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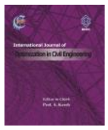

INTELLIGENT BUILDING ASSESSMENT BASED ON AN INTEGRATED MODEL OF FUZZY ANALYTIC HIERARCHY PROCESS AND FUZZY PREFERENCE DEGREE APPROACH (FAHP-FPDA)

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ABSTRACT

Intelligent building (IB) technologies have widespread applications in the building design and development. In this regard, it is necessary to develop intelligent building assessment models in order to satisfy the clients, professionals, and occupants' growing demands. To this end, this paper proposes an integrated analytic hierarchy process (AHP) and preference degree approach (PDA) under the fuzzy environment for the purpose of intelligent building assessment. Fuzzy AHP is employed to determine the local weights of performance criteria and the final weights of the intelligent building alternatives. Since, the final weights of intelligent buildings (IBs) are in the form of fuzzy numbers, fuzzy PDA is utilized to prioritize the intelligent buildings. Finally, fuzzy AHP-fuzzy PDA is proposed to assess the performance of five intelligent building alternatives in Isfahan, Iran.

Keywords: intelligent building assessment; fuzzy decision making; fuzzy AHP; fuzzy PDA.

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1. INTRODUCTION

There are various definitions of intelligent buildings in the related literature. European Intelligent Building Group in the U.K defines intelligent building as “the one that creates an environment which maximizes the effectiveness of the building’s occupants while at the same time enabling the efficient management of resources with minimum life-time costs of hardware and facilities”. This main emphasis of this definition has been placed on the users’

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requirements, while the definition proposed by Intelligent Building Institute of the United States lays the main emphasis on technologies. This institute defines intelligent building as ‘a building which provides a productive and cost-effective environment through the optimization of its four basic elements, including structures, systems, services; and management as well as the interrelationships between them’ [1]. Different interpretations can be concluded from these definitions. Himanen [2] states a more balanced definition of intelligent building as follows ‘One’s performance can be implemented with environmental friendliness, flexibility and utilization of space, movable space elements and equipment, life cycle costing, comfort, convenience, safety and security, working efficiency, an image of high technology, culture, construction process and structure, long term flexibility and marketability, information intensity, interaction, service orientation, ability of promoting health, adaptability, reliability, and productivity’. The definitions proposed by Himanen [2] are so important that they reflect the significance of the integrated and intelligent systems in that they act as a balance between building contents, the organization, and services that determine whether or not the value objectives of clients, facility managers, and users are achieved. These objectives include the creation of a highly energy efficient and environmentally-friendly built environment with substantial safety, security, well-being and convenience, lower life-cycle cost, long term flexibility, and marketability. The fulfillment of these objectives will produce a building with the highest social, environmental, and economic values.

IBs employed sophisticated operational systems to improve lifecycle cost efficiency and environmental performance [3]. During the 1990s, the concept of IBs was associated with the relationship between “users, building systems, and the environment” as well as the key components of “quality of life”. The initial definition of intelligent building focuses on the role of technology in building design, while the current definition places the main focus on the role of user interactions and social changes where the dimension of quality of life are recommended [2, 4]. In this manner, a large number of similar definitions state that the current IBs should meet user expectations and quality of life. For example, Clements-Croome [5] stated that “intelligent buildings are not just about technology, it is more about their suitability for their planned use and success at fulfilling the brief”. Kaya and Kahraman [6] mentioned that the main focus of IBs has shifted towards the concept of learning capability and the linkage between occupants and the environment.

Some researchers have pointed to energy-saving as an important feature of IB technologies [7]. For example, Yang [8] recommended that “the main objective of the intelligent building design is to satisfy the occupants’ need with high energy efficiency”. Furthermore, the integration of user involvement with the sustainable energy performance of buildings as well as the adaptability of buildings to climatic changes are two key elements highlighted by Nguyen and Aiello [9] and Thompson et al. [10]. To meet the important objectives of intelligent buildings, such buildings should be highly responsive to user expectations, the environment, and the society, and should be capable of minimizing the environmental impacts and the wastes obtained from natural resources [11]. In addition, the operational costs can be reduced while the energy performance is maximized and the safety, health, and well-being are promoted [12].

