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Application of Multi-Criteria Method in Construction Material Selection

Orkun ALPTEKİN | Eskisehir Osmangazi University Directorate of Building Maintenance and Technique, Eskisehir, Turkey

ABSTRACT

In selection of construction materials and products, there are many criteria that should be considered according to the characteristics of them. These criteria also change according to the needs and alternatives. Therefore, material selection in construction is one of the important decision-making problems. In decision making problems, there are a few of multi- criteria decision methods that can be used in solving problems. Each of these methods uses numeric techniques to help decision makers choose among a discrete set of alternative decisions. This is achieved on the basis of the impact of the alternatives on certain criteria and thereby on the overall utility of the decision makers. In choice of which method can be used, it is important to have an understanding of the comparative value between the alternatives. In this article by examining the multi criteria methods, which ones should be used to choose the best material in different conditions is examined and by associating the material selection and multi criteria decision methods a flow diagram for material selection is proposed.

KEYWORDS : Construction Materials, Multi-Criteria Decision Making.

INTRODUCTION

In the architectural profession materials that make up the structure of the designed buildings must be defined. Architects are required to choose from a lot of different kinds of materials that have the same function. Moreover, the same kinds of materials as a result of the production of different companies may also have different features. Therefore, in the same type of material obtained from different manufacturers the choices between products are encountered as another decision problem.

The difficulty in material selection is not only associated with a variety of alternatives. In addition in the selection phase of materials many of the criteria as physical, mechanical, thermal, chemical, acoustic, optical, affordability, aesthetics and environmental impact classes must be taken into consideration. These criteria in the choice of materials used in the assessment are also in themselves are divided into sub-criteria. This situation makes the problem more complicated. A material that provides an optimal solution in one criterion can have low performance in other criterion according to other alternatives. Therefore, when choosing the ideal solution is tried to be made to the nearest alternative according to the criteria in evaluation. In decision making in the selection of materials architects are faced with a complex situation because of the ambiguity surrounding the decision situation and the difficulties in evaluation of alternatives and criteria. Thus in decision making accurate data and evaluation process away from the subjective decision are needed. In a decision problem, when it comes to evaluation of a combination of a number of conflicting criteria, this type of decision-making situations are investigated under multiple criteria decision making problems [1-5]. These types of problems can be solved by using several multi-criteria decision analysis methods. The method should be chosen considering the nature of the problem and the model building process.

MATERIALS AND METHODS

Traditional single criterion decision analysis is normally aimed at maximization of benefits with minimization of costs. But nowadays it has been concluded that these solutions are often not the most suitable ones. Also when there are more criteria in assessment of decision, there is a need to use in selection best solutions. Multi-criteria decision analysis is started to be used because of the necessity to develop multiple evaluations at the same time, taking into account different criteria of view highlighted by different decision makers. The decision making process constitutes at several steps. At first the different options must be identified; then a group of criteria to be used to compare the alternatives must be set; finally, all the scenarios must be judged regarding the fixed criteria with the aim to identify the most suitable options. Multi-criteria analysis method is not uniquely defined and a lot of techniques have been developed with the aim to better adapt the methodology to the specific problem to be solved, including all the preferences promoted by different decision makers [3]. The most commonly used multi criteria decision methods are Weighted Sum Method, Weighted Product Method, Analytical Hierarchy Process, PROMETHEE, ELECTRE and TOPSIS methods [2, 3, 6-8].

Weighted Sum Method

One of the best-known and most widely used methods of decision-making analysis methods is the weighted sum method. In this method numerical values are provided based on each criterion and each alternative. Then, weights demonstrating the importance of each criterion according to other criteria are determined. After the value of alternatives is multiplied by the weight criteria, the sum of these values are taken for all measures and then the resulting values are obtained. The alternative which provides the highest value between the alternatives is selected as the best alternative [5, 9]. In weighted sum method, if there is 'm' unit alternative and 'n' unit criteria, the following equation should provide by the best alternative.

$$P^{*} = \max_{m \geq i \geq 1} \sum_{i=1}^{n} a_{j} w_{j} \quad (1)$$

In this equation 'aij'indicates performance value of each alternative on the basis of each criteria and 'w_j' also indicates the degree of importance of each criteria [9].

