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SELECTION METHOD FOR SUSTAINABLE BUILDING

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Abstract

For a sustainable building industry, not only should the environmental and economic indicators be evaluated but also the societal indicators for building. Current indicators can be in conflict with each other, thus decision making is difficult to clearly quantify and assess sustainability.

For the sustainable building, the objectives of decreasing both adverse environmental impact and cost are in conflict. In addition, even though both objectives may be satisfied, building management systems may present other problems such as convenience of occupants, flexibility of building, or technical maintenance, which are difficult to quantify as exact assessment data. These conflicting problems confronting building managers or planners render building management more difficult.

This paper presents a methodology to evaluate a sustainable building considering socio-economic and environmental characteristics of buildings, and is intended to assist the decision making for building planners or practitioners.

The suggested methodology employs three main concepts: linguistic variables, fuzzy numbers, and an analytic hierarchy process. The linguistic variables are used to represent the degree of appropriateness of qualitative indicators, which are vague or uncertain. These linguistic variables are then translated into fuzzy numbers to reflect their uncertainties and aggregated into the final fuzzy decision value using a hierarchical structure.

Through a case study, the suggested methodology is applied to the evaluation of a building. The result demonstrates that the suggested approach can be a useful tool for evaluating a building for sustainability.

Keywords: Sustainable building, Decision making, Uncertainty, Trade-off Indicator, Fuzzy composition

1. Introduction

Sustainable building management has received much attention in recent years. Many communities throughout the world are struggling to develop efficient and effective tools for assessing sustainable buildings. However, there is no universal method or tool yet. Several building technologies and practices have emerged in recent years as alternatives for environmental sustainable building in meeting cost, time, and environmental quality goals of owners and contractors [1, 2, 3]. Some of these methods are used frequently in commercial markets but are not yet widely accepted in the world as standard practice. Alternative methods in sustainable building are finding increasing acceptance and use in other construction markets, both private and public.

For a sustainable building industry, not only should the environmental and economic

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indicators be evaluated but also the societal indicators for building. When current indicators are in conflict with each other, decision making is difficult to clearly quantify and assess sustainability [4].

For the sustainable building, high-cost management systems tend to have a lower adverse environmental impact, while low-cost management systems may not provide adequate protection. That is, the objectives of decreasing both adverse environmental impact and cost are in conflict. In addition, even though both cost and environmental objectives may be satisfied, other objectives such as convenience of occupants, flexibility of building, or technical maintenance may present problems because they are generally difficult to quantify as exact assessment data. These conflicting problems confronting building managers or planners render building management more difficult.

The purpose of this paper is to develop a method to evaluate a sustainable building considering socio-economic and environmental characteristics of buildings, and thus, to assist the decision making for building planners or practitioners in their efforts to achieve sustainable building construction.

2. Methodology

This research employs fuzzy set theory and hierarchical structure analysis to formulate a methodology for evaluating buildings, resulting in a final overall impact for sustainable building alternatives. Fuzzy sets, which were introduced by Zadeh [5], are used to describe the inherent imprecision and ambiguity associated with the criterion for sustainable building.

A systematic approach for the selection of sustainable building consistsof following four sequential steps:

Step 1 Selection of basic criteria, which influence to building alternatives,
Step 2. Normalization of basic criterion for direct comparison,
Step 3. Aggregation and weighting of normalized basic criteria, and
Step 4. Ranking of the proposed alternatives to choose the best one for a sustainable building.

2.1. Selection of basic criteria

A number of criteria, which relate to sustainable building, can be considered, such as governmental policy, operational constraints, economics, environmental and social considerations. These are employed as the input variables for basic criteria to evaluate buildings.

Since these basic criteria contain elements of uncertainty, these are estimated as a fuzzy number to help characterize their uncertainty, which is inherent to a given set with a degree of membership as shown in Figure 1.

Let $Z_i(x)$ be a fuzzy number for the ith basic criterion and its membership function $\mu[Z_i(x)]$ be a trapezoid (or triangle), where x denotes an element of the discrete set of a building being analyzed. Then, the membership function for each of the basic criteria can be constructed as shown in Figure 1, where $Z_{i,h}(x)$ is an interval value of the ith basic criteria at the confidence level h ($a \le Z_{i,h}(x) \le b$ for trapezoid, $a' \le Z_{i,h}(x) \le b'$ for triangle).