According to the aforementioned descriptions, the IBs definitions have undergone some changes and have been completed over time [3]. The main components of intelligence embedded in IBs are technology, function, and economy [13]. The key features of intelligence in the contexts can be classified as follows [3]:

(1) Environmental friendliness through sustainable design for the conservation of energy and water; waste management; and reduction of air pollution

(2) Effective space utilization and flexibility

(3) Economic justification of lifetime costs

(4) Health, sanitation, and well-being of people

(5) Working efficiency and effectiveness

(6) Safety and security in the face of earthquake, fire, disaster, and structural damages

(7) Culture; meeting user needs and expectations

(8) Effective innovative technology

The evolution of intelligent buildings indicates that the essential requirements and regulations are created from social, environmental, and economic perspectives to have an efficient and intelligent design. In this regard, building assessment is becoming more popular, as a standard method, for the evaluation of the new and existing building designs. Researchers and builders have assigned attention to the building assessment in order to succeed in the compliance of the intelligent building design with new rules and regulations. A major part of the intelligent building literature has been assigned to the development of an index for the evaluation of intelligent buildings [4, 14]. In this line of research, Asian Institute of Intelligent Buildings has introduced a novel index, entitled 'Intelligent Building Index' (IBI) for the performance measurement of intelligent buildings [15-16]. In this connection, So and Wong [17] proposed a novel intelligent building index (IBI) for the quantitative assessment of IBs. According to the developed index, intelligent buildings can be prioritized from A to E to show the overall intelligent performance [17]. Arkin and Paciuk [18] have introduced a novel index called "Magnitude of Systems' Integration" for intelligent building appraisal. Yang and Peng [19] employed MSIR index to determine the level of systems' integration of intelligent buildings. Preiser and Schramm [20] proposed a novel method to determine the intelligence level of intelligent buildings. Kolokotsa et al. [21] introduced a novel approach based on a matrix tool for the evaluation of buildings' intelligence. The main objective of the proposed matrix tool is to help managers with an efficient way for the improvement of energy and environmental performance of indoor buildings.

There are various models and approaches developed in the related literature that assess the performance of intelligent buildings. In this line of research, Vyas and Jha [22] applied principal component analysis to identify the green building attributes and developed an assessment model for the sustainability building assessment in India. Chen et al. [23] developed a cost-benefit evaluation tool for building intelligent systems by focusing on the energy consumption. Multi-criteria decision-making methods are efficient tools for intelligent building appraisal. These methods evaluate a set of alternatives based on the evaluation criteria. Most of the studies in this area have employed only the financial criteria for IB assessment and have ignored the other non-financial criteria. However, the inclusion of both financial and non-financial criteria is recommended for IB assessment [24]. The application of AHP method for intelligent building assessment can be found in the research carried out by Wong and Li [25] and ALwaer and Clements-Croome [26]. In this line of research, Chen et al. [27] proposed the employment of the analytic network process for evaluating the lifespan energy efficiency of intelligent buildings. Kutut et al. [28] utilized AHP and Additive Ratio Assessment (ARAS) methods to assess priority alternatives for the preservation of historic buildings. Medineckiene et al. [29] introduced AHP and ARAS methods for sustainable building assessment and certification. Raslanas et al. [30] proposed an assessment model based on the environmental, social, and economic sustainability for recreational buildings.

Some researchers proposed utilizing the fuzzy form of multi-criteria decision-making (MCDM) methods to measure the performance of intelligent buildings. In this connection, Kahraman and Kaya [31] developed a fuzzy multiple attribute utility (MAUT) model for the assessment of intelligent buildings. The goal of their proposed model is to solve problems of trading off the achievement of some objectives against other objectives to obtain the maximum overall utility. The authors utilized the proposed model to evaluate three alternative intelligent buildings for a business center in Istanbul, Turkey. Kaya and Kahraman [6] proposed two fuzzy MCDM models, namely fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and fuzzy AHP for intelligent building evaluation. The authors applied their proposed models to evaluate three intelligent building in Turkey. Ku et al. [32] uses fuzzy AHP and fuzzy transformation matrix for evaluation of intelligent green building policies in during 1999–2015. The authors presented that implementation of control measures in the stage of design and planning for new buildings is superior to the control in the stage of operation and management in effectiveness.

