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CONSTRUCTION SYSTEM SELECTION IN LOW-BED CAPACITY HEALTH BUILDINGS WITH FUZZY AHP IN EARTHQUAKE ZONES[1]

DEPREM BÖLGELERİNDE YAPILACAK DÜŞÜK YATAK KAPASİTELİ HASTANE YAPILARINDA FUZZY-AHP YÖNTEMİ İLE YAPIM SİSTEMİ SEÇİMİ

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Abstract: Purpose: Reconstruction of health buildings that were heavily damaged after the earthquake has become an important issue in Turkey. The negative performance of the construction systems of health buildings after major earthquakes necessitates the evaluation of the building system (CS) options, which can create an alternative to the market, according to various criteria. The main purpose of the study is to develop a systematic basis for the CS of 1816 health institutions to be rebuilt within the scope of the UDSEP 2023 project and to decide between alternatives in Turkey. In this study, the example of a hospital with a low bed capacity (20 beds) was discussed.

Method: In the application of the Methodology-Fuzzy Analytical Hierarchy Process (FAHP) method of the research, 40 expert opinions were taken at the stages of planning, construction and inspection of health buildings.

Findings: Experts in various fields of the construction industry have determined that CS performance is the primary criterion and cost is the secondary criterion for healthcare buildings in high seismic hazard areas. Conclusion: Among the CS alternatives, Structural Steel Frame (SSF) was determined as the most suitable structural system for earthquake zones.

Keywords: Construction System Selection, Multi-Criteria Decision Making (MCDM), Analytic Hierarchy Process (AHP), Fuzzy Analytic Hierarchy Process (FAHP)

Öz: Amaç: Türkiye'de deprem sonrası ağır hasar gören sağlık binalarının yeniden inşası önemli bir konu haline gelmiştir. Büyük depremlerden sonra sağlık bina yapı sistemlerinin olumsuz performansı, piyasaya alternatif oluşturabilecek yapı sistemi (YS) seçeneklerinin çeşitli kriterlerde değerlendirilmesini gerektirmektedir. Çalışmanın temel amacı, UDSEP 2023 projesi kapsamında yeniden inşa edilecek 1816 sağlık kuruluşunun YS'lerine sistematik bir altlık geliştirmek ve Türkiye'deki alternatifler arasında karar vermektir. Bu çalışmada düşük yatak kapasiteli (20 yataklı) hastane örneği ele alınmıştır.

Yöntem: Çalışmanın araştırma yöntemi, Bulanık Analitik Hiyerarşi Süreci (BAHP), Analitik Hiyerarşi Süreci (AHP) yönteminin Bulanık Mantık ile birlikte genişletildiği hibrit yöntem olarak iki çok kriterli karar verme (ÇKKV) yönteminin birleşiminden oluşmaktadır. Yöntemin uygulanmasında sağlık binalarının planlanması, inşası ve denetimi sırasında 40 uzman görüşü alınmıştır.

Bulgular: İnşaat sektörünün çeşitli çalışma alanlarındaki uzmanlar, deprem tehlikesi yüksek bölgelerdeki sağlık binaları için YS performansının birincil kriter, maliyetin ise ikincil kriter olduğunu belirlemişlerdir.

Sonuç: YS alternatifleri arasından Yapısal Çelik Çerçeve (YÇÇ) deprem bölgeleri için en uygun konstrüksiyon sistemi olarak belirlendi.

Anahtar Kelimeler: Yapı Sistemi Seçimi, Çok Kriterli Karar Verme (ÇKKV), Analitik Hiyerarşi Süreci (AHP), Bulanık Analitik Hiyerarşi Süreci (BAHP)

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INTRODUCTION

Earthquakes head the list of natural disasters, that lead to the loss of human life, affect large areas and cause death and destruction on a large scale (John, 2018:27-40). The magnitude of the material damage occurring during an earthquake is closely related to the characteristics of the earthquake, its distance to the earth, its depth & severity and the natural disasters it brings with it and/or triggers (tsunami, avalanche, triggering of a nuclear base, etc.). However, the quality of the built environment is also very important. Given the rapid population growth in large cities and unplanned and uncontrolled urbanization, it is likely that the devastation caused by earthquakes will be higher than expected. The fact that this destruction takes place in health buildings that need to serve in emergencies, reveals the importance of measures to be taken. In a modern and crowded society, it is essential that health services are provided without interruption.

