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A Decision Support System for Selecting Sustainable Material for Building Projects

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Abstract

The construction industry makes a vital contribution to the social and economic development of every country, but at the same time, its building sector has major impacts on the environment. With increased awareness and knowledge of these impacts, efforts are being made to avoid their adverse effects. Most important of these effects is appropriate selection and specification of sustainable building materials. In built environments where ecological, health, and ethical impacts are increasingly important, often the only way to choose from many different material alternatives is by relying on 'professional' judgment or past experience. A more objective method is essential for evaluating the tradeoffs between alternative materials on specific projects. The method should allow comparison of not only the technical performance and costs of materials, but also the immediate and long-term impacts their use has on the finite supply of natural resources and the ongoing needs for those resources by society.

An appraisal of sustainable material selection practices and procedures with UK based architects and designers were conducted through a series of targeted interviews and questionnaire surveys. An elaborate knowledge mining on aspects of material selection underpins the development of a structured building material selection model, using the Analytic Hierarchy Process (AHP) approach. This paper presents (i) a consolidated summary of interim findings from this ongoing research exercise on building material selection aspects and (ii) some basic highlights of the proposed AHP-based material selection system for building projects.

Keywords

Analytic hierarchy process, Sustainable material selection, Construction industry, Architects, Decision-making.

1. Introduction

The selection of building materials correctly among a vast number of alternatives is an important problem in building construction. It is a neglected area of design methods research, taking place largely in the detailed design phase where important decisions are made with regard to building assembly. A recently introduced aspect of the material selection process is that of sustainability, the implication been that materials should be selected that consume less energy in their manufacturing or are in some way less environmental damaging. Because this is a new criterion, we may assume that while there may be some products that have always been satisfactorily in this regard, there are still many more that are not so.

Sustainable building materials selections are deemed multi-criteria decision-making problems, in which multiple decision makers evaluate the attributes to deliver a project at hand against a large number of selection criteria. In some cases the inputs from different people are consolidated in specific group decision-making arrangements. The explicit incorporation of sustainability in the decision support process requires assessment of the social, economic and environmental consequences of potential options. This requires the use of sustainability criteria by which to assess these consequences in terms of whether the option is likely to move the system towards or away from sustainability objectives.

In general, supplier selections are deemed multi-criteria decision-making problems, in which cost, quality and several other factors are assessed. In some cases the inputs from different people are consolidated in specific group decision-making arrangements. Analytical Hierarchy Process (AHP) is a multi-objective decision-making approach that includes hierarchically arranging different objectives and sub-objectives, assessing their relative significance, making pair-wise comparisons, undertaking a structured analysis of available alternatives and thereby enabling more systematic decision making (Saaty, 1994). Some earlier research initiatives have demonstrated the appropriateness of AHP for building materials selection problems (including group decision scenarios), including Nydick and Hill (1992), Barbarosoglu and Yazgac (1997), Tam and Tummala (2001), Chan, (2003), Suresh Babu and Sharma (2005). Thus for the purposes of this research, the AHP-based approach is deemed a suitable strategy for developing the sustainable building materials selection framework. A basic overview of the AHPbased framework, along with some key extracts from this ongoing research is presented in this paper.

2. Overview of the Research Approach

The ongoing research in sustainable material selection is a part of a larger research on construction procurement which holistically aims to develop a set of useful knowledge bases and structured 'source selection' systems for the construction industry. These would include frameworks for (i) sustainable materials selection, (ii) contractor selection, (iii) consultant selection, and (iv) sub-contractor selection. Also, synergistic linkages of appropriate performance tracking mechanisms and integrated feed-back and feed-forward channels are targeted. Furthermore, suitable clusters of research approaches have been considered in this ongoing 'source selection' research exercise that includes: exploratory literature reviews, networking with domain experts and practitioners, series of questionnaire surveys and knowledge-mining interviews.

The research reports a section of sustainable materials selection-related research exercises that mainly include: (i) an extensive literature review on materials selection aspects; (ii) a few preliminary interviews with a couple of material specifiers; (iii) one preliminary questionnaire survey targeting the development of a set of material selection criteria and their significance levels; (iv) one focused questionnaire survey aiming to develop pair-wise comparisons of material selection goals and objectives in the AHP format; and (v) a set of structured interviews with various specifiers to mainly validate the selection frameworks, as well as obtain specific information/knowledge for this research. Table 1 provides an overview of the research approaches.

However, the research described in this paper was aimed at (i) describing the development and application of a set of sustainability criteria, which have been developed with building materials specifiers in the UK. They will be used in the proposed framework to facilitate the inclusion of sustainability in the decision-making process (2) the development of a new selection system through the application of a multi criteria evaluation model based on the 'analytical hierarchy process', or AHP (saaty,1980).