According to the aforementioned points, there is little literature, if any, on the intelligent building assessment by fuzzy MCDM methods. Fuzzy MCDM methods are efficient tools for the evaluation and prioritization of alternatives. To fulfil this gap, this paper proposes an integrated fuzzy AHP-fuzzy PDA model for the measurement of intelligent building alternatives under the fuzzy environment. The proposed model helps decision-makers easily determine the weights of the evaluation criteria and prioritize intelligent building alternatives. Furthermore, the proposed model supports the existing epistemic uncertainty in the data that should be gathered via expert opinion. Fuzzy AHP is used to determine the local weights of evaluation criteria and the final weights of intelligent building alternatives. Furthermore, fuzzy PDA helps decision-makers prioritize intelligent buildings based on their final weights. The proposed fuzzy AHP-fuzzy PDA is applied to measure and rank five intelligent building alternatives in Isfahan, Iran.

2. INTEGRATED FUZZY AHP AND FUZZY PDA MODEL

This paper was an attempt to propose an integrated method of fuzzy AHP and Fuzzy PDA model for intelligent building assessment. Fuzzy AHP helps decision-makers obtain the local weights of criteria, sub-criteria, and IB alternatives. Furthermore, it determines the final weights of IB alternatives. As the final weights of IB alternatives are in the form of fuzzy numbers, these alternatives cannot be prioritized based on their final weights. Fuzzy preference degree approach is an efficient tool for ranking the fuzzy numbers. Therefore, this paper proposes utilizing the fuzzy preference degree approach to prioritize IB alternatives based on their final fuzzy weights.

2.1 Fuzzy AHP

This section explains how fuzzy AHP can obtain the local weights of the evaluation criteria and the final weights of the intelligent building alternatives. The main steps of fuzzy AHP are as follows [33]:

Step 1: In the first step of applying fuzzy AHP, several pairwise comparisons are made to provide the fuzzy pairwise comparison matrix (PCM). Expert' opinions about the performance criteria are converted into fuzzy scales according to Table 1. Suppose $\tilde{A}^k = [\tilde{a}_{ij}^k]$ is the fuzzy judgment matrix of the *k*th expert, and $\tilde{a}_{ij}^k$ is the fuzzy evaluation between criterion *i* and criterion *j* of the *k*th expert. $\tilde{a}_{ij}^k$ represents a fuzzy triangular number. The following relations are used to provide a fuzzy PCM:

$$\begin{aligned} &\tilde{a}_{ij}^k = (l_{ij}^k, m_{ij}^k, u_{ij}^k) \\ &\tilde{a}_{ij}^k = (1,1,1) \ for\ i = j \\ &\tilde{a}_{ji}^k = \frac{1}{\tilde{a}_{ij}^k} = (\frac{1}{u_{ij}^k}, \frac{1}{m_{ij}^k}, \frac{1}{l_{ij}^k}) \end{aligned} \tag{1}$$

where l_{ij}^k, m_{ij}^k and u_{ij}^k denote the pessimistic, the most likely, and the optimistic values, respectively. According to formula (2), the geometric mean method is applied to aggregate the experts' judgments and obtain the aggregated fuzzy PCM ($\tilde{A}_{ij}$). As shown in formula (2), *l*, *m*, and *u* denote the minimum possible, the most likely, and the maximum possible values of a fuzzy number, respectively.

$$\begin{aligned} &\tilde{A}_{ij} = [\tilde{a}_{ij}]; \tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij});\ l_{ij} \le m_{ij} \le u_{ij};\ l_{ij}, m_{ij}, u_{ij} \in [\frac{1}{9}, 9] \\ &l_{ij} = (l_{ij}^1 \times l_{ij}^2 \times \cdots \times l_{ij}^K)^{1/K} \\ &m_{ij} = (m_{ij}^1 \times m_{ij}^2 \times \cdots \times m_{ij}^K)^{1/K} \\ &u_{ij} = (u_{ij}^1 \times u_{ij}^2 \times \cdots \times u_{ij}^K)^{1/K} \end{aligned} \tag{2}$$