After an earthquake occurred in Turkey (Gölcük) in 1999, seven hospital buildings became unusable due to heavy damage. As a result of the damage assessment studies, Turkish Authorities have taken important strategic decisions. In 2010, an action plan titled UDSEP 2023 (International Earthquake Strategy and Action Plan) was published. This action plan aims to demolish and rebuild 1816 buildings by 2023 that were damaged and functionally unsuitable for use as a health building. In this rebuilding process, to avoid similar scenarios, a decision-making mechanism was developed to determine CS for these structures in Turkey. In this decision process, which involves multiple criteria (structural, environmental, social, visual, economic...etc.) earthquake-resistant CS's role in Turkey's construction sector is evaluated by experts. This evaluation was made for the health buildings that will be rebuilt in earthquake high risk (1st and 2nd-degree hazard) regions in Turkey. However, according to the relevant circular of the Ministry of Health, it is obligatory to use earthquake isolators in health buildings with a capacity of 100 beds or more in 1st and 2nd degree earthquake zones in health buildings built in Turkey (TC Ministry of Health, 2022). However, in this study, since the sample of a sanitary structure with a capacity of less than 100 beds (20 beds) is considered within the scope of the study, there is no requirement for a seismic isolator, but the case with a seismic isolator is not considered in the study. Problem: The buildings that were heavily damaged in the earthquakes in the past showed that the buildings in these provinces where the earthquake occurred were not earthquake resistant. Among the heavily damaged buildings, there are hospital buildings that provide the first response to the injured after the disaster and that have to provide uninterrupted service during the earthquake, revealing the importance of the situation. In cooperation with the Turkish Ministry of Health and AFAD, these buildings (that affiliated to the Ministry of Health) were investigated in terms of earthquake resistance and suitability for use as health buildings. Accordingly, earthquake investigation and strengthening works in hospital buildings throughout Turkey between 1999 and 2010 were determined on the basis of building blocks (National Earthquake Strategy Action Plan 2023, 2010). In addition, within the scope of the International Earthquake Strategy and Action Plan 2023 (UDSEP 2023), which was prepared by AFAD in 2012 and is planned to be completed by 2023, it is planned to group the existing structures on the basis of their vulnerability and risks, to repair the structures that require repair, and to demolish and reconstruct the structures that need demolition. When hospital buildings are examined in the 2012 annual report; as a result of the earthquake investigation, 15 buildings that did not need to be strengthened, 245 buildings that were strengthened by earthquake examination, 1,215 buildings that were built in accordance with the 2007 earthquake regulations and that did not require earthquake examination were identified. In the examination, it was determined that 1,816 hospital blocks were not suitable for strengthening and needed to be rebuilt. Accordingly, two hypotheses were put forward in the study.

Hypothesis 1. Irreversible damage to health buildings built with reinforced concrete frame system in severe earthquakes causes health services to be interrupted after the earthquake. The brittle behavior of the reinforced concrete material against earthquake loads causes fractures in the structure system elements. It is thought that this problem can be prevented by using ductile and elastic building materials and elements in the construction of health buildings in areas with high earthquake risk.

Hypothesis 2. In the construction of public buildings in Turkey, the contractor firm is selected by the tender procedure. In the selection of the company, the institution that offers the most economical offer can be preferred. However, the performance criterion is of primary importance in the selection of the appropriate construction system for the hospital buildings to be built in the 1st and 2nd degree seismic zones, which have a high risk in terms of earthquake hazard. Among the construction systems, the option that provides these criteria and sub-criteria (strength, dead load, error rate) at the optimum level (maximum 10 strength-minimum dead load-minimum error rate) should be the most appropriate construction system for hospital buildings. minimum dead load-minimum error rate) should be the most appropriate construction system for hospital buildings.

CONTENT AND RESEARCH METHODOLOGY

The mainframe of the study consisted of three stages (figure 1). Firstly, CS alternatives were determined. Secondly, the method was determined, and a decision model was formed. In the determination of the criteria are three steps. First, a literature review was conducted and the criteria and alternatives that may be effective in the selection of the CS were listed. Next, by interviewing people who were actively involved in the planning, implementation, and supervision of health establishments, these criteria were examined, arranged as main and sub-criteria and new criteria were added in line with opinions and suggestions. Finally, to determine the

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appropriateness of these criteria and alternatives for health structures, and to re-evaluate deficiencies and errors through feedback, a body of experts in different fields of profession (architect, civil engineer, site supervisor, contractor, etc.) was pilot-surveyed. Thus, the hierarchical structure was created. As stated in the study, a 20-bed hospital structure was considered as a field study. The criteria published by the Ministry of Health for hospital buildings in 1st and 2nd degree earthquake zones were evaluated within this scope. In the comparison of the criteria a total of 40 expert opinions were consulted during the interviews with architects, civil engineers and contractors who were involved in the planning, constructing and controlling of the health establishments.

