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WEIGHTING THE UNIVERSAL DESIGN PRINCIPLES USING MULTI-CRITERIA DECISION MAKING TECHNIQUES

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Keywords
Design for All,
Universal Design,
Decision Making,
Multi Criteria Decision Making.

Abstract
Universal Design (UD) is the design of products and environments that can be used by all people in the widest possible way without the need for adaptation and custom design. It involves a wide range of design disciplines, including environments, products, and communication design. A working group of developers (architects, product designers and environmental design researchers) guided the design process without evaluating existing designs and identified seven UD principles to be used to educate designers and consumers about the properties of more useful products and environments. These principles are “Equitable Use”, “Flexibility in Use”, “Simple and Intuitive Use”, “Perceptible Information”, “Tolerance for Error”, “Low Physical Effort”, and “Size and Space for Approach and Use”. Prioritizing or weighting these principles can be handled as a Multi Criteria Decision Making (MCDM) problem. For this reason, in this paper we study the prioritizing of these principles using two of MCDM techniques with fuzzy numbers, namely AHP and ANP, and the results of both algorithms are compared. The main contribution of this paper is to prioritize UD principles using numerical methods with experts’ view. This work, which includes grading the principle 7 of Universal Design in itself, will be guiding for designers. To the authors’ knowledge, this will be the first interdisciplinary study which uses these two techniques for evaluating UD principles for developers.

ÇOK KRİTERLİ KARAR VERME TEKNİKLERİ KULLANILARAK EVRENSEL TASARIM İLKELERİNİN AĞIRLIKLANDIRILMASI

Anahtar Kelimeler
Herkes İçin Tasarım,
Evrensel Tasarım,
Karar Verme,
Çok Kriterli Karar Verme.

Öz
Evrensel Tasarım (UD), adaptasyon ve özel tasarım gerekmeden tüm insanlar tarafından en geniş şekilde kullanılabilecek ürün ve ortamların tasarımıdır. Ortamlar, ürünler ve iletişim tasarımı dahil olmak üzere çok çeşitli tasarım disiplinlerini içerir. Uzmanlardan oluşan bir çalışma grubu (mimarlar, ürün tasarımcıları ve çevre tasarım araştırmacıları), tasarım sürecini mevcut tasarımları değerlendirerek, tasarımcıları ve tüketicileri daha yararlı ürünlerin ve ortamların özellikleri hakkında eğitmek için kullanılacak yedi UD ilkesini belirlemiştir. Bu ilkeler “Eşit Kullanım”, ”Kullanımda Esneklik”, “Basit ve Sezgisel Kullanım”, “Algılanabilir Bilgi”, “Hatalara Dayanım”, “Düşük Fiziksel Çaba” ve “Yaklaşım ve Kullanım için Boyut ve Mekan” dır. Bu ilkelerin önceliklendirilmesi veya ağırlıklandırılması, Çok Kriterli Karar Verme (ÇKKV) yöntemi ile ele alınmıştır. Bu çalışmada, bu ilkelerin, ÇKKV yöntemleri olan AHP ve ANP yöntemleri, bulanık sayılar kullanılarak önceliklendirilmiş ve her iki yöntemin sonuçları karşılaştırılmıştır. Bu çalışmanın ana fikri, uzmanların görüşleri ile sayısal

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yöntemler kullanılarak Evrensel Tasarım ilkelerini ağırlıklandırmaktır. Evrensel tasarımın 7 ilkesini kendi içinde derecelendirmeyi içeren bu çalışma, tasarımcılar için yol gösterici olacaktır. Yazarların bilgisine göre bu çalışma, Evrensel Tasarım ilkelerini, uzman görüşlerine göre bu teknikler kullanılarak ağırlıklandıran literatürdeki ilk disiplinlerarası çalışma olacaktır.

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1. Introduction

The number of customers and users who neglect products due to inaccessibility, poor usability, and dissatisfaction with them is increasing. It has been shown that products and services developed for the elderly and the disabled in terms of usability and accessibility are generally beneficial to users.

It has been shown that products and services developed with older usability and accessibility for the elderly and disabled are generally beneficial to users. Where and when they exclude some people using a product or service often find it difficult or frustrating to use.

The aim of universal design; Whether it is buildings, open spaces, communication tools or home furnishings, it is to develop theories, principles and solutions to ensure that everyone uses the same physical solutions as widely as possible.

Within the concept of universal design there is both a vision and a concrete initiative to plan and realize all the buildings, environments and products that can be used by everyone and the children and the elderly in the widest possible extent, in different dimensions and abilities, persons.

The term UD first appeared in the 1980s. In 1985, the architect Ron Mace defined UD as “the design of products and environments to be usable by all people to the greatest extent possible, without the need for adaptation or specialised design.” Another early definition described UD as “. . . the universal design approach – designing all products, buildings and interiors to be usable by all people to the greatest extent possible” (Mace, et al., 1990). In 1995, the United Nations’ Standard Rules on the Equalization of Opportunities for Persons with Disabilities predicted participation and equal rights for individuals with functional limitations.