Table 1: The linguistic scale and underlying triangular fuzzy number

Linguistic scales	Scale of fuzzy number
$\tilde{1} = (1,1,1)$	Equally important
$\tilde{3} = (1,3,5)$	Weakly important
$\tilde{5} = (3,5,7)$	Essentially important
$\tilde{7} = (5,7,9)$	Very strongly important
$\tilde{9} = (7,9,9)$	Absolutely important

Step 2: In this step, the local fuzzy weight of each aggregated fuzzy PCM is calculated based on the geometric mean. Assume that $\tilde{f}_i$ denotes the geometric mean obtained from the *i*th row of the aggregated fuzzy PCM. Then, the non-normalized local weights $(\tilde{W}_i)$ can be calculated as follows:

$$\begin{aligned} \tilde{f}_i &= (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \ldots \otimes \tilde{a}_{in})^{1/n} \\ \tilde{W}_i &= \tilde{f}_i \otimes \left(\tilde{f}_1 \otimes \tilde{f}_2 \otimes \ldots \otimes \tilde{f}_n\right)^{-1} \end{aligned} \tag{3}$$

The non-normalized local weights are in the form of triangular fuzzy numbers $\tilde{W}_i = (L_i, M_i, U_i)$. Therefore, the fuzzy local weights can be calculated according to $\tilde{w}_i = (L_i, M_i, U_i) / Max\{U_i\}$. It should be noted that the fuzzy local weights of criteria, sub-criteria, and alternatives are obtained in this step.

Step 3: Suppose $\tilde{w}^C$, $\tilde{w}^{Sub}$ and $\tilde{w}^A$ are the matrices of local weights for criteria, sub-criteria, and alternatives, respectively. In AHP procedure, the final weight of each alternativeion of these matrices by each other. is obtained through the multiplicat $(\tilde{w}_j^f)$ Therefore, the final weights of the alternatives are calculated as follows:

$$\tilde{w}^f = \tilde{w}^C \otimes \tilde{w}^{Sub} \otimes \tilde{w}^A \tag{4}$$

According to the above formula, the final weights or the final scores of the alternatives, which are in the form of fuzzy triangular numbers, can be determined. It is a complex task to prioritize the alternatives based on their final scores; therefore, this paper suggests using the fuzzy preference degree approach to rank the alternatives. Fuzzy PDA is a powerful tool for prioritizing fuzzy numbers, which is explained in the next section.

2.2 Fuzzy preference degree approach

There are various ranking methods in the extant literature for the comparison of fuzzy numbers. One of them is fuzzy preference degree approach (PDA) that has been presented by Wang et al. [34]. Fuzzy PDA is an efficient method for comparing and prioritizing fuzzy triangular numbers. In this paper, the final scores of the alternatives (here intelligent buildings) are also stated in the form of fuzzy triangular numbers. Therefore, this paper employs Fuzzy PDA to prioritize IB alternatives based on their final weights, which are taken from fuzzy AHP method. To explain fuzzy PDA, suppose $\tilde{a} = (a_l, a_m, a_u)$ and $\tilde{b} = (b_l, b_m, b_u)$ are two triangular fuzzy numbers. According to the fuzzy arithmetic rules, $\tilde{a} - \tilde{b}$ is also regarded as a triangular fuzzy number with such possible fuzzy relations as $a_u \le b_l$, $(a_u > b_l) \cap (a_m > b_m)$, $a_l \ge b_u$ or $(a_m > b_m) \cap (a_l > b_u)$. Accordingly, the order of magnitude of $\tilde{a} > \tilde{b}$ and $\tilde{b} > \tilde{a}$ is defined as the following equations [34].

