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Universal usability evaluation by using an integrated fuzzy multi criteria decision making approach

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Abstract

Purpose – The purpose of this paper is to propose an integrated fuzzy approach to determine important universal usability problems (UUPs) by providing experts who behave like real users and to establish a work plan to correct the most important ones.

Design/methodology/approach – In this study, a fuzzy multi-criteria decision-making approach with three stages is proposed for the evaluation of universal usability. At the first stage, UUPs are identified by performing modified heuristic evaluation, and severity rating of each problem is determined by experts. At the second stage, critical problems are specified by applying the fuzzy Delphi considering these severity ratings. At the third stage, Fuzzy Decision Making Trial and Evaluation Laboratory approach is applied to prioritize critical problems as sub and main criteria. An illustrative example related to emergency service is performed to apply the proposed approach.

Findings – Results showed that the elevator button design, the elevator emergency button design and the position of the floor signboard are the first three problems that should be primarily improved as sub-criteria. In terms of main criteria, equitable use, simple and intuitive use, and perceptible information are the first three main criteria that should be improve in emergency service.

Originality/value – This study is original in terms of methodology and providing a new perspective for building design evaluation. The results can help the designers to see the UUPs in buildings, to focus the most important UUPs and to establish improvement ranking. These advantages provide time and cost-effective design improvement actions.

Keywords Universal design, Emergency service, Heuristic evaluation

Paper type Research paper

1. Introductıon

For product design, universal design (UD) considers all user groups such as children, pregnant mothers, adults, elderly people, people with temporary or permanent physical disabilities, people with mental illness and people with mental retardation (Story, 1998). In recent years, the number of these users has been increased and UD has become a hot topic for designers (Afacan and Erbug, 2009). A product designed considering UD principles can be used easily without adaptation or stigmatization by all kind of people (Steinfeld and Mullick, 1990).

There are seven UD principles as equitable use, flexibility in use, simple and intuitive use, perceptible information, tolerance for error, low physical effort, size and space for approach and use determined by a group of experts in the area of UD (Story, 1998). Equitable use principle explains that the design is useful and marketable to people with diverse abilities. Flexibility in use principle defines the design accommodates a wide range of individual preferences and abilities. Simple and intuitive use principle points out that the use of the design is easy to understand, regardless of the user's experience, knowledge, language skills or current concentration level. Perceptible information principle means that the design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities. Tolerance for error principle remarks that

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the design minimizes hazards and the adverse consequences of accidental or unintended actions. Low physical effort principle represents that the design can be used efficiently and comfortably and with a minimum fatigue level. Size and space for approach and use principle define appropriate size and space is provided for approach, reach, manipulation and use regardless of user's body size, posture or mobility.

UD is a process that integrated with difficulty with the current design practice because of designers' ways of thinking. Designers are usually not real users of the products that they design (Preiser, 2001). This leads a lack of empathy for an interpretation of the user needs especially diverse users. On the other hand a successful UD process should be built on a better understanding of real-user needs (Persad *et al.*, 2007; Darses and Wolff, 2006).

In terms of sufficiency of a product for UD, the usability has an important role. The term usability covers all the users' interest and user-friendly features of a product (Kanis, 1998). Usability aims to minimize discordance between products and users.

There are various studies related to the usability of products and designing products considering UD principles in the literature. However, building usability and sufficiency in terms of UD principles have not been studied by the researchers yet. Due to this, "universal usability of buildings" that aims to create universally usable buildings has become a hot topic.

A building's universal usability evaluation is a multi-criteria decision making (MCDM) problem because of considering more than one universal usability principles and having group decision-making structure. In many real-life evaluation cases, the group members formed by experts may come from different professions such as interior architecture, urban planning, etc. for building-related decisions and they have different levels of knowledge, experience and opinions. People make qualitative forecasting by using linguistic variables easily than quantitative predictions for MCDM problems. Additionally, it is usually improper to point an alternative or criterion with the direct numerical value (Liu *et al.*, 2014). Therefore, evaluations of people usually have some vagueness and uncertainty. Crisp numbered data are not sufficient to model the subjective nature of human thinking, judgment and preferences (Kannan *et al.*, 2014). Fuzzy logic proposed by Zadeh (1965) is a powerful tool to use and manage the quantitative or imprecisely defined qualitative data in a consistent way.

In this study, a three-stage fuzzy MCDM approach based on modified heuristic evaluation (MHE), Fuzzy Delphi (F-Delphi) and Fuzzy Decision Making Trial and Evaluation Laboratory (F-DEMATEL) is proposed for building universal usability evaluation. Heuristic evaluation (HE) commonly utilized in many research works is a powerful usability evaluation method. In HE, by giving tasks related to the issue, experts behave like users and they can easily understand the real needs of users. Seven UD principles form the set of heuristic rules for universal usability evaluation in this study. Additionally, a fuzzy scale is used for severity ratings in HE to determine the seriousness of the universal usability problem (UUP) defined by experts. In this wise, MHE is advanced. HE is not performed individually because one expert cannot determine all usability problems. So, evaluation effectiveness is provided by multiple experts. Additionally, improving all of these improper design conditions defined by experts is time consuming and not cost effective. The most important ones should be determined and improved at first. For this reason, F-Delphi is performed to determine the critical UUPs. Different from traditional F-Delphi, the weight of experts' opinions are considered when determining the most important problems. Fuzzy severity ratings are used to evaluate the importance of each UUP. F-Delphi is developed as a combination of traditional Delphi with fuzzy set theory to address ambiguity emerged in panel consensus of Delphi (Ishikawa *et al.*, 1993). F-Delphi is an advanced version of Delphi since it can handle the subjectivity of experts' assessments. It was stated by Noorderhaben (1995) that the solution to the fuzziness of common understanding, based on the experts' opinions, can be performed by applying the F-Delphi to a group decision. F-Delphi can use linguistic variables including "Low Importance," and "Moderate Importance" to determine the most important problems related to the decision issue. F-Delphi provides to the users with the advantage of Delphi method and reduction of the questionnaire time and cost (Hsu, 2010; Yu-Feng, 2008). F-Delphi can solve and evaluate the fuzziness of common understanding of experts on a variety of scales. In this aspect, F-Delphi is more useful for dealing with real-world phenomena than Delphi. F-Delphi is intended to model logical reasoning with vague or imprecise evaluations. It can reflect more accurately a human thinking system than Delphi which utilizes with a crisp scale. Then, to prioritize these critical problems, F-DEMATEL approach is utilized because a work plan is required for correcting the critical problems. DEMATEL has an ability to illustrate the interrelation between principles and reflect this interrelation to the principles' importance weights. Seven UD principles have interrelations with each other and they may affect each other.

This study has originality in terms of building design evaluation. Universal usability term for building is first decelerated in this study to the best of our knowledge and MCDM structure is applied first in this area. In this manner, this study provides a new perspective for building design evaluation. The results can help the designers to see the UUPs in buildings. This study can also help designers to focus the most important UUPs and to establish improvement ranking for work plan. These advantages provide time and cost-effective design improvement actions. In terms of emergency service universal usability evaluation, this study is also the first study to the best of our knowledge.

The rest of the paper is organized as follows: Section 2 contains literature review related to HE, F-Delphi and F-DEMATEL. Section 3 includes fuzzy algebra. Section 4 explains the proposed approach. Section 5 includes implementation of the proposed approach for emergency service of a private hospital. Section 6 includes conclusions, and discussions are given in Section 7.

2. Literature review related to HE, F-Delphi and F-DEMATEL

There are limited numbers of studies related to the HE. Chen and Macredie (2005) searched for the usability of electronic shopping by using HE. Tang *et al.* (2006) implemented HE to improve the usability of a telemedicine system. Kılıç and Güngör (2009) performed usability analysis of a university library website by using HE and analytic hierarchy process (AHP). Afacan and Erbug (2009) utilized HE for shopping mall design. Afacan (2010) proposed a universal HE model to improve the functional and physical performance of residential buildings. Inostroza *et al.* (2013) performed HE for touchscreen-based mobile devices. de Lima Salgado and Freire (2014) used HE for mobile usability. Hearst *et al.* (2016) evaluated information visualization via the interplay of HE and question-based scoring.

As seen from the literature, HE is only used for usability analysis of products excluding Afacan and Erbug's (2009) study. However, it can be utilized for improving building design as a quick and cost-effective tool. As highlighted in the study of Afacan and Erbug (2009), HE may have contributions to building design improvement due to its systematic inspection characteristics to find usability problems of building. However, there are some procedural disadvantages related to the HE and these disadvantages could not be overcome in Afacan and Erbug's (2009) study. First, HE requires more than one evaluators who have different opinions. These opinions should be aggregated in an accurate manner by using mathematical procedure. Second, these opinions are explained via using linguistic terms, such as "not a usability problem, minor usability problem, etc." Linguistic terms can be modeled with fuzzy logic in an effective way. It is not true to model them in a crisp manner because these terms include vagueness and uncertainty as in a human thinking system. Third, HE actually has MCDM structure due to more than one heuristic rules considered in evaluation that are made by more than one evaluators. Fourth, related to the third item, if HE is formed as an MCDM problem, it can be implemented for the comparison of more than one alternative (related to the evaluation issue) in terms of usability. Fifth, considered heuristic rules can affect each other and this effect cannot be reflected in the evaluation process with traditional HE.

In terms of F-Delphi, there are various studies in the literature. These studies are given as follows. Mikaeil *et al.* (2013) used fuzzy AHP (F-AHP), F-Delphi and Fuzzy Technique for Order Preference by Similarity to Ideal Solution (F-TOPSIS) methods to compare the different rock properties in the rock saw ability. Fang and Chyu (2013) utilized F-Delphi, Fuzzy Analytic Network Process (F-ANP) and F-DEMATEL to select color calibration device. Sayari *et al.* (2014) implemented F-Delphi for determining financial and credit risk of projects. Gil-Lafuente *et al.* (2014) performed F-Delphi and F-AHP for evaluating luxury resort hotels industry in Taiwan. Kazemi *et al.* (2015) implemented F-Delphi and F-AHP to rank the material selection criteria. Mousavi (2015) developed educational system strategies for university students by using F-Delphi and F-AHP. Sultana *et al.* (2015) developed a supplier selection model combining F-Delphi, F-AHP and F-TOPSIS. Lee and Seo (2016) developed a hybrid MCDM model for a cloud service selection problem using Balanced Scorecard (BSC), F-Delphi and F-AHP. Bouzon *et al.* (2016) used F-Delphi to obtain the critical list of barriers related to the inverse logistics. Zhang (2017) utilized F-Delphi and ANP to propose which low-carbon tourism strategy should be adopted in Chengguan District in the coming years. As seen from the literature, F-Delphi was integrated with different MCDM methodologies such as F-AHP, F-TOPSIS, F-ANP and ANP, etc. for different decision issues. However, none of these studies focus on improvement for methodological aspect. It has not been yet integrated with HE and F-DEMATEL. Additionally, F-Delphi has not been yet used for design-related decisions. However, it is a useful tool to determine design-related problems' criticality. In the proposed approach seriousness levels of UUPs obtained from HE were used in F-Delphi. Another fuzzy scale did not use to evaluate the importance of problems as in classical F-Delphi. In this term, the proposed approach provides a hybridization of HE and F-Delphi. Additionally, experts made their assessments after implementing tasks related to emergency service universal usability. These seriousness levels used in F-Delphi are more sensitive because of this task implementation stage. This is an original condition in terms of F-Delphi.

