Location of Urban Green Spaces with Emphasis on Effective Quality Factors Using Fuzzy AHP Method

Abdullah Jamali
PhD student in Urban Design, Yerevan state Academy of Fine Arts
jmli_jmli@yahoo.com

Abstract: Literature indicates that comparative ratios provide ambiguous and inaccurate judgments in many cases. Quality forecasts have been relatively more successful when compared to quantitative estimates. The uncertainty in preferential judgment leads to uncertainty in classification of other options and difficulty in stabilization of preferences. The objective of this article was to study and evaluate the effective quality factors in Location of the urban green spaces and their prioritization by using Fuzzy AHP method. This study offers a formulated strategy based on different views and expert opinions. The analysis for factor prioritization is to be performed in many ways to include different views and opinions. The analysis potentially presents the undefined relations in the applications of integrated and formulated strategies in different time spans. This analysis may provide a conclusive approach in location of decision making process to urban landscape designers. It provides an increased capability for identifying the factors and priorities that lead to the selection of a suitable site among many options.
[Abdullah Jamali. **Location of Urban Green Spaces with Emphasis on Effective Quality FactorsUsing Fuzzy AHP Method**. *Life Sci J* 2012;9(4):4003-4008] (ISSN:1097-8135). http://www.lifesciencesite.com. 596

Keywords: Designing City View, Quality Factors, Fuzzy AHP Method, Factor Analysis, Factor Prioritization.

Introduction

Traditionally, green space location would be decided based on common approaches without regard to quality requirements. Any empty space would get a green space label. This space would be added to per capita green space merely based on its area without considering any of the important quality factors.

The extended application of mathematical and computer modeling together with quantitative analysis has come to the aid of decision making processes. They have been helpful in scientific and improved design processes. Now, proper location of urban green spaces has become an important aspect of urban landscape design.

Uncertainty in the proper location always occurs when considering the diversity, changeability, and complexity of environmental factors that influence urban green spaces. The complexity attributed to environmental protection issues has rendered location based on a single criterion, i.e. per capita green space, ineffective. Decision making based on multiple criteria is now increasing in popularity.

The basic factors used in location of decision making process for landscape architectural design should be clearly converted from common principles into mathematical concepts. The rules and principles of the method should be defined as the first step. Then, the effective factors shall be assessed using the evaluation method. This method is an effective substitute for the classical methods.

Fuzzy AHP is an advanced analytical method vis-à-vis the classical AHP method. AHP method is a simple approach. However, it may lead to uncertainty in decision making when considering both qualitative and quantitative factors. The underling uncertainty may produce poor judgment and, consequently, inappropriate decisions.

Researchers have studied fuzzy AHP which is an extension of Saaty theorem. They have argued that fuzzy AHP produces sufficient explanation for various decision making processes when compared with the classical AHP method.

Weck et al. applied fuzzy AHP to study the production cycle alternatives. Cebi and Kahraman used fuzzy AHP to determine multi criteria for the selection of real estate for transportation companies. Kuo et al. devised a decision support system for selecting convenience store location through integration of fuzzy AHP and artificial neural network. Cheng offered a new algorithm for evaluating the naval tactical missile systems by fuzzy AHP based on the grade value of membership function.

Complicated systems show human experience and judgment in the form of ambiguous linguistic patterns. A better presentation of linguistic could be in the form quantitative data series. These data sets can be corrected by using the analytical methods of fuzzy set theorem. Classical AHP methods are commonly used in relatively palpable (non-fuzzy) decision making processes. These methods involve various degrees of biased judgment.

Classical AHP methods do not take into account the uncertainties related to the mental judgments of AHP that affect the selection and prioritization of criteria for a successful decision making. Classical AHP is still unable in reflect human thinking styles. Fuzzy AHP was proposed to avoid risks during implementation. It is a fuzzy format for solving fuzzy hierarchy problems.

Fuzzy AHP Analysis

AHP is a structured approach for organization and analysis of complicated decision making scheme. Thomas L. Saaty proposed this technique in 1970 based on mathematics and psychology principles. The original method has been studied and modified many times. AHP approach has special application in decision making. This method is used around the world for decision making in various fields including government, business, industry, health, and education.