Table 1: Basic Summary of the Research Methods.

Research method	Key details
Preliminary interviewing	• Main objectives include: (i) seek the architects views on sustainable design approaches; ascertain architects current practice in sustainable design, especially the selection of building materials; highlight obstacles to sustainable material selection. (ii) understanding the key issues and strategies of construction material selection; and (iii) Develop an appropriate AHP framework for material selection. • The preliminary interviews will be conducted in face-to-face mode using a semi-structured format. • 5 domain experts (architects) will be interviewed in this category.
Preliminary questionnaire survey	• Main objectives include: (i) consolidating the ratings (using a scale of '1 to 5', with '5' being very important) for a set of identified criteria's and sub-criteria's of construction materials selection; and (ii) Collecting some information regarding material selection approaches. • Pilot testing of the preliminary questionnaire will be conducted with 5 experts.
Focused questionnaire	• Main objectives include: obtaining pair-wise comparisons for the identified objectives and sub-objectives – to develop the survey priority ratings in Saaty's 9-point scale for the AHP-based material selection framework. • A set of hybrid approaches will be adopted for reaching the respondents of this questionnaire survey that include: a Delphic way of establishing connections with the previous set of respondents.

3. Analytic Hierarchy Process (AHP) Approach

Saaty (1980) first introduced AHP as a new approach to dealing with complex economic, technological, and socio-political problems, which often involve a great deal of uncertainty. A typical MADA method, AHP was developed to assist in the making of decisions that are characterized by a great number of interrelated and often contending factors. To make such decisions, the relative importance of the factors involved must be properly assessed in order to enable trade-offs among them. The main feature of AHP is its inherent capability of systematically dealing with a vast number of intangible and non-quantifiable attributes, as well as with tangible and objective factors. The overall procedure of the AHP is shown in Fig. 1.

3.1 AHP Basics

According to Saaty, AHP is based on a two-stage process: first, "decomposing the complexity" by identifying the ("small") factors that make up the ("big") problem and mapping their mutual relationships, and then "synthesizing the relations" by determining the relative weights of the factors and aggregating their cumulative effect vis-a-vis a single decision criterion. Five basic AHP elements were identified and are presented briefly below. They are elaborated on later, as required, in relation to the proposed framework.

3.1.1 Hierarchy construction

To "decompose the complexity," decision factors are organized in a hierarchy-type structure. The primary goal of the problem (e.g., selection of sustainable building materials) occupies the highest level of the structure, followed by "sets of attributes" that are organized in several more hierarchy levels. A typical second-level attribute set includes all of the secondary goals that together contribute to achieving the primary goal (e.g., cost, reusability, efficiency, and safety). These, in turn, are directly affected by all of the attributes in the set located one level lower (e.g., life cycle cost may be affected by production cost, maintenance cost, transportation cost, replacement cost, etc.), and so on, as dictated by the nature of the problem. Thus a set is located either under another attribute that is one level higher, or under the primary goal of the problem. Attributes that have no other attributes under them in the hierarchy structure are termed "leaf attributes." All in all, this hierarchy structure expresses the interrelationships between the various decision factors. At the lowest AHP hierarchy level is a set of feasible alternatives that are to be evaluated. Alternatives must be connected to all of the leaf attributes potentially affecting their evaluation.

3.1.2 Pair-wise comparisons

Once interrelationships between attributes (i.e., decision factors) are mapped by the hierarchy, relative weights of the attributes are determined by comparing them in pairs, separately for each set in the hierarchy. The results for each set are recorded in a separate "decision matrix." When comparing two attributes, the following must be determined: (1) which attribute is more important or has greater influence on the attribute one level higher in the hierarchy; and (2) what is the intensity of that importance (e.g., weak, strong, absolute). Verbal intensity assessments are translated into numbers (thus, in fact, converting qualitative evaluations into quantitative ones) according to a given scale (Saaty 1980). It should be noted that the pair-wise-comparison method is perhaps the cornerstone of the entire AHP philosophy, as it allows the user to systematically determine the intensities of interrelationships of a great—practically unlimited—number of decision factors.

3.1.3 Relative - weight calculation

One of Saaty's core theorems states that the eigenvector of the decision matrix established in the previous phase (i.e., the outcome of the pair-wise comparison process) is the priority vector of the attributes compared, which represents their relative weights with regard to the attribute located one level higher in the hierarchy.

AHP mathematical foundations are relatively simple; the reader is referred to Saaty (1980) for a more detailed presentation of the method and its calculation techniques.