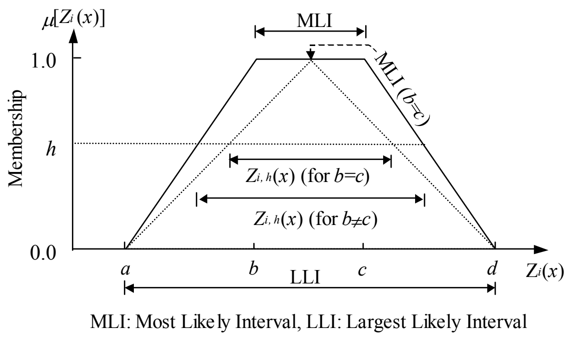


Figure 1 Trapezoidal (triangular) membership function of a fuzzy number

2.2. Normalization of basic criterion

The normalization process is performed by using the best and worst values, which can be assigned one of two methods (benchmark values or overall best and worst values of the *i*th basic criterion among the alternatives compared). The value of the *i*th fuzzy criterion is transformed into an *i*th normalized criterion with help of the predetermined best value (BZ_i) and worst value (WZ_i) for the *i*th basic criterion. The *i*th normalized basic criterion ($NC_{i,h}(x)$) can be calculated as follows:

$$NC_i(x)\ (when\ \ BZ_i \rangle\ WZ_i) = \begin{cases} 1, & Z_i(x) \geq BZ_i, \\ \dfrac{Z_i(x) - WZ_i}{BZ_i - WZ_i}, & WZ_i \langle Z_{i,h}(x) \langle BZ_i, \\ 0, & WZ_i \geq Z_i(x) \end{cases} \tag{1}$$

$$NC_i(x)\ (when\ \ BZ_i \langle\ WZ_i) = \begin{cases} 1, & Z_i(x) \leq BZ_i, \\ \dfrac{Z_i(x) - WZ_i}{BZ_i - WZ_i}, & BZ_i \langle Z_i(x) \langle WZ_i, \\ 0, & WZ_i \leq Z_i(x) \end{cases} \tag{2}$$

where $NC_{i,h}(x)$ is a normalized *i*th fuzzy criterion and $Z_i(x)$ is a value of the *i*th fuzzy criterion. BZ_i and WZ_i denote the best and worst values of the *i*th criterion, respectively. In the case of environmental impact, for example, the lower the impact, the better the choice. Thus, the best value (BZ_i) for the environmental impact should be less than the worst value (WZ_i). The basic criterion value for the environmental impact should be transformed into a normalized basic criterion value using equation (2) (since $BZ_i<WZ_i$).

2.3. Integrating procedure

The interrelationships among the basic criteria can be expressed by the use of a hierarchical structure as that illustrated in Figure 2. In this type of hierarchical structure, the elements of level 1 constitute the selected basic criteria. The criteria in the upper level can be obtained by integrating the criteria in the lower level. The integrating procedure continues until the final level fuzzy criterion is achieved.

Several parameters, such as the mean, median, maximum, minimum and mixed operators, have been proposed to determine the composite criteria. Among the operators, the mean operator is used as a composite of the criteria since it is commonly used in the fuzzy set theory.

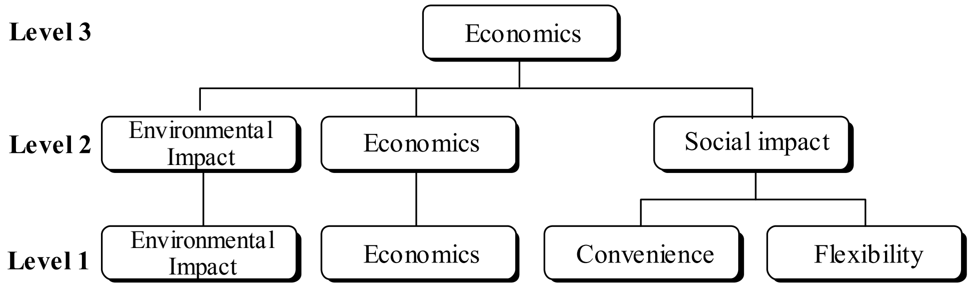
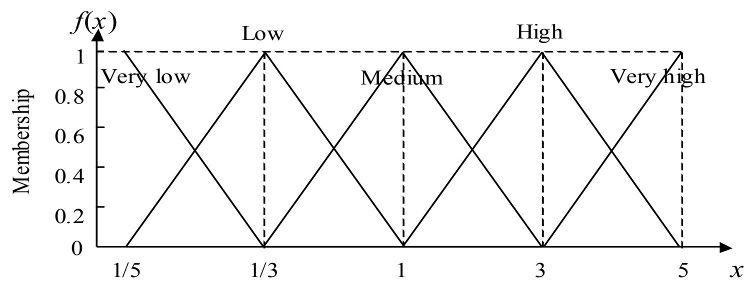