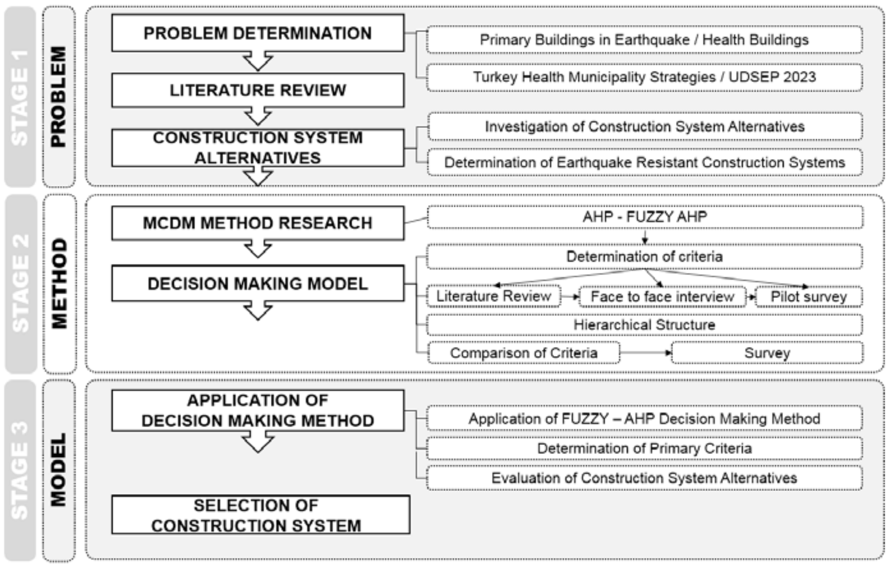

Figure 1. The Methodology of the Study

AHP (Analytic Hierarchy Process) is one of the methods developed by Thomas L. Saaty (Saaty, 1980:89-95; Saaty, 2008:83-98) as an MCDM technique for solving uncertain economic, technological and sociopolitical problems. However, in recent years, the classical AHP method has been criticized because the thought processes of the human brain do not always make logical decisions and there are often uncertainties. Therefore, in this study, it is proposed to use AHP integrated with fuzzy logic in the building system selection issue.

THEORETICAL FRAMEWORK

In the construction industry, problems that need to be solved in a short time and which have many different inputs, are frequently encountered. In this process, several practical methods are needed to transfer knowledge of the professionals' minds to the project process (Ferrada and Serpell, 2014:1-7; Murtaza et al, 1993:115-130). MCDM methods we discuss at this point, are based on modeling and analyzing the decision process according to the criteria of decision problems. There are many MCDM methods used in different decision problems and each MCDM method has both positive and negative aspects (Velasquez and Hester 2013:56-66; Espino et al., 2014:151-162; Mardani et al., 2015:516-571; Sabaei et al., 2015:30-35; Mulliner et al., 2016:146-156; Lee and Chang, 2018:883-896). In addition to the singular methods used to characterize different decision-making environments, studies show that these methods should be used together in some cases (Skibniewski and Chao, 1992:577-593; Ozdagoglu and Ozdagoglu, 2007: 65-85; Pan, 2008:958-965). At this point, AHP, which is one of the MCDM methods, is frequently used to solve various problems in the construction industry. However, classical AHP uses a limited scale (1 to 9) for criteria weighting. As such, it cannot reflect the human thinking process. This scale can be extended with the use of Fuzzy Synthetic Extent (FSE)/Fuzzy Extent Analysis (FEA) as the extension of AHP (Toksari and Toksari, 2011:51-70; Aggarwal and Singh, 2013:6-11; Ahmed and Kilic, 2015:435-438; Hanine et al., 2016:2-30; Iftikhar et al., 2017:1619-1628). (Pakdamar and Oknaz, 2018: 85-106) used Fuzzy logic in high-rise buildings modeling in architecture. By using FAHP and FSE, researchers conduct risk analysis or risk management problems (Tah and Carr, 2000:107-119; Shang et al., 2005:391-409; Cheung et al. others, 2001:117-127; Seresht et al., 2018:37-107; Fayek and Lourenzutti, 2018:3-35) and select location (Ho et al., 2018:117-127; Hanine et al., 2016:2-30), equipment and construction methods (Bansal et al., 2017:122-132; Gluch and Baumann, 2004:571-580; Chen et al., 2010:235-244; Pan et al., 2012:1239-1250) for different building typologies in the construction industry. Bostancioglu is investigated at Turkey's building stock's structures and their criteria for houses (Bostancioglu, 2021:1-30). However, no studies have been found related to CS selection, especially in earthquake regions. In this study, a systematic base has been developed with FAHP for the re-building process of health establishments in earthquake prone regions in the scope of the UDSEP 2023 project in Turkey.

AHP and FAHP

In issues involving complexity and uncertainty, people's experiences and judgments are expressed with linguistic variables. Therefore, the representation of the expression can be converted into quantitative data. The AHP method is often used in these cases. The AHP analyzes and formulates decisions in a complex and multi-criteria decision issue. Determining the relative importance of the criteria in AHP is based on binary comparisons (Miller, 1956:81-97; Kahraman et al., 2003:135-153). This method is preferred by researchers as a simple and powerful method, able to evaluate with a small number of participants, to make consistent analysis and to solve complex problems (Forman et al., 2001:469–486).

The hierarchical structure of the AHP method makes it easy to measure and synthesize the various factors of a complex decision-making process in a hierarchical way. However, although the classic AHP method is widely used to solve MCDM problems, the hierarchical structure may not fully reflect human thinking. The information used to make decisions in construction is not always definite, and experts prefer to express their knowledge using linguistic terms such as" average", "maximum" and "minimum" values. Therefore, more detail is required to determine the uncertainty than the scale [1, 3, 5, 7, and 9] (Cheng et al., 1999:423-435). To avoid these risks and to solve hierarchical fuzzy problems, FAHP was developed as a fuzzy extension of AHP to solve hierarchical fuzzy issues.