The DEMATEL has an ability to visualize pragmatically complicated causal relationships. DEMATEL can separate considered factors into cause group and effect group (Chang *et al.*, 2011). There are various studies that implement F-DEMATEL for different decision-making processes. Some of them are given as follows. Lin (2013) used F-DEMATEL to evaluate green supply chain management practices. Baykasoğlu *et al.* (2013) performed F-DEMATEL for truck selection. Tsao and Wu (2014) used F-DEMATEL for evaluation of design conditions for compound special-core drilling composite materials. Yeh and Huang (2014) utilized F-DEMATEL, Goal/Question/Metric (GQM) and F-ANP for determining wind farm location. Patil and Kant (2014) predicted success of knowledge management adoption in supply chain by utilizing F-DEMATEL. Altuntaş and Dereli (2014) performed F-DEMATEL for facility layout problem. Akyüz and Çelik (2015) evaluated critical operational hazards during the gas freeing process in crude oil tankers by using F-DEMATEL. Liu *et al.* (2015) implemented F-DEMATEL combining fuzzy weighted average for risk assessment in system failure modes and effects analysis (FMEA). Abdullah and Zulkifli (2015) implemented F-AHP and interval type-2 F-DEMATEL for human resource management. Luthra *et al.* (2016) used F-DEMATEL to evaluate the enablers in solar power developments. Vinodh *et al.* (2016) selected an agile concept using F-DEMATEL, F-ANP and F-TOPSIS. Sangaiah *et al.* (2017) proposed integrated F-DEMATEL, TOPSIS and ELECTRE approaches to evaluate knowledge transfer effectiveness with reference to global software development project outcome. Gölcük and Baykasoğlu (2016) analyzed DEMATEL and ANP hybridizations to clarify the position of this hybridization in terms of criteria interactions. They reviewed more than 500 papers and several books in Web of Knowledge, Wiley Online Library, SpringerLink, Science Direct, IEEE Xplore, Google Scholar, etc. They separate criteria interactions between two parts as criteria dependency and criteria interactivity. They also divide criteria dependency into three parts as structural dependency, causal dependency and preferential dependency. Structural dependency defines the dominance relations in the structure of criteria. Casual dependency means cause and effect relations between criteria. Preference dependency shows preference orders of alternatives changed when the levels of criteria are altered. Additionally, they supplied information related to the reasons for ANP-DEMATEL hybridization. They mentioned that ANP does not generate criteria clusters in a systematic way. To overcome this condition, they had seen that DEMATEL is preferred to use. In total, 43 percent of the reviewed papers by them had used DEMATEL for this aim. They stated that pairwise comparisons performed based on survey questions are cognitively demanding. This leads to occur a hard work in terms of forming super matrix based on inner dependency. In total, 8 percent of the reviewed studies had utilized DEMATEL to compute super matrix. Additionally, they also depicted that clusters in ANP assumed to be equally important. For this reason, 11 percent of the studies had performed DEMATEL to differentiate important weight clusters in ANP. Finally, according to their evaluations, criteria structure, unweighted supermatrix had been formed via utilizing DEMATEL in the 38 percent of the reviewed studies. Pandey and Kumar (2017) evaluated the criteria for human resource for science and technology based on an integrated F-AHP and F-DEMATEL approach. Baykasoğlu and Gölcük (2017) suggested a novel interval type-2 fuzzy MADM model including TOPSIS and DEMATEL integration. They performed a hierarchical decomposition approach to reduce inherent complexity of the decision problem. They also considered interdependencies among problem attributes in their proposed approach. They realized to model causal dependencies via utilizing their proposed approach.

As seen from the literature, F-DEMATEL has not been used for design-related decision problems. It has not been integrated with HE and F-Delphi. However, F-DEMATEL can provide support for design decisions in terms of modeling interrelations between design criteria.

3. Fuzzy algebra

Let X be the universe of discourse $X=\{x_1, x_2, ..., x_n\}$, a fuzzy set $\tilde{A}$ of X is defined by a membership function $\mu_{\tilde{A}}(x)$. It is called as the degree of membership x in $\tilde{A}$. In the concept of the fuzzy logic, x is the element in X which has membership grade in the [0, 1] interval. A fuzzy number is a fuzzy subset in the universe of discourse X (Huang *et al.*, 2001). There are various kinds of fuzzy numbers, such as triangular fuzzy numbers (TFNs), trapezoidal fuzzy numbers, bell-shaped fuzzy numbers, etc. Among them, TFNs are commonly used in applications as in this study. A fuzzy number which is denoted as (a_1, a_2, a_3) is called TFN. A TFN is indicated as $\tilde{a} = (a_1, a_2, a_3)$ where a_1 represents the smallest possible value, a_2 denotes the most promising value and a_3 indicates the largest possible value of $\tilde{a}$ providing $a_1 \leqslant a_2 \leqslant a_3$.

Let $\tilde{a} = (a_1, a_2, a_3)$ and $\tilde{b} = (b_1, b_2, b_3)$ are two positive TFNs, and r is a positive real number then the basic arithmetic operations of TFNs can be defined as in the following equations:

$$\tilde{a} + \tilde{b} = (a_1 + b_1, a_2 + b_2, a_3 + b_3), \tag{1}$$

$$\tilde{a} - \tilde{b} = (a_1 - b_3, a_2 - b_2, a_3 - b_1), \tag{2}$$

$$\tilde{a} \times \tilde{b} \cong (a_1 b_1, a_2 b_2, a_3 b_3), \tag{3}$$

$$r \times \tilde{b} = (ra_1, ra_2, ra_3), \tag{4}$$

$$\tilde{a} \div \tilde{b} \cong \left(\frac{a_1}{b_3}, \frac{a_2}{b_2}, \frac{a_3}{b_1}\right). \tag{5}$$

Additionally, fuzzy weighted average of TFNs is computed as in the following equation (Chen *et al.*, 2006):

$$a_1 = \min\{a_1\}, a_2 = \left(\prod_{j=1}^{m} a_2\right)^{1/n} \text{ and } a_3 = \max\{a_3\}. \tag{6}$$

4. The proposed methodology

The implementation steps of the proposed integrated fuzzy MCDM methodology are given below.

Stage 1. MHE implementation

Fuzzy logic combined with traditional HE methodology in this stage. Steps of the MHE are given below.

Step 1. Form expert group and perform the pre-evaluation training. In this step, l number of experts E_k, $k = 1, \ldots, l$ are informed about the application of the MHE and the principles of UD.

Step 2. Perform the actual evaluation. In the actual evaluation step, in order to evaluate the universal usability of the building, task scenarios which the UD principles can be tested by implementing them are created and experts are provided to perform these tasks in the related building.

Step 3. Perform debriefing. Once tasks are performed by experts, each expert prepares a list of problems that he or she has identified regarding UD principles related to the building. These lists, which are prepared by each expert, are discussed in an environment where all the experts are together. Then, final UUP list is prepared. Each UUP is indicated as P_j; $j = 1, \ldots, m$.

Step 4. Perform fuzzy severity rating. Experts score each problem on the combined problem list using fuzzy severity rating scale given in Table I. $\tilde{B}_j^k = (b_{j1}^k, b_{j2}^k, b_{j3}^k), (j = 1, \ldots, m)$ is the fuzzy severity rating of the kth expert for jth problem.

Stage 2. F-Delphi implementation

In this stage, F-Delphi is used to determine the important UUPs. The steps of the F-Delphi method proposed in this study are given below.

Step 5. Assign the fuzzy importance of each expert and aggregate the severity evaluation of each expert. $\tilde{\lambda}_k = (\lambda_{k1}, \lambda_{k2}, \lambda_{k3}), k = 1, \ldots, l$ is the fuzzy weight of each expert defined

Linguistic definition	Triangular fuzzy number
Not a usability problem	(0.00, 0.00, 0.25)
Cosmetic usability problem: need not be fixed unless extra time is available on project	(0.00, 0.25, 0.50)
Minor usability problem: fixing this should be given low priority	(0.25, 0.50, 0.75)
Major usability problem: important to fix, so should be given high priority	(0.50, 0.75, 1.00)
Usability catastrophe: imperative to fix this before a product can be released	(0.75, 1.00, 1.00)

Source: Kılıç and Güngör (2009)

Table I.
Fuzzy severity scale

according to the working experience related to the building design. $\tilde{\lambda}_k$ is defuzzified by Equation (7) and $(\tilde{\lambda}_k)_{def}$ is obtained. $(\tilde{\lambda}_k)_{def}$ is multiplied with $\tilde{B}_j^k$ and weighted fuzzy severity assessments $\tilde{C}_j^k = (c_{j1}^k, c_{j2}^k, c_{j3}^k)$ are obtained, then the weighted arithmetic mean is used for aggregating the assessment of experts. In this way, the weight of each problem $\tilde{F}_j = (f_{j1}, f_{j2}, f_{j3})$ is computed as shown in Equation (8):

$$\left(\tilde{\lambda}_k\right)_{def} = \frac{1}{4}(\lambda_{k1} + 2\lambda_{k2} + \lambda_{k3}), \tag{7}$$

$$\tilde{F}_j = \frac{\sum_{k=1}^{l} \lambda_k \tilde{C}_j^k}{l} = \left(\frac{\sum_{k=1}^{l} \lambda_k c_{j1}{}^k}{l}\right), \left(\frac{\sum_{k=1}^{l} \lambda_k c_{j2}^k}{l}\right), \left(\frac{\sum_{k=1}^{l} \lambda_k c_{j3}^k}{l}\right). \tag{8}$$

Step 6. Determine the important problems. In this step, a threshold value $\tilde{F}_{j_{tr}}$ is computed for comparing the weight of the each problem with this value. $\tilde{F}_{j_{tr}} = (f_{j1_{tr}}, f_{j2_{tr}}, f_{j3_{tr}})$ means the average of all problems' weight where $f_{j1_{tr}} = \min\{f_{j1}\}$, $f_{j2_{tr}} = (\prod_{j=1}^{m} f_{j2})^{1/n}$ and $f_{j3_{tr}} = \max\{f_{j3}\}$. If $\tilde{F}_j > \tilde{F}_{j_{tr}}$ problem j is accepted to improve. If $\tilde{F}_j > \tilde{F}_{j_{tr}}$ problem j is rejected to improve. Because $\tilde{F}_j$ and $\tilde{F}_{j_{tr}}$ are the fuzzy numbers, they should be transformed into the crisp values for comparison as in the following equations:

$$\left(\tilde{F}_j\right)_{def} = \frac{1}{4}(f_{j1} + 2f_{j2} + f_{j3}) \tag{9}$$

$$\left(\tilde{F}_{j_{tr}}\right)_{def} = \frac{1}{4}(f_{j1_{tr}} + 2f_{j2_{tr}} + f_{j3_{tr}}). \tag{10}$$

Stage 3. F-DEMATEL implementation

In this stage, F-DEMATEL is utilized to rank important problems determined in Stage 2. The steps of F-DEMATEL are given below.