$$p(\tilde{a} > \tilde{b}) = \begin{cases} 1 & if\ a_l \geq b_u \\ 0 & f\ a_u \leq b_l \\ \dfrac{(a_u - b_l)^2}{(a_u - b_l + b_m - a_m)(a_u - a_l + b_u - b_l)} & if\ (a_u > b_l) \cap (a_m \leq b_m) \\ 1 - \dfrac{(b_u - a_l)^2}{(b_u - a_l + a_m - b_m)(a_u - a_l + b_u - b_l)} & f\ (a_m > b_m) \cap (a_l < b_u) \end{cases} \tag{5}$$

$$p(\tilde{b} > \tilde{a}) = \begin{cases} 0 & if\ a_l \geq b_u \\ 1 & f\ a_u \leq b_l \\ 1 - \dfrac{(a_u - b_l)^2}{(a_u - b_l + b_m - a_m)(a_u - a_l + b_u - b_l)} & if\ (a_u > b_l) \cap (a_m \leq b_m) \\ \dfrac{(b_u - a_l)^2}{(b_u - a_l + a_m - b_m)(a_u - a_l + b_u - b_l)} & f\ (a_m > b_m) \cap (a_l < b_u) \end{cases} \tag{6}$$

According to Wang et al. [34], the following steps should be pursued to rank the fuzzy numbers.

Step 1: The matrix of degree of preference (*MP*): The elements of this matrix are obtained using equations (5) and (6). In this regard, equation (5) is used for the calculation of the upper elements of the diagonal matrix; and equation (6) is used for the calculation of the bottom elements of the diagonal matrix.

$$Mp = \begin{array}{c} \\ \tilde{\theta}_1 \\ \tilde{\theta}_2 \\ \vdots \\ \tilde{\theta}_n \end{array} \begin{array}{c} \begin{array}{cccc} \tilde{\theta}_1 & \tilde{\theta}_2 & \cdots & \tilde{\theta}_n \end{array} \\ \begin{bmatrix} - & P_{12} & \cdots & P_{12} \\ P_{12} & - & \cdots & P_{12} \\ \vdots & \vdots & \vdots & \vdots \\ P_{12} & P_{12} & \cdots & - \end{bmatrix} \end{array}$$

Step 2: This step is an attempt to find the above matrix's row wherein the order of preferences is equal to or greater than 0.5 for all the elements except the element on the major diagonal and the selected row is the one with the highest preference among the other rows.

Step 3: Here, the row and column of the alternative relating to step 2 are removed and this trend will continue until all the rows and alternatives are removed. In addition, the alternatives are ranked based on the priority of the removed rows and columns.

3. PROPOSED MODEL FOR IB ASSESSMENT IN ISFAHAN

Isfahan has always been the center for trade and commerce due to its strategic location. Since the assessment of an IB requires the consideration of numerous criteria, a fuzzy AHP and fuzzy PDA model are used to assess five intelligent buildings in Isfahan. The intelligent building criteria are selected according to the literature review [25-26], as presented in Table 2.

Table 2: Criteria and sub-criteria for intelligent building assessment

Engineering (C1)	Functionality (C11)
	Safety and structure (C12)
	Working efficiency (C13)
	Responsiveness (C14)
	Office automation (C15)
	Power supply (C16)
	System integration (C17)
Environmental (C2)	Energy consumption (C21)
	Water and Water Conservation (C22)
	Materials used, Durability and Waste (C23)
	Land use and Site selection (C24)
	Greenhouse Gas Emissions (Pollution) (C25)
	Indoor Environmental Quality (C26)
Economical (C3)	Economic performance and affordability (C31)
	Initial costs, operating and maintenance costs (C32)
	Life cycle costing (C33)
Socio-Cultural (C4)	Functionality, Usability and Aesthetic aspects (C41)
	Human comfort (C42)
	Health and sanitation (C43)
	Architectural considerations – cultural heritage integration and the compatibility with local heritage value (C44)
Technological (C5)	Work efficiency (C51)
	Use of high-tech system (C52)
	Use of advanced artificial intelligence(C53)
	Telecom and data system- Connectibility (C54)
	Security monitoring and access control system (C55)
	Addressable fire detection and alarm system (C56)
	Digital addressable lighting control system (C57)

For this purpose, a questionnaire is designed to gather the experts' opinions about the IB criteria, their sub-criteria, and IBs. The questionnaire is designed based on the paired comparisons according to the AHP method. Experts are interviewed through three sets of questions in the form of pairwise comparisons to design the questionnaire. The first set of the questions is the pair-wise comparison questions across all possible combinations of the criteria. In this set, the criteria are compared to each other with respect to the goal. In the second set of questions, the sub-criteria are compared to each other with respect to the relevant criterion. Finally, in the second set of questions, the alternatives are compared with each other with respect to the sub-criteria. The first set of the questions is presented in Table 3. An example of these questions is: "Which criteria do you prefer with respect to your goal and to what degree?"