The Center for Universal Design defines universal design and the purpose of the concept in the following way (Center of UD, 1997):

"Universal design is the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaption or specialized design"

"The intent of the universal design concept is to simplify life for everyone by making products, communications, and the built environment more usable by more people at little or no extra cost. The universal design concept targets all people of all ages, sizes and abilities."

Seven principles of Universal Design (UD) were proposed in 1997 (Center of UD, 1997) to guide developers (designers, product developers and architects) to create more useful mainstream products and more accessible public environments. These principles are “Equitable Use”,”Flexibility in Use”, “Simple and Intuitive Use”, “Perceptible Information”, “Tolerance for Error”, “Low Physical Effort”, and “Size and Space for Approach and Use”.

UD has influenced the concepts of "Design for All", "accessible or unobstructed design" and "container design" developed in different socio-cultural and professional environments. A controversial debate discusses the meaning and appropriateness of these terms.

Design for All includes design for everyone, designs for human diversity, social inclusion and equality (Hogan, 2004). Accessible or barrier-free design provides guidelines for people with disabilities to access public open spaces and commercial facilities (ADA, 1994).

Inclusive design includes a strategic framework and related processes that guide decision makers and product designers in understanding and responding to the needs of different users (British Standard Draft, 2004).
The real point thus seems to be a question of justice: to what extent is it possible to design something that, at the same time, allows for equitable use by everyone and respects the diversity in people's capacities (Bianchin and Heylighen, 2018).

Inclusive design prescribes addressing the needs of the widest possible audience in order to consider human differences. Taking differences seriously, however, may imply severely restricting "the widest possible audience" (Bianchin and Heylighen, 2018).

Today, UD goes far beyond lifting barriers and can be seen as guidelines to increase availability for products and environments as much as possible. UD removes discrimination through its implementation and thus promotes social inclusion in all members of society. UD also discusses how appearance affects social perceptions. The UD identifies, for example, targets. breaking physical barriers and redefining disability as a universal state, a state of difference shared by all (Wijk, 1997). This means that UD covers issues such as aging, gender, cultural differences and sustainability.

UD has been strengthened with some important features. First, it extends the design focus to a much wider population than people with disabilities. Second, instead of focusing on UD, restructuring and adaptation, focus on new thinking in the development of initiatives and strategies to produce new solutions; innovative approach. Through the creation of third, UD, a flexible product and environment with good usability, everyone strives for full social participation throughout the entire life span. Everyone is not the only universal solution that fits. It deals with solutions that provide flexibility in use and use.

The purpose can be used by anyone as an integrated architectural quality. There is no natural conflict between the definitions of the architect and the universal design. However, architecture has not been characterized by everyone as an object of functionality. Other factors for design have become more decisive. Over the past few years, development has been taking into account groups with special needs. This usually leads to special solutions in addition to normal solutions. This leads to the separation of groups within the population. The solutions are often the most degraded, if they relate to new projects or adaptations of existing ones. In addition, these solutions are often more expensive than integrated solutions that take into account everything.

In this paper, weighting UD principles and designing according to these weights that are difficult for designers, architects, and interior architects are handled.

Selecting or prioritizing alternatives from a set of available alternatives with respect to multiple criteria is often referred to multi-criteria decision-making (MCDM). MCDM is a well-known branch of a general class of operation research models which deal with decision problems in the presence of a number of decision criteria. This class is further divided into multi-objective decision-making (MODM) and multi-attribute decision-making (MADM). There are several methods in each of the above categories. Priority-based, outranking, distance-based and mixed methods are also applied to various problems. Each method has its own characteristics and such methods can also be classified as deterministic, stochastic and fuzzy methods (Pohekar and Ramachandran, 2004).

Afacan and Demirkan (2010) proposed a priority-based approach for satisfying diverse users' needs, capabilities and expectations in a design process conducted in a computer environment. They applied the planning game technique and the AHP technique using a cost–value approach in prioritising the diverse requirements.

Chou (2012) improved the shortcomings of traditional AHP method and proposed a linguistic evaluation approach for UD with the aim of constructing a hierarchy for evaluation using criteria against the UD principles, developing a convenient and effective eigenvalue algorithm for deriving the weights of criteria, and aggregating preference information and ranking the order of decision alternatives by using linguistic variables.

Yılmaz Kaya and Dağdeviren (2016) proposed an integrated approach to evaluate occupational safety equipment by considering UD and technical requirements. Two MCDM methods, AHP and fuzzy PROMETHEE were employed to handle the evaluation process in their study.

Unlike the above studies, in this paper we apply two MCDM methods to weight the Universal Design principles, namely fuzzy AHP and fuzzy ANP. This is the first paper in the literature to apply these two techniques for the numerically prioritization of Universal Design principles.