AHP helps decision makers to identify the right decision. The right decision is the one which is the most appropriate for a given objective according to the understanding of the decision maker(s) of the problem under consideration. AHP provides a logical and comprehensive framework for a decision making process. This framework provides for quantification and definition of elements that are critical in making decisions which could contribute to achieving the overall objectives. An AHP user breaks down the problem into a hierarchy of simpler problems that could individually be analyzed. Elements of the hierarchy should explain every aspect (tangible and intangible) of decision making process. They could further measure, estimate, and define - totally or partially - any factor that is useful in the decision making process.

Fuzzy AHP is an approach for classifying decision making options in order to select the best option when decision maker has multi criteria. This approach answers this question: "which option?" Decision maker uses fuzzy AHP to select options that fit the best with the decision criteria. The selection process involves the classification of decision making options using a quantitative scoring scheme. Every decision option is classified against decision criteria.

Many applications have been proposed using fuzzy AHP. This study uses Extent Analysis method proposed by Chang on the chosen problem. Extent analysis method of fuzzy AHP depends on the feasibility degree of every criterion. Triangular fuzzy numbers are assigned to linguistic variables based on responses received on questionnaire forms. These numbers establish a given level in the hierarchy of pairwise comparison matrix. The result of every matrix level and a new set **(l, m, u)** is calculated. Values for $\mathbf{l_i / l_i, m_i / m_i, u_i / u_i, (i=1,2,\ldots, n)}$ are calculated to find a triangular fuzzy number for each criteria in the same way the last $\mathbf{M_i}$ $\mathbf{(l_i , m_i , u_i)}$ set for $\mathbf{M_i}$ criteria is used in the process. Membership function is constructed for each criterion in the next step and their commonalities are identified through pairwise comparison.

A common point is found for each comparison in fuzzy logic. The membership number for each point is mapped to its weight. The degree of membership can be defined as the feasibility of that amount. The minimum degree of feasibility that is attributed to a given criterion is measured in conditions that feasibility is highest relative to others. This feasibility is also considered as weight of the criterion before normalization. The weight of every criterion obtained through this process is normalized and named as the degree of importance or the final weight for hierarchy.

In applying the extend analysis of Chang to hierarchical processes, every criterion is selected and is subjected to extend analysis, which is identified as $\mathbf{g_i}$. Therefore, **m** limit analysis for each criterion can be calculated from the following formula:

The objective of this formula is to obtain a value for $\mathbf{g_j}$ where the set **(i=1; 2; 3…. n)** and all of $\mathbf{M_{gj}^{j}}$ **(j=1; 2…. . m)** are triangular fuzzy numbers (TFNs). The analysis steps of Chang are discussed below.

Step 1: Fuzzy Number

The fuzzy number of combined limit of $\mathbf{S_i}$ is defined in formula 1 after considering the hierarchical criterion.

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes [\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}]^{-1} \quad (1)$$

Formula 2 is obtained next.

$$\sum_{j=1}^{m} M_{gi}^{j} \quad (2)$$

Limit analysis of **m** for a given matrix is given in formula 3 after fuzzification process.

$$\sum_{j=1}^{m} M_{gi}^{j} = (\sum_{j=1}^{m} lj ; \sum_{j=1}^{m} m_j ; \sum_{j=1}^{m} uj ;) \quad (3)$$

A new set of **(l, m, u)** is calculated to be used in formula 4.

$$[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}]^{-1} \quad (4)$$

In this set **l** is the lowest limit, **m** is the highest possible number, and **u** is the highest limit. Formula 5 is obtained after fuzzification of $\mathbf{M_{gj}^{j}}$ **(j=1; 2; 3…. . m).**

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = (\sum_{j=1}^{m} lj ; \sum_{j=1}^{m} m_j ; \sum_{j=1}^{m} uj ;) \quad (5)$$

Reverse vector analysis of formula 5 produces formula 6 as explained below.

$$[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}]^{-1} = \{ \frac{1}{\sum_{j=1}^{m} uj ;} ; \frac{1}{\sum_{j=1}^{m} m_j ;} ; \frac{1}{\sum_{j=1}^{m} lj ;}] \quad (6)$$

Step 2: Feasibility Degree of $M_2 = (l_2 ; m_2 ; u_2) \geq M_1 = (l_1 ; m_1 ; u_1)$ is defined as formula 7: **x** and **y** represent the numbers on axis of the function for each criterion.

These terms are treated equally in formula 8.

In this formula, **d** is the highest common point

$$V(M_2 \geq M_1) = \begin{cases} 1 & if \ m_2 \geq m_1 \\ \dfrac{l_1 - u_2}{(l_1 - u_2) + (u_1 - l_2)} & otherwise \end{cases} \quad (8)$$

between μ_{M1} and μ_{M2}. We need values for **V (M2 ≥ M1)** and **V (M1 ≥ M2)** in order to compare **M1** and **M2**.