Step 7. Determine the criteria and set up direct relation matrix. Criteria are divided into two groups as main criteria and sub-criteria. Main criteria are denoted as MC_j, $j = 1, \ldots, m$. Sub-criteria are indicated as $SC_{j_t} = \{SC_{1_1}, SC_{2_1}, \ldots, SC_{v_m}\}, (t = 1, \ldots, v); (j = 1, \ldots, m)$. Critical problems form sub-criteria and their categories as seven UD principles form main criteria. Each expert evaluates main and sub-criteria in terms of their influence on each other by using fuzzy influence scores (FISs) given in Table II. Sub-criteria evaluation of each expert is represented as, $\tilde{D}_{jtz}^k = (d_{jtz1}^k, d_{jtz2}^k, d_{jtz3}^k), (t = 1, \ldots, v); (j = 1, \ldots, m); (z = 1, \ldots, v)$, where $\tilde{D}_{jtz}^k$ is the evaluation of kth expert that shows the degree to which the sub-criterion

Table II. Fuzzy influence score scale

	FIS		
Linguistic term	d_{jtz1}^k/d_{ji1}^k	d_{jtz2}^k/d_{ji2}^k	d_{jtz3}^k/d_{ji3}^k
No influence	0.00	0.00	0.25
Very low influence	0.00	0.25	0.50
Low influence	0.25	0.50	0.75
High influence	0.50	0.75	1.00
Very high influence	0.75	1.00	1.00

t affects the sub-criterion z included in jth main criterion and $\tilde{D}_{jtz}^{k}$ forms Direct Relation Matrix for the sub-criteria $[\tilde{D}]_{\text{sub}}^{k}$. $[\tilde{D}]_{\text{sub}}^{k}$ is shown for the first main criterion in Equation (11) as an example. Evaluation of main criteria of each expert is indicated as $\tilde{D}_{ji}^{k} = (d_{ji1}^{k}, d_{ji2}^{k}, d_{ji3}^{k}), (j = 1, \ldots, m); (i = 1, \ldots, m)$, and $\tilde{D}_{ji}^{k}$ forms Direct Relation Matrix $[\tilde{D}]_{\text{main}}^{k}$ for main criteria shown in Equation (12):

$$\left[\tilde{D}\right]_{\text{sub}}^{k} = \begin{bmatrix} \left(d_{1111}^{k}, d_{1112}^{k}, d_{1113}^{k}\right) & \left(d_{1121}^{k}, d_{1122}^{k}, d_{1123}^{k}\right) & \cdots & \left(d_{11v1}^{k}, d_{11v2}^{k}, d_{11v3}^{k}\right) \\ \left(d_{1211}^{k}, d_{1212}^{k}, d_{1213}^{k}\right) & \left(d_{1221}^{k}, d_{1222}^{k}, d_{1223}^{k}\right) & \cdots & \left(d_{12v1}^{k}, d_{12v2}^{k}, d_{12v3}^{k}\right) \\ \vdots & \vdots & \vdots & \vdots \\ \left(d_{1v11}^{k}, d_{1v12}^{k}, d_{1v13}^{k}\right) & \left(d_{1v21}^{k}, d_{1v22}^{k}, d_{1v23}^{k}\right) & \cdots & \left(d_{1vv1}^{k}, d_{1vv2}^{k}, d_{1vv3}^{k}\right) \end{bmatrix}, \tag{11}$$

$$\left[\tilde{D}\right]_{\text{main}}^{k} = \begin{bmatrix} \left(d_{111}^{k}, d_{112}^{k}, d_{113}^{k}\right) & \left(d_{121}^{k}, d_{122}^{k}, d_{123}^{k}\right) & \cdots & \left(d_{1m1}^{k}, d_{1m2}^{k}, d_{1m3}^{k}\right) \\ \left(d_{211}^{k}, d_{212}^{k}, d_{213}^{k}\right) & \left(d_{221}^{k}, d_{222}^{k}, d_{223}^{k}\right) & \cdots & \left(d_{2m1}^{k}, d_{2m2}^{k}, d_{2m3}^{k}\right) \\ \vdots & \vdots & \vdots & \vdots \\ \left(d_{m11}^{k}, d_{m12}^{k}, d_{m13}^{k}\right) & \left(d_{m21}^{k}, d_{m22}^{k}, d_{m23}^{k}\right) & \cdots & \left(d_{mm1}^{k}, d_{mm2}^{k}, d_{mm3}^{k}\right) \end{bmatrix}. \tag{12}$$

Step 8. Set up the weighted evaluation matrix for each expert. Each element of $[\tilde{D}]_{\text{sub}}^{k}$ and $[\tilde{D}]_{\text{main}}^{k}$ is multiplied with the weight of each expert λ_k; $(k = 1, \ldots, l)$ as in Equation (3). $\tilde{E}_{jtz}^{k} = (e_{jtz1}^{k}, e_{jtz2}^{k}, e_{jtz3}^{k})$ values for sub-criteria and $\tilde{E}_{ji}^{k} = (e_{ji1}^{k}, e_{ji2}^{k}, e_{ji3}^{k})$ values for main criteria are obtained as an element of weighted evaluation matrix of sub-criteria and main criteria denoted as $[\tilde{E}]_{\text{sub}}^{k}$, $[\tilde{E}]_{\text{main}}^{k}$, respectively. $[\tilde{E}]_{\text{sub}}^{k}$ is given in Equation (13) for the sub-criteria included in the first main criterion as an example:

$$\left[\tilde{E}\right]_{\text{sub}}^{k} = \begin{bmatrix} (e_{1111}^{k}, e_{1112}^{k}, e_{1113}^{k}) & (e_{1121}^{k}, e_{1122}^{k}, e_{1123}^{k}) & \cdots & (e_{11v1}^{k}, e_{11v2}^{k}, e_{11v3}^{k}) \\ (e_{1211}^{k}, e_{1212}^{k}, e_{1213}^{k}) & (e_{1221}^{k}, e_{1222}^{k}, e_{1223}^{k}) & \cdots & (e_{12v1}^{k}, e_{12v2}^{k}, e_{12v3}^{k}) \\ \vdots & \vdots & \vdots & \vdots \\ (e_{1v11}^{k}, e_{1v12}^{k}, e_{1v13}^{k}) & (e_{1v21}^{k}, e_{1v22}^{k}, e_{1v23}^{k}) & \cdots & (e_{1vv1}^{k}, e_{1vv2}^{k}, e_{1vv3}^{k}) \end{bmatrix}. \tag{13}$$

Step 9. Aggregate the weighted evaluation matrix of all experts. Assessments of experts are aggregated by Equation (14), and aggregated weighted evaluation matrix for sub-criteria $[\tilde{C}]_{\text{sub}}$ is constructed. Equation (15) is used for structuring the same matrix as $[\tilde{C}]_{\text{main}}$ for the main criteria. The element of $[\tilde{C}]_{\text{sub}}$ is denoted as $\tilde{C}_{jtz} = \left(c_{jtz1},\ c_{jtz2}, c_{jtz3}\right)$, $(j = 1, \ldots, m); (t = 1, \ldots, v); (z = 1, \ldots, v)$. The element $[\tilde{C}]_{\text{main}}$ is indicated as $\tilde{C}_{ji} = \left(c_{ji1},\ c_{ji2}, c_{ji3}\right), (j = 1, \ldots, m); (i = 1, \ldots, m)$:

$$\tilde{C}_{jtz} = \frac{\sum_{k=1}^{l} \lambda_k \tilde{E}_{jtz}^{k}}{l} = \left(\frac{\sum_{k=1}^{l} \lambda_k e_{jtz1}^{k}}{l}\right), \left(\frac{\sum_{k=1}^{l} \lambda_k e_{jtz2}^{k}}{l}\right), \left(\frac{\sum_{k=1}^{l} \lambda_k e_{jtz3}^{k}}{l}\right), \tag{14}$$

$$\tilde{C}_{ji} = \frac{\sum_{k=1}^{l} \lambda_k \tilde{E}_{ji}^k}{l} = \left(\frac{\sum_{k=1}^{l} \lambda_k e_{ji1}^k}{l}\right), \left(\frac{\sum_{k=1}^{l} \lambda_k e_{ji2}^k}{l}\right), \left(\frac{\sum_{k=1}^{l} \lambda_k e_{ji3}^k}{l}\right). \tag{15}$$

Step 10. Normalize the aggregated weighted evaluation matrix. For the normalization process, each column elements of $[\tilde{C}]_{\text{sub}}$ and $[\tilde{C}]_{\text{main}}$ is summed as in Equation (16) for the sub-criteria and Equation (17) for the main criteria. Summation of each column elements of $[\tilde{C}]_{\text{sub}}$ is denoted as $p_{jtz} = (p_{jtz1}, p_{jtz2}, p_{jtz3}), (j = 1, \ldots, m); (t = 1, \ldots, v); (z = 1, \ldots, v)$. Summation of each column elements of $[\tilde{C}]_{\text{main}}$ is denoted as $p_{ji} = (p_{ji1}, p_{ji2}, p_{ji3}), (j = 1, \ldots, m); (i = 1, \ldots, m)$:

$$p_{jtz1} = \sum_{j=1}^{m} \sum_{t=1}^{v} \sum_{x=1}^{v} c_{jtz1},$$

$$p_{jtz2} = \sum_{j=1}^{m} \sum_{t=1}^{v} \sum_{x=1}^{v} c_{jtz2},$$

$$p_{jtz3} = \sum_{j=1}^{m} \sum_{t=1}^{v} \sum_{x=1}^{v} c_{jtz3}, \tag{16}$$

$$p_{ji1} = \sum_{j=1}^{m} \sum_{i=1}^{m} c_{ji1},$$

$$p_{ji2} = \sum_{j=1}^{m} \sum_{i=1}^{m} c_{ji2},$$

$$p_{ji3} = \sum_{j=1}^{m} \sum_{i=1}^{m} c_{ji3}. \tag{17}$$

The maximum column value of $[\tilde{C}]_{\text{sub}}$ is indicated as $\tilde{O}_{\text{sub}} = (o_{\text{sub1}}, o_{\text{sub2}}, o_{\text{sub3}})$. $\tilde{O}_{\text{sub}}$ is computed as in Equation (18) for the sub-criteria. The maximum element of $[\tilde{C}]_{\text{main}}$ is presented as $\tilde{O}_{\text{main}} = (o_{\text{main1}}, o_{\text{main2}}, o_{\text{main3}})$. Each column element of $[\tilde{C}]_{\text{sub}}$ and $[\tilde{C}]_{\text{main}}$ is divided by $\tilde{O}_{\text{sub}}$ and $\tilde{O}_{\text{main}}$, respectively. Then, Normalized Aggregated Weighted Evaluation Matrix for sub-criteria $[\tilde{X}]_{\text{sub}}$ and for main criteria $[\tilde{X}]_{\text{main}}$ are set up. The element of $[\tilde{X}]_{\text{sub}}$ is denoted as $\tilde{x}_{jtz} = (x_{jtz1}, x_{jtz2}, x_{jtz3})$:

$$o_{\text{sub1}} = max p_{jtz1},$$

$$o_{\text{sub2}} = max p_{jtz2},$$

$$o_{\text{sub3}} = max p_{jtz3}. \tag{18}$$

Step 11. Set up total relation matrix. Total Relation Matrix $[\tilde{T}]_{\text{sub}}$ and $[\tilde{T}]_{\text{main}}$ are constructed for the sub and main criteria, respectively. The elements of $[\tilde{T}]_{\text{sub}}$ are denoted as

