



A FUZZY DECISION SUPPORT SYSTEM FOR SUSTAINABLE CONSTRUCTION PROJECT SELECTION: AN INTEGRATED FPP-FIS MODEL

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Abstract. Sustainability has become a key concern for project selection in construction industries. Determining the best sustainable project based on various sustainability attributes is a very complicated decision. Accordingly, developing a suitable decision support framework can be very helpful for decision makers to attain planned business goals and complete projects at the right time with good quality. This research develops a decision support model which helps managers to understand the concept of sustainability in construction project selection and choose the best project using a new integrated Multi-Criteria Decision Making (MCDM) approach under uncertainty by integrating Fuzzy Preference Programming (FPP) as a modification of Fuzzy Analytical Hierarchy Process (FAHP), with Fuzzy Inference System (FIS) as a fuzzy rule-based expert system. In the first phase of the research, fifteen sustainability attributes were selected. In the second phase, the final weight of each attribute was computed by using FPP. In the last phase, the most appropriate project was selected by running the weighted FIS. The results showed that Project 3 (P3) is the best project. Finally, two different evaluative tests were also applied to verify the validity and robustness of the developed model.

Keywords: sustainability, project selection, sustainable project selection, multi-criteria decision making.

Introduction

Nowadays, due to increasing public awareness of environmental protection and social issues, organizations should not only be worried about their economic activities, but they must also be very serious in their environmental and social matters. A concept which focuses on environmental impacts, social responsibilities and economic activities simultaneously is called sustainability. Lozano et al. (2015) stated that sustainability in companies means all the organizational activities which strongly contribute to sustainability balance, consisting of the economic, environmental and social aspects.

The literature of sustainability reported that this concept has been applied in different fields such as tourism, textile, supply chain, and oil and gas (Castro-Alvarez et al.,

2018; Heravi et al., 2017; Lambin & Thorlakson, 2018; Lozano et al., 2015; Mowforth & Munt, 2015; Shen et al., 2017). As can be seen, one of the fields in which sustainability is being implemented is Construction Industry (CI) (Lopes et al., 2017; Mavi & Standing, 2018). Heravi et al. (2017) stated that ten percent of gross domestic products and seven percent of employments belong to CI. Furthermore, Ma et al. (2017) reported that CI is among the three most important contributors of carbon emission and it demands a huge amount of energy.

Project selection is one of the main activities in CI which helps managers to monitor and control different operations (Abdel-Basset et al., 2019). The objective of project selection is to determine the most suitable project

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on the basis of the defined evaluative attributes. Therefore, selecting a suitable sustainable project is one of the major concerns in the context of Sustainable Construction Industry (SCI). By focusing on the literature, it is observed that Sustainable Project Selection (SPS) has become a crucial issue in SCI (Siew, 2016). Several studies showed that the advantages of applying sustainability in construction project selection are very important for managers in CI. For example, Mavi and Standing (2018) stated that it is needed to develop a comprehensive list of sustainability attributes and sub-attributes in order to aid decision makers of construction companies to understand the concept of sustainability in CI and SPS. Heravi et al. (2017) indicated that determining sustainable projects in CI is a very essential subject which needs more attention from academics and practitioners. They also mentioned that developing a framework which provides both a proper definition about sustainability criteria and a decision support system is one of the necessities in this area.

Multi-Criteria Decision Making (MCDM) is about selecting the best alternative among several alternatives based on various criteria. Basically, SPS is a complicated process which depends on different criteria such as availability of capital, safety, time, etc. So, it can be concluded that this is a MCDM process (Mavi & Standing, 2018). Moreover, this process is easily faced with negative effects of risk (Carr & Tah, 2001; Mousavi et al., 2015). Thus, developing a decision support framework using appropriate attributes is very helpful in this context. Particularly, the issue of SPS strongly needs experts' knowledge and experiences, and data sets for real-world problems can have fuzzy uncertainties such as ambiguity, vagueness and imprecision (Fallahpour et al., 2016; Gitinavard et al., 2017; Vahdani, 2016). It is also difficult for decision makers and managers to express their thoughts by applying exact numbers in decision making. Hence, in SPS, it will be more advantageous to collect the data sets for the importance degree of each criterion and performance of each alternative using a fuzzy or linguistic-based technique in order to analyze the projects and select the best one. In essence, developing a framework which can deal with ambiguity, vagueness and imprecision is beneficial (Borujeni & Gitinavard, 2017). Fuzzy set theory, developed by Zadeh (1978) as a method to cope with the problem of exact data collection in real world, has been widely used in decision making (Ebrahimnejad et al., 2017; Erdogan et al., 2017; Gitinavard et al., 2017; Govindan et al., 2019; Nguyen et al., 2018; N. Prascevic & Z. Prascevic, 2017). Therefore, many fuzzy MCDM methods (Mohammed et al., 2019a, 2019b; Zhou et al., 2018a, 2018b) such as FANP, FTOPSIS, FAHP, FDEA, etc., have been applied for decision making under uncertainty.

In the area of SPS, it is observed that previous models have not used a very comprehensive list of criteria for project evaluation in terms of sustainability. Other main issues are to obtain the importance of each evaluative factor and to assess the performance of each alternative with regard to a number of attributes that are usually nonspe-

cific and fuzzy in nature. Generally, the importance degree of sustainability evaluative factors for SPS has not been considered in many previous studies. In other areas, AHP is being utilized attributes weight determination. However, the original AHP uses the classical eigenvector prioritization method, which does not consider human judgment. Therefore, the conventional AHP is less useful when dealing with uncertainty. In order to cope with this problem, various fuzzy prioritization techniques have been proposed. In this research, a fuzzy version of AHP known as Fuzzy Preference Programming (FPP), with less additional aggregation procedures, is employed. Another research gap is that fuzzy knowledge-based systems for evaluating and selecting suitable alternatives in SPS are under-developed. Previous researchers have literally used mathematical models for SPS and there is a lack of fuzzy expert systems in this area.