Table 3: Questions for pairwise comparisons of criteria

Criterion	Absolutely important	Very strongly important	Essentially important	Weakly important	Equally important	Weakly important	Essentially important	Very strongly important	Absolutely important	Criterion
Engineering (C1)	□	□	□	□	□	□	□	□	□	Environmental (C2)
Engineering (C1)	□	□	□	□	□	□	□	□	□	Economical (C3)
Engineering (C1)	□	□	□	□	□	□	□	□	□	Socio-Cultural (C4)
Engineering (C1)	□	□	□	□	□	□	□	□	□	Technological (C5)
Environmental (C2)	□	□	□	□	□	□	□	□	□	Economical (C3)
Environmental (C2)	□	□	□	□	□	□	□	□	□	Socio-Cultural (C4)
Environmental (C2)	□	□	□	□	□	□	□	□	□	Technological (C5)
Economical (C3)	□	□	□	□	□	□	□	□	□	Socio-Cultural (C4)
Economical (C3)	□	□	□	□	□	□	□	□	□	Technological (C5)
Socio-Cultural (C4)	□	□	□	□	□	□	□	□	□	Technological (C5)

Behfar intelligent building is the first company that provides clients with intelligent building services. The main objective of Behfar Middle East Company is to provide appropriate services for intelligent building systems based on the new and up-to-date standards regarding the control of buildings with different functionalities. Some of the intelligent building services provided by Behfar Company include intelligent lighting system, intelligent safety system, intelligent ventilation and air conditioning systems, intelligent audio and video systems, intelligent communication systems, intelligent electrical appliances, and so on. The company will ensure the technical quality of its projects with the help of a trained personnel and through cooperation with a large group of intelligent building engineers in the Middle East. The company has implemented several projects in the field of design and implementation of intelligent building control system in Isfahan, Iran. This article has selected 5 major projects in the field of intelligence building that were conducted by the company. In this study, these intelligent buildings are used as five alternatives, namely Museum of Isfahan province (IB1), Noor Residential Tower (IB2), Meir Official and commercial building (IB3), Asseh Official building (IB4), and professors' Hotel in Isfahan University (IB5). It is noteworthy that although these buildings have different usages, they are compared with each other in terms of the concept of intelligence. In other words, they are evaluated and compared according to the level of their intelligence.

Fifteen experts are selected to complete the questionnaires. To decide upon the desired number of experts, the current researchers used the method conducted by Tüysüz and Kahraman (2006) wherein11 information technology (IT) managers are benefited from to evaluate the risk of the IT projects by AHP method. Furthermore, Kaya and Kahraman [6] used fuzzy Topsis to evaluate 3 IBs in Turkey by interviewing 4 experts. However, all the experts who are able to compare and evaluate the criteria and intelligent building alternatives were used in this paper. Therefore, 15 experts were selected to be interviewed and to complete the questionnaire. Seven experts out of the 15 ones are professors in Civil Engineering and Industrial Engineering. The remaining experts are sufficiently experienced in construction management. They have participated in several projects in the field of design and implementation of intelligent building control systems. They are fully involved in the five intelligent building projects under study.

The experts' opinions are first used to obtain some linguistic evaluations about the criteria, sub-criteria, and alternatives. Thereafter, they are converted to fuzzy numbers according to Table 1 and, then, the fuzzy pairwise comparison matrix is formulated. According to the linguistic scales shown in Table 1, the fuzzy decision matrices for criteria with respect to goals, sub-criteria with respect to criteria, and IB alternatives with respect to sub-criteria are achieved from the questionnaire already filled out by the 15 different experts. For achieving the aggregated fuzzy PCM, the geometric mean, shown in formula (2), is used. For example, the aggregated fuzzy PCM, reported in Table 4, is calculated based on the fifteen experts' opinions. After the provision of the fuzzy PCM, the fuzzy local weights and fuzzy global weights are calculated according to formulas (3) and (4). The fuzzy local weights and the fuzzy global weighs are reported in Table 5.