Step 3: Convex Fuzzy Number

The feasibility degree of a convex fuzzy number greater than the convex fuzzy number **k** is obtained from $\mathbf{M_i}$ **(i = 1, 2, 3, 4, 5, ... , k)** which is defined by the least number for **V (M ≥** $\mathbf{M_i}$**), i = 1, 2, 3, 4, 5, ... , k**.

We assume **k ≠ i** for **k = 1, 2, 3, 4, 5, ... , n** in order to calculate the weighted vector in formula 9.

d (Ai) = min V (Si≥Sk) (9)

In this equation $\mathbf{A_i}$ **(i=1, 2, 3…. n)**

Step 4: Normalization

Normalized weighted vectors in formula 10 are:

W = (d^T(A1), d^T (A2), d^T d^T (A3), d^T (A4), d^T (A5), d^T (A6), ..., dd^T (An) $)^T$ (10)

W are non-fuzzy numbers.

Effective Quality Factors in Location of Urban Green Space

Effective quality factors were identified by reviewing the available journal articles relevant to the evaluation of urban green spaces and by interviewing the experts in the field. Nine criteria

(7)

were identified as effective quality factors: Sustainability, Aesthetics, Safety, Connectivity and Accessibility, Legibility, Desirability, Dependency, Adaptability, Biodiversity.

A questionnaire was prepared to determine the degree of significance for each factor. The respondents were asking to select the related linguistic variables to be used in the evaluation of the questions. Triangular fuzzy numbers proposed by Chang are adapted for quantifying the evaluation based on the provided scale. The results are, then, expanded (Table 1).

Table 1 - Fuzzy Numbers (Chang)

Number	Qualification
(7/2,4,9/2)	Very Strong
(5/2,3,7/2)	Strong
(1,1,1)	Equal
(3/2,2,5/2)	Weak
(2/3,1,3/2)	Very Weak

This study used fuzzy analysis in location of decision making based on the selected criteria. Thirty questionnaires were distributed to expert individuals in order to devise a suitable model for location of urban green spaces. Pairwise comparisons were carried out on proposed sites by considering every criterion with special emphasis on quality factors. The comparisons were based on fuzzy indexes provided in table 1.

The followings are two samples of the questions on the questionnaire.

Question 1: How significant is factor 1 relative to factor 2?

Question 2: What is the priority of site 1 vis-à-vis site 2 over factor 1?

Questions were organized in a table before distribution to the experts. These questions are identical for both classical AHP and fuzzy AHP. The significance weights are calculated by using the method proposed for each approach.

For example, contiguity and accessibility are reported as weak when comparing site 1 with site. The number reported in the table for this comparison is (2/3, 1, 3/2). It means that the accessibility of site 2 is more suitable than site 1. The suitability is presented by triangular fuzzy numbers. Similarly, answers obtained from thirty questionnaires were evaluated using fuzzy AHP formulas.

Respondents had one week to fill out the questionnaires. This time was given to provide enough time to experts to visit the site and evaluate their location of criteria. The results of analysis are presented in the next table.

Criteria were identified and compared for best fit according to fuzzy AHP method. The criteria were calculated by using the relevant process and classified based on the given hierarchy.

The following calculations were performed to obtain significance numbers for the first level.

Step1:

$$\left(\sum_{j=1}^{m} lj\,;\sum_{j=1}^{m} m_j\,;\sum_{j=1}^{m} uj\,;\right) = (79.36, 98.75, 123.05)$$

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = (0.01, 0.01, 0.013)$$

$$S1 = M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = (10.17, 13, 15.5) \otimes (0.0.01, 0.0.01, 0.013) = (0.083, 0.132, 0.195)$$

$$S2 = M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = (14, 17, 20.5) \otimes (0.0.01, 0.0.01, 0.013) = (0.114, 0.172, 0.258)$$

$$S3 = M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = (14.07, 17.5, 21.17) \otimes (0.0.01, 0.0.01, 0.013) = (0.114, 0.175, 0.267)$$

$$S4 = M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = (7.34, 9.58, 12.69) \otimes (0.0.01, 0.0.01, 0.013) = (0.60, 0.97, 0.160)$$

$$S5 = M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = (8.19, 9.83, 12.07) \otimes (0.0.01, 0.0.01, 0.013) = (0.67, 0.100, 0.152)$$