3.1.4 Aggregation of relative weights

Once relative weights are calculated for each set of attributes at every level of the hierarchy and respective local priority vectors are produced, the overall score of each alternative, representing the preference of one alternative over another, can now be obtained. Aggregation is achieved by multiplying local priority vectors of each set of attributes by the relative weights of the respective attributes immediately above them, starting at the lowest level and ending at the primary goal level. The new vector obtained is no longer local but rather inclusive for the entire hierarchy. The sum total of all such computations for each leaf attribute in the hierarchy is 1.00. The overall score of the alternatives is obtained by multiplying the local priority vector of the alternatives with respect to each leaf attribute by the inclusive priority vector of that leaf attribute, and summing the products.

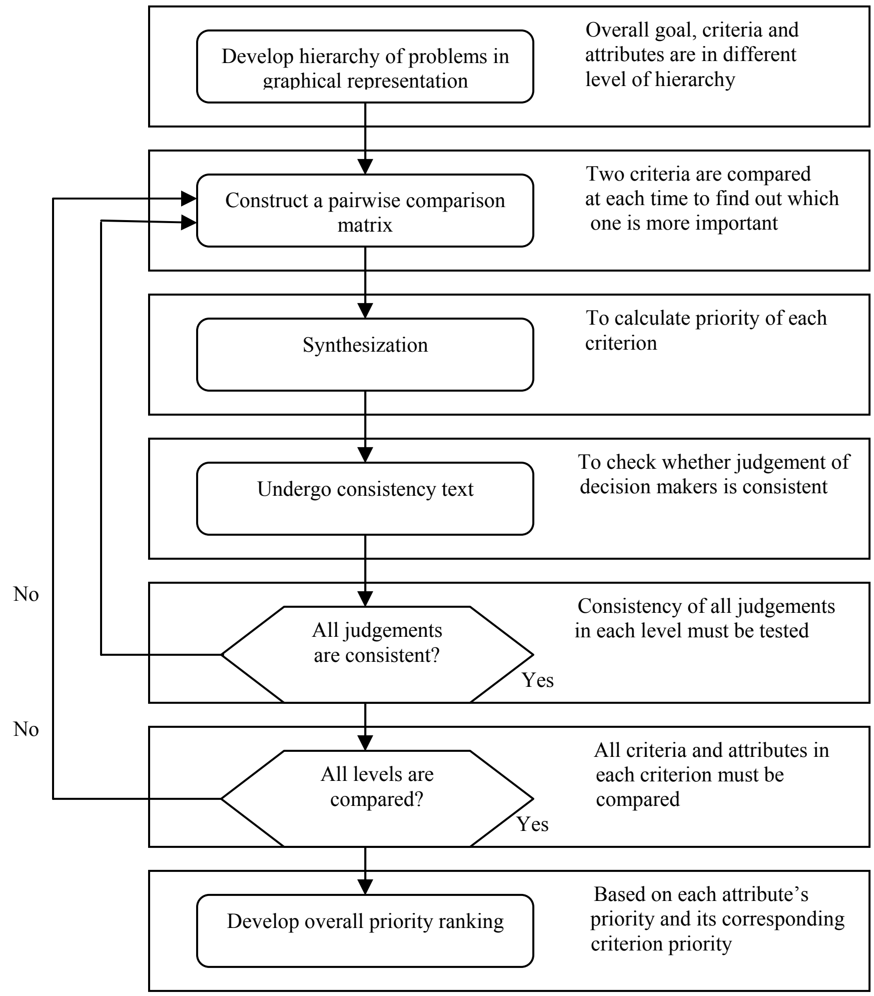

Figure 1: Phases in the decision-making process

3.1.5 Consistency ratio

The fifth element of AHP, the "Consistency Ratio" (CR) measure, is a tool for controlling the consistency of pair-wise comparisons. Since one of the advantages of AHP is its ability to allow subjective judgment, and with intuition playing an important role in the selection of the best alternative, absolute consistency in the pair-wise comparison procedure should not be expected. "Absolute consistency" means, for example, that if x is more important than y by a factor of 2, and y is more important than z by a factor of 3, then x should be more important than z by a factor of 6. The CR, introduced by Saaty (1980) and computed using a formula he developed, enables one to control the extent of inconsistency to a maximum desirable level, for each decision matrix and for the entire hierarchy. Based on numerous empirical studies, Saaty (1980) stated that to be acceptable (i.e., for tolerable inconsistency), the CR must be less than or equal to 0.10 (irrespective of the nature of the problem); if this condition is not fulfilled, a revision of the comparisons is recommended. It must be stressed, however, that an acceptable CR does not guarantee a "good" final selection outcome. Rather, it ensures only that no intolerable conflicts exist in the comparisons made, and that the decision is logically sound and not a result of random prioritization.