Table 4: The fuzzy PCM of main criteria

	C1	C2	C3	C4	C5
C1	(1.000,1.000,1.000)	(0.500,0.681,0.940)	(0.143,0.167,0.201)	(0.210,0.243,0.291)	(0.181,0.222,0.291)
C2	(1.064,1.468,2.000)	(1.000,1.000,1.000)	(0.478,0.539,0.621)	(0.736,0.860,1.000)	(0.328,0.384,0.474)
C3	(4.976,5.993,7.005)	(1.609,1.855,2.091)	(1.000,1.000,1.000)	(2.216,2.503,2.754)	(1.704,1.857,1.992)
C4	(3.440,4.111,4.761)	(1.000,1.163,1.359)	(0.363,0.400,0.451)	(1.000,1.000,1.000)	(1.064,1.139,1.238)
C5	(3.440,4.500,5.536)	(2.110,2.604,3.052)	(0.502,0.538,0.587)	(0.808,0.878,0.940)	(1.000,1.000,1.000)

The results of Table 5 show that the local weight of the economical criterion (C2) is equal to (0.823, 0.916, 1), which has taken up the highest weight in comparison with the weights of other criteria. In other words, the economical criterion is of great importance for the purpose of assessing intelligent buildings. Furthermore, the local weight of the technological criterion (C5) is equal to (0.516, 0.586, 0.650), which reveals the high importance of the technological criterion for intelligent buildings assessment compared to the other criteria. The local weights of the intelligent building alternatives are also determined in the same way.

Table 5: The results of fuzzy AHP

Criteria	Fuzzy local weight	Sub-criteria	Fuzzy local weight	Fuzzy global weight
C1	(0.128, 0.150, 0.182)	C11	(0.240, 0.514, 1.000)	(0.031, 0.077, 0.182)
		C12	(0.024, 0.050, 0.112)	(0.003, 0.008, 0.020)
		C13	(0.066, 0.164, 0.389)	(0.008, 0.025, 0.071)
		C14	(0.036, 0.069, 0.205)	(0.005, 0.010, 0.037)
		C15	(0.258, 0.515, 0.792)	(0.033, 0.077, 0.144)
		C16	(0.019, 0.040, 0.090)	(0.002, 0.006, 0.016)
		C17	(0.032, 0.082, 0.182)	(0.004, 0.012, 0.033)

				C21	(0.034,	0.073,	0.201)	(0.009,	0.023,	0.075)
				C22	(0.043,	0.107,	0.216)	(0.012,	0.034,	0.081)
				C23	(0.457,	0.705,	0.889)	(0.125,	0.224,	0.333)
C2	(0.273,	0.318,	0.374)	C24	(0.259,	0.590,	1.000)	(0.071,	0.188,	0.374)
				C25	(0.066,	0.147,	0.415)	(0.018,	0.047,	0.155)
				C26	(0.081,	0.216,	0.504)	(0.022,	0.069,	0.189)
				C31	(0.065,	0.120,	0.252)	(0.053,	0.110,	0.252)
C3	(0.823,	0.916,	1.000)	C32	(0.069,	0.146,	0.251)	(0.057,	0.133,	0.251)
				C33	(0.442,	0.741,	1.000)	(0.364,	0.679,	1.000)
				C41	(0.069,	0.171,	0.341)	(0.031,	0.083,	0.183)
C4	(0.440,	0.486,	0.538)	C42	(0.329,	0.669,	0.864)	(0.145,	0.325,	0.465)
				C43	(0.166,	0.371,	1.000)	(0.073,	0.180,	0.538)
				C44	(0.134,	0.314,	0.795)	(0.059,	0.152,	0.427)
				C51	(0.326	0.492,	0.780)	(0.168,	0.288,	0.507)
				C52	(0.293	0.747,	1.000)	(0.151,	0.438,	0.650)
				C53	(0.079	0.292,	0.703)	(0.041,	0.171,	0.457)
C5	(0.516,	0.586,	0.650)	C54	(0.116	0.274,	0.907)	(0.060,	0.161,	0.590)
				C55	(0.050	0.141,	0.353)	(0.026,	0.083,	0.230)
				C56	(0.039	0.102,	0.286)	(0.020,	0.060,	0.186)
				C57	(0.031	0.077,	0.222)	(0.016,	0.045,	0.144)