Figure 2 Composite structure for basic criterion

Let ⊕ and ⊗ be fuzzy addition and multiplication operators, then the composite of criteria for building alternative *i* can be obtained by the mean operator.

$$D_i(x) = \frac{1}{k} \otimes \{(W_1 \otimes NC_{i1}) \oplus (W_2 \otimes NC_{i2}) \oplus \cdots \oplus (W_k \otimes NC_{ik})\} \tag{3}$$

where $D_i(x)$ is the fuzzy composite index of building alternative *i*, and NC_{ik} is the normalized fuzzy criterion *k* of building alternative *i*. W_k is the weight indicating the relative importance of criterion *k*. The weighting parameters are determined based on the degree of relative importance of each criterion. However, it is very difficult to give a relative importance as a precise number. Thus, it is more useful to give these weighting parameters in linguistic value rather than precise numbers. These linguistic values, "very low", "low", "less medium", "medium", "more medium", "high", and "very high", are then converted into fuzzy numbers using the triangular membership functions which are shown in Figure 3. It becomes more meaningful to quantify a subjective measurement into a range rather than in a precise value [6].



Very low (1/5, 1/5, 1/3), Low (1/5, 1/3, 1), Medium (1/3, 1, 3), High (1, 3, 5), Very high (3, 5, 5)

Figure 3 Membership function for linguistic values

To obtain the weighting of a criterion, let $NC_{ik}(x)$ be the normalized criterion *k* in group *i* and W_{ik} be the weighting of criterion *k* of group *i*, a_{ij} be the element of fuzzy reciprocal matrix. The geometric row means of each fuzzy reciprocal matrix is calculated. Then the normalization of geometric row means is obtained in order to give the importance in terms of weighting of each criterion.

Geometric row mean (*GRM*) in group *i* is given by,

$$GRM_i = (a_{i1} \otimes a_{i2} \otimes a_{i3} \otimes \cdots \otimes a_{ik})^{1/k} \tag{4}$$

And normalized *GRM* (W_{ik}) in group *i* is given by,

$$W_{ik} = GRM_i \; \phi \; (GRM_{i1} \oplus GRM_{i2} \oplus GRM_{i3} \oplus \cdots \oplus GRM_{ik}) \qquad (5)$$

Since decisions are based on the testing of all of the weighted descriptions for each alternative, the criterion must be integrated in some manner in order to make a decision. Aggregation is the process by which the fuzzy sets that represent the outputs of each criterion influencing building are integrated into a single fuzzy set. Aggregation is done only once for each output variable, just prior to the final step.

For ease of implementation and powerfulness in problem solving, Chen's method [7] is used to rank the fuzzy performance index as a final step. It represents the final preference order for fuzzy performance index.

3. Illustrative example

A hypothetical building selection problem is designed to demonstrate the computational process of a sustainable building selection algorithm considering environmental and economic impacts as well as social impact.

Three alternatives (A_1, A_2, and A_3) are chosen to illustrate an example for evaluation. In order to simplify the algorithm of the process, four kinds of basic criteria were selected: environmental impact (ENI), economics (ENS), occupant's convenience of building (COV), and building's flexibility (FLX). Of the selected basic criteria, COV and FLX are generally difficult to quantify, thus they are represented as linguistic terms as shown in Figure 3. Table 1 shows the basic criteria values assumed and their normalization values for this illustrative example. The assigned linguistic value is transferred by numerical value using the membership function for a linguistic value (Figure 3). For example, linguistic term 'Low (1/5, 1/5, 1/3)' for COV in A_1, is transferred into normalized value (0.0, 0.03, 0.17) using the equation (1) with a help of best value (5) and worst value (1/5).