$\tilde{T}_{jtz} = (t_{jtz1},\ t_{jtz2},\ t_{jtz3})$. The elements of $[\tilde{T}]_{\text{main}}$ are denoted as $\tilde{T}_{ji} = (t_{ji1},\ t_{ji2},\ t_{ji3})$. $[I]$ is indicated as identity matrix. $\tilde{T}_{jtz}$ is computed as in the following equation:

$$\tilde{T}_{\text{sub}} = \tilde{X}_{\text{sub}} + \tilde{X}^2_{\text{sub}} + \tilde{X}^3_{\text{sub}} + \cdots = \sum_{z=1}^{\infty} \tilde{X}^z_{\text{sub}} = \tilde{X}_{\text{sub}}\left(I - \tilde{X}_{\text{sub}}\right)^{-1}. \tag{19}$$

Step 12. Compute the relation and prominence values. The row summation of $[\tilde{T}]_{\text{sub}}$ is denoted as $\tilde{D}_{jtz} = (u_{jtz1}, u_{jtz2}, u_{jtz3})$, and the sum of columns is indicated as $\tilde{R}_{jtz} = (r_{jtz1}, r_{jtz2}, r_{jtz3})$. $\tilde{D}_{jtz}$ and $\tilde{R}_{jtz}$ are computed as in Equations (20) and (21) for the sub-criteria. The row summation of $[\tilde{T}]_{\text{main}}$ is denoted as $\tilde{D}_{ji} = (u_{ji1}, u_{ji2}, u_{ji3})$, and the sum of columns is indicated as $\tilde{R}_{ji} = (r_{ji1}, r_{ji2}, r_{ji3})$. $\tilde{D}_{ji}$ and $\tilde{R}_{ji}$ are computed as shown in Equations (22) and (23) for the main criteria:

$$\tilde{D}_{jtz} = \left(\sum_{j=1}^{m}\sum_{t=1}^{v}\sum_{z=1}^{v} u_{jtz1}, \sum_{j=1}^{m}\sum_{t=1}^{v}\sum_{z=1}^{v} u_{jtz2}, \sum_{j=1}^{m}\sum_{t=1}^{v}\sum_{z=1}^{v} u_{jtz3}, \tag{20}$$

$$\tilde{R}_{jtz} = \left(\sum_{j=1}^{m}\sum_{t=1}^{v}\sum_{z=1}^{v} r_{jtz1}, \sum_{j=1}^{m}\sum_{t=1}^{v}\sum_{z=1}^{v} r_{jtz2}, \sum_{j=1}^{m}\sum_{t=1}^{v}\sum_{z=1}^{v} r_{jtz3}, \tag{21}$$

$$\tilde{D}_{ji} = \left(\sum_{j=1}^{m}\sum_{t=1}^{v}\sum_{z=1}^{v} u_{ji1}, \sum_{j=1}^{m}\sum_{t=1}^{v}\sum_{z=1}^{v} u_{ji2}, \sum_{j=1}^{m}\sum_{t=1}^{v}\sum_{z=1}^{v} u_{ji3}, \tag{22}$$

$$\tilde{R}_{ji} = \left(\sum_{j=1}^{m}\sum_{t=1}^{v}\sum_{z=1}^{v} r_{ji1}, \sum_{j=1}^{m}\sum_{t=1}^{v}\sum_{z=1}^{v} r_{ji2}, \sum_{j=1}^{m}\sum_{t=1}^{v}\sum_{z=1}^{v} r_{ji3}. \tag{23}$$

Then, $\tilde{D}_{jtz} + \tilde{R}_{jtz} = (g_{jtz1}, g_{jtz2}, g_{jtz3})$ and $\tilde{D}_{jtz} - \tilde{R}_{jtz} = (h_{jtz1}, h_{jtz2}, h_{jtz3})$ are computed for the sub-criteria. $\tilde{D}_{ji} + \tilde{R}_{ji} = (g_{ji1}, g_{ji2}, g_{ji3})$ and $\tilde{D}_{ji} - \tilde{R}_{ji} = (h_{ji1}, h_{ji2}, h_{ji3})$ are computed for the main criteria. $\tilde{D}_{jtz} + \tilde{R}_{jtz}$ and $\tilde{D}_{ji} + \tilde{R}_{ji}$ values are called as prominence, $\tilde{D}_{jtz} - \tilde{R}_{jtz}$ and value $\tilde{D}_{ji} - \tilde{R}_{ji}$ are named as relation.

Step 13. Defuzzyfy the fuzzy relation and prominence values. Crisp values of $\tilde{D}_{jtz} + \tilde{R}_{jtz}$ and $\tilde{D}_{jtz} - \tilde{R}_{jtz}$ denoted as $(\tilde{D}_{jtz} + \tilde{R}_{jtz})_{def}$ and $(\tilde{D}_{jtz} + \tilde{R}_{jtz})_{def}$ for the sub-criteria are computed for each sub-criterion as in Equations (24) and (25). Crisp values of $\tilde{D}_{ji} + \tilde{R}_{ji}$ and $\tilde{D}_{ji} - \tilde{R}_{ji}$ denoted as $(\tilde{D}_{ji} + \tilde{R}_{ji})_{def}$ and $(\tilde{D}_{ji} + \tilde{R}_{ji})_{def}$ for the main criteria are computed for each main criterion as in Equations (26) and (27):

$$\left(\tilde{D}_{jtz} + \tilde{R}_{jtz}\right)_{def} = \frac{1}{4}(g_{jtz1} + 2g_{jtz2} + g_{jtz3}), \tag{24}$$

$$\left(\tilde{D}_{jtz} - \tilde{R}_{jtz}\right)_{def} = \frac{1}{4}(h_{jtz1} + 2h_{jtz2} + h_{jtz3}), \tag{25}$$

$$\left(\tilde{D}_{ji} + \tilde{R}_{ji}\right)_{def} = \frac{1}{4}(g_{ji1} + 2g_{ji2} + g_{ji3}), \tag{26}$$

$$\left(\tilde{D}_{ji}-\tilde{R}_{ji}\right)_{def}=\frac{1}{4}\left(h_{ji1}+2h_{ji2}+h_{ji3}\right). \tag{27}$$

Step 14. Compute the initial weight of each sub-criterion and the weight of each main criterion. The initial weight of SC_{jt} denoted as w_{jt} satisfying $\sum_{t=}^{v} w_{jt}=1$ for each MC_j and the weight of MC_j indicated as w_j satisfying $\sum_{t=}^{m} w_j=1$ are computed by using Equations (28) and (29), respectively (Baykasoğlu and Gölcük, 2017):

$$w_{jt}=\sqrt{\left(\tilde{D}_{jtz}+\tilde{R}_{jtz}\right)_{def}^{2}+\left(\tilde{D}_{jtz}-\tilde{R}_{jtz}\right)_{def}^{2}}, \tag{28}$$

$$w_{j}=\sqrt{\left(\tilde{D}_{ji}+\tilde{R}_{ji}\right)_{def}^{2}+\left(\tilde{D}_{ji}-\tilde{R}_{ji}\right)_{def}^{2}}. \tag{29}$$

Step 15. Compute the final weight of each sub-criterion. The final weight of each sub-criterion is denoted as $(w_{jt})_f$ satisfying $\sum_{t=1}^{v}\left(w_{jt}\right)_f=w_j$ and it is computed by using the following equation:

$$\left(w_{jt}\right)_f=w_{jt}\times w_j. \tag{30}$$

The flowchart of the proposed approach is given in Figure 1.

5. A case study: an emergency service universal usability evaluation

The integrated fuzzy methodology proposed in this study is applied for evaluating universal usability of an emergency service of a private hospital. The hospital's emergency service provides services 24 h a day, 7 days a week, with the necessary equipment and experienced health personnel to intervene in all kinds of medical emergency cases. The emergency department serves patients from all age groups. For this reason, emergency service should ensure equally welcome, enhance autonomy and flexibility to all people.

Stage 1. MHE implementation

Step 1. Form expert group and perform the pre-evaluation training. In this study, five experts who work various hospital projects from different disciplines are chosen. Three of them are interior architects, one of them is architects, and the other one is urban planner. This expert distribution is formed according to Turkish Public Procurement Legislation. This legislation states that a close collaboration is required between interior architects, architects and urban planner for large-scale building projects' design (Law on Public Procurement Contracts, 2008).

Experts were given information about MHE, UD principles and usability. Each expert's office was visited and the layout of the emergency service was examined together. Afterwards, the emergency service of the hospital was visited separately with each expert and observations were made on the spot.

The age range of the expert group is between 25 and 45. First expert who is 1.76 m and 89 kg is an interior architect and he has nearly 16 years working experience. Second expert who is 1.63 m and 70 kg is an interior architect, and he has nearly 12 years working experience. Third expert is also an interior architect who is 1.80 m and 82 kg. He has nearly seven years working experience. Fourth expert has nearly four years working experience, and she is an architect who is 1.65 m and 60 kg. The last expert has nearly two years experiences. He is an urban planner. He is 1.77 m and 64 kg. As seen from these information, each expert has different physiological features. In this way, it is ensured that emergency service can evaluate with different viewpoints.

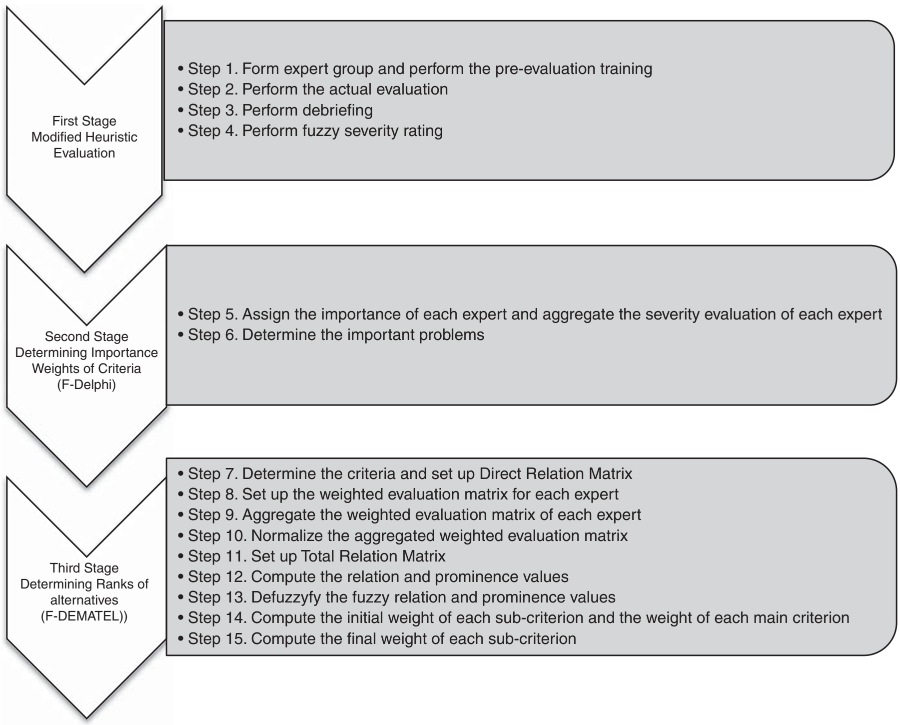

Figure 1.
The steps of the proposed approach

Step 2. Perform actual evaluation. Seven UD principles were used as a heuristic set, and task scenarios were identified by the experts group that created non-compliance in the emergency service in terms of UD principles. In this step, how to perform these tasks is explained to ensure that the experts are examining the building parallel with the universal usage goals. Task scenarios for universal usability evaluation are given in Table III.

