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Product-cost modelling approach for the development of a decision support system for optimal roofing material selection

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ABSTRACT

Selection of optimal roofing materials is very important but it is a complex and onerous task as varieties of materials are available for housing roof construction. In order to select suitable materials, an extensive range of criteria would need to be considered. This paper presents the framework and the development of a knowledge-based decision support system for material selection implemented in roofing material selection domain, called 'Knowledge-based Decision Support system for roofing Material Selection and cost estimating' (KDSMS). It was developed to facilitate the selection of optimal materials for different roof sub elements. The system consists of a database and knowledge base that is equipped with an inference engine. The former is used to store different types of roofing materials with assigned attribute values. The later is used to hold qualitative and quantitative knowledge which were collected from domain experts and other technical literatures such as building regulations, price guide book and product catalogues. The proposed system employs the TOPSIS (Technique of ranking Preferences by Similarity to the Ideal Solution) multiple criteria decision making method to solve materials selection and optimisation problem. This study utilised the available roofing materials in the UK housing market in developing the system reported. The main contribution of the developed system is that it provides a tool for the architects, quantity surveyors or self house builder to select optimal materials from a wide array of possibilities for different roof sub elements and also to estimate the conceptual cost for the roof element in the early stage of building design.

1. Introduction

Different types of materials and technologies are available for building design and construction while new materials and advanced technologies are continuously being introduced into the market (Wong & Li, 2008). The selection of materials is a complex procedure and it is difficult to match materials based on design requirements (Ashby, Brechet, Cebon, & Salvo, 2004). Materials are generally selected from the existing catalogues of materials and traditionally experts apply trial and error methods or use experiences to choose new materials or materials having better performance (Shanian & Savadogo, 2006). It is acknowledged that the selection of appropriate materials may reduce the energy consumption and maintenance cost of buildings (Papadopoulos & Giama, 2007). As buildings are responsible for significant impact on the environment, eco-friendly materials are becoming popular for housing construction (Hymers, 2006).

Moreover, there is an increasing demand for sustainable and energy-efficient construction (UNEP, 2001) and the use of environmental friendly materials (Chan & Tong, 2007; Roaf, Fuentes, & Thomas, 2007). However, there is a lack of public awareness about sustainable and energy-efficient construction and these issues are unfamiliar to many architects, engineers, and contractors (UNEP, 2001). Evidences from literature suggest that the building owners and clients tend to emphasise the initial cost rather than operating cost (Wilson et al., 1998). Karolides (2006) and Woolley (2006) emphasised that the amount of energy needed can be reduced by using high performance and extra insulation, which is the easiest and least expensive way to solve energy problem.

Architects or cost engineers need to consider several factors in order to select optimum materials to meet clients' requirements. In order to solve this problem of material selection in a way that meets design and clients' requirements and results in sustainable construction, it is required to analyse and synthesis a multitude of criteria (Perera, Odeyinka, & Bi, 2009a, 2009b). Different approaches regarding materials selection have been devised for different purposes. For instance, knowledge-based or expert systems have been developed to select materials for different purposes.

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Bullinger, Warschat, and Fischer (1991) proposed a knowledge-based system to select optimal materials for construction with fibre-reinforced composite materials. Soronis (1992) proposed a method for the selection of roofing materials where several factors have been taken into consideration to assess durability only. Chen, Sun, and Hwang (1995) developed an intelligent system for composite material selection in structural design. Mahmoud, Aref, and Al-Hammad (1996) developed a method for selection of finishing materials that covered floors, walls and ceilings. Mohamed and Celik (1998) proposed a knowledge-based method regarding materials selection and cost estimating for a residential building where users could choose their preferred one from a list of materials without evaluation and synthesis of multiple design criteria and client requirements. Instead of expert or knowledge-based systems, Perera and Fernando (2002) proposed a cost modelling system for roofing material selection where several factors are identified and considered in the selection process.