Table 1 Membership function for linguistic values

Basic Criterion			Alternative		
			A_1	A_2	A_3
ENI			70	50	90
ENS			92	90	78
COV			Low	High	Medium
FLX			High	Medium	Low
Basic Criterion	Best Value	Worst Value	Alternative		
			A_1	A_2	A_3
ENI	50	90	0.50	1.00	0.00
ENS	78	92	0.00	0.14	1.00
COV	5	1/5	(0.0, 0.03, 0.17)	(0.17, 0.583, 1.0)	(0.03, 0.17, 0.583)
FLX	5	1/5	(0.17, 0.583, 1.0)	(0.03, 0.17, 0.583)	(0.0, 0.03, 0.17)

ENI: Environmental impact related to alternative building during the life cycle, EMS: Expenditure to which the alternative operate with minimum cost during the life cycle, COV: Convenience of occupants during their operation (public transportation, parking area, recreation area, etc.), FLX: Alternative building's flexibility for occupants' requirements

The best and worst values used to normalize the basic criterion were determined from the fuzzy representations of each criterion. The value of importance for each criterion may vary according to the opinion of different decision makers or society type. Thus, four types of judgment scale for each criterion were assumed based on possible society type (A, B, C and D, Table 2). Judgment scale 'type A' regarded all criteria as having the same importance. While 'type B' is most concerned about "economics", least concerned about "environmental impact" and somewhat concerned about "social impact ". 'Type C' is most concerned with "environmental impact", least concerned about "economic impact", and somewhat concerned about "social impact". 'Type D' is most concerned about "social impact", followed by "environmental impact", and "economic impact".

Based on these scales, weightings were given for each of the criterion. When calculating the weightings, decision makers hardly give clear-cut opinions, thus a linguistic weighting set W, W={VL, L, M, H, VH}, where VL=very low, L=low, M=medium, H=high, and VH=very high, is used to evaluate the importance of the criteria using Figure 3. The weightings are applied to level 1 (integrating of COV and FLX) and 2 (integrating of ENI, ENS and Social impact). In this study, the weightings in level 1 considered three cases (case 1: COV has high importance than FLX, case 2: FLX has high importance than COV, and case 3: COV and FLX have similar importance). The weightings for level 2 are assigned based on the four types of judgment scale. These results are presented in Table 2.

Table 2 Fuzzy weightings for alternatives

Level	Judgment scale	Criterion	Case 1		Case 2	
			Linguistic Scale	Fuzzy Weighting (W)	Linguistic Scale	Fuzzy Weighting (W)
1	-	COV	High	(0.309, 0.750, 1.545)	Low	(0.138, 0.249, 0.691)
		FLX	Low	(0.138, 0.249, 0.691)	High	(0.309, 0.750, 1.545)
2	A	ENI	Equal	(0.333, 0.333, 0.333)	Equal	(0.333, 0.333, 0.333)
		ENS	Equal	(0.333, 0.333, 0.333)	Equal	(0.333, 0.333, 0.333)
		SOI	Equal	(0.333, 0.333, 0.333)	Equal	(0.333, 0.333, 0.333)
	B	ENI	LC	(0.064, 0.105, 0.293)	LC	(0.064, 0.105, 0.293)
		ENS	MC	(0.271, 0.637, 1.234)	MC	(0.271, 0.637, 1.234)
		SOI	SC	(0.109, 0.258, 0.722)	SC	(0.109, 0.258, 0.722)
	C	ENI	MC	(0.271, 0.637, 1.234)	MC	(0.271, 0.637, 1.234)
		ENS	LC	(0.064, 0.105, 0.293)	LC	(0.064, 0.105, 0.293)
		SOI	SC	(0.109, 0.258, 0.722)	SC	(0.109, 0.258, 0.722)
	D	ENI	SC	(0.109, 0.258, 0.722)	SC	(0.109, 0.258, 0.722)
		ENS	LC	(0.064, 0.105, 0.293)	LC	(0.064, 0.105, 0.293)
		SOI	MC	(0.271, 0.637, 1.234)	MC	(0.271, 0.637, 1.234)

Case 1: COV (Convenience of occupants) has high importance than FLX (Flexibility of building)
Case 2: FLX (Flexibility of building) has high importance than COV (Convenience of occupants)
Judgment scale:
A: All criteria have the same importance
B: Most concerned about "economics", least concerned about "environmental impact" and somewhat concerned about "social impact ".
C: Most concerned with "environmental impact, least concerned about "economic impact", and somewhat concerned about "social impact".
D: Most concerned about "social impact", somewhat concerned about "environmental impact", and lease concerned about "economic impact".