Experts individually examined the emergency service according to the heuristics by performing predetermined tasks and explain the UUPs based on UD principles.

Table III.
Task scenarios

Task scenario number	Task scenarios
1	Use the main entrance on the first floor to enter the hospital and go to the emergency service floor using an elevator and make a patient registration
2	Use the main entrance on the first floor to enter the hospital and go to the emergency service floor using stairs and make a patient registration
3	Make a patient registration using the emergency service entrance
4	Go to the doctor's office in the emergency room, register for the MR department
5	Get out of the doctor's office and make registration for the ultrasound department
6	Get out of the doctor's office and refer to the x-ray section
7	Get out of the doctor's office and refer to the tomography section
8	Get out of the doctor's office and go to the plaster room
9	Use the toilets on the emergency service floor
10	Park your car in the emergency service's car park

Task scenarios for analyzing sufficiency in terms of UD are formed according to five categories as mentioned in Danford and Tauke (2001). These are given as follows: first, circulation systems: in the context of circulation systems, ramps, elevators, escalators, hallways corridors, etc. are evaluated; second, entering and existing: determining and approaching the entrance and exit, maneuvering through them are considered in entering and existing category. Third, way finding: paths, markers, nodes, edges, zones, districts analyzed. Graphical way finding is also evaluated in terms of text, pictograms, maps, photographs, models and diagrams usage in the building. Fourth, receiving product/services: in this category, service desks, waiting areas and shops are evaluated. Fifth, public amenities: public telephones, restrooms (toilets) seating units, etc. are analyzed.

Step 3. Perform debriefing. Five experts expressed briefly the UUPs that they have noticed in emergency service. Then, the observers record the indicated usability problems and the comments made by the experts and aggregated the problems for forming final problem list. In total, 38 problems $P_j; j = 1, 2, 3, \ldots, 38$ are identified for the final list given in Table IV.

Step 4. Perform fuzzy severity rating. Experts scored each problem in the final problem list using fuzzy severity scale in Table II. Fuzzy severity ratings of the first expert are given in Table V as an example.

Stage 2. F-delphi implementation

Step 5. Assign the importance of each expert and aggregate the severity evaluation of each expert. Weights of five experts $\tilde{\lambda}_k$, $k = 1, \ldots, 5$ were assigned according to their working experiences as in Table VI. Then $\tilde{\lambda}_k$ values were converted in to $\left(\tilde{\lambda}_k\right)_{def}$ by using Equation (7).

The weighted severity of each problem $\tilde{C}_j^k = (c_{j1}^k, c_{j2}^k, c_{j3}^k)$ is computed with Equation (3). Weighted severity assessments for the first expert, $\tilde{C}_j^1$ are given in Table VII as an example.

Then, aggregated weighted fuzzy severity assessments of all experts $\tilde{F}_j$ depicted in Table VIII are computed as in Equation (8).

Step 6. Determine the important problems. The fuzzy threshold value $\tilde{F}_{j_{tr}}$ is determined as (0.02, 0.13, 0.20) by using Equation (6), then this value is converted to crisp one as $(\tilde{F}_{j_{tr}})_{def} =$ 0.12 as in Equation (9). Finally, all the $\tilde{F}_j$ values are computed in a crisp manner, $(\tilde{F}_{j_{tr}})_{def}$ as in Equation (10) then these values are compared with and $(\tilde{F}_{j_{tr}})_{def}$. Thus, accepted and rejected problems are identified as in Table IX.

As seen from Table IX, 26 UUPs are accepted for prioritizing and 12 problems are rejected.

Stage 3. F-DEMATEL implementation

Step 7. Determine the criteria and set up direct relation matrix. In total, 26 critical problems $\mathrm{SC}_{j_t} = \left\{\mathrm{SC}_{1_1}, \mathrm{SC}_{2_1}, \ldots, \mathrm{SC}_{1_1}, \mathrm{SC}_{2_{26}}\right\}, (t = 1, \ldots, 7); (j = 1, \ldots, 26)$ formed sub-criteria and their categories as seven UD principles formed main criteria. Each accepted UUP is grouped under the related UD principles. These groups are decided by five experts as in Table X.

Additionally, $[\tilde{D}]_{\mathrm{sub}}^1$ for the sub-criteria in the first main criterion for the first expert is given in Table XI as an example.

Step 8. Set up the weighted evaluation matrix of each expert. $[\tilde{E}]_{\mathrm{sub}}^k$ and $[\tilde{E}]_{\mathrm{main}}^k$ are formed as in Equation (3). Here, only $[\tilde{E}]_{\mathrm{main}}^1$ is given in Table XII for the main criteria for the first expert as an example.

Problem number (P_j)	Problem definitions
P_1	The design of hospital entrance doors is not suitable for people with disabilities (such as people with wheelchairs)
P_2	No measures have been taken to prevent airflow at the entrance doors. This has a negative effect on conditions such as temperature control within the hospital and prevention of spread of infection
P_3	The ramp at the emergency room entrance is steep
P_4	The design of the par area near the entrance of the emergency service park is not suitable. When there is a car approaching the entrance gate, there is no space for a second car
P_5	The entrance ramp on the main entrance is narrow and rugged for wheel chairs
P_6	The ramps in front of the entrances are closed with parked cars. There are no warning signs in these areas to prevent this situation
P_7	The revolving door in the main entrance is at high speed for the use of people with disabilities
P_8	When entering the hospital from the main entrance, the emergency service is four floors below. If the emergency service is carried out by using floor stairs, this causes fatigue
P_9	The floor sign was hanged away from the main entrance. When entering the hospital there is not a signboard that orients the patient to the emergency service until reaching the floor signboard
P_{10}	"Emergency" in the floor signboard is written in an ordinary manner as same as the other department names
P_{11}	The button design of the elevator is very complex for using. Floor numbers and buttons cannot be matched
P_{12}	There is no sensor on the revolving door at the emergency entrance
P_{13}	The elevator does not have a telephone for emergency situations
P_{14}	There are no audible warnings in the elevator such as floor warning or door opening and closing warning
P_{15}	The emergency situation bell in the elevator has yellow color. It has the same size as the other buttons and it is mounted at high level
P_{16}	The elevator call buttons do not have up and down arrows
P_{17}	When entered to the main entrance, after getting off the elevator, there is only one signboard that orients to emergency service. There is no signboard orienting the emergency service at the end of this corridor
P_{18}	The section names in the room entrances are written in small font
P_{19}	There are no screens and no audible warnings on the doctors' room doors, MR, tomography, plaster room, x-ray, and ultrasound sections such as patient information in inside the room or sequence information to inform the patient
P_{20}	Measures to prevent the spread of infection between the patient and the staff in the bank where patients are registered are not taken (e.g. the bank with glass walls)
P_{21}	In the corridors, there are no places for old, disabled people, etc. to climb while walking
P_{22}	The manual doors at the entrance of the hospital, the doors used to pass the area where the stairs are, toilets' doors create the necessity to keep the door open for people with disabilities when entering or exiting from these doors because of the stuffers on these doors
P_{23}	There are no floor coverings for visually impaired people
P_{24}	The manual doors at the entrance of the hospital, the doors used to pass the area where the stairs are, toilets' doors require power to open these doors because of the stuffers on these doors
P_{25}	There are no signboards for orienting to doctors' rooms, MR, tomography, plaster room, X-ray, ultrasound and toilets
P_{26}	The area where MR, x-ray, ultrasound and tomography in it is separated by sliding door. This section gives the feeling that it does not belong to the emergency service
P_{27}	"Information" is only written on the registration, x-ray, MR, tomography banks. It is not mentioned which bank belongs to which section
P_{28}	The toilet is positioned very close to the ultrasound waiting area
P_{29}	The hospital has short and numerous corridors, such as a maze

(*continued*)

Table IV. The aggregated final universal usability problem list

Problem number (P_j)	Problem definitions
P_{30}	Washbasin of toilet for disabled is assembled at a high level, and it has been selected in large size so this leads to create problem for reaching tap
P_{31}	The toilets are not suitable for children usage
P_{32}	Washbasins are too short for tall people
P_{33}	Paper towel machine is assembled at a high level and it can use by reaching. Additionally, there is a large wash basin in front of the machine
P_{34}	The sensory systems in the toilets detect slowly. The light is turning on late and after the door is closed, it is dark inside
P_{35}	Toilets are not cleaned sufficiently
P_{36}	Hygienic cleaning materials are not available in the toilets
P_{37}	The difference between hot and cold water in the taps is not obvious
P_{38}	The electrical sockets are not covered

Table IV.

Table V.
Fuzzy severity ratings of the first expert

Problem number (P_j)	Fuzzy severity ratings $\tilde{B}_j^1$ b_{j1}^1	b_{j2}^1	b_{j3}^1	Problem number (P_j)	Fuzzy severity ratings $\tilde{B}_j^1$ b_{j1}^1	b_{j2}^1	b_{j3}^1
P_1	0.50	0.75	1.00	P_{20}	0.50	0.75	1.00
P_2	0.25	0.50	0.75	P_{21}	0.50	0.75	1.00
P_3	0.25	0.50	0.75	P_{22}	0.50	0.75	1.00
P_4	0.50	0.75	1.00	P_{23}	0.75	1.00	1.00
P_5	0.50	0.75	1.00	P_{24}	0.50	0.75	1.00
P_6	0.75	1.00	1.00	P_{25}	0.50	0.75	1.00
P_7	0.25	0.50	0.75	P_{26}	0.00	0.25	0.50
P_8	0.00	0.25	0.50	P_{27}	0.25	0.50	0.75
P_9	0.25	0.50	0.75	P_{28}	0.00	0.25	0.50
P_{10}	0.25	0.50	0.75	P_{29}	0.25	0.50	0.75
P_{11}	0.50	0.75	1.00	P_{30}	0.75	1.00	1.00
P_{12}	0.50	0.75	1.00	P_{31}	0.75	1.00	1.00
P_{13}	0.50	0.75	1.00	P_{32}	0.25	0.50	0.75
P_{14}	0.50	0.75	1.00	P_{33}	0.25	0.50	0.75
P_{15}	0.50	0.75	1.00	P_{34}	0.50	0.75	1.00
P_{16}	0.25	0.50	0.75	P_{35}	0.50	0.75	1.00
P_{17}	0.25	0.50	0.75	P_{36}	0.50	0.75	1.00
P_{18}	0.00	0.25	0.50	P_{37}	0.25	0.50	0.75
P_{19}	0.00	0.25	0.50	P_{38}	0.75	1.00	1.00

Table VI.
Weights of five experts

DMs DM_k	Work experience (years)	Fuzzy weights of DMs $\tilde{\lambda}_k = (\lambda_{k1}, \lambda_{k2}, \lambda_{k3})$	Crisp weights of DMs $(\tilde{\lambda}_k)_{def}$
DM_1	15 <	(0.75, 1.00, 1.00)	0.37
DM_2	10–15	(0.50, 0.75, 1.00)	0.30
DM_3	5–9	(0.25, 0.50, 0.75)	0.20
DM_4	3–4	(0.00, 0.25, 0.50)	0.10
DM_5	1–3	(0.00, 0.00, 0.25)	0.03

Step 9. Aggregate the weighted evaluation matrix of each expert. Aggregated weighted evaluation matrix for sub-criteria $[\tilde{C}]_{sub}$ and main criteria $[\tilde{C}]_{main}$ are constructed by Equations (14) and (15). $[\tilde{C}]_{main}$ for the main criteria is given in Table XIII as an example.