Analytic Hierarchy Process (AHP) is one of the common methods with which to solve MCDM problems. The first application to solve MCDM problem in the literature was Saaty's choosing a school for his son using AHP (Saaty, 1980).

The AHP is an approach that is suitable for dealing with complex systems related to make a choice among several alternatives with providing a comparison of the considered criteria and alternatives. AHP is based on the subdivision of the problem in a hierarchical form. By reducing complex decisions to a series of simple comparisons and rankings, then synthesizing the results, AHP not only helps the analysts to arrive at the best decision, but also provides a clear rationale for the choices made. The objective of using AHP is to identify the preferred alternative and also to determine a ranking of the alternatives when all the decision criteria are considered simultaneously (Mahmoodzadeh et al., 2007).

The analytic network process (ANP) is also another common method with which to solve MCDM problems. The decision problem is structured hierarchically at different levels in the methodology (Mikhailov, 2003). The local priorities in ANP are established by means of pairwise comparisons and judgments (Promentilla et al., 2008). The analytical network process is a generalization of Saaty's Analytical Hierarchy Process, which is one of the most widely employed decision support tools (Promentilla et al., 2006). The priorities in the ANP are assessed indirectly by means of pairwise comparison judgments (Mikhailov and Singh, 2003).

ANP is a useful tool for prediction and for representing a variety of competitors, their assumed interactions and their relative strengths to wield influence in making a decision (Tuzkaya et al., 2010).

The rest of this paper is organized as follows: a brief description about Universal Design principles is given in Section 2, the problem definition is described in Section 3. Fuzzy AHP methodology and fuzzy ANP methodology are presented in Section 4 and Section 5, respectively. In Section 6, we show an application of fuzzy AHP methodology and fuzzy ANP methodology in prioritization of Universal Design principles. Computational results are given in this section. Finally, comparison of the results and future research directions are discussed in Section 7, which concludes the paper.

2. Universal Design Principles

Universal design, that is, usability by all people, should be seen as one of the factors that creates this integrity to provide us with good environments. Universal design principles can be seen as a link in the quality assurance process that follows the product or project from the beginning of the planning process to the final result.

To make the UD concept more useful, the Universal Design Center at North Carolina State University has developed seven principles aimed at supporting the evaluation of existing designs, guiding the design process, and having information about designers and consumers of more useful products and environments.

The seven Universal Design principles are presented below (Story et al., 2001):

PRINCIPLE ONE: Equitable Use

The design is useful and marketable to people with a diverse range of abilities.

PRINCIPLE TWO: Flexibility in Use

The design accommodates a wide range of individual preferences and abilities.

PRINCIPLE THREE: Simple and Intuitive Use

Use of product or service is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.

PRINCIPLE FOUR: Perceptible Information

The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.

PRINCIPLE FIVE: Tolerance for Error

The design minimises hazards and the adverse consequences of accidental or unintended actions.

PRINCIPLE SIX: Low Physical Effort

The design can be used efficiently and comfortably and with a minimum of fatigue.

PRINCIPLE SEVEN: Size and Space for Approach and Use

Appropriate size and space is provided for approach, reach, manipulation, and use, regardless of user's body size posture or mobility.

In addition to these principles, considerations must be given to a whole series of other conditions in the process of planning and development. These may include social considerations, economy, aesthetic design, sustainable development, cultural qualities etc (Aslaksen et al., 1997).

3. Problem Definition

As we explained above, Universal Design principles are crucial in today's world. Prioritizing the Universal Design principles was chosen for this study and fuzzy AHP and fuzzy ANP approaches were used. We asked five sector experts with the same weights (namely architect, interior architect and designer) about the problem of determining the most important principle. Seven principles were weighted accordingly.

In the numerical example, the architect, the interior architect, and the designer need to prioritize the Universal Design principles. For this problem, seven principles that were defined in the literature are handled as criteria, as seen in Figure 1. The arrows in Figure 1 represent the hierarchy of the problem.

The Universal Design principles that were handled as criteria in this paper are; "Equitable Use (P1)", "Flexibility in Use (P2)", "Simple and Intuitive Use (P3)", "Perceptible Information (P4)", "Tolerance for Error (P5)", "Low Physical Effort (P6)", and "Size and Space for Approach and Use (P7)".

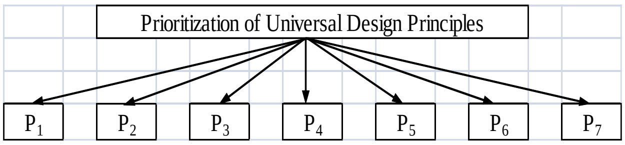

Figure 1. Hierarchy of the problem

4. Fuzzy AHP Methodology

Analytic Hierarchy Process (AHP) is one of the common methods with which to solve MCDM problems. The decision problem is structured hierarchically at different levels in this methodology (Mikhailov, 2003). The local priorities in AHP are established using pairwise comparisons and judgments (Promentilla et al., 2008). The priorities in the AHP are assessed indirectly from pairwise comparisons judgments (Mikhailov, 2003).