This paper is aimed at proposing a hybridized fuzzy MCDM method to evaluate construction projects with respect to sustainability attributes and select the most appropriate sustainable project along with a case study in Iran. To this end, FPP is integrated with FIS to first compute the importance weight of each criterion and then select the best alternative under uncertainty. It is worth mentioning that this is the first paper which integrates FPP with FIS for selecting construction projects using sustainability criteria. This research targets the CI in Iran as the case study because this industry is one of the largest in the country. Several reports have shown that the yearly income in the Iranian CI amounted to US\$38.4 billion (Malek Akhlagh et al., 2013). From another perspective, CI is of the biggest contaminant in the case country and it strongly affects energy consumption. Therefore, there is a need to help this industry to transition towards sustainability. In short, it can be stated that the main objectives of this study are to:

- Determine and define the suitable evaluative criteria for SPS to help decision makers in understanding the concept of sustainability in CI.
- Develop an integrated FPP-FIS model for SPS in CI.
- Determine the importance weights of the sustainability criteria for SPS.
- Develop a fuzzy expert system which serves as a model for assessing projects based on the sustainability criteria.

The rest of current research is as follows. Next section provides the related conducted investigations. The research method is formed in Section 2. Section 3 provides the real case study. Then, the robustness of the proposed model is validated. Discussion and managerial implications are presented in Sections 5 and 6, respectively. Finally, conclusions are given.

1. Literature review

In construction project selection, there are two main issues which are: i) Determining the suitable criteria or attributes for evaluating the projects, and ii) Using an appropriate decision making technique for evaluating the projects and selecting the best alternative.

1.1. Criteria applied in construction project selection

As project selection is a MCDM process, the first step is to determine the proper evaluative criteria for alternative assessment. Numerous criteria have been applied in construction project selection. For example, Maghsoodi and Khalilzadeh (2018) used four criteria which were time, cost, quality and safety for selecting the best project. Hatefi and Tamošaitienė (2018) applied factors such as cost, information on risks and financial risks, technology promotion after project completion, positive impact on the region's economy, increasing social justice, creating equal job opportunities, welfare and economic growth, use of eco-friendly technologies, preventing nature destruction, etc. Zolfani et al. (2018) utilized criteria such as energy consumption, environmental impact, society and financial return. Frini and BenAmor (2015) applied several indicators such as carbon footprint, old forest areas, habitat of caribou index, economic benefits, etc., for selecting the most appropriate project. Doulabi and Asnaashari (2016) identified a set of success factors for healthcare facility construction projects in Iran. Lückmann (2015) utilized time, price, quality and customer satisfaction as the best attributes for evaluating several alternatives. Serrador and Turner (2015) applied time, cost and performance efficiency, while Taylan et al. (2014) used five attributes known as risk related to time, risk related to cost, risk related to safety, risk related to quality, and risk related to environmental sustainability for determining the most suitable project. In another study, criteria such as safety and environment were found to be important by Alzaharani and Emsley (2013) for selecting projects in CI.

1.2. MCDM techniques applied in construction project selection

The literature reported that various MCDM methods have been used in this area such as ANP, TOPSIS, AHP, DEA, etc. Some of the new pertinent studies are presented below.

Maghsoodi and Khalilzadeh (2018) conducted a research for evaluating the critical success factors of construction projects in Iran. Firstly, they listed the essential success attributes by focusing on previous studies, and these attributes were used as alternatives. Then, a questionnaire was developed on the basis of the attributes such as time, cost, quality and safety, and it was distributed to experts for data collection. Finally, the best alternative was determined by using FTOPSIS.

Hatefi and Tamošaitienė (2018) developed an integrated decision making model under uncertainty by hybridizing FAHP with Grey Relational Analysis (GRA). A list of effective sustainability criteria for evaluating construction projects was identified. Then, by performing GRA, the best project was determined. They stated that the combined model is useful in ranking and selecting the most proper alternative. Furthermore, they mentioned that their study opens new insights for managers and researchers to understand the concept of sustainability in CI.

An integrated decision making model for selecting the best construction project of hotels in Iran was proposed by Zolfani et al. (2018). In their model, Stepwise Weight Assessment Ratio Analysis (SWARA) and Complex Proportional Assessment (COPRAS) were combined. Using SWARA, the weights of the criteria were computed, and then by applying COPRAS, the most appropriate alternative was determined.

Tavana et al. (2015) developed a fuzzy method for assessing projects and finding the best one based on several factors. It has three folds and each fold consists of several steps and procedures. In the first phase, DEA was applied for initial screening. Then, TOPSIS was used for ranking the projects, and finally a Linear Integer Programming (LIP) model was generated for determining the most appropriate project. The developed model showed that the combination of MCDM and LIP is useful to select the best alternative.

Abdel-Basset et al. (2019) hybridized TOPSIS with DEMATEL under a neutrosophic environment to develop a new method for selecting the most appropriate project. The neutrosophic set theory was applied to cope with uncertainty. The importance degree of each attribute was computed by DEMATEL and the most suitable project was determined by TOPSIS. This investigation proved that the neutrosophic set theory is a good potential technique to overcome the ambiguity of data in real-world problems.

