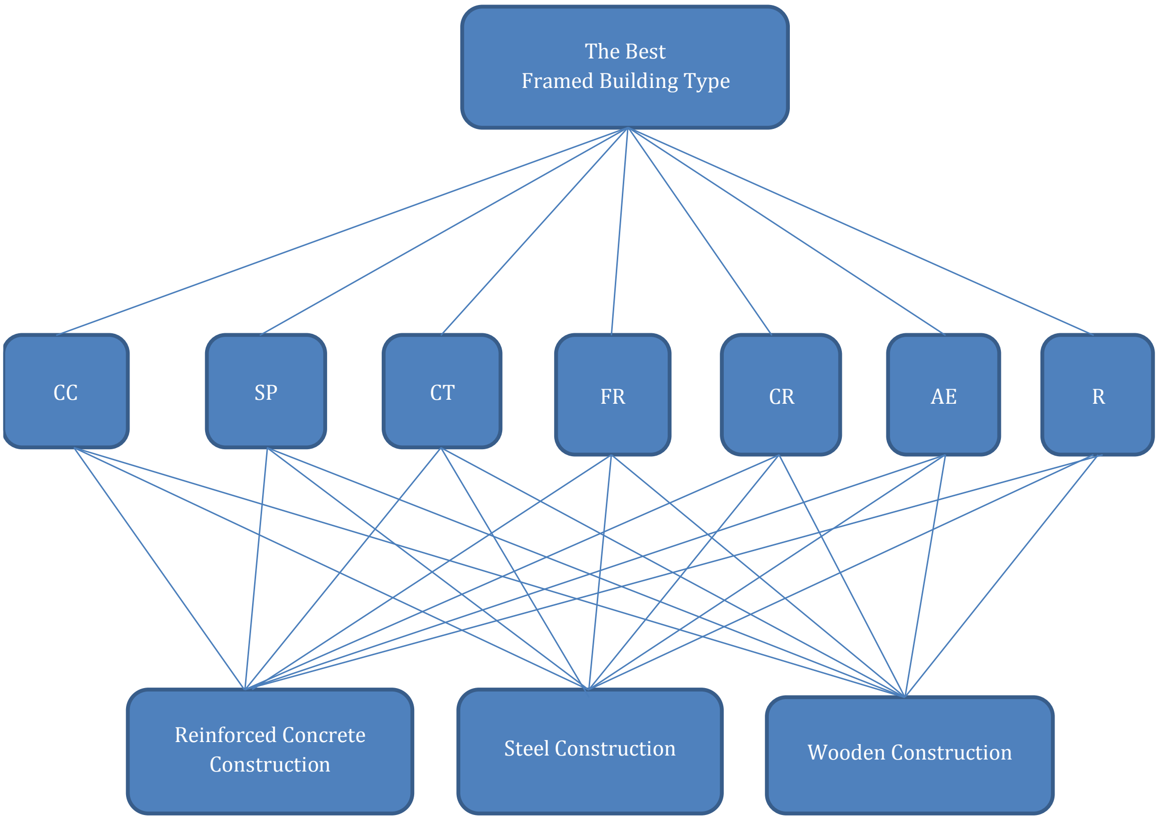

Fig. 1. Hierarchical structure of the model.

Table 2. Pairwise comparison matrix of criteria.

	SP	CT	FR	CC	AE	CR	R
SP	-	MI	I	EI	I	I	MI
CT		-	I	MI	I	I	I
FR			-	I	MI	EI	I
CC				-	I	I	I
AE					-	MI	EI
CR						-	MI
R							-

Table 3. The weights of criteria calculated by FAHP.

Criteria	W
Structural Performance	0.23
Construction Time	0.26
Fire Resistance	0.1
Construction Cost	0.26
Architecture Esthetics	0.05
Corrosion Resistance	0.05
Recycling	0.05

5.2. Selection of the framed building type

Fuzzy MOORA is used for the selection of framed building types. While Chen's fuzzy linguistic scale is used which is shown in Table 4, fuzzy evaluation matrix for framed building types are as in Table 5. After calculation the rank of systems were acquired, the ranking of framed building types are given on Table 6.

Table 4. Chen's fuzzy linguistic scale (Chen, 1992).

Linguistic variables	Fuzzy scale
Very Low (VL)	(0,0,0.1)
Low (L)	(0,0.1,0.3)
Medium Low (ML)	(0.1,0.3,0.5)
Medium (M)	(0.3,0.5,0.7)
Medium High (MH)	(0.5,0.7,0.9)
High (H)	(0.7,0.9,1)
Very High (VH)	(0.9,1,1)

Table 5. Fuzzy evaluation matrix for ERP system types.

	SP	CT	FR	CC	AE	CR	R
Reinforced Concrete Construction	ML	ML	VH	MH	ML	MH	ML
Steel Construction	VH	MH	MH	ML	M	M	VH
Wooden Construction	M	MH	ML	ML	VH	VH	MH

Table 6. Comparison between system types based on criteria.

