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Fuzzy Evaluation Method of Virtual Reality for Urban Landscape Design

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ABSTRACT:

The purpose of this study is to use virtual reality (VR) modeling techniques and fuzzy set theory to create a multi-dimensional and multi-factor fuzzy synthetic evaluation method using VR in Urban Landscape Design. This would allow the general evaluation of Urban Landscape Design results to be enumerated, quantified and computerized. Landscape designers could then receive immediate feedback on the relative quality of urban landscape design decisions. The Chunghua Road pedestrian zone in Taipei City was selected as the subject of this case study. Three VR landscape design options were proposed for evaluation, and the results showed that the use of VR did stimulate interest and identification ability among the test subjects. The use of the fuzzy general evaluation method to choose between options therefore helped to increase the confidence of design decisions.

Keywords: Urban Landscape Design, Virtual Reality, Fuzzy Synthetic Evaluation

1. FOREWORD

In recent years there has been a constant flux in ideas when it comes to Landscape Design (Kirk 1963, Rapoport 1977, Wang & Ho 1986, Sheppard 1989, Meggs 1995, Bishop 2003). From the passive to the active, from layouts into spaces, from physical environments into ecologies and from computer generated montages into 3D computer animated models. The rapid advances in computer technologies have led to significant changes in the content and direction of Landscape Design. The widespread use of mathematical and computer techniques combined with quantitative analysis has led to more scientific design decisions and improved design quality. People's preference for landscaping is determined by a variety of visual sensory factors such as the plantings, color, texture, forms, dimensions, spaces and installations. Through the juxtaposition of these factors a unique image is created. Due to the variety, mutability and complexity of the landscape image conditions, a high level of uncertainty exists. It is this uncertainty that leads to its randomness and fuzziness. As landscape design for urban areas is an exercise that involves multiple criteria, traditional methods of assessment do not adequately reflect many of the qualitative requirements. Through the use of fuzzy mathematics, it is possible to make the fuzzy concepts, fuzzy identification, fuzzy evaluation and fuzzy decision-making of qualitative descriptions mathematical and quantifiable (Ho and Wang 2000).

2. VIRTUAL REALITY

Advancements in Computer Aided Design (CAD) technology has seen landscape design become so detailed as to rival real-world imagery. Landscape designers now also favor the use of CAD technology to give users a more direct understanding of the overall landscape design. In recent years, computer technology has progressed to the stage where Virtual Reality can be created. A three-dimensional virtual environment can be simulated using a computer; then physical tools such as digital gloves, 3D glasses and 3D display helmets are used to provide very realistic visual, audio and even tactile simulations. For a person placed in such a virtual environment it's practically identical to the real world. Evaluation factors that affect virtual reality landscape design include street functionality, building interface, space scenario, street furniture, planting effect and visual simulation. Due to the increasing complexity of the environment, criteria based on just one standard are now of little practical value. Decision-making methods for multiple criteria are now attracting increasing attention. Most decision problems feature multiple people and multiple criteria, with some criteria being hard to describe in precise numerical values. Landscape design in particular involves a lot of effect factors that use subjective language-based judgments. To apply the conventional concept of precision (non-fuzzy), we must have clearly defined rules or boundaries in order to make judgments. It is, however, difficult to reconcile rules and narratives using this approach. Additionally, there are many things in the real-world that involve a certain level of fuzziness. To overcome this bottleneck in conventional ideas, this study used the fuzzy set theory to propose an evaluation method different from traditional approaches. By applying this to the problem of multi-criteria decision-making in virtual reality landscape design, we have provided a new alternative design research method.