AHP had been applied in a variety of contexts: from the simple everyday problem of selecting a school to the complex problems of designing alternative future outcomes of a developing country, evaluating political candidacy, allocating energy resources, and so on (Ozdagoglu and Ozdagoglu, 2007).

To have a significant impact on the performance of the building with respect to the various design criteria, Nassar et al. (2003) developed a computer tool for selecting the best combination of building assemblies for each particular design situation. They used AHP to determine the relative importance weights for the different criteria.

To select equipments for construction projects Shapira and Goldenberg (2005) presented a selection model based on AHP with a view to providing solutions for the systematic evaluation of soft factors, and the weighting of soft benefits in comparison with costs.

Bitarafan et al. (2012) selected the appropriate method which can consider all the criteria of reconstructing the damaged areas that can be useful for decision makers in managing crises. They introduced the AHP method for calculating the relative importance of the criteria and their weights.

The fuzzy AHP technique can be viewed as an advanced analytical method developed from the traditional AHP. The AHP's subjective judgment, selection and preference of decision-makers have great influence on the success of the method. The conventional AHP still cannot reflect the human thinking style. Avoiding these risks on performance, the fuzzy AHP, an extension of AHP with fuzzy numbers, was developed to solve the hierarchical fuzzy problems. Buckley extended Saaty's AHP to the case where the evaluators are allowed to employ fuzzy ratios in place of exact ratios to handle the difficulty for people to assign exact ratios when comparing two criteria and derive the fuzzy weights of criteria by geometric mean method (Hsieh et al., 2004).

In the literature many researchers (Laarhoven and Pedrycz, 1983; Buckley, 1985a; Buckley, 1985b; Boender et al., 1989; Chang, 1996; Ribeiro, 1996; Lootsma, 1997) who had studied the fuzzy AHP, had provided evidence that fuzzy AHP shows relatively more sufficient description of these kind of decision making processes compared to the traditional AHP methods (Ozdagoglu and Ozdagoglu, 2007).

Fuzzy AHP can be used for the evaluation and ranking of alternatives (Kahraman et al., 2004; Mikhailov and Tsvetinov, 2004; Rodríguez et al., 2013). Buyukozkan et al. (2008) proposed fuzzy AHP method to evaluate e-logistics-based strategic alliance partners. Cascales and Lamata (2008) proposed fuzzy AHP for management maintenance processes where only linguistic information was available. Alias et al. (2009) used F-AHP technique to rank alternatives to find the most reasonable and efficient use of river system.

Zeng et al. (2007) presented a risk assessment methodology to cope with risks in complicated construction situations. A modified analytical hierarchy process with fuzzy numbers was used to structure and prioritize diverse risk factors. An illustrative example on risk analysis in a shopping centre was used to demonstrate their proposed methodology.

Pan (2008) presented a fuzzy AHP model to select an appropriate bridge construction method. A case study involving an actual highway project was presented to illustrate the use of the proposed model in the paper. Also the use of the model and the capability of the model were shown with the results.

Pan (2009) presented a fuzzy AHP approach to select an appropriate excavation construction method. A case study concerning a foundation construction project was presented in the paper. The author used Buckley's fuzzy AHP approach to analyze the problem.

Nieto-Morote and Vila (2011) presented a risk assessment methodology based on the fuzzy sets theory and on the AHP. In this paper, a problem on risk assessment of a rehabilitation project of a building had been presented as a numerical example.

Kog and Yaman (2014) analyzed 133 peer-reviewed academic studies that published between 1992 and 2013 and classified them as contractor selection, contractor pre-qualification and weighting criteria. According to their paper, the statistical models, fuzzy set theory, and AHP are the most preferred methods in order to solve contractor selection problem.

Taylan et al. (2014) used analytic tools to evaluate the construction projects and their overall risks under incomplete and uncertain situations. They categorized the construction projects using fuzzy AHP and fuzzy TOPSIS methodologies. In their study Fuzzy AHP was used to create weights for fuzzy linguistic variable of construction projects overall risk. For the application thirty construction projects were studied with respect to five main criteria: time, cost, quality, safety and environment sustainability. Their results showed that these methodologies are able to assess the overall risks of construction projects, select the project that has the lowest risk with the contribution of relative importance index.

Andric and Lu (2016) proposed a framework of disaster risk assessment combining Fuzzy Analytical Hierarchy Process (FAHP) with fuzzy knowledge representation and fuzzy logic techniques into a single integrated approach. They applied FAHP approach to ranking risk factors since it is more systematic, accurate and effective than traditional AHP.