The fuzzy theory was first developed by Zadeh, L. to provide decision-making capabilities in the presence of uncertain and ambiguous information, often expressed linguistically (Zadeh, 1965:338-353; Li et al., 2007:40-49). In fuzzy sets, each object is characterized by a membership (characteristic) function ranging from zero to one. A symbol indicating the fuzzy set is represented by an approximate value (~). There are two fuzzy numbers which are triangular and trapezoidal in general (Baykal and Beyan, 2004: 140-154). In this study, triangular fuzzy numbers (TFN) are used. A TFN is indicated by $\tilde{M}$ and simply indicated by (1| m, m|u) or (1, m, u). The parameters l, m and u, respectively, indicate the smallest possible value, the ideal value and the largest possible value that define the fuzzy event (Kahraman et al., 2003:135-153).

Many different methods have been developed for the use of fuzzy theory with AHP. (Laarhoven and Pedrycz; 1983:229-241) defined triangular membership functions and compared fuzzy rates. For this, they proposed the least-squares technique. Only triangular fuzzy numbers can be used in this method and it requires many calculations even for a small problem. (Buckley; 1985:233-247), developed the use of linguistic variables in the calculation of fuzzy weights AHP as an extension of the geometric mean method. Blurring is easy in this method. However, it requires a lot of calculations. (Boender et al., 1989:133-143) developed the approach of (Laarhoven and Pedrycz, 1983:229-241). In this proposal, decisions of multiple, or group decision-makers can be modeled. However, it requires many calculations. (Chang, 1996:649-655) and (Zhu et al., 1999:450-456) introduced a new approach to synthetic extent analysis values of pairwise comparisons in Fuzzy-AHP. This method requires less processing and is simple in weighting decision variables compared to classical AHP. Therefore, Chang's Fuzzy Synthetic Extent Analysis method is used with the classical AHP and the steps are given below:

I.Step: Forming Hierarchy

The main cause of the problem is at the highest level of the hierarchic structure. At the following hierarchy level, some criteria affect this purpose and also at the next level, there are sets of sub-criteria related to these criteria. As with a typical hierarchical structure, the set of criteria at the secondary level contribute to the achievement of the primary goal. At the lowest level, there are appropriate alternatives. In the studies

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conducted in the selection of construction methods, a different number of criteria were determined under different titles. (Bansal et al., 2017:122-132) suggested prefabricated construction systems in terms of financial, environmental and social criteria in the selection of suitable CS for sustainable structures in their works, and using the FAHP method and identified 33 criteria under 3 main criteria in their studies comparing on-site and prefabricated construction systems. (Gluch and Baumann, 2004:571-580) stated that material, time, labor and transportation costs should be taken into consideration in the selection of CS. (Chen et al.,2010:235-244) identified 33 performance criteria, 16 economic criteria, 8 social criteria, and 9 environmental criteria. (Pan et al., 2012:1239-1250), developed 50 criteria under the cost, time, quality, health and safety, sustainability etc.

In this study, as a result of literature review, the preliminary interview with the experts and pilot survey, 6 main criteria (Economic Factors (CF), Time Factors (TF), Performance Factors (PF), Architectural Factors (AF), Environmental Factors and Social Factors (SF)) and 19 sub-criteria are determined. Reinforced Concrete Frame (RCF), Structural Steel Frame (SSF), Prefabricated Reinforced Concrete Frame (PRF) and Tunnel Frame (TF) were determined as the construction system alternatives (Figure 2).