3.1. Results and discussion

Figure 4 shows an example on the graphical output of the fuzzy representations. The x-axis and y-axis in Figure 4 indicate the fuzzy distance and the membership function of each alternative to its position towards the ideal solution. The larger the x-axis, the better the alternative to the ideal solution. The alternative with the decision index of the largest number should be chosen as the best one.

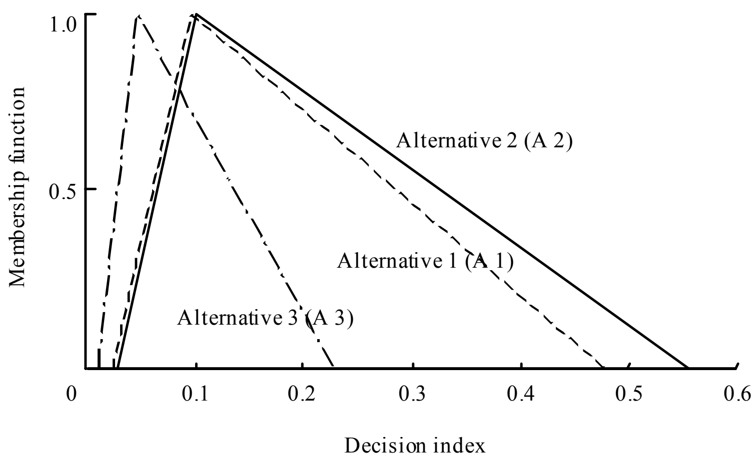


Figure 4 Example of fuzzy performance for each alternative

However, it may be difficult to make a decision when the membership function representing alternatives overlap each other. Thus, to transfer the fuzzy numbers with the membership function of triangular shape to precise values and make a clear comparison between each of the alternatives, the ranking method for the fuzzy numbers is applied. The results are presented in Table 3.

Table 3 Ranking of alternative for each case

		Judgment scale			
		A	B	C	D
Case 1	A 1	0.045	0.026	0.144	0.181
	A 2	**0.542**	0.142	**0.339**	**0.270**
	A 3	0.347	**0.396**	0.030	0.122
Case 2	A 1	0.139	0.052	0.175	0.124
	A 2	**0.532**	0.135	**0.349**	**0.177**
	A 3	0.359	**0.424**	0.028	0.038
Case 3	A 1	0.112	0.042	0.196	0.135
	A 2	**0.791**	0.155	**0.425**	**0.276**
	A 3	0.511	**0.460**	0.035	0.060

Bold: Best one for each case and judgment scale

In Table 3, the larger the ranking value for the alternative, the closer the choice is to the best one. In all cases that were calculated with four types of scenarios, similar results were produced, that is, that alternative 2 and alternative 3 are ranked as higher than alternative 1. The results suggested that alternative 2 and 3 were good choices for the sustainable building in the example illustration. Alternative 3 was only ranked as first in the judgment scale "B", which is most concerned economics without any consideration to the environmental impact. Alternative 2 was ranked from first to second in all of cases, which indicated that it considered all of criteria (economic impact, environmental impact, and social impact) or did not include an extreme defect. Therefore, alternative 2 would be chosen as the best alternative for the sustainable building in this example.

4. Conclusion

Decision making in the engineering field sometimes must be carried out based on available data and information that are often vague, imprecise and uncertain by nature. Selection of the sustainable building is a typical example.

To deal with this difficulty effectively, a systematic approach that supports decision makers in evaluating a sustainable building, which contain uncertainties, is proposed. In the suggested approach, the uncertainties and the qualitative human thoughts, which are difficult to measure as quantitative values, for the criteria associated with building are represented as fuzzy numbers, and these fuzzy numbers are normalized to compose the criteria directly under a hierarchical structure. In addition, the final result may vary with the value of importance assigned to each of criteria, which may vary according to the opinion of different decision makers or society type. Thus, the fuzzy weights assigned to each of criteria to aggregate into more global criteria are reflected in the different society type or policy.

This approach could also be applicable to other situations where available data are uncertain and conflicting relationships in building exist.

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