	SP	CT	FR	CC	AE	CR	R
Reinforced Concrete Construction	(0.1,0.3,0.5)	(0.1,0.3,0.5)	(0.9,1,1)	(0.5,0.7,0.9)	(0,0.1,0.3)	(0.5,0.7,0.9)	(0.1,0.3,0.5)
Steel Construction	(0.9,1,1)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.1,0.3,0.5)	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.9,1,1)
Wooden Construction	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(0.1,0.3,0.5)	(0.1,0.3,0.5)	(0.9,1,1)	(0.9,1,1)	(0.5,0.7,0.9)

Table 7. Normalized aggregated ratings for each alternative.

	SP	CT	FR	CC	AE	CR	R
Reinforced Concrete Construction	(0.05,0.149,0.248)	(0.054,0.161,0.269)	(0.415,0.461,0.461)	(0.333,0.467,0.6)	(0.05,0.15,0.25)	(0.224,0.313,0.402)	(0.046,0.138,0.23)
Steel Construction	(0.447,0.496,0.496)	(0.269,0.377,0.484)	(0.23,0.32,0.415)	(0.067,0.2,0.333)	(0.15,0.25,0.35)	(0.134,0.224,0.313)	(0.415,0.461,0.461)
Wooden Construction	(0.198,0.248,0.347)	(0.269,0.377,0.484)	(0.046,0.138,0.23)	(0.067,0.2,0.333)	(0.45,0.5,0.5)	(0.402,0.402,0.447)	(0.23,0.32,0.415)

According to the calculations based on FAHP method, steel construction is selected as the best solution (1st) throughout the considered framed building techniques. Wooden and then reinforced concrete constructions are the 2nd and 3rd in the final ranking.

6. Conclusions

The main objective of this study was to propose comprehensive criteria to evaluate framed building types by using fuzzy AHP and valuable ranking of framed building types by using fuzzy MOORA. This paper contributes to civil engineering literature as well as the validity of developed criteria for framed building types based on the guidance of scholars. It is possible to consider different parameters and different weight ratios to seek the optimal solution. Another parametric evaluation of construction techniques will yield new results. However, this paper has an importance to enlighten the related studies and make scholars discuss on the selection of framed building types. Choosing of a suitable construction technique is a difficult MCDM problem that includes both quantitative and qualitative objectives. It is difficult to measure the performance of the existing construction types, which we managed to do that by getting help from civil engineer scholars. This study, proposed a fuzzy integrated model that can assess and choose the best framed building type by using of FAHP and FMOORA methods. Implementing of a practical decision making method for assessment and evaluating construction techniques is the major contribution of this study. For the next studies, this integrated method can be adjusted to diverse MCDM problems.

The proposed model may be used to evaluate alternatives successfully through various selection problems. Future researches may try to extend this study as an integration of more fuzzy integrated MCDM techniques to solve many other decision making problems on many other disciplines.

Table 8. Weighted normalize fuzzy decision matrix.

	SP	CT	FR	CC	AE	CR	R
Reinforced Concrete Construction	(0.011,0.034,0.057)	(0.014,0.042,0.07)	(0.04,0.046,0.046)	(0.087,0.12,0.156)	(0.002,0.007,0.012)	(0.011,0.016,0.02)	(0.002,0.007,0.011)
Steel Construction	(0.103,0.114,0.114)	(0.07,0.1,0.126)	(0.023,0.03,0.04)	(0.017,0.052,0.087)	(0.007,0.012,0.017)	(0.007,0.011,0.016)	(0.021,0.023,0.023)
Wooden Construction	(0.046,0.057,0.08)	(0.07,0.098,0.126)	(0.005,0.014,0.023)	(0.017,0.052,0.087)	(0.022,0.025,0.025)	(0.02,0.02,0.022)	(0.011,0.016,0.021)

Table 9. The fuzzy ratio method.

	$\tilde{y}_i$	BNP	Rank
Reinforced Concrete Construction	(-0.032,-0.053,-0.079)	-0.05447	3
Steel Construction	(0.073,0.043,-0.001)	0.038578	1
Wooden Construction	(0.017,-0.018,-0.041)	-0.01409	2

Table 10. The fuzzy reference point approach.

	SP	CT	FR	CC	AE	CR	R	$\max_j d(\tilde{r}_j, \tilde{x}^*_{ij})$	Rank
Reinforced Concrete Construction	0.583011	0	0	0.46188	0.588103	0.204939	0.541289	0.588103	3
Steel Construction	0	0.373002	0.23495	0	0.418854	0.349285	0	0.418854	1
Wooden Construction	0.381209	0.373002	0.541289	0	0	0	0.23495	0.541289	2

Table 11. The fuzzy multiplicative form.

	$\widetilde{U}_i'$	BNP	Rank
Reinforced Concrete Construction	(0.001,0.09,2.25)	0.780333	3
Steel Construction	(0.081,0.833,8.82)	3.244778	1
Wooden Construction	(0.027,0.5,6.3)	2.275667	2

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