3. FUZZY EVALUATION METHOD

Urban landscape design is a relatively complicated technical system engineering discipline that creates a complex system with multiple factors, multiple indicators and multiple objectives. As the complexity of the system increases, the uncertainty and imprecision in the descriptive system increases as well. Uncertainties and impressions possess both randomness and tend to be fuzzy as well. People evaluate a subject through reasoned judgments. Their reasoning and judgments are usually fuzzy as well, so the ultimate decision is a fuzzy decision. This study therefore chose to use the Fuzzy Evaluation Method (Wang, 2003) to evaluate virtual reality proposals in urban landscape design. This provides decision makers with a reference they can use to determine the relative merits of proposals. The evaluation method follows the steps listed below:

3.1. ESTABLISH A FACTOR SET (U) FOR THE URBAN LANDSCAPE DESIGN EVALUATION INDEX SYSTEM

To evaluate virtual reality proposals for urban landscape design, one must first establish a criteria system. This enables an understanding of the relationships between influencing factors so the system can make the desired evaluation. Taking landscape design elements and visual simulation theory into account while also referring to the research results of relevant experts and scholars, the proposed urban landscape design evaluation factor set was as follows:

U= {Spatial Function, Building Interface, Spatial Scenario, Street Furniture, Planting Effect, Visual Simulation}

3.2. ESTABLISH A FACTOR WEIGHTING SET (A)

The Fuzzy AHP method was chosen for this study as people’s preferences in urban landscape design vary from person to person. To reflect the importance of each evaluation factor ui, all were assigned a corresponding weighting ai (i =1,2,…,n) with the set of all weightings A =(a_1, a_2,…,a_n) referred to as the factor weighting set. Since factors vary in their importance, the weighting of the factors chosen above must be determined to provide a reference for weightings during evaluation. The weighting set can therefore be considered the fuzzy subset of the factor set and can be expressed as:

$$\underline{A} = \frac{a_1}{u_1} + \frac{a_2}{u_2} + ... + \frac{a_m}{u_m}$$

3.3. ESTABLISH THE EVALUATION SET (V)

To investigate the evaluators' preference for urban landscape design virtual reality proposals, this study set up a five-level scale for the evaluators' comments and assessment of the proposals. This resulted in the Evaluation Set V = {Very poor (v_1), Poor (v_2), Average (v_3), Good (v_4), Very Good (v_5)}

3.4. ESTABLISH THE FUZZY RELATIONSHIP MATRIX (R)

The subject is evaluated according to the i-th factor (ui) in the factor set. Its degree of membership to the j-th element (vj) in the evaluation set is rij. The result of the evaluation for the i-th factor ui can be expressed as the following fuzzy set:

$$\mathrm{R}i = \frac{ri_1}{v_1} + \frac{vi_2}{v_2} + ... + \frac{ri_n}{v_n}$$

Ri is referred to as the single factor evaluation set, Ri = (ri_1, ri_2,…,ri_n)

Combine the degree of membership behavior of each single factor evaluation set to form a fuzzy relationship matrix:

$$\underline{R} \quad \begin{pmatrix} R_1 \\ R_2 \\ \vdots \\ R_m \end{pmatrix} = \begin{vmatrix} r_{11} & r_{12} \cdots & r_{1n} \\ r_{21} & r_{22} \cdots & r_{2n} \\ \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} \cdots & r_{mn} \end{vmatrix}$$

The single factor evaluation set can actually be treated as the evaluation given for each factor in the proposals derived from factor set u and the evaluators' understanding of the proposals' descriptions. The evaluation method is based mainly on the fuzzy rate score with language meaning defining the score intervals. Each interval represents one triangular fuzzy number with the midpoint of the interval being the expert's chosen answer and the lower/upper values being range of rate scores acceptable to the expert.

As the integration of similarity degree at this stage is more straightforward than the integration of factor weightings, the rate scores in the scale are mathematically significant. The method used to derive the weightings was therefore not necessary for the factors.