The final weights of the intelligent building alternatives are calculated according to formula 4, as reported in Table 6. As per the results of Table 6, the final weights of the alternative are in the form of fuzzy triangular numbers and, hence, it is difficult to prioritize the alternatives based on their final fuzzy weights. Therefore, this paper proposes utilizing the fuzzy preference degree approach to obtain the full ranking of the alternatives. The final fuzzy weights of IB alternatives are applied to implement the fuzzy PDA. According to Wang et al. [34], the provision of MP matrix is the first step in the implementation of the fuzzy PDA. The MP matrix indicates the degree of preference of the alternatives relative to each other, as reported in Table 7. Through the application of steps 2 and 3 of the fuzzy PDA procedure on the MP matrix, the ranks of IB alternatives are determined. According to MP matrix, the order of preference for all the elements in the first row is greater than 0.5 and, hence, IB1 has the highest preference among the other rows. After the removal of the first row and the first column from MP matrix, all elements of the fourth row will be greater than 0.5. Therefore, the fourth row or IB4 takes up the highest preference among IB alternatives after IB1. Here, the fourth row and the fourth column of MP matrix are removed and, then, the elements of the fifth row will become greater than 0.5. Thus, IB5 gets the third rank among IB alternatives. With the application of this procedure, IB3 and IB2 obtain the fourth and fifth ranks, respectively. According to the aforementioned points, the full ranking of IB alternatives is as $IB1 > IB4 > IB5 > IB3 > IB2$ which has also been reported in the last column of Table 6.

Table 6: The final fuzzy weights of IB alternatives

IB alternatives	Final weights	Rank
IB1	(0.251, 1.108, 3.576)	1
IB2	(0.029, 0.129, 0.734)	5
IB3	(0.021, 0.112, 0.864)	4
IB4	(0.013, 0.226, 1.090)	2
IB5	(0.011, 0.146, 1.189)	3

Table 7: The final fuzzy weights of IB alternatives

	IB1	IB2	IB3	IB4	IB5
IB1	-	0.960	0.944	0.907	0.897
IB2	0.040	-	0.471	0.357	0.375
IB3	0.056	0.529	-	0.391	0.406
IB4	0.093	0.643	0.609	-	0.512
IB5	0.103	0.625	0.594	0.488	-

It is noteworthy that the five intelligent building alternatives are ranked based on their level of intelligence. The results of ranking the intelligent buildings reveal that Museum of Isfahan province (IB1) has the highest intelligence level among the five intelligent buildings. In the next orders, Asseh Official building (IB4) and professors' Hotel in Isfahan University (IB5) are placed in the second and third ranks in terms of the intelligence level, respectively. Finally, Meir Official and commercial building (IB3) and Noor Residential Tower (IB2) have inappropriate conditions in terms of the level of intelligence among the other buildings.

4. CONCLUDING REMARKS

Building intelligence helps people satisfy their conflicting demands from the building and organization as well as their personal demands. Contrary to the passive inert buildings, intelligent buildings take advantage of a comfortable status through intelligent services, such as security and safety; thermal, acoustical, ventilation, and air-conditioning control systems; fire detection and alarm system; building integrity; etc. In this regard, new standards, rules, and regulations are generated to support intelligent services. Intelligent building assessment is a popular and efficient way to show whether or not building are constructed in accordance with new standards, rules, and regulations. The present paper aimed at proposing an integrated fuzzy AHP-fuzzy PDA model for intelligent building assessment. The proposed model protects the existing uncertainty in the evaluation criteria by means of the concept of fuzzy theory. Fuzzy AHP was used to determine the local weights of the evaluation criteria and the final weights of the intelligent building alternatives. Since the final weights of IB alternative were in the form of fuzzy numbers, the fuzzy preference degree approach would be used to compare the fuzzy numbers and obtain the full ranking of IB alternatives. Finally, the proposed model was applied to assess the five real intelligent buildings in Isfahan.

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