Problem number (P_j)	Weighted fuzzy severity ratings $\tilde{C}_j^1$			Problem number (P_j)	Weighted fuzzy severity ratings $\tilde{C}_j^1$		
	b_{j1}^1	b_{j2}^1	b_{j3}^1		b_{j1}^1	b_{j2}^1	b_{j3}^1
P_1	0.19	0.28	0.37	P_{20}	0.19	0.28	0.37
P_2	0.09	0.19	0.28	P_{21}	0.19	0.28	0.37
P_3	0.09	0.19	0.28	P_{22}	0.19	0.28	0.37
P_4	0.19	0.28	0.37	P_{23}	0.28	0.37	0.37
P_5	0.19	0.28	0.37	P_{24}	0.19	0.28	0.37
P_6	0.28	0.37	0.37	P_{25}	0.19	0.28	0.37
P_7	0.09	0.19	0.28	P_{26}	0.00	0.09	0.19
P_8	0.00	0.09	0.19	P_{27}	0.09	0.19	0.28
P_9	0.09	0.19	0.28	P_{28}	0.00	0.09	0.19
P_{10}	0.09	0.19	0.28	P_{29}	0.09	0.19	0.28
P_{11}	0.19	0.28	0.37	P_{30}	0.28	0.37	0.37
P_{12}	0.19	0.28	0.37	P_{31}	0.28	0.37	0.37
P_{13}	0.19	0.28	0.37	P_{32}	0.09	0.19	0.28
P_{14}	0.19	0.28	0.37	P_{33}	0.09	0.19	0.28
P_{15}	0.19	0.28	0.37	P_{34}	0.19	0.28	0.37
P_{16}	0.09	0.19	0.28	P_{35}	0.19	0.28	0.37
P_{17}	0.09	0.19	0.28	P_{36}	0.19	0.28	0.37
P_{18}	0.00	0.09	0.19	P_{37}	0.09	0.19	0.28
P_{19}	0.00	0.09	0.19	P_{38}	0.28	0.37	0.37

Table VII. Weighted fuzzy severity ratings of the first expert

Problem number (P_j)	Aggregated weighted fuzzy severity ratings $\tilde{F}_j$			Problem number (P_j)	Aggregated weighted fuzzy severity ratings $\tilde{F}_j$		
	f_{j1}	f_{j2}	f_{j3}		f_{j1}	f_{j2}	f_{j3}
P_1	0.13	0.18	0.20	P_{20}	0.07	0.11	0.16
P_2	0.04	0.07	0.12	P_{21}	0.12	0.17	0.20
P_3	0.07	0.12	0.17	P_{22}	0.09	0.14	0.19
P_4	0.10	0.15	0.20	P_{23}	0.14	0.19	0.20
P_5	0.11	0.16	0.19	P_{24}	0.07	0.12	0.17
P_6	0.13	0.18	0.20	P_{25}	0.08	0.13	0.18
P_7	0.10	0.15	0.18	P_{26}	0.04	0.08	0.13
P_8	0.04	0.09	0.14	P_{27}	0.06	0.11	0.16
P_9	0.08	0.13	0.18	P_{28}	0.02	0.06	0.11
P_{10}	0.10	0.15	0.18	P_{29}	0.05	0.09	0.14
P_{11}	0.09	0.14	0.19	P_{30}	0.14	0.19	0.20
P_{12}	0.09	0.14	0.19	P_{31}	0.13	0.18	0.20
P_{13}	0.12	0.17	0.20	P_{32}	0.08	0.13	0.17
P_{14}	0.13	0.18	0.20	P_{33}	0.06	0.11	0.16
P_{15}	0.11	0.16	0.20	P_{34}	0.07	0.12	0.17
P_{16}	0.06	0.11	0.16	P_{35}	0.09	0.14	0.18
P_{17}	0.07	0.12	0.17	P_{36}	0.08	0.13	0.18
P_{18}	0.05	0.10	0.15	P_{37}	0.06	0.11	0.16
P_{19}	0.05	0.10	0.15	P_{38}	0.08	0.13	0.16

Table VIII. Aggregated weighted severity assessments

Step 10. Normalize the aggregated weighted evaluation matrix. Normalized Aggregated Weighted Evaluation Matrix for sub-criteria $[\tilde{X}]_{sub}$ and for main criteria $[\tilde{X}]_{main}$ are set up by using Equations (16)–(18). Table XIV shows $[\tilde{X}]_{main}$ as an example.

Step 11. Set up total relation matrix. Total Relation Matrix for sub-criteria $[\tilde{T}]_{sub}$ and for main criteria $[\tilde{T}]_{main}$ given in Table XV is constructed by using Equation (20).

Problem number (P_j)	Crisp aggregated severity ratings $(\tilde{F}_j)_{def}$	Decision	Problem number (P_j)	Crisp aggregated severity ratings $(\tilde{F}_j)_{def}$	Decision
P_1	0.17	Accept	P_{20}	0.11	Reject
P_2	0.08	Reject	P_{21}	0.16	Accept
P_3	0.12	Accept	P_{22}	0.14	Accept
P_4	0.15	Accept	P_{23}	0.18	Accept
P_5	0.15	Accept	P_{24}	0.12	Accept
P_6	0.17	Accept	P_{25}	0.13	Accept
P_7	0.14	Accept	P_{26}	0.08	Reject
P_8	0.09	Reject	P_{27}	0.11	Reject
P_9	0.13	Accept	P_{28}	0.06	Reject
P_{10}	0.14	Accept	P_{29}	0.09	Reject
P_{11}	0.14	Accept	P_{30}	0.18	Accept
P_{12}	0.14	Accept	P_{31}	0.17	Accept
P_{13}	0.16	Accept	P_{32}	0.13	Accept
P_{14}	0.17	Accept	P_{33}	0.11	Reject
P_{15}	0.16	Accept	P_{34}	0.12	Accept
P_{16}	0.11	Reject	P_{35}	0.14	Accept
P_{17}	0.12	Accept	P_{36}	0.13	Accept
P_{18}	0.10	Reject	P_{37}	0.11	Reject
P_{19}	0.10	Reject	P_{38}	0.13	Accept

Table IX. Accepted and rejected problems

Step 12. Compute the fuzzy prominence and relation values. $\tilde{D}_{jtz}$ and $\tilde{R}_{jtz}$ are computed as in Equations (21) and (22) for the sub-criteria. $\tilde{D}_{ji}$ and $\tilde{R}_{ji}$ seen in Table XVI as an example are computed as in Equations (23) and (24) for the main criteria. Then, $\tilde{D}_{jtz}+\tilde{R}_{jtz}$ and $\tilde{D}_{jtz}-\tilde{R}_{jtz}$ are computed for the sub-criteria. $\tilde{D}_{ji}+\tilde{R}_{ji}$ and $\tilde{D}_{ji}-\tilde{R}_{ji}$ are calculated for the main criteria by using Equations (1) and (2).

Step 13. Defuzzyfy the relation and prominence values. $(\tilde{D}_{jtz}+\tilde{R}_{jtz})_{def}$ and $(\tilde{D}_{jtz}-\tilde{R}_{jtz})_{def}$ seen in Table XVII for the sub-criteria are computed by using Equations (25) and (26). $(\tilde{D}_{jtz}+\tilde{R}_{jtz})_{def}$ and $(\tilde{D}_{jtz}-\tilde{R}_{jtz})_{def}$ presented in Table XVI for the main criteria are computed as in Equations (27) and (28).

As seen from Table XVII, among the sub-criteria included in equitable use (MC_1) main criterion, toilet design (SC_{15}) and washbasin design (SC_{16}) because of having the smallest negative crisp prominence value are the most affected sub-criteria. For the crisp relation values, floor covering design is the most related to the other sub-criteria in the equitable use (MC_1) main criterion. Design of entrance door sub-criterion (SC_{1_1}) has the least number of relationship with the other sub-criteria in the equitable use (MC_1) main criterion.

As seen from Table XVIII, simple and intuitive use (MC_3) criterion because of having the biggest positive crisp prominence value has the most effect on the other main criteria. Flexibility in use (MC_2) because of having the smallest crisp prominence value is the most affected main criterion. According to the crisp relation values, perceptible information criterion (MC_4) is the most related to the other main criteria. Tolerance for error (MC_5) has the least relation with the other main criteria.

Step 14. Compute the initial weight of each sub-criterion and the weight of each main criterion. w_{jt} shown in Table XVIII and w_j shown in Table XVI are computed by using Equations (29) and (30), respectively.

As seen from Table XVI, equitable use (MC_1) and simple and intuitive use (MC_3) main criteria have the highest importance.

Criteria main/ sub MC_j/SC_{j_t}	Definition	Short definition
MC_1	Equitable use	
SC_{11}	The design of hospital entrance doors is not suitable for people with disabilities (such as people with wheelchairs)	Design of entrance door
SC_{12}	There are no audible warnings in the elevator such as floor warning or door opening and closing warning	Elevator audible warning system
SC_{13}	In the corridors, there are no places for old, disabled people, etc. to climb while walking	Walking support in corridors
SC_{14}	There are no floor coverings for visually impaired people	Floor covering design
SC_{15}	The toilets are not suitable for children usage	Toilet design
SC_{16}	Washbasins are too short for tall people	Washbasin assembly
MC_2	Flexibility in use	
SC_{21}	The revolving door in the main entrance is at a high speed for the use of people with disabilities	Speed of revolving doors
SC_{22}	No measures have been taken to prevent airflow at the entrance doors. This has a negative effect on conditions such as temperature control within the hospital and prevention of spread of infection	Emergency door motion system
MC_3	Simple and intuitive use	
SC_{31}	"Emergency" in the floor signboard is written in an ordinary manner as same as the other department names	Floor signboard design
SC_{32}	The button design of the elevator is very complex for using. Floor numbers and buttons cannot be matched	Elevator button design
SC_{33}	The emergency situation bell in the elevator has yellow color. It has the same size as the other buttons and it is mounted at high level	Elevator emergency bottom design
MC_4	Perceptible information	
SC_{41}	The floor sign was hanged away from the main entrance. When entering the hospital there is not a signboard that orients the patient to the emergency service until reaching the floor signboard	Position of the floor signboard
SC_{42}	When entered to the main entrance, after getting off the elevator, there is only one signboard that orients to emergency service. There is no signboard orienting the emergency service at the end of this corridor	Emergency service signboard position
SC_{43}	There are no signboards for orienting to doctors' rooms, MR, tomography, plaster room, X-ray, ultrasound and toilets	Orienting signboards
MC_5	Tolerance for error	
SC_{51}	The ramp at the emergency room entrance is steep	Steep of ramp
SC_{52}	The ramp on the main entrance is narrow and rugged for wheel chairs	Width of ramp
SC_{53}	The elevator does not have a telephone for emergency situations	Telephone for emergency situation
SC_{54}	The sensory systems in the toilets detect slowly. The light is turning on late and after the door is closed, it is dark inside	Light sensory system
SC_{55}	Toilets are not cleaned sufficiently	Cleanliness of the toilets
SC_{56}	Hygienic cleaning materials are not available in the toilets	Hygienic cleaning materials
SC_{57}	The electrical sockets are not covered	Safety of electrical socket
MC_6	Low physical effort	
SC_{61}	The manual doors at the entrance of the hospital, the doors used to pass the area where the stairs are, toilets' doors create the necessity to keep the door open for people with disabilities when entering or exiting from these doors because of the stuffers on these doors	Necessity to keep the door open

(*continued*)

Table X. Sub and main criteria

Criteria main/ sub MC_j/SC_{j_t}	Definition	Short definition
SC_{62}	The manual doors at the entrance of the hospital, the doors used to pass the area where the stairs are, toilets' doors requires power to open these doors because of the stuffers on these doors	Required power to open the doors
MC_7	Size and space for approach	
SC_{71}	The design of the car park near the entrance of the emergency service park is not suitable. When there is a car approaching the entrance gate, there is no space for a second car	Car park design
SC_{72}	The ramps in front of the entrances are closed with parked cars. There are no warning signs in these areas to prevent this situation	Parking restriction signboards
SC_{73}	Washbasin of toilet for disabled is assembled at high level and it has been selected in large size so this leads to create problem for reaching tap	Washbasin design in disabled toilets

Table X.