3.5. FUZZY EVALUATION OF PROPOSALS (B)

Jointly evaluate the influence of all factors to arrive at the correct evaluation results. Taking the weights of each factor into account in the single factor evaluation matrix will allow the combined influence of all factors to be represented in a reasonable manner. The fuzzy evaluation can therefore be expressed as:

$$\mathrm{B} = \mathrm{A} \bullet R = (a_1, a_2, \ldots a_m) \bullet \begin{pmatrix} R_1 \\ R_2 \\ \vdots \\ R_m \end{pmatrix} = \begin{vmatrix} r_{11} & r_{12} \cdots & r_{1n} \\ r_{21} & r_{22} \cdots & r_{2n} \\ \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} \cdots & r_{mn} \end{vmatrix}$$

$$= (b_1, b_2, \cdots b_n)$$

Here B is referred to as the fuzzy evaluation set. This defines the concrete evaluation results for the urban landscape design virtual reality proposals.

4. CASE STUDY

The Zhonghua Street Ximen Pedestrian Area in Taipei City's Wanhua District (Fig. 1) was selected as the case study for empirical research. Pedestrianization can be interpreted as a kind of spatial practice on the representation of space. The pedestrianization efforts made to Ximending around 1990 left much room for improvement. The No. 6 Ximen exit’s surroundings for example formed both the entry square and a “landmark” for waiting so was not user friendly. The defects included inappropriate transition buffer space, lack of overhead cover against sun or rain and lack of appropriate waiting space. The cycle path network through the Zhonghua Street pedestrian zone was clearly marked out and there are no special street furniture designs installed. The overall result was one of unbelievably atrocious building interface and spatial quality. Comprehensive improvement projects were therefore proposed.

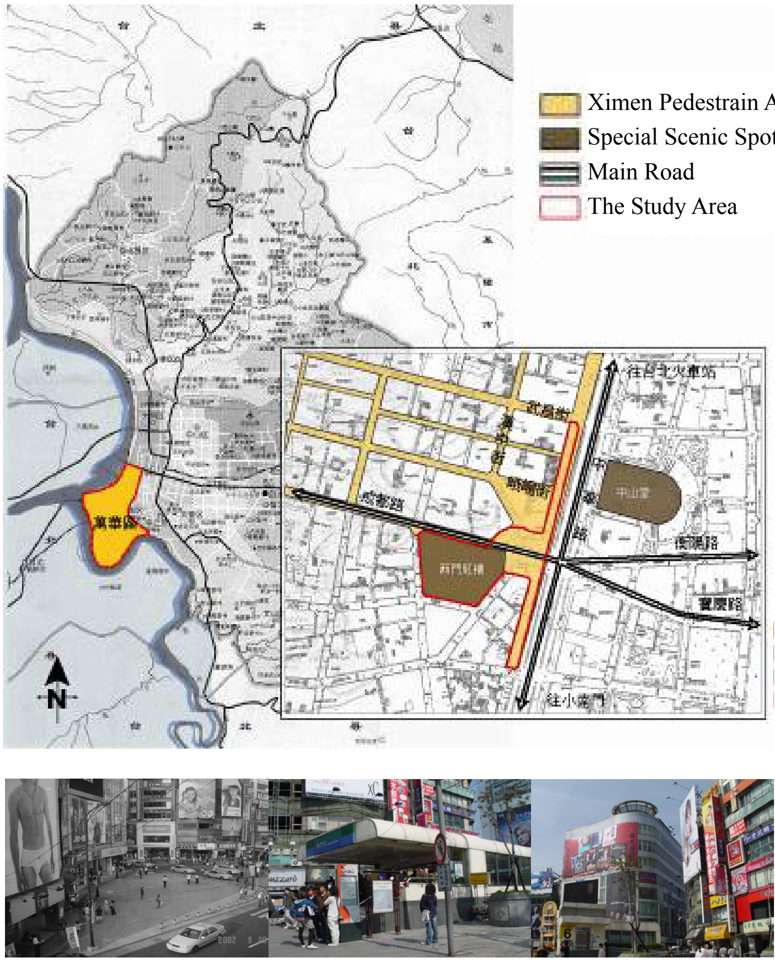
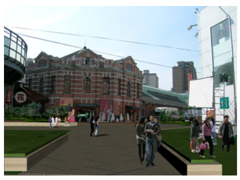


Figure 1:-Location of empirical study

4.1. PROPOSALS

First, the three pedestrian zone landscape design candidate proposals were modeled in 3D using AutoCAD and 3D Max 7.0. The models were then imported using Virtual Reality tools into the Virtools Dev 3.5 software to create three proposals' VR space (Table 1). The landscape designers could then immerse themselves in the realistic virtual environment to interact with and experience their design.