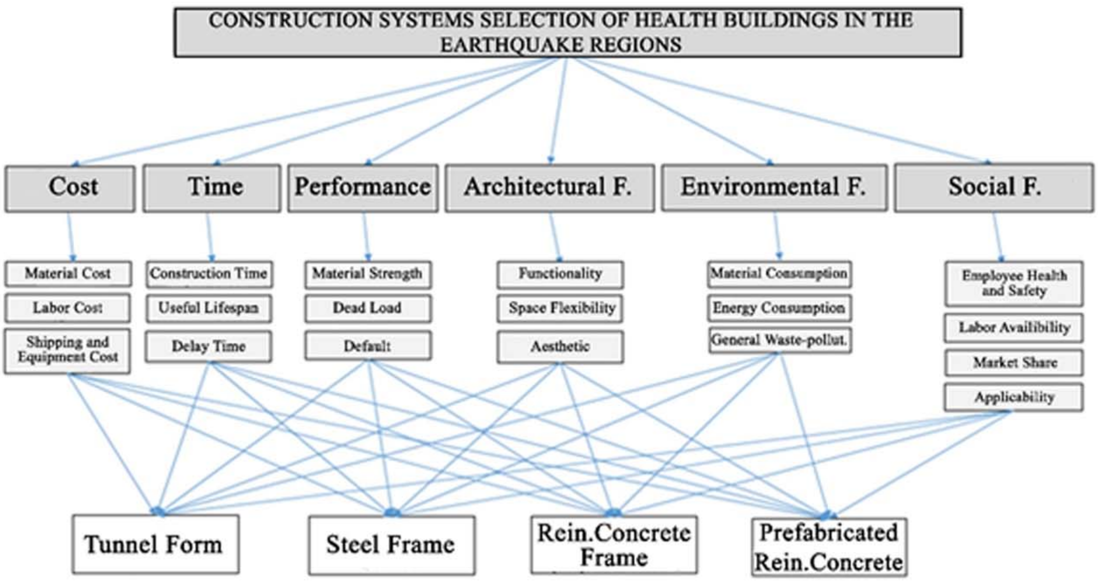

Figure 2. Hierarchical Structure of Selected Decision Problem in the Study

II.Step: Pairwise Comparison

A pairwise comparison of criteria survey was considered by experts. They evaluated the superiority of two criteria in each row. A comparison scale was prepared in two ways. Whichever criterion is superior, the degree of superiority on the criterion side is selected.

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By using the value scale (Table 1), expert opinions are converted to fuzzy numbers.

Table 1. Value Scale

TFN Value Scale	Linguistic Equivalent
(1,1,1)	Equal Important (EI)
(2,3,4)	Some Important (SI)
(4,5,6)	More Important (MI)
(6,7,8)	Too Important (TI)
(8,9,10)	Extremely Important (EI)

III.Step: Relative Weights Calculation

To obtain relative weights using synthetic extent values, the following operations are performed:

Let X = $\{x_1, x_2,\ldots,x_n\}$ be a set of objects and U = $\{u_1, u_2,\ldots, u_m\}$ a set of targets. Each object is analyzed for each target, (gi), respectively.

Therefore, in m expansion analysis, the values for each object;

M_{gi}^{j} ‘,M_{gi}^{2} , ……., M_{gi}^{m}, i=1,2,3,….., n

These all M_{gi}^{j} "s j = (1, 2, 3,…, m) are the triangular fuzzy numbers showing the lowest, most likely and highest values are indicated by l, m, u (Figure 3).

The components and form of the triangle membership function are given below:

$$\mu_M (x; l, m, u) = \begin{cases} \frac{(x-1)}{(m-1)}, & \text{if} \quad l \le x \le m \\ \frac{(u-x)}{(u-m)}, & \text{if} \quad m \le x \le u \\ 0 & \text{if} \quad x > u \text{ or } x < 1 \end{cases}$$

Numerous different operations have been defined in triangular fuzzy numbers. However, the basic operations to be used in this method are as follows:

$M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$, M_1 and M_2 to be two fuzzy numbers. Mathematical operations of these numbers;

1. Summation: $M_1 + M_2=(l_1, m_l, u_1,) + (1_2, m_2, u_2) = (l_1+1_2, m_l+ m_2, u_1+ u_2)$

2. Multiplication: $M_1 \times M_2=(l_1, m_l, u_1) . (1_2, m_2, u_2) = (l_1.1_2, m_l. m_2, u_1. u_2)$

3. Inversion: $(M_1)^{-1}=(l_1, m_l, u_1)^{-1} \sim (1/ u_1, 1/ m_l, 1/ l_1)$

Chang's extent analysis method can be applied by the following 4 steps:

<u>1. Stage:</u> The fuzzy synthetic extent value (S_i) according to the i'th object is defined as follows:

$$Si=\sum_{j=1}^{m} M_{gi}^{j} * \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \quad \text{Equation (1)}$$

To obtain $\sum_{j=1}^{m} M_{gi}^{j}$ the fuzzy sum of m extent analysis value is as follows:

$$\sum_{j=1}^{m} M_{gi}^{j}=\left[\sum_{j=1}^{m} \boldsymbol{l j}, \sum_{j=1}^{m} \boldsymbol{m j}, \sum_{j=1}^{m} \boldsymbol{u j}\right] \quad \text{Equation (2)}$$

To obtain the $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$, the sum of the fuzzy values M_{gi}^{j} j= (1, 2,..., m) calculated as follows:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}=\left[\frac{1}{\sum_{j=1}^{m} \boldsymbol{u j}}, \frac{1}{\sum_{j=1}^{m} \boldsymbol{m j}}, \frac{1}{\sum_{j=1}^{m} \boldsymbol{l j}}\right] \quad \text{Equation (3)}$$

<u>2. Stage:</u> $\widetilde{M}_1 = (l_1, m_1, u_1)$ and $\widetilde{M}_2 = (l_2, m_2, u_2)$ as two triangular fuzzy numbers, the degree of likelihood of the equation $\widetilde{M}_2 \geq \widetilde{M}_1$ is given below.
The likelihood of $M_2= (l_2, m_2, u_2) \geq M_1=(l_1, m_1, u_1)$:

$$V (\widetilde{M}_2 \geq \widetilde{M}_1)= y\geq x \sup[\min(\mu_{\widetilde{M}1}(x), \ \mu_{\widetilde{M}2} \ (y)] \quad \text{Equation (4)}$$