Taylan et al. (2014) integrated FAHP with FTOPSIS to compute the weights of the evaluative attributes and select the best alternative in the area of construction project selection. Five main factors related to time, cost, quality, safety and environmental sustainability were selected for assessing thirty construction projects.

In another research, Gumusay et al. (2016) proposed an integrated model to evaluate suitable sites for marina construction in Istanbul, Turkey, by utilizing Geographic Information System (GIS) and AHP. Specifically, AHP was applied to compute the weight of each criterion and a grading system was proposed for the area selection of marinas.

2. Methodology

In methodology, the used techniques for the integrated FPP-FIS model and the presented structure for selecting the best sustainable construction project are explained.

2.1. Computing the weights of the evaluative factors using FPP

As Mikhailov (2004) stated, there are three stages for calculating the criteria weights (see Figure 1).

2.2. FIS for decision making

In FIS, the opinions of experts are normally used to make the fuzzy rules. In this research, based on the experts' opinions of the case company, the fuzzy rules were developed. If there are C criteria and M membership func-

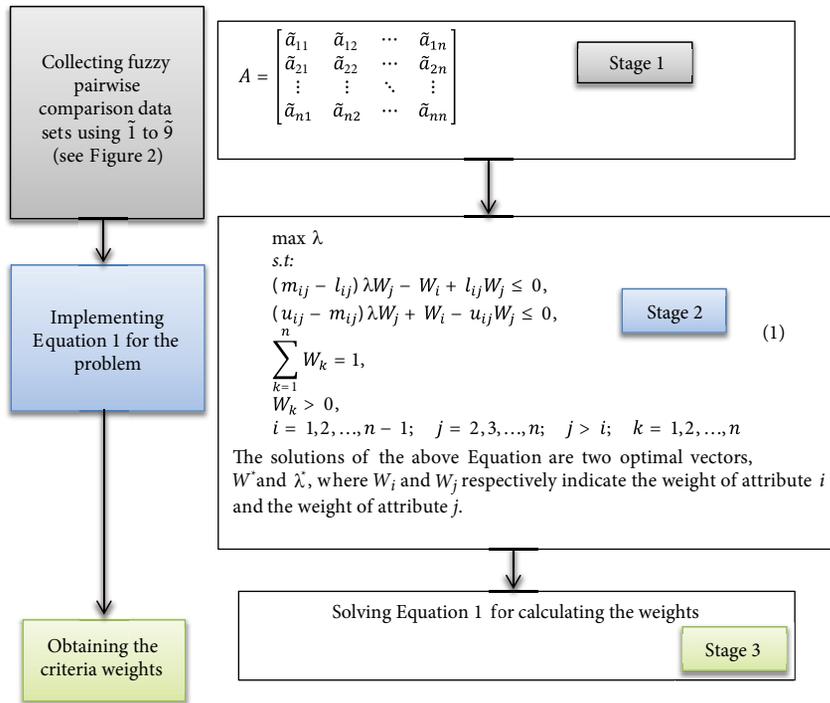


Figure 1. The steps of FPP

tions, the number of rules is M^C . For example, if we have 10 criteria and 5 membership functions, the number of rules would be 9765625. In order to avoid rule explosion and accommodate a larger number of attributes, Amindoust et al. (2012) suggested that the experts could make the rules based on only two inputs (if $C = 2$ and $M = 5$, the number of rules is 25). In this research, after having a meeting with the experts of the case company and explaining the way of making the rules for performance evaluation, Table 1 was developed as the fuzzy rule base and the following five membership functions were used:

- Very Poor = (1,2,3) = (VP);
- Poor = (2,3,4) = (P);
- Moderate = (3,4,5) = (M);
- Good = (4,5,6) = (G);
- Very Good = (5,6,7) = (VG).

The fuzzy performance numbers were defuzzified into exact values using Eqn (2) (the Graded Mean Integration (GMI) representation method) (Chen & Hsieh, 1999).

$$\mathfrak{g}(\tilde{N}) = \frac{(l+4m+u)}{6}. \quad (2)$$

After determining the crisp values, they were employed as an input to FIS. To run the FIS, two inputs were used

Table 1. The fuzzy rule base

Second input	First input				
	VP	P	M	G	VG
VP	VP	VP	P	P	M
P	VP	P	P	M	M
M	P	P	M	M	G
G	P	M	M	G	G
VG	M	M	G	G	VG

for obtaining one output based on the reason explained above. In the process of selecting two by two inputs, if any remained, it would be treated as an output in that particular category (Singh et al., 2018). This process was continued until all the determined criteria were included in the hierarchical FIS and the output for each dimension was reduced to one. In short, the steps of this method for SPS are delineated as follows:

- Collecting the data sets from the experts where they are asked to express their opinions about the performance of a set of sustainability criteria with respect to a construction project using the linguistic variables (VP, P, M, G, VG) described above.
- Defuzzifying the fuzzy values to exact numbers by applying the GMI formula. If there is more than one expert, the aggregated value is computed by using Eqn (3).
- Running the FIS for each project to compute its overall performance based on the sustainability criteria.