Weighted Product Method

Weighted product method is similar to weighted sum method. The differences between them are by eliminating measurement units this method can be used in single and multi-dimensional decision problems. In the weighted product method, each alternative is compared by multiplying the rates determined for each criterion. In determining the proportion of the values, the weight of the corresponding criteria is situated as a base. The following multiplication is done in comparison of 'AK and AL' alternatives.

$$R(A_K / A_L) = \prod_{j=1}^{N} \left(a_K / a_{1,j}\right)^{w_j} \quad (2)$$

If R (AK /AL) value is greater than R (AL /AK) when deciding 'AK',alternative precedes the 'AL' alternative. The best alternative is an alternative that has ratio equal to or better than all other alternatives [9].

Analytical Hierarchy Process

Theanalytic hierarchy process(AHP) was developed byThomas L. Saatyin the 1970's and has been extensively studied and refined since then as a structured technique for organizing and analyzingcomplex decisions, based onmathematics. It is used around the world in a wide variety ofdecision situations, in fields such as engineering, business, industry, healthcare and education [10-13]. The essence of the process is decomposition of a complex problem into a hierarchy with goal at the top of the hierarchy, criterions and sub-criterions at levels and sub-levels of the hierarchy, and decision alternatives at the bottom of the hierarchy. Elements at given hierarchy level are compared in pairs to assess their relative preference with respect to each of the elements at the next higher level [14]. In this method the relative importance between two criteria is measured according to a numerical scale from 1 to 9. The value of 1 indicates equal importance, 3 moderately more, 5 strongly more, 7 very strongly and 9 indicates extremely more importance [10-14].

After determining the criteria of the importance of values, specified options for selection is evaluated with pairwise comparisons of each sub-criterion. As a result of evaluation each alternative take over the normalized scores over the main criteria creates matrix of pairwise comparisons' [5, 11]. Then, the relative weights are determined using the method of the Eigen vectors. By combining the relative weights a choice is made from decision alternatives.

Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)

PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) method is a multi-criteria decision-making method which was developed by Brans in 1982. PROMETHEE method, in comparison with other multi-criteria decision analysis methods is quite simple sorting method in theory and practice. PROMETHEE ranking method has been successfully applied to problems which consists a finite number of criteria and sorting conflicting criteria. The advantage of PROMETHEE Method is easily applied to qualitative data and it can be used without the need for a linear evaluation model. When it is compared with other methods of performance evaluation, it is easier to perform and is usually not necessary to define input and output that cannot easily be determined. Two types of information is needed in application of this method. One of them is information regarding the relative importance of the criteria and the other one is information regarding the decision maker's preferred function [5]. Implementation of this method basically consists of five steps.

In the first stage preferred function is defined for each criterion. This function gets a value in the range of (0, 1). If there is no difference between criteria or in the case of uncertain preferred, it gets the value 0, in the case of certain preferred, it gets value 1. There are six type of preferred function in using this method. In the second stage, in considering preferred function for the criteria, a common preferred function is determined for each alternative pair located in alternatives. Then common preferred function which belongs to a and b is determined by

$$P(a,b) = \begin{cases} 0 & , \ f(a) \le f(b) \\ p[f(a) - f(b)], & f(a) > f(b) \end{cases} \quad (3)$$

equity. Schematic representation of common preferred function is as follows:

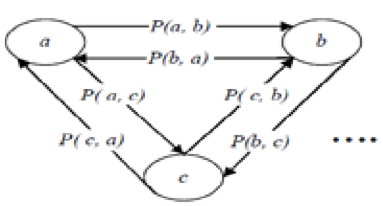

Figure 1: Schematic representation of common preferred function.

Preferred indexes for common preference functions defined for each pair of alternatives is determined by using

$$\pi(a,b) = \frac{\sum_{i=1}^{k} w_i \times P_i(a,b)}{\sum_{i=1}^{k} w_i} \quad (4)$$

equity. Weights w_i that expressing the relative importance of each criteria are determined by decision-makers.