And equation is expressed as follows:

$$V (\widetilde{M}_2 \geq \widetilde{M}_1)=hgt (\widetilde{M}_1 \cap \widetilde{M}_2)= \begin{cases} 1, & m_2 > m_1 \\ 0, & l_1 > u_2 \\ \dfrac{l1 - u2}{(m2-u2)-(m1-l1)}, & \text{other} \end{cases} \quad \text{Equation (5)}$$

Where d is the coordinate of the highest intersection point D between μM_1 and μM_2 (Figure 4);

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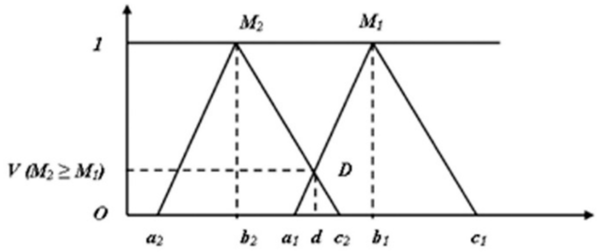

Figure 4. The Intersection of M_1 and M_2

To compare M_1 and M_2, it must be both V ($M_1 \geq M_2$) and V ($M_2 \geq M_1$).

3. Stage: The probability that a convex fuzzy number is greater than the convex fuzzy value of k can be defined as M_i (i = 1,2,… .., k) as follows:

$V (M = M_1 , M_2 ,…., M_k) = V[(M = M_1) \text{ and } (M = M_2) \text{ and } … (M = M_k)]$

$= \min V (M = Mi), (i = 1, 2, 3 ,…., k)$

If the above equality is provided, the following assumptions are made:

If $d' (Ai) = \min V (S_i \geq S_k)$, k = 1, 2, 3… n; ≠ i, the weight vector is:

$W' = (d'(A_1), d'(A_2)… d'(An))^T$, A_i =(i= 1, 2, 3, …n)

4. Stage: Normalized weight vectors are shown with the following equation:

$W= (d (A_1), d (A_2)… d (A_n))^T$

IV.Consistency Ratio

After the FAHP steps are completed, it is necessary to check consistency whether the relative importance of the criteria is meaningful. Consistency Ratio (CR) is a tool used to check the consistency of pairwise comparisons. The subjective judgment can be assessed, and intuition plays an important role in selecting the best alternative. Absolute consistency is not possible in the pairwise comparison procedure. In the calculation of consistency analysis, the relative vector is multiplied by the clarified pairwise comparison matrix and a new vector is obtained. The first element of the new vector is divided into the first element of the relative importance vector, the second element is divided into the second, the n'th element is divided into n'th formed by a third vector. The arithmetic average of the elements of the vector gives a value close to the largest eigen value $\lambda_{max.}$

To check the judicial discrepancies, the CR (Consistency Ratio) of the matrix is created by the equations given below. λ_{max}, the maximum value of relative weight vector, CI, consistency index, n criterion number;

CR=CI/RI Equation (6)

CI=(λ_{max} - n)/(n-1) Equation (7)

RI (Random Index) is an experimental value that depends on n (Table 2).

Table 2. Random Index

n	3	4	5	6	7	8
RI	0.58	0.90	1.12	1.24	1.32	1.41

Based on a large number of experimental studies, the CR should be less than or equal to 0.10 to be acceptable (tolerable) (Saaty, 1980:89-95). The fact that CR is less than or equal to 0.10 guarantees that there is no clear dispute in the comparisons, that the decision is a rational decision and that the criteria are not randomly weighted (Shapira and Goldenberg, 2005:1263-1273). In cases where this condition cannot be achieved, subjective judgments should be reviewed.

FINDINGS

The determination of the criteria in this study was carried out in three stages: First, literature review and selection of construction system criteria and alternatives are listed. These criteria have been examined by people who are actively involved in the planning, implementation and supervision of health institutions, and are organized as main and sub-criteria. new criteria have been added with opinions and suggestions, and some criteria that may have the same meaning have been reduced. Finally, the opinions of some experts from different professions (architects, civil engineers, site managers, etc.) were taken to verify the suitability of these criteria and alternatives to healthcare structures, to identify deficiencies and errors, and to correct them through feedback. Thus, the hierarchical structure of the decision-making model was established. Comparing the criteria; 40 experts (45% architects, 50% civil engineers, 5% contractors) involved in the planning, construction and control of health institutions. 60% of the decision makers regarding health buildings have completed their undergraduate degree, 35% have completed their master's degree and 5% have completed their doctorate. In the first part of the questionnaire, general information about the decision makers (gender, age, education level, occupation, position and work experience) was evaluated. In the second part, the purpose of the survey and how the participants should evaluate the survey were explained and they were asked to evaluate the relative importance of the criteria. In the third part, it is requested to compare the construction system alternatives according to all main and sub-criteria. Traditional MCDM methods enable people to translate their perceptions into numerical scales. There are many MCDMs developed with this approach

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and used in different fields. As one of these methods, AHP (Analytical Hierarchy Process), Thomas L. Saaty (Saaty, 1980:89-95); (Saaty, 2008:83-98) is used to solve economic, technological and sociopolitical problems.