Ozdemir and Ozdemir (2018) studied the evaluation of store plan alternatives produced with shape grammar using fuzzy AHP and fuzzy ANP. Then they compared the obtained results of these techniques.

In the F-AHP and F-ANP, to evaluate the decision-makers' preferences, pairwise comparisons are structured using triangular fuzzy numbers (a_l, a_m, a_u). The m x n fuzzy matrix can be given as in Eq. 1. The element a_{mn} represents the comparison of the component m (row element) with component n (column element). If $\tilde{A}$ is a pairwise comparison matrix (Eq. 1), it is assumed that the reciprocal, and the reciprocal value, i.e. $1/a_{mn}$, is assigned to the element a_{mn} (Tuzkaya and Onut, 2008; Tuzkaya et al., 2010):

$$\tilde{A} = \begin{pmatrix} (1,1,1) & a_{12}^{l}, a_{12}^{m}, a_{12}^{u} & \dots & a_{1n}^{l}, a_{1n}^{m}, a_{1n}^{u} \\ \left(\frac{1}{a_{11}^{u}}, \frac{1}{a_{11}^{m}}, \frac{1}{a_{11}^{l}}\right) & (1,1,1) & \dots & a_{2n}^{l}, a_{2n}^{m}, a_{2n}^{u} \\ \dots & \dots & \dots & \dots \\ \left(\frac{1}{a_{1n}^{u}}, \frac{1}{a_{1n}^{m}}, \frac{1}{a_{1n}^{l}}\right) & \left(\frac{1}{a_{2n}^{u}}, \frac{1}{a_{2n}^{m}}, \frac{1}{a_{2n}^{l}}\right) & \dots & (1,1,1) \end{pmatrix} \quad (1)$$

Zadeh (1965) introduced the fuzzy set theory to deal with the uncertainty due to imprecision and vagueness. A major contribution of fuzzy set theory is its capability of representing vague data. A triangular fuzzy number that defined as (l,m,u) , where l ≤ m ≤ u, denote the smallest possible value, the most promising value and the largest possible value.

The steps of fuzzy AHP can be listed as follows (Hsieh et al., 2004; Kaya and Kahraman, 2011):

Step 1: Determine alternatives, criteria and subcriteria to be used in the model
Step 2: Create a hierarchy including goal, criteria, subcriteria, and alternatives.
Step 3: Evaluate the relative importance of the criteria using pairwise comparisons. Assign linguistic terms to the pairwise comparisons by asking which criterion is more important than the other with fuzzy numbers.

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \dots & \tilde{a}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & 1 \end{bmatrix} \quad (2)$$

$$= \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \dots & \tilde{a}_{2n} \\ \dots & \dots & \dots & \dots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \dots & 1 \end{bmatrix} \quad (3)$$

Step 4: Define the fuzzy geometric mean and fuzzy weight of each criterion.

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \dots \otimes \tilde{a}_{in})^{1/n}, \quad \tilde{w}_i \quad (4)$$

$$= \tilde{r}_i \otimes (\tilde{r}_1 \oplus \dots \oplus \tilde{r}_n)^{-1} \quad (5)$$

where $\tilde{a}_{in}$ is the fuzzy comparison value of criterion i to criterion n, thus, $\tilde{r}_i$ is the geometric mean of fuzzy comparison value of criterion i to each criterion, $\tilde{w}_i$ is the fuzzy weight of the ith criterion.
Step 5: Defuzzify and normalize the fuzzy weights.

5. Fuzzy ANP methodology

The analytic network process (ANP) is a generalization of the analytic hierarchy process (AHP) which can take the inner and outer dependencies among multiple criteria into consideration. ANP is used to determine the priorities of the elements in the network and the alternatives of the goal. ANP allows modeling complex and dynamic environments which are influenced by changing external factors (Meade and Sarkis, 1998). ANP is an excellent methodology which can deal with several issues by considering dependencies between nodes and clusters of criteria (Oztaysi et al., 2011).

Buckley's fuzzy AHP algorithm (Hsieh et al., 2004; Haghighi et al., 2010; Kaya and Kahraman, 2011) based fuzzy ANP is used for weighting the Universal Design principles in this paper. Fuzzy ANP allows measuring qualitative factors by using fuzzy numbers instead of crisp values in order to make decisions easier and obtain more realistic results (Oztaysi et al., 2013).

In the literature, the fuzzy ANP method has been used to solve problems like research and development project selection (Mohanty et al., 2005), performance evaluation (Yellepeddi, 2006), quality function deployment implementation (Ertay et al., 2005), enterprise resource planning (ERP) software selection (Ayag and Ozdemir, 2007), tourism type prioritization (Demirel et al., 2010), etc.

Oztaysi et al. (2011) compared the CRM performances of e-commerce firms using a multiple criteria decision making (MCDM) approach - ANP. A sensitivity analysis also provided in order to monitor the robustness of the proposed ANP framework to changes in the weights of evaluation criteria. Their results showed that the ranking among the alternatives are sensitive to changes in the parameters.