In the third stage positive (Φ^+) and negative (Φ^-) superiorities are determined for each alternatives. Positive and negative superiorities for alternative aare calculated by respectively with

$$\Phi^+(a) = \sum \pi(a,x) \qquad x = (b,c,d,...) \quad (5)$$

equities. Sum of $\sum \pi(a,x)$ indicates preference of alternative anoverall other alternatives. $\Phi^+(a)$ refers to how well alternative *a*is. Sum of $\sum \pi(x,a)$ indicates preference of other alternatives over alternative a.$\Phi^-(a)$refers to how bad alternative *a* is. Positive and negative superiority calculated for alternative a is shown in Figure 2 [5, 15, 16].

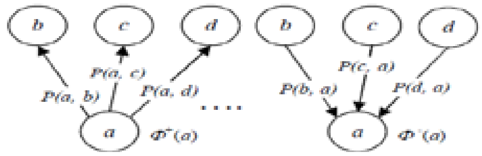

Figure 2:Positive and negative superiority calculated for alternative a.

In the fourth stage partial priorities are determined by PROMETHEE I. Cases that they cannot be compared and preferences of alternatives according to each other are determined by the aid of partial priorities. [5, 15-16]. If any of the

i. $\Phi^+(a) > \Phi^+(b)$ and $\Phi^-(a) < \Phi^-(b)$, (6)

ii. $\Phi^+(a) > \Phi^+(b)$ and $\Phi^-(a) = \Phi^-(b)$,

iii. $\Phi^+(a) = \Phi^+(b)$ and $\Phi^-(a) < \Phi^-(b)$

conditions are provided, alternative a is preferred over alternative b. If, $\Phi^+(a) = \Phi^+(b)$ and $\Phi^-(a) = \Phi^-(b)$ conditions are provided, alternative a is identical to alternative b. If

i. $\Phi^+(a) > \Phi^+(b)$ and $\Phi^-(a) > \Phi^-(b)$, (7)

ii. $\Phi^+(a) < \Phi^+(b)$ and $\Phi^-(a) < \Phi^-(b)$

conditions are provided, alternative a cannot be compared with alternative b.

In the last stage of method, strict priorities for alternatives are calculated by the aid of $\Phi(a) = \Phi^+(a) - \Phi^-(a)$ equity with PROMETHEE II and full sorting of alternatives is determined by evaluation of alternatives in the same plane by the aid of strict priorities. In this case, if $\Phi(a) > \Phi(b)$ is, alternative ais superior to alternative b. If $\Phi(a) = \Phi(b)$ is, alternative a is same as alternative b [5, 15, 16].

The Elimination and Choice Translating Reality (ELECTRE)

ELECTRE (Elimination EtChoixTraduisant la Realité) is a multiple criteria decision-making method that put forward by Roy, Beneyoun and colleagues in 1966. Method is based on comparisons of binary superiority in alternative decision points for each assessment factor and it provides complete ordering of the alternatives. Alternatives that are preferred over most of the criteria and that do not cause an unacceptable level of discontent for any of the criteria are chosen by this method. Graphs for strong and weak relationships are developed by using the concordance, discordance indices and threshold values are used in an iterative procedure to obtain the ranking of alternatives. This index is defined in the range (0–1), provides a judgment on degree of credibility of each outranking relation and represents a test to verify the performance of each alternative. The index of global concordance C_{ik}represents the amount of evidence to support the concordance among all criteria, under the hypothesis that A_i outranks A_k. It is defined as follows,

$$C_{ik} = \sum_{j=1}^{m} W_j c_j(A_i A_k) / \sum_{j=1}^{m} W_j \quad (8)$$

whereW_j is the weight associated with j[th]criteria. Finally, the ELECTRE method yields a whole system of binary outranking relations between the alternatives. Because the system is not necessarily complete, the ELECTRE method is sometimes unable to identify the preferred alternative. It only produces a core of leading alternatives. This method has a clearer view of alternatives by eliminating less favorable ones, especially convenient while encountering a few criteria with a large number of alternatives in a decision making problem [3, 14, 17-19].

The Technique For Order Preference By Similarity To Ideal Solutions (TOPSIS)

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method was developed in 1981 by Hwang and Yoon. The basic concept of this method is that the selected alternative should have the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution in geometrical sense. TOPSIS method is used in common with for solving multi-criteria decision problems to provide a wider conciliatory way and easy calculation process.TOPSIS is a method that compares a set of alternatives by identifying weights and normalizing scores for each criteria and calculating the geometric distance between each alternative and the ideal alternative, which is the best score in each criteria. TOPSIS method consists of six steps in the solution process. These steps are forming decision matrix, forming standard decision matrix, forming the standard weighted decision matrix, determination of positive ideal and negative ideal solution, calculation of individual measurements and calculation of similarity to ideal solution. Applying the steps outlined above the criteria are ranked according to suitable alternatives [5].