2.3. Aggregation method

Let's assume $\tilde{I}_j = \left[(I_{jl}, I_{jm}, I_{ju}) \right]$ is the TFN of the weight or value of j^{th} criterion. When the number of experts is more than one person, the aggregated weight or value for each criterion is calculated as:

$$I_{jl} = \frac{1}{d} \sum_{k=1}^d I_{jl}^k, \quad I_{jm} = \frac{1}{d} \sum_{k=1}^d I_{jm}^k, \quad I_{ju} = \frac{1}{d} \sum_{k=1}^d I_{ju}^k, \quad (3)$$

where d is the number of experts and $\tilde{I}_j^k = \left[(I_{jl}^k, I_{jm}^k, I_{ju}^k) \right]$ denotes the k^{th} expert's thought for the weight or value of j^{th} attribute.

2.4. The developed FPP-FIS model

After computing the global weight of each criterion (from FPP) and determining the crisp performance value of each criterion, the global weights and crisp performance values of the corresponding criteria were multiplied to obtain the weighted performance ratings as input data to FIS. It could be observed that after multiplication, the values were reduced. To solve this problem, these numbers were normalized. Overall, the steps of the developed FPP-FIS model are as follows:

Step 1: Determining the evaluative sustainability attributes.

Step 2: Collecting the data sets for the importance weight of each attribute and computing their global weights.

Step 3: Collecting the data sets for the performance value of each attribute with respect to a construction project and obtaining their crisp performance values.

Step 4: Multiplying the global weights with the crisp performance values.

Step 5: Running the FIS for each project to compute its overall performance based on the sustainability criteria.

Step 6: Ranking the projects and selecting the most suitable alternative.

3. Case study

In order to implement the developed integrated FPP-FIS model for project selection with respect to sustainability criteria, a real construction case company in Iran, called “company ABFA” henceforth, has been selected. In the recent decades, company ABFA was known as one of the top ten construction companies in Iran. In the past five years, it was considered as one of the top three best construction companies in the country. The company is trying to have an accurate project selection system with the purpose of increasing its performance based on sustainability criteria.

The developed FPP-FIS decision support model was applied to evaluate six construction projects in Iran with respect to sustainability attributes. All the six projects are about recreational and commercial complex or recreational and tourism complex. These types of projects have been high on the agenda in Iran in the last two decades. These projects are:

- Aflak recreational and commercial complex (P1);
- Aayat recreational, commercial and official complex (P2);
- Cyrus the great recreational and tourism complex (P3);
- Rostam E Dastan recreational and tourism complex (P4);
- Sepahan recreational and commercial complex (P5);
- Vahdat recreational and commercial complex (P6).

3.1. Determining the suitable attributes or criteria

As shown in Section 2.4, the first step of the model is to determine a list of evaluative criteria. To this end, a comprehensive review of the literature was conducted and a list of criteria was selected from the literature. In this re-

search, there were three experts (two from academia and one from CI) for determining the suitable sustainability criteria. The first expert is a professor in civil engineering (project management) with 19 years of experience in collaboration with the industry. The second expert is an associate professor in civil engineering (environmental development) with 11 years of teaching in this area with a focus on sustainability. The third expert is the project manager of company ABFA with 23 years of experience in CI.

The initial list of the evaluative criteria (including 3 categories with 15 attributes) was presented to the experts. After two rounds of discussion and revision, they expressed their satisfaction on the suitability of the set of criteria and did not request any further change. Table 2 presents the final set of criteria along with their definitions.

Table 2. The determined criteria for evaluation

Category	Criteria	Definition
Economic	Initial cost (C11)	The initial cost for starting the project.
	Period of construction (C12)	The duration needed for completing the project.
	Financial risk (C13)	The financial risk or loss that may be incurred by the project.
	Risk of extra time (C14)	The risk of requiring extra time for finishing the project.
	Level of technology (C15)	The level of technology which is applied in the project.
	Size and level of difficulties of the project (C16)	The size, scale and level of complexities of the project.
Social	Effect of the project on the growth of the region (C21)	The project must bring benefits to the growth of the region.
	Safety of other projects in the region (C22)	The project must not affect the safety of other existing projects in the region.
	Project suitability based on government standards (C23)	The project suitability must be aligned with the legal rules and standards defined by the government.
	Safety of the people in the region (C24)	The project must be safe and non-hazardous for the people in the region.
	Job opportunities for the residents in the region (C25)	The project must bring new job opportunities for the residents in the region.
Environmental	Air pollution (C31)	The project must not produce gases and particles that are harmful to the environment.
	Toxic materials (C32)	The project must not use and dispose dangerous toxic materials during construction.
	Noise pollution (C33)	The project must not produce noise pollution during construction.
	Nature destruction (C34)	The project must not cause destruction to the natural environment of the region.

3.2. Computing the weights of the criteria using FPP

The second step of the proposed model is collecting the data sets for the importance degree of each criterion. To do this, questionnaires were developed and distributed to four experts of company ABFA. The first expert from the company is the head of operation assessment with 13 years of experience. The second expert is the project manager with 23 years of experience in CI. The third expert is the financial manager with 17 years of experience and the fourth one is the health, safety and environment manager with 19 years of experience.

They were asked to give their opinions about the importance degree of each aspect and each criterion based on a TFN scale from $\tilde{1}$ to $\tilde{9}$ (see Figure 2). Specifically, they evaluated the importance degree of each aspect in comparison with other aspects and each criterion in comparison with other criteria (known as pairwise comparison). After collecting the data sets, the aggregated values were obtained using Eqn (3). Then, by applying FPP, the crisp local weights of the aspects and crisp local weights of the criteria were computed, respectively. Table 3 shows the collected data sets from the experts and the local weight of

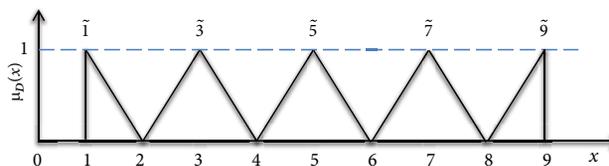


Figure 2. TFN for comparison

each aspect (calculated using Eqn (1)). Tables 4a, 4b and 4c show the local weight of each criterion in each aspect.