$$S6 = M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = (7.40, 9.17, 11.97) \otimes (0.0.01, 0.0.01, 0.013) = (0.60, 0.93, 0.151)$$

$$S7 = M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = (5.64, 7.17, 9.47) \otimes (0.0.01, 0.0.01, 0.013) = (0.46, 0.73, 0.119)$$

$$S8 = M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = (6.80, 8.17, 9.97) \otimes (0.0.01, 0.0.01, 0.013) = (0.55, 0.83, 0.126)$$

$$S9 = M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = (5.75, 7.33, 9.73) \otimes (0.0.01, 0.0.01, 0.013) = (0.47, 0.74, 0.123)$$

Step2: Using these vectors,

V(S1>S2) = 0.67 ; V(S1>S3) = .064; V(S1>S4)= 1; V(S1>S5)= 1; V(S1>S6)= 1; V(S1>S7)= 1; V(S1>S8)= 1; V(S1>S9)= 1

…………

V(S9>S1)= 0.41;V(S9>S2) = 0.08 ;V(S9>S3) = .007;V(S9>S4)= 0.73;V(S9>S5)= 0.69;V(S9>S6)= 0.77; V(S9>S7)= 1; V(S9>S8)= 0.89;

Step3: Thus the weight vector from step2 is found as:

W^{t} = (0.64, 0.97, 1, 0.36, 0.33, 0.30, 0.05, 0.11, 0.07)

Step4: With normalize, $W_{Goal} =$ (0.167, 0.253, 0.262, 0.095, 0.086,.079, 0.012,.028,0.020)

With similar calculate for each of items related with 9 factors. (Table2)

Table 2- Matrix of criteria based on EA method - AHP Fuzzy

Criteria	Aesthetics			Safety			Sustainability			Connectivity and accessibility			Legibility			Dependency			Desirability			Biodiversity			Adaptability		
Aesthetics	1.00	1.00	1.00	0.67	1.00	1.50	1.50	2.00	2.50	0.67	1.00	1.50	0.67	1.00	1.50	1.50	2.00	1.50	2.50	3.00	3.50	1.00	1.00	1.00	0.67	1.00	1.50
Safety	0.67	1.00	1.50	1.00	1.00	1.00	0.67	1.00	1.50	3.50	4.00	4.50	2.50	3.00	3.50	0.67	1.00	1.50	1.50	2.00	2.50	2.50	3.00	3.50	1.00	1.00	1.00
Sustainability	0.40	0.50	0.67	0.67	1.00	1.50	1.00	1.00	1.00	2.50	3.00	3.50	1.50	2.00	2.50	2.50	3.00	3.50	2.50	3.00	3.50	1.50	2.00	2.50	1.50	2.00	2.50
Connectivity and accessibility	0.67	1.00	1.50	0.22	0.25	0.29	0.29	0.33	0.40	1.00	1.00	1.00	0.67	1.00	1.50	0.67	1.00	1.50	0.67	1.00	1.50	2.50	3.00	3.50	0.67	1.00	1.50
Legibility	0.67	1.00	1.50	0.29	0.33	0.40	0.40	0.50	0.67	0.67	1.00	1.50	1.00	1.00	1.00	2.50	3.00	3.50	1.00	1.00	1.00	1.00	1.00	1.00	0.67	1.00	1.50
Dependency	0.67	0.50	0.67	0.67	1.00	1.50	0.29	0.33	0.40	0.67	1.00	1.50	0.29	0.33	0.40	1.00	1.00	1.00	0.67	1.00	1.50	0.67	1.00	1.50	2.50	3.00	3.50
Desirability	0.29	0.33	0.40	0.40	0.50	0.67	0.29	0.33	0.40	0.67	1.00	1.50	1.00	1.00	1.00	0.67	1.00	1.50	1.00	1.00	1.00	0.67	1.00	1.50	0.67	1.00	1.50
Biodiversity	1.00	1.00	1.00	0.29	0.33	0.40	0.40	0.50	0.67	0.29	0.33	0.40	1.00	1.00	1.00	0.67	1.00	1.50	0.67	1.00	1.50	1.00	1.00	1.00	1.50	2.00	2.50
Adaptability	0.67	1.00	1.50	1.00	1.00	1.00	0.40	0.50	0.67	0.67	1.00	1.50	0.67	1.00	1.50	0.29	0.33	0.40	0.67	1.00	1.50	0.40	0.50	0.67	1.00	1.00	1.00
weight	0.167			0.253			0.262			0.095			0.086			0.079			0.012			0.028			0.02		

Table 3 provides a sample calculation for fuzzy evaluation matrix.