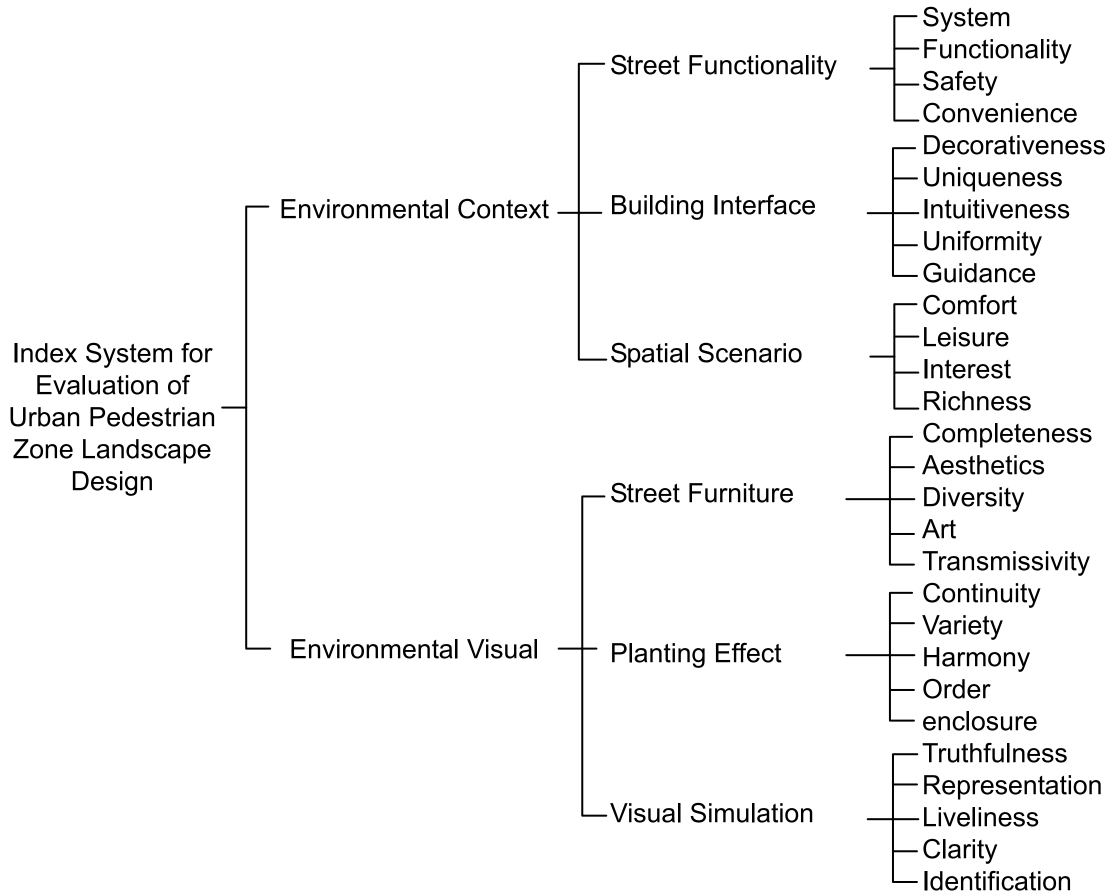
Table 1: – Virtual Reality Candidate Proposals

	Present Scene	Proposal A	Proposal B	Proposal C
Ximen Landscape Design Improvement Proposals				
				