Subsequently, by multiplying the local weight of each aspect with the local weight of its corresponding criterion, the global (final) weight of each criterion was obtained. Table 5 presents the global weights of the sustainability criteria.

3.3. Evaluating the projects using the weighted FIS

In order to evaluate the projects, the linguistic data sets were collected from the four experts and these data were aggregated using Eqn (3). Then, the crisp performance values were computed by applying Eqn (2) (see Appendix , Table A.1). Following this, the weighted crisp performance values (as the inputs for FIS) were calculated by multiplying the global weights with the crisp performance values. Table 6 provides the weighted crisp performance values. The FIS was implemented in MATLAB 2017b. As explained earlier, two criteria were used for executing one FIS and this process is shown in Figure 3.

The application of FIS can be illustrated by a rule viewer. As an example, the rule viewer of the FIS related to C11 and C12 for the first project is depicted in Figure 4. In this rule viewer, each rule is a row of plots and each column is an input or criterion. The output can be detected from the output column. Each FIS in the developed model has two inputs and five membership functions. Therefore, the number of rules was 25. After completing the operations in all the stages, the performance value of a project was computed. This process was applied for each project and among the six alternatives, Project 3 (P3) (performance = 4.892) was the most appropriate project followed by P6 (performance = 4.710), P4 (performance = 3.993), P1 (performance = 3.744), P5 (performance = 3.701) and P2 (performance = 3.533).

4. Validation and sensitivity analysis

In the integrated model, FPP and FIS were used. So, two validation methods were performed to show the robustness of the developed model: 1) Checking the consistency index for FPP and 2) Using different defuzzification techniques such as Smallest of Maximum (SOM), Bisector of Area (BOA), Mean of Maximum (MOM), Largest of Maximum (LOM) and Center of Area (COA) for FIS (Amindoust & Saghafinia, 2017).

4.1. Checking the consistency index

Mikhailov (2004) pointed out that the consistency index, λ must be greater than zero and less than or equal to one.

Table 3. The opinions of the experts about the aspects and the local weight of each aspect

	Economic	Social	Environmental
Expert 1			
Economic	1	$\tilde{1}$	$\tilde{2}$
Social		1	$\tilde{4}$
Environmental			1
Expert 2			
Economic	1	$\tilde{1}$	$\tilde{4}$
Social		1	$\tilde{1}$
Environmental			1
Expert 3			
Economic	1	$\tilde{2}^{-1}$	$\tilde{2}^{-1}$
Social		1	$\tilde{3}$
Environmental			1
Expert 4			
Economic	1	$\tilde{1}$	$\tilde{3}$
Social		1	$\tilde{4}$
Environmental			1
Aggregated Fuzzy Values			
Economic	1	(0.833, 0.875, 1.75)	(1.583, 2.375, 3.25)
Social		1	(2.25, 3, 4)
Environmental			1
The local weight of the aspect	0.402	0.283	0.315
The value of λ for FPP ($0 \leq \lambda \leq 1$)	0.9034		

Table 4a. The aggregated values and local weights of the criteria in the economic aspect

	C11			C12			C13			C14			C15			C16		
C11	1	1	1	1	2	3	3.5	4.5	5.5	4.25	5.25	6.25	6.75	7.75	8.75	2.75	3.75	4.75
C12				1	1	1	4.75	5.75	6.75	6.25	7.25	8.25	2.75	3.75	4.75	6.5	7.5	8.5
C13							1	1	1	1	2	3	3.25	4.25	5.25	5.5	6.5	7.5
C14										1	1	1	3.75	4.75	5.75	4.5	5.5	6.5
C15													1	1	1	3	4	5
C16																1	1	1
	C11			C12			C13			C14			C15			C16		
Local weight	0.23410			0.19875			0.11756			0.15360			0.13526			0.16073		
The value of λ for FPP ($0 \leq \lambda \leq 1$)										0.8403								

Table 4b. The aggregated values and local weights of the criteria in the social aspect

	C21			C22			C23			C24			C25		
C21	1	1	1	1	2	3	3.5	4.5	5.5	4.25	5.25	6.25	6.75	7.75	8.75
C22				1	1	1	4.75	5.75	6.75	6.25	7.25	8.25	2.75	3.75	4.75
C23							1	1	1	1	2	3	3.25	4.25	5.25
C24										1	1	1	3.75	4.75	5.75
C25													1	1	1
	C21			C22			C23			C24			C25		
Local weight	0.2598			0.1952			0.1102			0.1986			0.2362		
The value of λ for FPP ($0 \leq \lambda \leq 1$)										0.7963					

Table 4c. The aggregated values and local weights of the criteria in the environmental aspect

	C31			C32			C33			C34			
C31	1	1	1	2.75	3.75	4.75	2.25	3.25	4.25	4.25	5.25	6.25	
C32				1	1	1	4.75	5.75	6.75	3.5	4.5	5.5	
C33							1	1	1	1	2	3	
C34										1	1	1	
	C31			C32			C33			C34			
Local weight	0.3598			0.2952			0.1350			0.2100			
The value of λ for FPP ($0 \leq \lambda \leq 1$)										0.8759			