Tuzkaya et al. (2010) proposed an integrated fuzzy multi-criteria decision making methodology for selecting material handling equipment. The proposed approach utilizes fuzzy sets, ANP and the preference ranking organization method for enrichment evaluations (PROMETHEE).

Tuzkaya and Onut (2008) proposed a model for selecting the most convenient transportation mode by considering the effects of criteria on the alternative modes and relations among the criteria clusters and subcriteria using fuzzy ANP.

Buyukozkan et al. (2004) used fuzzy ANP to prioritize design requirements by taking into account the degree of the interdependence between customer needs and design requirements and their dependence.

Ebrahimnejad et al. (2012) studied a construction project problem with multiple criteria in a fuzzy environment and proposed a new two-phase group decision-making approach. This approach integrated a modified analytic network process (ANP) and an improved compromise ranking method, VIKOR.

Zhou et al. (2013) proposed a flexibility measurement model of enterprise resources planning (ERP) based on a fuzzy analytic network process (FANP). Hung et al. (2012) applied the fuzzy analytic network process model to evaluate the strategic impact of new integrated circuit (IC) manufacturing technologies within Taiwan's packaging industry.

The steps of fuzzy ANP can be listed as follows (Yasmin et al., 2013):

Step 1: Determine alternatives, criteria and subcriteria to be used in the model

Step 2: Create a network including alternatives, criteria, subcriteria, inner and outer dependencies among the model.

Step 3: Construct pairwise matrices of the components by the experts with fuzzy numbers.

Step 4: Construct the fuzzy comparison matrix by using triangular fuzzy numbers:

Step 5: Calculate fuzzy eigen value to find whether the constructed matrix is consistent or not:

To verify the consistency of the comparison matrix, Saaty proposed a consistency index (C.I.) and consistency ratio (C.R.). The consistency index of a matrix is given by

$$C.I. = (\lambda_{max} - n)/(n-1) \quad (6)$$

$$C.R = C.I/R.I \quad (7)$$

where, R.I is Random Consistency Index. The consistency index should be less than or equal to 0.10.

Step 6: Forming initial supermatrix of the network of ANP is composed by listing all nodes horizontally and vertically.

Step 7: Obtaining weighted supermatrix by multiplying the unweighted supermatrix with the corresponding cluster priorities

Step 8: Calculating limited supermatrix by limiting the weighted supermatrix by raising it to sufficiently large power so that it converges into a stable supermatrix (i.e, all columns being identical).

6. Application: Evaluation of Universal Design Principles

In this paper we apply two MCDM methods to weight the Universal Design principles, namely fuzzy AHP and fuzzy ANP. Then, the obtained results of these techniques are compared. The layout of the application case can be seen from Figure 2.