Table 3 - Importance coefficient of criteria and alternatives- AHP fuzzy

Criteria / Alternatives	Aesthetics	Safety	Sustainability	Connectivity and accessibility	Legibility	Dependency	Desirability	Biodiversity	Adaptability	Result
Weight	**0.167**	**0.253**	**0.262**	**0.095**	**0.086**	**0.079**	**0.012**	**0.028**	**0.020**	
Site1	0.217	0.144	0.195	0.290	0.228	0.264	0.220	0.201	0.285	0.205
Site2	0.297	0.220	0.226	0.173	0.301	0.242	0.245	0.324	0.257	**0.243**
Site3	0.277	0.255	0.211	0.196	0.203	0.283	0.289	0.124	0.101	0.233
Site4	0.142	0.196	0.168	0.115	0.102	0.105	0.083	0.262	0.303	0.159
Site5	0.017	0.087	0.184	0.212	0.093	0.082	0.128	0.033	0.044	0.111
Site6	0.050	0.099	0.016	0.014	0.073	0.025	0.035	0.056	0.009	0.049

Conclusions

1. The current policy in urban design is to give equal weight to quality factors compared to the quantitative factors that traditionally have been used to evaluate types of green spaces to meet various needs of target users.
2. Site selection based on proper quality criteria is a part of the location of requirements for urban green space.
3. Consideration of quality criteria makes it easier to achieve location of objectives for urban

green spaces that are more congruent with environmental protection requirements.

4. Location of urban green spaces are a fuzzy decision making problem that involves judgment about many quality factors. This study presented a multi criteria decision making method established based on fuzzy mathematical analysis method. This method improves the certainty of decision making.
5. An evaluation model can be made by using a systematic analytical method intended to evaluate the relation between factors, layers, and sub factors that are effective in location of urban green spaces.
6. Meeting the study objectives in location of urban green spaces based on expert opinions and careful planning required many details. Using different method before offering a suitable design may be beneficial in obtaining useful results and improving productivity.

References

1. Anderson, P. 1999. Complexity Theory and Organization Science Organization Science.
2. Ann Arbor. and Ulrich's Kaplan, (2004) Humanscape : Environments for People,
3. Bishop.D. and Rohrmann.B. (2003)Subjective responses to simulated and real environments: a comparison, Landscape and urban planning Journal, Vol 65, Amsterdam : Elsevier Press.
4. Booth, N. K. 1983: Basic Elements of Landscape Architectural Design, New York: Elsevier Science Publishing Co., Inc.
5. Bouyssou, D. et al. (2000) Evaluation and Decision Models: A Critical Perspective, Boston: Kluwer Academic Publishers.
6. Cebi, S. and Kahraman, C. (2010) Fuzzy multi criteria group decision making for real estate investments, Proceedings of The Institution of Mechanical Engineers Part I-journal of Systems and Control Engineering.
7. Chang, D. Y. (1996) Fuzzy Analytic Hierarchy Process: Extend Analysis Method, Fuzzy sets and systems Journal.
8. Cheng C.H., Yang K. L., Hwang C.L., (1999) Evaluating attack helicopters by AHP based on linguistic variable weight, European Journal of Operational Research.
9. Conway.H. (2004) Parks need people need parks: the skills shortage in parks, New York : Cambridge University Press.
10. Larson.C. D. and H. Forman.E.H. (2007) Application of the Analytic Hierarchy Process to Select Project Scope for Videologging and Pavement Condition Data Collection, 86th Annual Meeting Compendium, Transportation Research Record Journal.
11. Leung, L. C. and Chao, D. (2000) On Consistency and Ranking of Alternatives in Fuzzy AHP, European Journal of Operational Research.
12. Marsh, W. M. (2005) Landscape Planning: Environmental applications, New York: John Wiley & Sons.
13. Marsh. W. (2005) Landscape Planning Environmental applications, Hoboken, NJ : Wiley Press.
14. Saaty.T.L. and Peniwati.K. (2008) Group Decision Making: Drawing out and Reconciling Differences, Pittsburgh, PA: RWS Press.
15. Wang, H. F. (2004) Multi Criteria Decision Analysis: From Certainty to Uncertainty, Taiwan: Ting Long Book.

9/04/2012