Table 5. The global weights of the sustainability criteria

Criteria	Global Weight
C11	$0.402 \times 0.2341 = 0.094$
C12	0.080
C13	0.047
C14	0.062
C15	0.054
C16	0.065
C21	0.074
C22	0.055
C23	0.031
C24	0.056
C25	0.067
C31	0.113
C32	0.093
C33	0.043
C34	0.066

If $\lambda < 0$, the initial opinions are unacceptable while if $\lambda = 1$, the initial thoughts are perfectly consistent. The value of λ for the aspects pairwise comparison is 0.9034. In terms of the economic aspect, the value of λ for its corresponding criteria is 0.8403. With respect to the social and environmental dimensions, the values of λ for their corresponding criteria are 0.7963 and 0.8759, respectively. As these numbers are positive and close to one, it can be concluded that the global weights are reliable and the model is applicable.

4.2. Applying different defuzzification methods

It is recommended that to verify the robustness of a FIS-based model, sensitivity analysis via changing the defuzzification method is an appropriate way (Singh et al., 2018). To this end, five different methods (COA, BOA, MOM, SOM and LOM) were analyzed. Table 7 shows that by changing the defuzzification method, the rankings of the projects are comparatively similar; which means the model is valid. It is seen that P3 is still the most suitable project for company ABFA.

Table 6. The weighted crisp performance values for FIS

	C11	C12	C13	C14	C15	C16	C21	C22	C23	C24	C25	C31	C32	C33	C34
P1	0.423	0.380	0.165	0.310	0.149	0.374	0.370	0.248	0.109	0.168	0.385	0.565	0.233	0.108	0.165
Normalized Value	78.189	82.609	70.213	86.835	55.185	100.000	86.854	78.481	70.323	52.174	100.000	86.923	43.551	43.725	55.556
P2	0.329	0.280	0.118	0.155	0.162	0.179	0.259	0.165	0.109	0.112	0.184	0.254	0.326	0.151	0.198
Normalized Value	60.813	60.870	50.213	43.417	60.000	47.861	60.798	52.215	70.323	34.783	47.792	39.077	60.935	61.134	66.667
P3	0.541	0.400	0.212	0.295	0.270	0.293	0.426	0.303	0.155	0.322	0.335	0.565	0.535	0.215	0.297
Normalized Value	100.000	86.957	90.213	82.633	100.000	78.342	100.000	95.886	100.000	100.000	87.013	86.923	100.000	87.045	100.000
P4	0.470	0.280	0.118	0.217	0.162	0.374	0.204	0.316	0.140	0.196	0.201	0.650	0.256	0.215	0.297
Normalized Value	86.876	60.870	50.213	60.784	60.000	100.000	47.887	100.000	90.323	60.870	52.208	100.000	47.850	87.045	100.000
P5	0.541	0.400	0.212	0.310	0.135	0.163	0.259	0.165	0.085	0.280	0.302	0.396	0.279	0.215	0.165
Normalized Value	100.000	86.957	90.213	86.835	50.000	43.583	60.798	52.215	54.839	86.957	78.442	60.923	52.150	87.045	55.556
P6	0.329	0.460	0.235	0.357	0.189	0.309	0.426	0.248	0.078	0.252	0.369	0.650	0.326	0.247	0.297
Normalized Value	60.813	100.000	100.000	100.000	70.000	82.620	100.000	78.481	50.323	78.261	95.844	100.000	60.935	100.000	100.000