				
Design Concept	The defects included inappropriate transition buffer space, lack of overhead cover against sun or rain and lack of appropriate waiting space. The cycle path network through the Zhonghua Street pedestrian zone was clearly marked out and there are no special street furniture designs installed. The overall result was one of unbelievably atrocious building interface and spatial quality. Comprehensive improvement projects were therefore proposed.	Green vegetation is planted to beautify the landscape. This creates a recreation space with landscaping and natural elements that pedestrians will find more welcoming. To maintain pedestrian visibility, vegetation should use trees with higher crowns rather than short close-grown bushes. This avoids the plantings impacting adversely on scenery and public safety.	The design establishes a complete and contiguous pedestrian space. Pedestrian traffic is encouraged for destinations within walking distance through a tightly defined environmental framework and efficient spatial layout. Trees, flowers and plants help to define the space's direction enhancing the visual quality of service.	Create a quality pedestrian environment with space for the public to play and relax. Variety of visual landscape is enhanced through the use of variable paving colors and materials. Emphasis is given to open public spaces to improve pedestrian comfort. Street furniture is neatly arranged and elegant lighting provided. The design also calls for motor vehicle-pedestrian separation system and cycling space to be installed.

4.2. ESTABLISHING THE FACTOR SET OF THE EVALUATION INDEX SYSTEM

This study consulted literature relating to urban landscape evaluation and visual simulation factors (Litton, 1974; Jones & Jones, 1977; Kaplan & Kaplan, 1978; Ho & Wang, 1986, 2000; Sheppard, 1989; Booth, 1990, Farenc et al, 2000; Bishop & Rohrmann, 2003; Fukahori & Kubota, 2003; Boian et al, 2004) to draw up a preliminary evaluation index system (Table 2). Layer 1 contained 2 items: Environmental Context and Landscape Visual; Layer 2 contained 6 items including Spatial Composition; Layer 3 contained 28 items including System.

Table 2: Index System for Evaluation of Urban Pedestrian Zone Landscape Design



4.3. FILTERING OF EVALUATION FACTORS AND EXPERT WEIGHTING

The setting of each factor's weighting used FAHP software to calculate the

Table 3: Index System for Evaluation of Urban Pedestrian Zone Landscape Design

Target Layer	Level 1	Layer 2	Evaluation Factor	
Index System for Evaluation of Urban Pedestrian Zone Landscape Design (1)	Environmental Context (0.4)	Street Functionality (0.289)	System (0.319)	【0.046】
			Safety (0.280)	【0.040】
			Convenience (0.401) *	【0.058】
		Building Interface (0.485) *	Decorativeness (0.432) *	【0.105】
			Uniqueness (0.220)	【0.053】
			Intuitiveness (0.090)	【0.022】
			Uniformity (0.258)	【0.063】
		Spatial Scenario (0.226)	Comfort (0.430) *	【0.049】
			Leisure (0.333)	【0.038】
			Richness (0.238)	【0.027】
	Environmental Visual(0.6)*	Street Furniture (0.297)	Completeness (0.288)	【0.043】
			Aesthetics (0.330)	【0.049】
			Art (0.382) *	【0.057】
		Planting Effect (0.203)	Continuity (0.293)	【0.030】
			Variety (0.108)	【0.011】
			Harmony (0.252)	【0.026】
			Order (0.347) *	【0.035】
		Visual Simulation (0.5) *	Truthfulness (0.108)	【0.027】
			Representation (0.305) *	【0.076】
			Liveliness (0.235)	【0.059】
			Clarity (0.244)	【0.061】
			Identification (0.109)	【0.027】

( ) Parentheses indicate expert weighting
* indicates highest weighting for that factor set
【】Relative weighting

Consistency Index (C.I.) and Consistency Ratio (C.R.); when C.I. < 0.1, the degree of consistency was viewed as satisfactory; when C.R. < 0.1, the rate score within the matrix was usable. The derived evaluation factors and their weightings are shown in Table 3.

4.4. VIRTUAL REALITY PROPOSAL SURVEY RATING

In this study, the fuzzy rating scores on the proposals from experts and non-experts were integrated through similarity to derive the fuzzy rating score intervals for the factors in each proposal as shown in Table 4.