The application steps of the method for the main criteria are given below. The same steps are followed for the comparison of the construction systems according to the sub-criteria. Accordingly, the numerical distribution of the 40 expert statements in the comparison of the main criteria is given in Table 3.

Table 3. Main Criteria Comparison Matrix

	Left Criterion Better				**Equal**	**Right Criterion Better**					
	EI (8,9,10)	**TI** (6,7,8)	**MI** (4,5,6)	**SI** (2,3,4)	**EI** (1,1,1)	**SI** (2,3,4)	**MI** (4,5,6)	**TI** (6,7,8)	**EI** (8,9,10)		**Expert**
CF	3	6	9	3	18	1	0	0	0	**TF**	40
CF	1	4	3	2	13	3	5	5	4	**PF**	40
CF	0	1	5	4	6	5	13	5	1	**AF**	40
CF	1	7	8	5	12	3	4	0	0	**EF**	40
CF	0	5	9	6	4	6	6	4	0	**SF**	40
TF	2	1	2	1	6	4	10	5	9	**PF**	40
TF	1	1	9	2	7	7	7	4	2	**AF**	40
TF	2	4	9	10	5	3	6	1	0	**EF**	40
TF	1	2	9	5	5	6	8	4	0	**SF**	40
PF	5	4	12	2	7	2	1	6	1	**AF**	40
PF	3	8	8	7	7	2	3	1	1	**EF**	40
PF	3	10	14	7	3	0	1	2	0	**SF**	40
AF	1	3	6	4	15	3	4	4	0	**EF**	40
AF	2	2	12	4	9	6	3	2	0	**SF**	40
EF	1	4	8	4	11	6	3	2	1	**SF**	40

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When AHP and FAHP are implemented with several experts, expert opinions can be calculated separately. However, in this study, a large number of expert opinions were consulted to keep the sensitivity and consistency at a high level. The linguistic variables in paired comparison matrix are converted to fuzzy numbers according to Table 1. By taking the geometric mean of expert opinions, the fuzzy comparison matrix is created (Table 4).

Table 4. Fuzzified Comparison Matrix

	CF			TF			PF			AF			EF			SF		
CF	1	1	1	2.12	2.39	2.64	0.63	0.72	0.82	0.45	0.54	0.67	1.56	1.84	2.14	0.95	1.18	1.46
TF	0.37	0.41	0.47	1	1	1	0.32	0.37	0.44	0.64	0.77	0.93	1.41	1.76	2.15	0.79	0.97	1.19
PF	1.20	1.37	1.56	2.26	2.67	3.09	1	1	1	1.41	1.76	2.15	1.82	2.20	2.59	2.89	3.55	4.21
AF	1.48	1.82	2.19	1.06	1.29	1.54	0.49	0.56	0.66	1	1	1	0.97	1.12	1.28	1.26	1.51	1.81
EF	0.46	0.54	0.64	0.46	0.56	0.70	0.38	0.45	0.54	0.77	0.89	1.02	1	1	1	1.07	1.27	1.51
SF	0.68	0.84	1.04	0.83	1.03	1.26	0.23	0.28	0.54	0.55	0.65	0.79	0.66	0.78	0.92	1	1	1

The fuzzy sum of the l, m, u values in each row is calculated (Table 5, A). To obtain the $\sum_{j=1}^{m} M_{gi}^{j}$ in Equation (1), it is necessary to perform the fuzzy addition on m values according to Equation (2) and calculate the inverse of the vector given in Equation (3). Accordingly, the fuzzy synthetic extent (FSE) values are given in Table 5, B. For each pair of synthetic extent values, the probabilities of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ $M_2 \geq M_1$ are checked according to Equation (5) (Table 5, C). The possibility degree of M_2 is considered the minimum value for each line, considering Equation (4). So, the minimum value of each row in $M_2 \geq M_1$ matrix is obtained (0.18, 0, 1, 0.13, 0, 0) (Table 5, D). By normalizing (N) these values (dividing the value of each row by the column total) and the weights (W) of each criteria W= (CF(0.13), TF(0.0), PF(0.76), AF(0.10), EF(0.00), SF(0.00) are obtained. As a result, PF(0.76) criterion has the highest score.

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Table 5. Getting Weights of Criteria

	A			B			C						D		
	Fuzzy Sum of Each Row			**Fuzzy Synthetic Extent (FSE)**			**Possibility of M2 ≥ M_1**						**Possibility of (M_2)**	**N**	**W**
	(l	**m**	**u)**	**(l**	**m**	**u)**									
CF	6.73	7.69	8.75	0.13	0.18	0.24		1	0.18	1	1	1	0.18	0.13	**0.13**
TF	4.54	5.30	6.19	0.09	0.12	0.17	0.37		0	0.47	1	1	0	0	**0**
PF	10.59	12.57	14.62	0.21	0.29	0.40	1	1		1	1	1	1	0.76	**0.76**
AF	6.28	7.32	8.51	0.12	0.17	0.23	0.91	1	0.13		1	1	0.13	0.09	**0.10**
EF	4.17	4.73	5.43	0.08	0.11	0.14	0.15	0.80	0	0.26		1	0	0	**0**
SF	3.97	4.59	5.57	0.08	0.10	0.15	0.18	0.78	0	0.28	0,95		0	0	**0**

As a result of the consistency checking λ_{max} = 6.22, and by using equation (6) and equation (7), CR=0.0365 ≤ 0.1 is obtained. So, the comparison is consistent. The PF (0.76) is determined as the most important criteria for health buildings to be constructed in earthquake zones. By following the same steps, the scores obtained by the construction systems according to the main criteria are given in Table 6.