Multi Criteria Decision Analysis Methods in Material Selection

Knowledge of the parameters in the selection of materials and evaluation of the performance of the building with the specified measurement methods play an important role in facilitating the decision of architects. However selection of the most appropriate alternative is a very complex situation because selection criteria contain different numerical facts and data. In one or more criteria a material can be better choice but in the other criteria it can be worse. Thus when determining the material forming the structure in the design phase, establishment of a model of material selection that compares alternatives according to the criteria expressed in different units. In figure proposed model is started by defining a simplified flowchart schema.

Simple schema model is designed to provide the data required for the assembly which serves as a base pattern. First decision makers determine the decision making problems. After definition of requirements of materials, candidate materials are selected from the material database. Then the data of the properties of materials is determined. After the definition of criteria weights each candidate materials are evaluated by a multi-criteria decision method. Alternatives are ranked according to the scores they have achieved in used method. Finally decision maker selects the alternative by comparing the scores. Figure 3 indicates flow diagram of material selection.

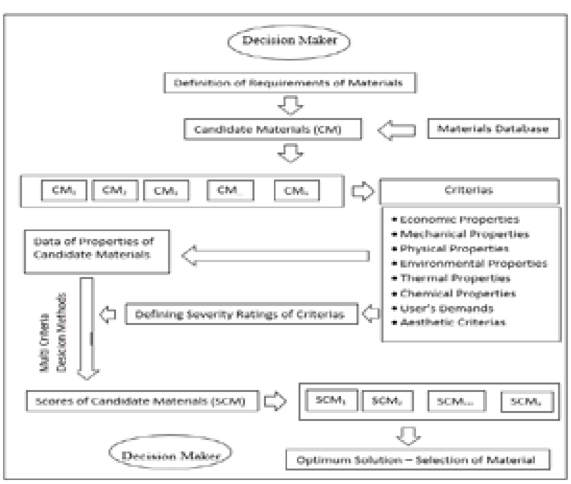

Figure 3: Flow Diagram of Material Selection

Discussion

In all those adopted methodologies, it is revealed that the relative importance or priority weights assigned to the considered evaluation criteria have an immense role in obtaining the accurate rankings of the material alternatives. However, it is not clear what is the effect of those criteria weights or number of criteria in the material selection decision matrix on the solution accuracy and ranking performance of the adopted multi-criteria decision methods. Obviously, the least important criteria (having the minimum weight) has the minimum influence on the performance of these methods and intuitively, it can be claimed that the material selection results would be principally dictated by the most important criteria having the maximum weight [20]. So defining the problem clearly, criteria weights and selection of method which is more suitable is getting very important for having better solutions.

Using weighted sum method and weighted product methods are easier and more suitable in assessments of criteria that have similar units. When there are different units for assessment, Analytical Hierarchy Method, ELECTRE, PROMETHEE and TOPSIS methods are getting more suitable to use. In these methods, most commonly used methods are Analytical Hierarchy method and TOPSIS. If the criteria weights are defined by subjective decisions Analytical Hierarchy method, if they are defined by objective decisions TOPSIS is mostly preferred. In addition with the increase of criteria and alternatives, hierarchical structure also increases. This causes loss of time and effort during the evaluation [5-27].

CONCLUSION

In this article it has shown that using multi criteria decision analysis methods in selection of construction materials is quite suitable. There are a lot of multi criteria decision analysis methods and that many of these methods have been applied to material selection purposes. All of these methods can be used in multi-criteria problems. Each of the methods has its own advantages and disadvantages. It is not possible to claim that any one of the methods is generally more suitable than the others are. The choice of method mostly depends on the criteria that effects the problem and preferences of the decision makers. But these methods work in different ways so decision makers can have different solutions when they use different methods in same problems. It doesn't mean that methods are wrong. But because of having different recommendations it is important to consider the suitability, validity and user-friendliness of the methods for different problems.

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