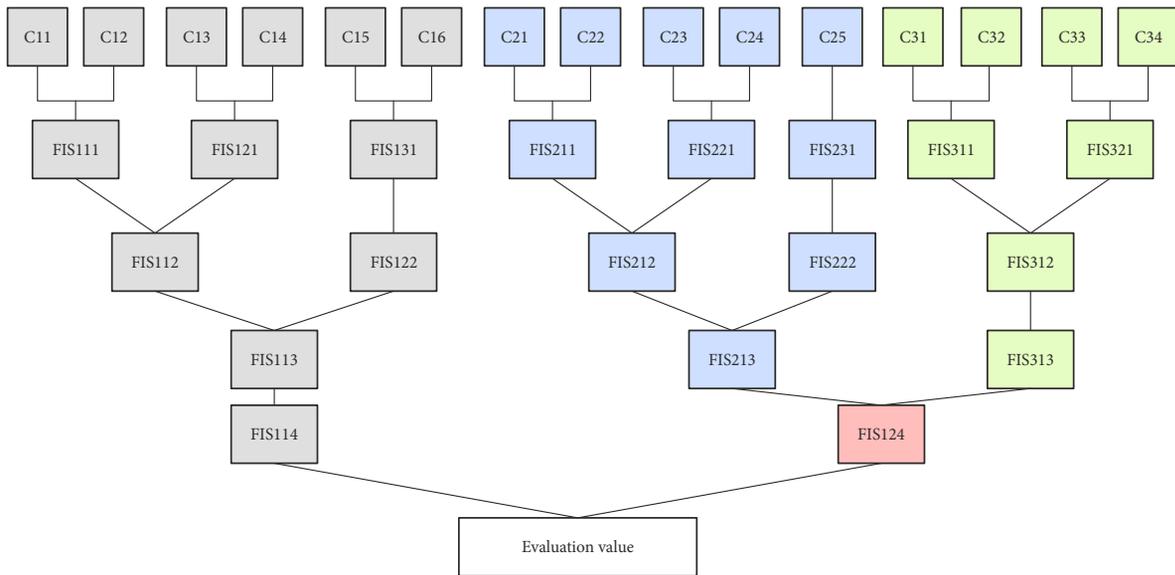


Figure 3. The process of implementing FIS using the weighted inputs

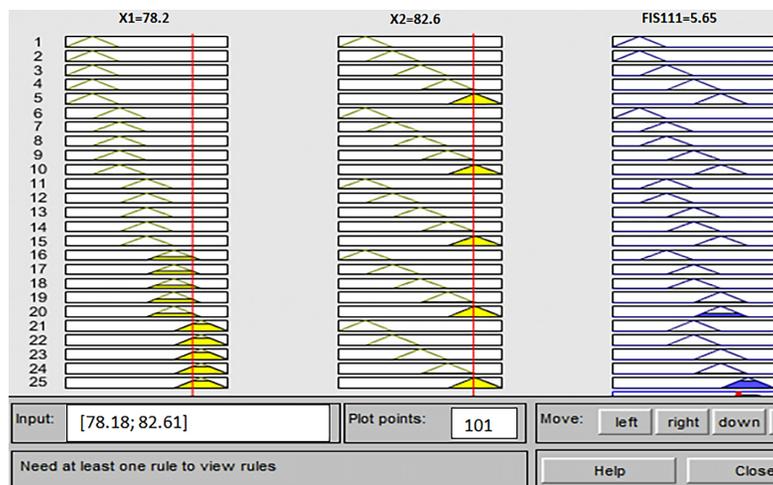


Figure 4. Rule viewer of the FIS associated with criteria C11 and C12 for the first project

Table 7. Validation and ranking of the projects

Project	Defuzzification methods				
	COA	BOA	MOM	SOM	LOM
P1	3.739	3.852	3.790	3.824	4.014
Ranking	4	4	4	5	4
P2	3.561	3.190	3.430	3.770	3.773
Ranking	6	6	6	6	6
P3	4.892	4.814	4.440	4.897	4.664
Ranking	1	1	1	1	1
P4	3.991	3.923	3.810	3.885	4.091
Ranking	3	3	3	4	3
P5	3.704	3.700	3.540	3.972	3.974
Ranking	5	5	5	3	5
P6	4.714	4.681	4.050	4.361	4.604
Ranking	2	2	2	2	2

5. Discussion

In this research, a comprehensive literature review was conducted to determine a list of sustainability criteria for SPS. By using FPP, the global weight of each criterion was obtained. Then, a fuzzy rule-based approach was developed to evaluate the projects and select the best alternative. The findings from the weighting process show that among the three main sustainability categories, the economic aspect with a local weight of 0.402 is the most important based on the experts' opinions. This implies that the economic aspect which covers criteria such as initial cost (C11), period of construction (C12), financial risk (C13), risk of extra time (C14), level of technology (C15), and size and level of difficulties of the project (C16) is very crucial for the managers. In comparison with previous studies, this result is in line with the findings obtained by Hatefi and Tamošaitienė (2018) and Zolfani et al. (2018). The environmental aspect with a local weight of 0.315 is the second most important aspect and it includes air pollution (C31), toxic materials (C32), noise pollution (C33), and nature destruction (C34). Similarly, Siew (2016) has shown that environmental-based attributes are the second most important criteria for assessing the sustainability of construction projects. This finding has also been echoed in the research conducted by Zolfani et al. (2018). The social aspect has a local weight of 0.283 and it covers effect of the project on the growth of the region (C21), safety of other projects in the region (C22), project suitability based on government standards (C23), safety of the people in the region (C24), and job opportunities for the residents in the region (C25). Comparatively, Mavi and Standing (2018) have shown that the third most crucial success factor for sustainable construction project management is related to the social aspect. Overall, the most important criterion is air pollution (C31) from the environmental aspect with a global weight of 0.113. It is followed by initial cost (C11) and toxic materials (C32). This shows that environmental-based attributes are given priority by the experts in this research. Moreover, the results show that the best alternative is P3. In the second place and third

place are P6 and P4, respectively and P2 is the least preferred alternative.

Two different tests were applied to demonstrate the validity and robustness of the developed model under uncertainty. The first test was checking the consistency index λ . Consistency is higher if λ is closer to one. The results show that the λ values for all the pairwise comparisons are close to one. The second test was using different defuzzification methods. In all the defuzzification methods, P3 is found to be the best alternative.

6. Managerial implications

This study provides several managerial and practical implications for managers of construction projects, especially those in Iran. These implications can be studied from two perspectives: i) Incorporation of the sustainability concept into construction project evaluation and selection and ii) Development of the hybridized FPP-FIS model. The results gained from these two perspectives are very useful to practitioners in this field.

This research has generated a suitable list of sustainability-focused criteria for SPS. Fifteen criteria in three aspects (economic, social and environmental) were determined and their definitions were given. This list of criteria along with their definitions can help managers to understand the concept of sustainability for construction project selection. The global weights obtained for the criteria can also provide hints to managers in setting their priorities and emphasis for SPS.

An effective hybridized FPP-FIS model was developed to evaluate the projects with respect to the sustainability criteria. FPP was performed to manage the weighting problem of the initial AHP. In addition, FIS was used as an expert system to assess the projects because it could deal with the problem of uncertainty and vagueness. The developed model can also be utilized by decision makers to assess and select sustainable locations or technologies for construction projects. By applying this model, managers in CI can recognize and select alternatives which will decrease environmental impacts while bringing benefits to the economy and society.