Table 6. Weights of Construction Systems Alternatives

	CF	**TF**	**PF**	**AF**	**EF**	**SF**	**Normalized Weights**
RCF	0.39	0.23	0.06	0.12	0.14	0.75	0.22
SSF	0.29	0.47	0.59	0.86	0.42	0.16	0.37
TF	0.21	0.14	0.19	0.00	0.11	0.00	0.08
PRF	0.31	0.14	0.39	0.10	0.30	1.00	0.30

It is seen that the most suitable CS is the SSF with the highest score (0.37) (Table 7). RCF (0.22), TF (0.08) and PRF system (0.30) follow respectively. RCF is superior in terms of economic (0.39) and social (0.75) criteria, whereas in all other criteria the steel framework system is superior. The PRF is superior to the TF in terms of all the criteria except the performance.

DISCUSSION

The characteristics of earthquakes depend on their size (intensity) and where they occur. Depending on the region where the earthquake occurred (rural or urban), the extent of the damage can vary, from the use of poor quality materials to inadequate workmanship, with the damage assessment studies carried out after the earthquakes. In the damage assessment studies carried out to date, it has been observed that the damages in the buildings are caused by insufficient engineering-architecture service and architectural design. The complete and correct application of the structure together with the suitable construction system design is important in this regard. It would be appropriate to reconstruct the health buildings evaluated within the scope of this study, in accordance with the purpose of the UDSEP 2023 project and by choosing the right construction system. In this study, a health structure with a capacity of 20 beds was discussed and the criteria of the Ministry of Health were evaluated in this context. Since the use of seismic isolators is not a necessity in this context, it is included in this study.

Therefore, deciding on the choice of the construction system for the construction of these structures is especially important in terms of emergency response to the injured in disaster situations. The criteria that deal with the decision problem in terms of health structures are mentioned in the first part of the article. Technical personnel and experts with at least 10 years of experience in the field took part in the determination of the appropriate construction system in health buildings and the weighting of the criteria for this. The decision made in the selection of the construction system, materials, equipment, labor, etc. in the building production sector. It also affects many sub-branches. In addition, it is important that the cost-time-quality cycle is optimal for the efficient use of resources in construction projects. Addressing this relationship in terms of alternatives to same or similar level construction systems in the industry is a complex process. In this process, a solution was made with a decision support system based on expert opinions. Implementation of the system is possible with the help of people experienced in the construction/construction industry. At this point, it was possible to overcome indecision situations by developing decision-making mechanisms with a team of experts in the field of project management and construction. With the BAHP hybrid decision support system, which is the decision mechanism used in this study, in the solution of the decision problem, other possibilities between 0 and 1 have been evaluated apart from the final judgments (1-true, 0-false). In this system, the opinions of 40 experts were taken.

According to expert evaluations;

✓ Among the criteria evaluated in the selection of the construction system, it is the performance factor with the highest score (0.76).

✓ This is followed by cost (0.13) and architecture (0.10) factors, respectively.

✓ It has been seen that social and environmental factors are not effective (0.00) together with the time criterion in the selection of the construction system for health buildings in earthquake zones.

When the total score of the building systems from all criteria is evaluated, the steel frame system has the highest score (2,8241). This is followed by the reinforced concrete carcass system (1.7248), the tunnel formwork system (1.3396) and the reinforced concrete prefabricated system (1.0882).

When the construction systems where the health buildings will be built are reviewed, although the construction systems are made more durable with certain rules in the current earthquake design regulations, the flexibility rate in systems built with reinforced concrete materials (reinforced concrete carcass, tunnel formwork, etc.) is lower than steel construction systems. However, it is not possible to prevent some deformations from occurring during or after an earthquake in alternatives to the construction system built with concrete.

CONCLUSION

Performance criteria for health buildings (1st and 2nd degree earthquake zones) have been determined as the most important criteria in areas with high earthquake hazard. This method can be applied to different MCDM problems by re-determining the criterion weights in different building types and in different earthquake zones.

It is not enough to ensure the safety of buildings alone and to prevent material damage and loss of life in earthquakes. Establishing safe assembly areas during and after an earthquake is also an important process in reducing earthquake damage. Arrangements such as planning the open spaces that can be used after the earthquake and the establishment of the transportation network should be made. It is possible that BAHP, which is used as a decision-making method in this study, can be handled with different criteria in other studies. However, the shortcomings of BAHP, which is a hybrid method, or the positive and negative effects of its use with another MCDM method should be investigated.

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