Step 15. Compute the final weight of each sub-criterion. $(w_{jt})_f$ given in Table XVIII is computed by using Equation (30).

As seen from Table XVIII, elevator button design (SC_{32}) and elevator emergency button design $\left(SC_{3_3}\right)$ have the highest importance.

6. Conclusion

In this study, a three-stage integrated fuzzy approach is proposed for universal usability evaluation. A case study for universal usability evaluation of a private hospital emergency service is given.

Results showed that the elevator button design, the elevator emergency button design and the position of the floor signboard are the first three problems that should be primarily improved as sub-criteria. In terms of main criteria, equitable use, simple and intuitive use and perceptible information are the three most important UD principles that should be improve in emergency service. As seen from the sub-criteria results, elevator button design and the elevator emergency button design are related to simple and intuitive use main criterion, the position of the floor signboard is related to perceptible information. Additionally, in terms of crisp prominence values, elevator button design sub-criterion has the highest crisp impact value among the other sub-criteria.

The elevator button design creates confusion for the users in terms of matching the floor numbers and buttons. The elevator emergency button is designed in the same size as the floor buttons in yellow and positioned at a high level. This is in contrast to the principle of simple and intuitive use. In order to improve these problems, it is preferable to design the button on the elevators in which the button numbers are embossed. The emergency button should be red that evokes an emergency and it should have a size that can be distinguished from other buttons at the time of panic. If possible, it should be positioned lower than the other buttons. Thus, people with wheelchairs or people in short stature will be able to use this button comfortably.

When you enter from the main entrance on the first floor of the hospital there is only a signboard that directs you to the elevators. Until the elevator area is reached, there is no signboard that presents floor information or orients emergency service. This creates inconvenience in terms of perceptible information principle. Patients in emergency conditions are more stressful, tense and in physically more difficult conditions than the other patients. For this reason, the route of the emergency service should be specified clearly and recognizable. The floor plan located in the elevator area should be positioned close to the entrance. The floor and direction information of the emergency service should be written in a colorful and large font which can be distinguished from other units.

Table XI. Fuzzy effect evaluations of the first expert for the main criteria

Main criteria MC_j	Fuzzy effect evaluation $\tilde{D}_{ji}^{1}$ MC_1 d_{j11}^1	d_{j12}^1	d_{j13}^1	MC_2 d_{j21}^1	d_{j22}^1	d_{j23}^1	MC_3 d_{j31}^1	d_{j32}^1	d_{j33}^1	MC_4 d_{j41}^1	d_{j42}^1	d_{j43}^1	MC_5 d_{j51}^1	d_{j52}^1	d_{j53}^1	MC_6 d_{j61}^1	d_{j62}^1	d_{j63}^1	MC_7 d_{j71}^1	d_{j72}^1	d_{j73}^1
MC_1	0.00	0.00	0.25	0.00	0.25	0.50	0.25	0.50	0.75	0.25	0.50	0.75	0.00	0.00	0.25	0.25	0.50	0.75	0.25	0.50	0.75
MC_2	0.00	0.25	0.50	0.00	0.00	0.25	0.00	0.25	0.50	0.00	0.25	0.50	0.00	0.00	0.25	0.00	0.25	0.50	0.00	0.25	0.50
MC_3	0.25	0.50	0.75	0.00	0.25	0.50	0.00	0.00	0.25	0.50	0.75	1.00	0.75	1.00	1.00	0.00	0.00	0.25	0.00	0.00	0.25
MC_4	0.25	0.50	0.75	0.00	0.25	0.50	0.50	0.75	1.00	0.00	0.00	0.25	0.75	1.00	1.00	0.00	0.00	0.25	0.00	0.00	0.25
MC_5	0.00	0.00	0.25	0.00	0.00	0.25	0.25	0.50	0.75	0.25	0.50	0.75	0.00	0.00	0.25	0.25	0.50	0.75	0.25	0.50	0.75
MC_6	0.50	0.75	1.00	0.25	0.50	0.75	0.00	0.00	0.25	0.00	0.00	0.25	0.50	0.75	1.00	0.00	0.00	0.25	0.00	0.25	0.50
MC_7	0.25	0.50	0.75	0.00	0.25	0.50	0.00	0.00	0.25	0.00	0.00	0.25	0.50	0.75	1.00	0.50	0.75	1.00	0.00	0.00	0.25

Table XII. Weighted evaluation matrix of the main criteria for the first expert

	Weighted fuzzy effect assessment $\tilde{E}_{ji}^{k}$																				
	MC_1			MC_2			MC_3			MC_4			MC_5			MC_6			MC_7		
Main criteria MC_J	e_{ji1}^{1}	e_{ji2}^{1}	e_{ji3}^{1}	e_{ji1}^{1}	e_{ji2}^{1}	e_{ji3}^{1}	e_{ji1}^{1}	e_{ji2}^{1}	e_{ji3}^{1}	e_{ji1}^{1}	e_{ji2}^{1}	e_{ji3}^{1}	e_{ji1}^{1}	e_{ji2}^{1}	e_{ji3}^{1}	e_{ji1}^{1}	e_{ji2}^{1}	e_{ji3}^{1}	e_{ji1}^{1}	e_{ji2}^{1}	e_{ji3}^{1}
MC_1	0.00	0.00	0.09	0.00	0.09	0.19	0.09	0.19	0.28	0.09	0.19	0.28	0.00	0.00	0.09	0.09	0.19	0.28	0.09	0.19	0.28
MC_2	0.00	0.09	0.19	0.00	0.00	0.09	0.00	0.09	0.19	0.00	0.09	0.19	0.00	0.00	0.09	0.00	0.09	0.19	0.00	0.09	0.19
MC_3	0.09	0.19	0.28	0.00	0.09	0.19	0.00	0.00	0.09	0.19	0.28	0.37	0.28	0.37	0.37	0.00	0.00	0.09	0.00	0.00	0.09
MC_4	0.09	0.19	0.28	0.00	0.09	0.19	0.19	0.28	0.37	0.00	0.00	0.09	0.28	0.37	0.37	0.00	0.00	0.09	0.00	0.00	0.09
MC_5	0.00	0.00	0.09	0.00	0.00	0.09	0.09	0.19	0.28	0.09	0.19	0.28	0.00	0.00	0.09	0.09	0.19	0.28	0.09	0.19	0.28
MC_6	0.19	0.28	0.37	0.09	0.19	0.28	0.00	0.00	0.09	0.00	0.00	0.09	0.19	0.28	0.37	0.00	0.00	0.09	0.00	0.09	0.19
MC_7	0.09	0.19	0.28	0.00	0.09	0.19	0.00	0.00	0.09	0.00	0.00	0.09	0.19	0.28	0.37	0.19	0.28	0.37	0.00	0.00	0.09

Main criteria MC_j	Aggregated weighted evaluation $\tilde{C}_{ji}$																				
	MC_1			MC_2			MC_3			MC_4			MC_5			MC_6			MC_7		
	c_{ji1}	c_{ji2}	c_{ji3}	c_{ji1}	c_{ji2}	c_{ji3}	c_{ji1}	c_{ji2}	c_{ji3}	c_{ji1}	c_{ji2}	c_{ji3}	c_{ji1}	c_{ji2}	c_{ji3}	c_{ji1}	c_{ji2}	c_{ji3}	c_{ji1}	c_{ji2}	c_{ji3}
MC_1	0.00	0.00	0.05	0.04	0.08	0.13	0.05	0.10	0.15	0.02	0.07	0.12	0.00	0.00	0.05	0.05	0.10	0.15	0.06	0.11	0.16
MC_2	0.04	0.08	0.13	0.00	0.00	0.05	0.01	0.06	0.11	0.00	0.05	0.10	0.00	0.01	0.06	0.00	0.03	0.08	0.02	0.05	0.10
MC_3	0.07	0.12	0.17	0.00	0.05	0.10	0.00	0.00	0.05	0.11	0.16	0.20	0.12	0.17	0.19	0.00	0.01	0.06	0.00	0.01	0.06
MC_4	0.07	0.12	0.17	0.00	0.05	0.10	0.11	0.16	0.20	0.00	0.00	0.05	0.11	0.16	0.19	0.00	0.01	0.06	0.00	0.00	0.05
MC_5	0.00	0.00	0.05	0.00	0.00	0.05	0.05	0.10	0.14	0.04	0.09	0.14	0.00	0.00	0.05	0.02	0.06	0.11	0.04	0.08	0.13
MC_6	0.07	0.12	0.17	0.02	0.05	0.10	0.00	0.01	0.06	0.00	0.01	0.06	0.06	0.11	0.16	0.00	0.00	0.05	0.02	0.06	0.11
MC_7	0.07	0.12	0.16	0.02	0.05	0.10	0.01	0.02	0.07	0.00	0.00	0.05	0.08	0.13	0.18	0.05	0.10	0.15	0.00	0.00	0.05