Chan and Tong (2007) acknowledged the fact that the decision to select appropriate material is not simply a consideration of cost and materials properties but also there is a need to consider environmental impacts. It is identified that the selection of material is a key issue for the environment (Chan & Tong, 2007) and the choice of material is the optimal way to achieve the energy efficient construction of a building (Krope & Goricanec, 2009). In view of the foregoing, the design team needs to consider several factors in order to select the more suitable materials to meet clients' requirements. In order to solve this problem of material selection in a way that meets the requirement of the design team and those of the construction clients and results in sustainable construction and cost effective solutions, it is required to simultaneously analyse and synthesise multitudes of criteria in order to achieve an optimum solution. It is identified that few decision support systems have been devised for roofing materials selection but the proposed systems do not have the facility to select the appropriate materials by evaluating them with respect to the multitudes of criteria to be considered in order to meet the clients' expectations. Some systems attempt to solve the problem of materials selection by adopting rule-based knowledge representation in terms of IF-THEN rules. However, it is difficult to rank the most suitable materials using conditional expressions. This clearly indicates a research gap with respect to selecting the optimum roofing materials by analysing and synthesising a multitude of design and client's requirements that are both cost effective and sustainable. In order to fill this gap, it is necessary to develop a system that has the capability of simultaneously evaluating multiple criteria in the optimisation of materials selection for roof design. Hence, this research aims to bridge the current knowledge gap by developing a knowledge-based decision support system, called Knowledge-based Decision support System for roofing Material Selection and cost estimating (KDSMS). Its aim is to optimise the selection of roofing materials and model the associated cost for the roof element at an early stage of building design. This system adopts the Technique Of ranking Preferences by Similarity to the Ideal Solution (TOPSIS) method to solve Multi Criteria Decision Making (MCDM) problems. The advantage of this method is its efficiency and simplicity to use and the ability to rank the materials indisputably (Shanian & Savadogo, 2006).

Architects, Cost Engineers, Quantity Surveyors and self builders are the potential users of this system. It has the potential of assisting them in selecting optimal materials from the list of alternatives based on the level of importance of the criteria set by them. In addition, the system estimates the cost of the optimal materials selected to determine the budget. This system also can be used to educate the users about new materials by providing relevant information.

2. Methodology

The essence of this research is to develop a method for evaluating multitudes of criteria in order to select optimal roofing materials and also to estimate the associated cost. Extensive literature review was carried out as an initial step to identify the multitude of criteria to consider in roofing material selection. This was followed by structured questionnaire survey and interviews of domain experts in order to elicit the relevant knowledge for building the decision support system. Upon developing the system, relevant data were also gathered to test and evaluate the system. The data set included elemental costs, total roof costs and the level of importance attached to selection criteria of material. The data set were collected from case study projects obtained from housing developers in order to evaluate the system. Fig. 1 illustrates the research methodology used in developing the system.

The key stages of the research methodology are explained in detail in the following subsections.

2.1. Knowledge gathering

A forum of domain experts consisting of four industry specialists (Architects and Quantity Surveyors) and academics were used as the main source for knowledge elicitation. Relevant knowledge was elicited both at the pre and post development phases of the system. The elicited knowledge can be divided into qualitative and quantitative categories.

Qualitative knowledge includes material selection criteria, material selection process, material selection regulations for thermal requirements and cost adjustment techniques. The qualitative knowledge were compiled into rules and built into the knowledge base. Material selection criteria for different roof sub elements were identified through extensive literature review. Fifteen criteria were initially identified (Rahman et al., 2009a, Perera, Odeyinka, & Bi, 2009b). Material selection criteria, cost estimating and adjustment processes were identified through a questionnaire survey of the domain experts. This was followed by further interviews. The expert forum was also involved in validating the inclusion of the criteria and also in determining the subjective or objective type from the identified material evaluation criteria. Ten quantitative criteria were decided by the expert forum for the selection process. Out of the ten material selection criteria identified in Table 1, five were used for roof structure, eight criteria were used for roof coverings, seven criteria were used for roof insulation, five criteria were used for roof drainage, six criteria were used for roof lights and two were used for roof features. These ten roofing material selection criteria represent the attributes or properties of materials. Thermal regulation guidelines were obtained from Technical Booklet F (2008), Conservation of fuel and power, by Building Regulations of Northern Ireland.

The qualitative knowledge acquired from domain experts was conceptualised and then analysed using Inferential Modelling Technique and by applying top-down and bottom-up techniques (Chen et al., 1995 cited in Zhou, Huang, & Chan, 2004). Using these techniques, the main tasks were decomposed into several subtasks. Then the subtasks were further decomposed so that each of them can be handled easily. 2 shows the process decomposition diagram of the KDSMS system consisting of three main tasks, namely, *Select Material*, *Estimate Cost* and *Maintain System*; and some other associated subtasks. Top-down technique was applied to the *Select Material* and *Maintain System* tasks to decompose it into subtasks to define material selection tasks and maintain materials for different roof sub elements. Conversely, bottom-up technique was applied to *Estimate Cost* task where cost of different roof sub element was estimated separately to obtain the total cost.