Conclusions, limitations and future work

The current study has combined FPP with FIS to introduce a model for assessing and selecting construction projects using 15 evaluative criteria under 3 sustainability aspects. Literally, there is a lack of attention on developing suitable decision support models for SPS under uncertainty. From the context of decision making models for SPS, the combination of FPP-FIS is new. Using FPP, the local weights of the aspects and criteria, and the global weights of the criteria were obtained. Then, by utilizing FIS, the performances of the projects were computed and the best alternative according to the attributes was obtained. The contributions of the investigation are:

- A comprehensive list of evaluative sustainability criteria for SPS was generated.

- A hybridized fuzzy MCDM model was developed for evaluating and selecting the most suitable project under uncertainty and vagueness.
- The application of FPP and FIS and their integration were performed for the first time in the area of SPS.
- The application of FPP weights in FIS made the evaluation process more representative and reliable.

Although this research is new, there are some limitations. Firstly, the developed model was implemented in an Iranian construction company and thus, the findings obtained could not be generalized to every country. Fifteen evaluative attributes were utilized in this study but the criteria in other companies or countries could be different and researchers can use more or different criteria for decision making. The pairwise comparisons for all the sustainability aspects and criteria were time consuming (Rezaei, 2015). By increasing the number of criteria, the time required for computing their weights would increase. Moreover, two inputs were utilized for the FIS structure in this study. Raising the number of inputs would increase the number of fuzzy rules and make the process more complicated.

As FPP is a time consuming approach, the Best-Worst Method (BWM) as a new weighting technique can be considered in future research. Some of the evaluative criteria may have effects on other criteria, so techniques such as Fuzzy Decision Making Trial and Evaluation Laboratory (FDEMATEL) etc., are appropriate to determine the relationships between these attributes in future studies. Finally, other MCDM methods can be used and their results can be compared with this research.

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Author contributions

Overall, all authors contributed to writing, revising and improving the final manuscript.

Disclosure statement

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APPENDIX

Table A.1. The experts' opinions about the projects

		C11	C12	C13	C14	C15	C16	C21	C22	C23	C24	C25	C31	C32	C33	C34
P1	Exp. 1	M	M	P	M	P	VG	G	M	P	P	VG	G	VP	P	VP
	Exp. 2	G	G	M	VG	VP	VG	G	G	M	P	VG	M	VP	VP	VP
	Exp. 3	G	G	M	G	P	VG	G	G	M	P	VG	VG	P	P	P
	Exp. 4	M	G	P	G	P	G	G	M	P	P	G	G	P	VP	P
Aggregated Crisp Value		4.5	4.75	3.5	5	2.75	5.75	5	4.5	3.5	3	5.75	5	2.5	2.5	2.5
P2	Exp. 1	P	M	VP	P	P	P	M	P	M	VP	P	VP	P	M	P
	Exp. 2	M	P	VP	VP	P	VP	M	P	P	VP	VP	VP	M	P	P
	Exp. 3	M	P	P	VP	P	P	M	P	P	VP	P	VP	M	P	P
	Exp. 4	P	M	P	P	P	P	VP	P	M	VP	P	P	P	M	P
Aggregated Crisp Value		3.5	3.5	2.5	2.5	3	2.75	3.5	3	3.5	2	2.75	2.25	3.5	3.5	3
P3	Exp. 1	VG	G	M	M	G	M	VG	VG	G	VG	G	G	G	G	M
	Exp. 2	VG	G	G	G	G	G	VG	VG	M	VG	G	VG	VG	G	M
	Exp. 3	VG	G	G	G	G	G	VG	G	VG	VG	G	M	VG	G	G
	Exp. 4	G	G	M	G	G	M	G	G	G	G	G	G	VG	G	G
Aggregated Crisp Value		5.75	5	4.5	4.75	5	4.5	5.75	5.5	5	5.75	5	5	5.75	5	4.5
P4	Exp. 1	G	M	VP	P	P	VG	P	G	M	P	P	VG	P	G	M
	Exp. 2	G	P	VP	M	P	G	VP	VG	G	M	P	VG	VP	G	G
	Exp. 3	G	P	P	M	P	VG	P	VG	G	M	P	VG	P	G	G
	Exp. 4	G	M	P	P	P	VG	P	VG	M	P	P	G	P	G	M
Aggregated Crisp Value		5	3.5	2.5	3.5	3	5.75	2.75	5.75	4.5	3.5	3	5.75	2.75	5	4.5
P5	Exp. 1	VG	G	M	G	VP	VP	P	P	P	G	M	P	P	G	VP
	Exp. 2	VG	G	G	M	VP	VP	M	P	VP	G	G	M	P	M	VP
	Exp. 3	G	G	G	VG	P	P	M	P	P	G	G	M	P	VG	P
	Exp. 4	VG	G	M	G	P	P	P	P	P	G	M	P	P	G	P
Aggregated Crisp Value		5.75	5	4.5	5	2.5	2.5	3.5	3	2.75	5	4.5	3.5	3	5	2.5
P6	Exp. 1	M	VG	M	VG	M	G	VG	M	P	G	VG	VG	M	VG	M
	Exp. 2	P	VG	VG	VG	M	G	VG	G	VP	G	VG	G	M	VG	G
	Exp. 3	P	G	G	VG	P	G	VG	G	P	M	G	VG	P	VG	G
	Exp. 4	M	VG	G	G	P	M	G	M	VP	M	G	VG	P	G	M
Aggregated Crisp Value		3.5	5.75	5	5.75	3.5	4.75	5.75	4.5	2.5	4.5	5.5	5.75	3.5	5.75	4.5