4.5. FUZZY EVALUATION OF VIRTUAL REALITY PROPOSALS

Table 4: Table of Fuzzy Rating Scores for Each Factor in Each Proposal

	Proposal A	Proposal B	Proposal C
System	(11.92,19.97,28.02)	(8.89,16.93,24.98)	(13.33,21.38,29.42)
Safety	(8.61,16.95,25.28)	(15.27,22.90,30.53)	(8.08,16.27,24.46)
Convenience	(13.37,21.13,28.90)	(11.38,19.57,27.76)	(18.32,25.25,32.19)
Decorativeness	(13.86,21.77,29.68)	(4.73,12.64,20.55)	(12.18,20.52,28.85)
Uniqueness	(8.61,16.94,25.28)	(9.73,17.92,26.11)	(5.85,14.18,22.51)
Intuitiveness	(13.85,21.90,29.94)	(11.32,19.65,27.99)	(12.79,20.69,28.60)
Uniformity	(18.35,25.55,32.76)	(10.77,19.10,27.44)	(13.32,21.23,29.14)
Comfort	(13.33,21.52,29.71)	(11.39,19.44,27.49)	(13.03,20.94,28.85)
Leisure	(14.72,22.63,30.54)	(9.17,17.50,25.84)	(8.33,16.67,25.00)
Richness	(14.12,22.17,30.22)	(9.18,17.51,25.84)	(9.44,17.49,25.54)
Completeness	(14.11,21.88,29.65)	(7.79,16.12,24.46)	(7.23,15.56,23.89)
Aesthetics	(10.00,18.33,26.66)	(7.22,15.41,23.60)	(6.12,14.45,22.78)
Art	(12.23,20.28,28.33)	(8.06,16.40,24.73)	(7.78,15.96,24.15)
Continuity	(11.40,19.73,28.06)	(10.56,18.61,26.65)	(12.21,19.98,27.75)
Variety	(8.33,16.67,25.00)	(10.22,17.99,25.75)	(6.64,14.42,22.19)
Harmony	(10.59,18.64,26.69)	(11.92,19.97,28.02)	(13.01,21.06,29.11)
Order	(9.73,17.92,26.11)	(10.56,18.47,26.38)	(11.07,19.12,27.16)
Truthfulness	(11.92,20.25,28.59)	(11.36,19.27,27.18)	(11.08,19.27,27.46)
Representation	(13.00,21.19,29.38)	(6.94,14.85,22.75)	(10.56,18.46,26.37)
Liveliness	(12.98,21.03,29.08)	(13.27,21.46,29.65)	(12.18,19.67,27.16)
Clarity	(13.55,21.75,29.94)	(4.72,12.91,21.10)	(16.93,23.88,30.82)
Identification	(13.60,21.64,29.69)	(11.96,19.87,27.78)	(3.34,18.34,26.87)

Note: In (a, b, c), a represents the left limit of the triangular fuzzy number, b represents the midpoint value of the triangular fuzzy number and c represents the right limit of the triangular fuzzy number.

After deriving the ratings for each factor in each proposal, the overall evaluation of the proposals can be carried out to identify the proposal with the higher rating. To make the calculation process and results clearer, it was decided that the calculations would use the middle values of the rating intervals. The calculation method for the combined evaluation sets is as follow:

$$B = A \cdot \underline{R}$$

$$= (0.046,0.040,0.058,0.105,0.053,0.022,0.063,0.049,0.038,0.027,0.043,0.049,0.057,0.030,0.011,0.026,0.035,0.027,0.076,0.059,0.061,0.027) \cdot \begin{pmatrix} 19.97, & 16.93, & 21.38 \\ 16.95, & 22.90, & 16.27 \\ 21.13, & 19.57, & 25.25 \\ 21.77, & 12.64, & 20.52 \\ 16.94, & 17.92, & 14.18 \\ 21.90, & 19.65, & 20.69 \\ 25.55, & 19.10, & 21.23 \\ 21.52, & 19.44, & 20.94 \\ 22.63, & 17.50, & 16.67 \\ 22.17, & 17.51, & 17.49 \\ 21.88, & 16.12, & 15.56 \\ 18.33, & 15.41, & 14.45 \\ 20.28, & 16.40, & 15.96 \\ 19.73, & 18.61, & 19.98 \\ 16.67, & 17.99, & 14.42 \\ 18.64, & 19.97, & 21.06 \\ 17.92, & 18.47, & 19.12 \\ 20.25, & 19.27, & 19.27 \\ 21.19, & 14.85, & 18.46 \\ 21.03, & 21.46, & 19.67 \\ 21.75, & 12.91, & 23.88 \\ 21.64, & 19.87, & 18.34 \end{pmatrix}$$

$$= (20.754, 17.342, 19.183)$$

The results of the calculation showed that Proposal A (20.754 points) was slightly superior to Proposal C (19.183 points) and also Proposal B (17.342 points). The fuzzy evaluation results of the factors in each proposal showed that out of the 22 factors evaluated, Proposal A was superior to Proposal C on 16 factors. The biggest difference among these was “Completeness” with a difference of approximately 6.32%. This showed that for landscape visual, Proposal A’s use of street furniture to define the street’s character was superior to Proposal C in terms of completeness. Proposal A was superior to Proposal B on 16 factors as well, with the biggest difference being “Decorativeness” with a difference of 9.13%. This showed that for the environmental context, Proposal A’s use of decorativeness to enhance/beautiful the exterior of the building interface was superior to Proposal B. Proposal C was superior to Proposal B in 12 factors, with the biggest difference being “Clarity” where the difference was 10,97%. This showed that in landscape visual, Proposal C’s content, details and overall presentation in its virtual reality space was more easily discerned than Proposal B. Proposal C was better than Proposal A in 6 factors, the biggest difference being in “Harmony” where the difference was about 2.42%. This showed that for landscape visual, Proposal C’s planting effect achieved a better harmony in the streetscape than Proposal A. Proposal B was superior to Proposal A in 6 factors, the biggest difference being in “Safety” where the difference was 5.95%. This showed that in environmental context, Proposal B’s street functionality offered better safety within the pedestrian space than Proposal A. All three proposals had similar scores for “Liveliness”. This might be due to the use of virtual reality tools for visual simulation of urban pedestrian zone landscape design. VR enhanced the design elements’ shape, color, appearance and texture, strengthening the impression left on the audience. The similar scores may therefore be due to the strong impression left and the broad acceptance of the VR-based presentation format.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

1. Landscape design for urban pedestrian zones is a fuzzy decision making question that involves making a judgment from numerous fuzzy factors. A new multiple objective decision-making method that uses fuzzy math theory and methods was shown to be feasible. Using this evaluation method, the reliability of decision-making for urban pedestrian zones in landscape design was improved.

2. This method can be combined with computer-aided design technologies to establish a combined system analysis model that has both qualitative and quantitative characteristics. This promotes the automation of landscape design for urban pedestrian zones.

3. Using the system analysis method to investigate the relationships between influencing factors, layers and component factors in landscape design for urban pedestrian zones so as to establish an evaluation model is feasible.

4. Landscape design for urban pedestrian zones is an extremely detailed undertaking. To accomplish the project objectives, thorough planning by using VR to create a representation of the design can help improve efficiency and results.

5.2. RECOMMENDATIONS

1. Continue to develop and refine this model so it can be translated into software for actual use in landscape design for urban pedestrian zones. There exists a real requirement for quantification standards to be defined for factors so evaluation can be made simpler and more objective.

2. Create modules and databases using VR technology. Also set up an expert

system to help with designers' analysis and assessments so landscape design for urban pedestrian environments can be made more scientific and precise. It will also allow the designer to provide the general public with a cross-platform method of communication.

3. Incorporate landscape elements' natural ambient factors such as light, water and sound into the study. This will add weight to the index system, concept and decision-making in landscape design for urban pedestrian zones, making them more comprehensive.

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