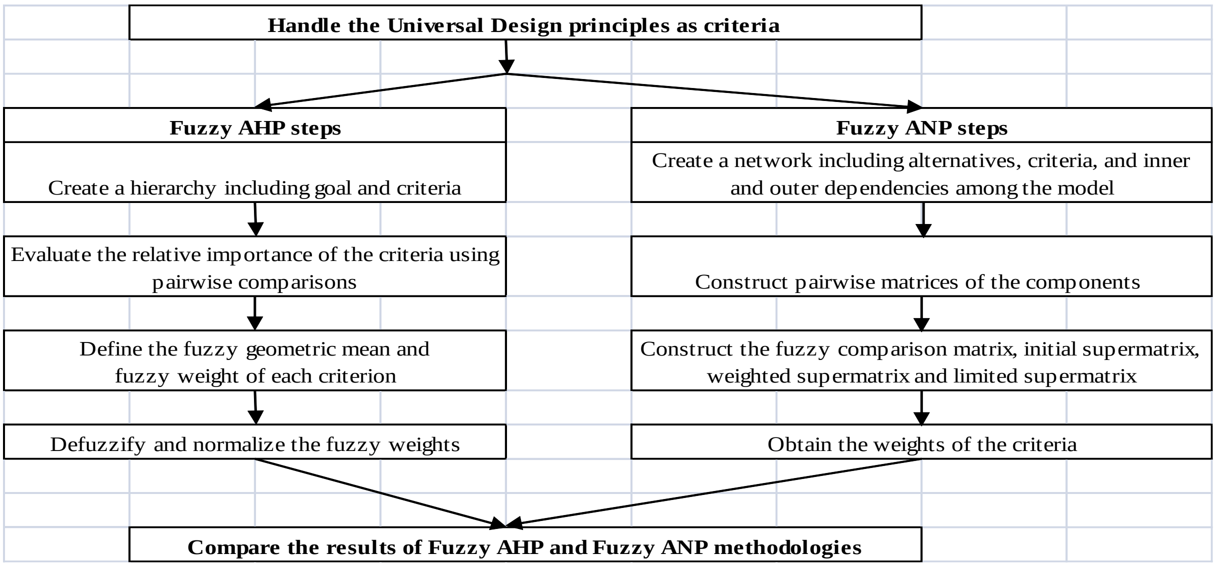

Figure 2. The layout of the application case

6.1. Computational Results of Fuzzy AHP Methodology

To solve the problem using fuzzy AHP, we used fuzzy numbers as shown in Table 1 and compared our results with those of experts. Evaluations of the criteria by five experts can be seen in Table 2. Different experts' assessments are aggregated using arithmetic mean method. A triangular fuzzy number that defined as (l, m, u), where l ≤ m ≤ u, denote the smallest possible value, the most promising value and the largest possible value. E1, E2, E3, E4, and E5 denote experts' evaluations, respectively.

The fuzzy weight matrix of the criteria according to the goal is given in Tables 3. The evaluation and the methodology described above produced the results shown in Table 4.

Table 1. Relationship between fuzzy numbers and degrees of linguistic importance

Low/high Levels		
Label	Linguistic Terms	Fuzzy Numbers
E	Just equal	(1,1,1)
SL	Slightly Low	(1,1,3)
M	Middle	(1,3,5)
SH	Slightly High	(3,5,7)
H	High	(5,7,9)
VH	Very High	(7,9,9)
EH	Extra High	(9,9,9)

Table 2. Average values used in Fuzzy AHP and Fuzzy ANP

Criteria	Importance Value	l	m	u	E1	l	m	u	E2	l	m	u	E3	l	m	u	E4	l	m	u	E5	l	m	u
P1	H	5	7	9	H	5	7	9	VH	7	9	9	H	5	7	9	VH	7	9	9	SH	3	5	7
P2	VH	7	9	9	EH	9	9	9	EH	9	9	9	H	5	7	9	EH	9	9	9	SH	3	5	7
P3	H	5	7	9	SH	3	5	7	H	5	7	9	EH	9	9	9	VH	7	9	9	M	1	3	5
P4	SH	3	5	7	SH	3	5	7	SH	3	5	7	EH	9	9	9	SL	1	1	3	H	5	7	9
P5	H	5	7	9	VH	7	9	9	VH	7	9	9	H	5	7	9	M	1	3	5	H	5	7	9
P6	H	5	7	9	EH	9	9	9	H	5	7	9	VH	7	9	9	SL	1	1	3	H	5	7	9
P7	EH	9	9	9	EH	9	9	9	EH	9	9	9	VH	7	9	9	EH	9	9	9	EH	9	9	9

Table 3. Fuzzy weight matrix of the criteria according to the goal

	l	m	u
P1	0.08	0.16	0.29
P2	0.08	0.16	0.47
P3	0.06	0.12	0.23
P4	0.03	0.09	0.17
P5	0.06	0.12	0.23
P6	0.06	0.12	0.23
P7	0.08	0.24	0.62

Table 4. Results of the application using Fuzzy AHP

Criteria	Weights	Ranking
P1	14.34%	3
P2	19.13%	2
P3	11.12%	4
P4	7.91%	5
P5	11.12%	4
P6	11.12%	4
P7	25.26%	1

According to the results in Table 4 the ranking is obtained as P7>P2>P1.

6.2. Computational Results of Fuzzy ANP Methodology

To solve the problem using fuzzy ANP, we used fuzzy numbers as shown in Table 1 and compared our results with those of experts. Evaluations of the principles by five experts were the same as the values of the fuzzy AHP that can be seen in Table 2 and Table 3. Also initial supermatrix, weighted supermatrix and the limited supermatrix can be seen from Table 5-7. The evaluation and the methodology described above produced the results shown in Table 8.

Table 5. Initial supermatrix

	P1	P2	P3	P4	P5	P6	P7
P1	0.00000	0.17736	0.16137	0.15574	0.16137	0.16137	0.19190
P2	0.22335	0.00000	0.21526	0.20774	0.21526	0.21526	0.25598
P3	0.12982	0.13751	0.00000	0.12075	0.12511	0.12511	0.14878
P4	0.09230	0.09777	0.08896	0.00000	0.08896	0.08896	0.10579
P5	0.12982	0.13751	0.12511	0.12075	0.00000	0.12511	0.14878
P6	0.12982	0.13751	0.12511	0.12075	0.12511	0.00000	0.14878
P7	0.29489	0.31235	0.28419	0.27428	0.28419	0.28419	0.00000

Table 6. Weighted supermatrix

	P1	P2	P3	P4	P5	P6	P7
P1	0.00000	0.17736	0.16137	0.15574	0.16137	0.16137	0.19190
P2	0.22335	0.00000	0.21526	0.20774	0.21526	0.21526	0.25598
P3	0.12982	0.13751	0.00000	0.12075	0.12511	0.12511	0.14878
P4	0.09230	0.09777	0.08896	0.00000	0.08896	0.08896	0.10579
P5	0.12982	0.13751	0.12511	0.12075	0.00000	0.12511	0.14878
P6	0.12982	0.13751	0.12511	0.12075	0.12511	0.00000	0.14878
P7	0.29489	0.31235	0.28419	0.27428	0.28419	0.28419	0.00000