Table XIII. Aggregated weighted evaluation matrix for main criteria

Table XIV. Normalized Aggregated Weighted Evaluation Matrix for main criteria

Main criteria MC_j	Normalized Aggregated Weighted Evaluation $\tilde{X}_{ji}$																				
	MC_1			MC_2			MC_3			MC_4			MC_5			MC_6			MC_7		
	x_{ji1}	x_{ji2}	x_{ji3}	x_{ji1}	x_{ji2}	x_{ji3}	x_{ji1}	x_{ji2}	x_{ji3}	x_{ji1}	x_{ji2}	x_{ji3}	x_{ji1}	x_{ji2}	x_{ji3}	x_{ji1}	x_{ji2}	x_{ji3}	x_{ji1}	x_{ji2}	x_{ji3}
MC_1	0.00	0.00	0.14	0.04	0.15	0.36	0.05	0.17	0.40	0.02	0.12	0.33	0.00	0.00	0.14	0.05	0.17	0.40	0.07	0.19	0.44
MC_2	0.04	0.15	0.36	0.00	0.00	0.14	0.01	0.10	0.30	0.00	0.08	0.27	0.00	0.01	0.15	0.00	0.05	0.21	0.02	0.08	0.27
MC_3	0.08	0.21	0.46	0.00	0.08	0.26	0.00	0.00	0.14	0.12	0.27	0.54	0.13	0.30	0.50	0.00	0.02	0.17	0.00	0.02	0.16
MC_4	0.08	0.21	0.47	0.00	0.08	0.26	0.12	0.27	0.54	0.00	0.00	0.14	0.12	0.28	0.50	0.00	0.02	0.16	0.00	0.00	0.14
MC_5	0.00	0.00	0.14	0.00	0.00	0.14	0.05	0.17	0.37	0.04	0.15	0.37	0.00	0.00	0.14	0.02	0.11	0.31	0.04	0.14	0.36
MC_6	0.08	0.22	0.47	0.02	0.09	0.28	0.00	0.02	0.16	0.00	0.02	0.16	0.06	0.19	0.43	0.00	0.00	0.14	0.02	0.10	0.30
MC_7	0.08	0.21	0.44	0.02	0.08	0.27	0.01	0.03	0.19	0.00	0.00	0.14	0.09	0.23	0.49	0.06	0.18	0.42	0.00	0.00	0.14

Table XV. Total relation matrix for main criteria

Main criteria MC_j	Total relation assessment $\tilde{T}_{ji}$																				
	MC_1			MC_2			MC_3			MC_4			MC_5			MC_6			MC_7		
	t_{ji1}	t_{ji2}	t_{ji3}	t_{ji1}	t_{ji2}	t_{ji3}	t_{ji1}	t_{ji2}	t_{ji3}	t_{ji1}	t_{ji2}	t_{ji3}	t_{ji1}	t_{ji2}	t_{ji3}	t_{ji1}	t_{ji2}	t_{ji3}	t_{ji1}	t_{ji2}	t_{ji3}
MC_1	0.02	0.40	−0.49	0.04	0.35	−0.16	0.06	0.47	−0.30	0.03	0.40	−0.31	0.02	0.42	−0.48	0.05	0.39	−0.18	0.07	0.41	−0.16
MC_2	0.04	0.39	−0.20	0.00	0.14	−0.26	0.01	0.31	−0.23	0.00	0.28	−0.23	0.00	0.27	−0.38	0.00	0.20	−0.22	0.03	0.24	−0.18
MC_3	0.09	0.60	−0.33	0.01	0.31	−0.29	0.03	0.43	−0.42	0.13	0.61	−0.09	0.15	0.72	−0.25	0.01	0.29	−0.41	0.01	0.30	−0.40
MC_4	0.09	0.59	−0.32	0.01	0.30	−0.28	0.13	0.64	−0.12	0.02	0.38	−0.38	0.14	0.69	−0.24	0.01	0.28	−0.41	0.01	0.28	−0.41
MC_5	0.01	0.32	−0.42	0.00	0.16	−0.30	0.06	0.42	−0.20	0.05	0.38	−0.17	0.02	0.35	−0.37	0.02	0.28	−0.19	0.04	0.30	−0.17
MC_6	0.09	0.47	−0.21	0.02	0.25	−0.17	0.01	0.28	−0.39	0.01	0.24	−0.37	0.07	0.45	−0.24	0.01	0.20	−0.29	0.03	0.30	−0.15
MC_7	0.09	0.51	−0.27	0.03	0.26	−0.21	0.02	0.32	−0.42	0.01	0.26	−0.43	0.10	0.53	−0.22	0.07	0.39	−0.08	0.01	0.24	−0.30

7. Discussion

This study shows that hospital managers and architects should use UD principles as a design guide for emergency services to satisfy all kinds of people needs. Among the various institutions and buildings that receive members of the public, emergency services welcome

Main criteria MC_j	$\tilde{D}_{ji}$ u_{ji1}	u_{ji2}	u_{ji3}	$\tilde{R}_{ji}$ r_{ji1}	r_{ji2}	r_{ji3}	Crisp prominence $(\tilde{D}_{ji}+\tilde{R}_{ji})_{def}$	Crisp relation $(\tilde{D}_{ji}-\tilde{R}_{ji})_{def}$	w_j
MC_1	0.29	2.83	−2.09	0.43	3.27	−2.24	2.15	−0.22	0.18
MC_2	0.09	1.83	−1.70	0.11	1.77	−1.67	1.01	0.02	0.08
MC_3	0.43	3.25	−2.18	0.32	2.87	−2.08	2.18	0.19	0.18
MC_4	0.42	3.16	−2.16	0.25	2.54	−1.98	1.98	0.30	0.16
MC_5	0.22	2.20	−1.81	0.50	3.43	−2.18	2.00	−0.59	0.17
MC_6	0.22	2.20	−1.83	0.17	2.02	−1.76	1.31	0.08	0.11
MC_7	0.32	2.51	−1.92	0.20	2.07	−1.78	1.49	0.22	0.12

Table XVI. Fuzzy and crisp prominence and relation values of main criteria

Sub-criteria SC_{j_t}	Crisp prominence $(\tilde{D}_{jtz}+\tilde{R}_{jtz})_{def}$	Crisp relation $(\tilde{D}_{jtz}-\tilde{R}_{jtz})_{def}$	Sub-criteria SC_{j_t}	Crisp prominence $(\tilde{D}_{jtz}+\tilde{R}_{jtz})_{def}$	Crisp relation $(\tilde{D}_{jtz}-\tilde{R}_{jtz})_{def}$
SC_{11}	3.62	−0.74	SC_{43}	0.53	−0.49
SC_{12}	2.55	0.42	SC_{51}	−0.22	−0.01
SC_{13}	3.48	−0.31	SC_{52}	−0.22	0.01
SC_{14}	5.11	0.63	SC_{53}	−0.57	0.00
SC_{15}	−1.58	0.00	SC_{54}	0.01	0.57
SC_{16}	−1.58	0.00	SC_{55}	1.31	−0.29
SC_{21}	2.22	−0.51	SC_{56}	1.22	−0.13
SC_{22}	2.22	0.51	SC_{57}	−0.41	−0.16
SC_{31}	3.59	−1.19	SC_{61}	5.39	−0.54
SC_{32}	14.89	1.24	SC_{62}	5.39	0.54
SC_{33}	14.20	−0.05	SC_{71}	8.99	0.52
SC_{41}	0.44	0.73	SC_{72}	8.99	−0.52
SC_{42}	0.39	−0.24	SC_{73}	−0.40	0.00

Table XVII. Crisp prominence and relation values of sub-criteria

Sub criteria SC_{j_t}	Initial weight w_{jt}	Final weight $(w_{jt})_f$	Sub-criteria SC_{j_t}	Initial weight w_{jt}	Final weight $(w_{jt})_f$
SC_{11}	0.20	0.0400	SC_{43}	0.35	0.0500
SC_{12}	0.14	0.0200	SC_{51}	0.05	0.0100
SC_{13}	0.19	0.0300	SC_{52}	0.05	0.0100
SC_{14}	0.29	0.0500	SC_{53}	0.12	0.0200
SC_{15}	0.09	0.0200	SC_{54}	0.12	0.0200
SC_{16}	0.09	0.0200	SC_{55}	0.29	0.0500
SC_{21}	0.50	0.0400	SC_{56}	0.27	0.0400
SC_{22}	0.50	0.0400	SC_{57}	0.10	0.0200
SC_{31}	0.12	0.0200	SC_{61}	0.50	0.0550
SC_{32}	0.45	0.0800	SC_{62}	0.50	0.0550
SC_{33}	0.43	0.0800	SC_{71}	0.49	0.0588
SC_{41}	0.42	0.0700	SC_{72}	0.49	0.0588
SC_{42}	0.23	0.0400	SC_{73}	0.02	0.0024

Table XVIII. Initial and final weights of sub-criteria the most number of people with disabilities, children, pregnant woman, elderly people, etc. These people with different features, due to their health problems or physical features, are vulnerable, weak, sometimes have reduced mobility and are often psychologically distressed. The primary purpose of emergency services is to welcome these different kinds of people and to help them to get well. To fulfill this role in an efficient way, a role accomplished by the various doctors and the other related personnel, it must be possible to conduct it in a specially adapted environment. This is why the reception, the care, the stay services in emergency departments must take place under the appropriate conditions possible in terms of quality and hygiene as well as in terms of safety and ease of use. In this context, the emergency service design and its equipment play a crucial role.

The emergency service should provide the same means of use for all users and the design of these areas should avoid segregating or stigmatizing any users. All users should have equal availability for provisions for privacy, security and safety. These conditions may provide equatable use principle. In terms of flexibility in use principle, emergency service design should provide choice in methods of use and should accommodate right- or left-handed access and use. Additionally emergency service design should facilitate the user's accuracy and precision. It is important for flexibility in use principle that design should provide adaptability to the user's pace. Emergency service design should eliminate unnecessary complexity, and design should be consistent with user's expectations and intuition. It is also important to accommodate a wide range of literacy and language skills in terms of inner design. Design should provide effective prompting and feedback during and after task completion. These are vital for simple and intitutive use principle. In terms of perceptible information principle, different modes (pictorial, verbal, tactile) for redundant presentation of essential information should be used in emergency service to make easy of use. Design should provide adequate contrast between essential information and its surroundings. Instructions or directions in emergency service should assure to understand the information easily. Used sign or direction boards and instructions in emergency service should provide compatibility with a variety of techniques or devices used by people with sensory limitations. In terms of health institutions, it is very essential to provide warnings for hazards and errors. Design should ensure to fail-safe features for people. It should discourage unconscious action in tasks that require vigilance. These are required to provide tolerance for error principle in emergency service. To maintain low physical effort principle in emergency service, design should allow user to maintain a neutral body position and minimize repetitive actions and required physical effort. Finally, for size and space for approach and use principle, emergency service design should assure a clear line of sight to important elements for any seated or standing user and allow reach to all components easily for any seated or standing user. It is also important for this principle that emergency service design should assure adequate space for the use of assistive devices or personal assistance especially people with wheelchairs or people with other physical disabilities.

To the best of our knowledge, this study is original in terms of methodology and providing a new perspective for building design evaluation. For the methodological aspect of future researches, the proposed approach can be combined with intuitionistic fuzzy sets, hesitant fuzzy sets, neutrosophic sets and stochastic processes. Different buildings' designs can be compared by using the proposed methodology. In addition, the proposed methodology can be combined with several ranking methods as TOPSIS, PROMETHEE, VIKOR, etc.

Different scenarios can be performed by using the proposed approach. For example, without using experts, this approach can be performed with different real-user groups, such as people with physical disabilities, visual disabilities, hearing loss or pregnancy, etc. In this way, important universal usability criteria and the best building design can be identified for different viewpoints and results obtained from different user groups can be integrated for establishing the best building design. Additionally, universal usability evaluation of different buildings studies can be performed for undeveloped, developing and developed countries. By carrying out a comparative study related to this theme, differences of user needs and expectations related to different buildings can be obtained based on UD principles.

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