4. Development of Sustainability criteria

4.1 Sustainability Criteria

Sustainability criteria are defined here as the set of factors that may be used to assess which of a range of options, in this case for building materials, offers the greatest contribution to achieving sustainability objectives. In trying to develop a generic set of criteria, it is essential to consider two key factors. What use will be made of this set of criteria? To what extent can any set of criteria encompass the range of issues to be considered under the heading of 'sustainability'? Some of these issues have been considered in approaches developed by other researchers. However, it was found that most publications did not incorporate social/cultural criteria directly into decision making, but instead incorporated these indirectly into technical or economic criteria. Consequently, a set of sustainability criteria was proposed in which the demands of the end user are translated into functional criteria that have to be fulfilled by the technology. The common thread running through these various approaches was thus the production of a structured classification of criteria, which would be forward-looking in order to be useful in decision making, and would be relevant to the decision-making process in question.

4.2 Criteria Developed

The approach taken in this project to developing categories appropriate to sustainable materials selection aimed to draw on the strengths of others approaches to develop a structure that would encapsulate the richness and diversity of sustainability. This would be based on a hierarchy, consisting of a small number of high-level primary criteria, which would cascade down to a larger number of more specific, secondary criteria. Table 1 shows the classification of the four categories. These categories aim to encapsulate the economic, environmental and social principles of sustainability, together with functional criteria, which relate primarily to the ability of building materials to sustain and enhance the performance of the functions for which it is designed. Within each category, a small number of primary criteria are specified (see Table 2).

4.3 Validation of Criteria

In order to validate the above set of generic sustainability criteria, interview was conducted with building materials specifiers in the UK. In these interviews, participants were asked to assess whether the proposed criteria provide for an accurate and comprehensive assessment of sustainability, whether any criteria should be added to or be removed from the set and, finally, to rank the criteria in order of importance. These exercises showed broad support for the criteria chosen, though it was recognized that many of the primary criteria, e.g. material performance, cover more than one category, e.g. environmental as well as functional. These exercises also provided information for formalized multi-criteria analyses to be carried out in the case studies to demonstrate the use of the model.

The following set of guidelines has been developed for framework to aid the choice of specific criteria to assess the options under consideration.

(1) Comprehensiveness
The criteria chosen should cover the four categories of economic, environmental, social and functional, in order to ensure that account is being taken of progress towards sustainability objectives. The criteria chosen need to have the ability to demonstrate movement towards or away from sustainability, according to these objectives.

(2) Applicability
The criteria chosen should be applicable across the range of options under consideration. This is needed to ensure the comparability of the options.

(3) Transparency
The criteria should be chosen in a transparent way, so as to help stakeholders to identify which criteria are being considered, to understand the criteria used and to propose any other criteria for consideration.

(4) Practicability
The set of criteria chosen must form a practicable set for the purposes of the decision to be assessed, the tools to be used and the time and resources available for analysis and assessment. Clearly, the choice of sustainability criteria will influence the outcome of the decision being made, as will the method of comparison or aggregation chosen.

The above factors provide initial guidance in the choice of criteria, but how they are to be applied in practice will be built up with experience and review of sustainability assessment across a range of different decisions. There is likely to be a significant element of 'learning by doing'.

Table 2: Set of Primary Criteria

Criteria's	Economic	Environmental	Functional	Social/Cultural
Life cycle cost	●			
Affordability	●			
Reused materials		●		
Potential for recycling or reuse		●		
Recycled content		●		
Method of extraction of raw materials		●		
Potential of material as an environmental hazard		●		
Embodied energy within material		●		
Environmental statutory compliance		●		
Amount of likely wastage in use of material		●		
Production of hazardous by-products and wastes in processing of material		●		
Method of extraction of raw materials		●		
Performance of the material			●	
Reliability			●	
Health and safety				●
Durability			●	
Market pricing of comparable resources	●			

5. Concluding Remarks

This paper has described the development and potential application of a set of sustainability criteria for use in a framework to aid the explicit incorporation of sustainability assessment into decision-making processes for building material selection. The complex tasks of comparing available options and good decision-making using multi-criteria considerations are regarded as daunting challenges by many material specifiers. Hence developing suitable systematic approaches and appropriate structured decision-making frameworks for sustainable building material selection was considered in this research. The full decision support process and case studies will be described in the framework currently being developed for use in the UK construction industry.

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