Table 7. Limited supermatrix

	P1	P2	P3	P4	P5	P6	P7
P1	0.14702	0.14702	0.14702	0.14702	0.14702	0.14702	0.14702
P2	0.18514	0.18514	0.18514	0.18514	0.18514	0.18514	0.18514
P3	0.11827	0.11827	0.11827	0.11827	0.11827	0.11827	0.11827
P4	0.08713	0.08713	0.08713	0.08713	0.08713	0.08713	0.08713
P5	0.11827	0.11827	0.11827	0.11827	0.11827	0.11827	0.11827
P6	0.11827	0.11827	0.11827	0.11827	0.11827	0.11827	0.11827
P7	0.22591	0.22591	0.22591	0.22591	0.22591	0.22591	0.22591

Table 8. Results of the application using Fuzzy ANP

Criteria	Weights	Ranking
P1	14.70%	3
P2	18.51%	2
P3	11.83%	4
P4	8.71%	5
P5	11.83%	4
P6	11.83%	4
P7	22.59%	1

According to the results in Table 8 the ranking is obtained as P7>P2>P1.

The impact of interactivity among the criteria in fuzzy ANP is the reason of the variations in the weights.

Given these results, it is fair to say that paying attention to Principle P7 is the most reasonable outcome, followed by the others (Table 9).

Table 9. Comparison of the results using Fuzzy AHP and Fuzzy ANP

	AHP		ANP	
Criteria	Weights	Ranking	Weights	Ranking
P1	14.34%	3	14.70%	3
P2	19.13%	2	18.51%	2
P3	11.12%	4	11.83%	4
P4	7.91%	5	8.71%	5
P5	11.12%	4	11.83%	4
P6	11.12%	4	11.83%	4
P7	25.26%	1	22.59%	1

7. Conclusion

The design of the environment is now just a matter of creating beautiful environments and buildings and good architecture; In the finished project the nature implies more and more to meet the demands of qualifications. Good projects are just a few of these aesthetics. All factors must integrate and shape in an integrity that creates good environments, architecture and design. Universal design or usability by all people should become a natural and integral part of the architecture.

In fact, the needs of individuals identified as disabled are not very different from those of the majority or the standard user. Every disabled person has equal freedom and electoral rights at home, work and in the city as a member of society just like other urbanites.

Thoughts for people with disabilities is the center of universal design passion. Often as a social entity, the wishes and requirements of persons with disabilities are the same as those of young, old, women, men, or other individuals described as “standard, normal”. It is absolutely necessary for all individuals with different characteristics to spend time together, to have an active or passive activity in a common place, sociologically and psychologically. Keeping a group separate can sometimes mean “stigmatising” or keeping it separate for the group that is kept separate, as opposed to the expected benefit. The concept of” universal design", or design for all, is also expressed and popularized by this awareness. In this context, people need to settle in their thinking structures as a way of incorporating them into life rather than decoupling the disabled people. However, these issues should be seen in relation to the needs and wants of the rest of the population, whether children, elderly, women, men, or people of different ethnic backgrounds and traditions. As far as possible, there may be different interests and conflicts in these areas to implement a universal design in buildings, open spaces and products. With the different needs of disabled people being central, it is not enough to plan and design the whole population.

In this paper, multi criteria-decision making techniques, fuzzy AHP and fuzzy ANP methods are used for the prioritization of Universal Design (UD) principles. Then, the obtained results of these techniques are compared. As a result of evaluation process, these two MCDM methods, fuzzy AHP and fuzzy ANP, have determined the most suitable result as P7 (Size and Space for Approach and Use). The ranking of the other principles are P2>P1 (Flexibility in Use > Equitable Use) in both methods with close weights and normalized values.

The impact of interactivity among the criteria in fuzzy ANP is the reason of the variations in the weights. The main advantage of the proposed model is to indicate the impact of this interactivity and to evaluate the UD principles using MCDM. The main contribution of this paper is to prioritize UD principles using numerical methods with experts' view.

The general limitation of the proposed model is the costly and exhausting information requested from experts (approx. 30 pairwise comparisons per one expert). Other limitations of the model are the preferences of the expert including uncertainty and conflicts and there is often needed more than one expert to make decisions.

As regards future research, UD principles could be solved by other MCDM techniques with fuzzy numbers to explain interactivity among the criteria, and more solutions compared for principles evaluation processes during designs. Also, the intuitionistic fuzzy sets could be used to handle with the hesitancy of the decision-makers and intelligent software to calculate solutions automatically could be developed.

Conflict of Interest

No conflict of interest was declared by the authors.

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