A KNOWLEDGE-BASED DECISION SUPPORT SYSTEM FOR ROOFING MATERIALS SELECTION AND COST ESTIMATING: A CONCEPTUAL FRAMEWORK AND DATA MODELLING

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A plethora of materials is available to the modern day house designer but selecting the appropriate material is a complex task. It requires synthesising a multitude of performance criteria such as initial cost, maintenance cost, thermal performance and sustainability among others. This research aims to develop a Knowledge-based Decision support System for Material Selection (KDSMS) that facilitates the selection of optimal material for different sub elements of a roof design. The proposed system also has a facility for estimating roof cost based on the identified criteria. This paper presents the data modelling conceptual framework for the proposed system. The roof sub elements are modelled on the Building Cost Information Service (BCIS) Standard Form of Cost Analysis. This model consists of a knowledge base and a database to store different types of roofing materials with their corresponding performance characteristics and rankings. The system's knowledge is elicited from an extensive review of literature and the use of a domain expert forum. The proposed system employs the multi criteria decision method of TOPSIS (Technique of ranking Preferences by Similarity to the Ideal Solution), to resolve the materials selection and optimisation problem. The KDSMS is currently being developed for the housing sector of Northern Ireland.

Keywords: TOPSIS, cost modelling, knowledge-based system, decision support system, roofing material selection.

INTRODUCTION

There are different types of materials and technologies available for roof design and construction while new materials and advanced technologies are continuously being introduced into the market (Soronis, 2002; Wong and Li, 2008). Architects have to meet client's requirements for material selection in the most efficient manner (Ashworth, 2004). High quality building with life time cost effectiveness is always preferred by the clients (Schade, 2007). As a result, architects and other members of design team need to consider several factors in order to select the more suitable materials to meet clients' requirements. But the selection of materials is always a

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complex procedure (Mahmoud *et al.*, 1996) and it is a problem to match materials based on design requirements (Ashby *et al.* 2004).

It is acknowledged that material selection has significant impact on the cost of a building (Malin, 2000; Mohamed and Celik, 2002); however the selection of appropriate materials may reduce the energy consumption and maintenance cost of buildings (Papadopoulos and Giama, 2007). Moreover, the selection of appropriate materials may impact significantly on the environment that helps to improve the decision making of green construction (Castro-Lacouture *et al.*, 2009). It is documented that buildings are responsible for significant impact on the environment; hence eco-friendly materials are becoming popular (Hymers, 2006; Spiegel and Meadows, 2006). The design team needs appropriate information to compare materials with the clients' requirements in order to choose the right materials (van Kesteren, 2008). In order to solve this problem of material selection in a way that meets design and clients' requirements and results in sustainable construction, analysis and synthesis of multitudes of information is required. Different approaches regarding materials selection have been devised for different purposes. Multiple criteria approach have been considered regarding material selection for different application areas, such as engineering (Rao, 2008; Shanian and Savadogo, 2006; Ashby *et al.*, 2004), flywheel production (Jee and Kang, 2000), and manufacturing process (Chan and Tong, 2007). Moreover, knowledge-based or expert systems have been developed to select materials for different purposes; Chen *et al.* (1995) proposed a method for composite material selection in structural design. Mahmoud *et al.* (1996) explained 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 be able to choose their preferred one from list of materials without evaluation and synthesis of multiple design criteria and client requirements. Unlike the expert or knowledge-based system, Perera and Fernando (2002) proposed a cost modelling system for roofing material selection where several factors have been identified and considered in the selection process. Soronis (1992) proposed an approach to the selection of roofing materials where several factors have been taken into consideration to assess durability. It is identified that very few approaches have been developed for roofing materials selection. Some methods that have been developed for materials selection in other sectors are not suitable for the selection of building materials because every sector has its own selection criteria to meet the design requirements.

This clearly indicates that there is a research gap with respect to selecting the appropriate roofing materials and technologies that analyse and synthesise multitude of design and client's requirements to produce optimal solutions that are cost effective and sustainable. This requires considering multiple criteria ranging from initial cost and maintenance cost to durability and sustainability. The information overload may exacerbate this appropriate material and technology selection. This research aims to bridge this knowledge gap by developing a Knowledge-based Decision support System for Material Selection (KDSMS) that helps to optimise the selection of roofing materials and technologies. It assists the users in selecting materials according to importance of pre-defined criteria. This system also educates the users about new materials by providing relevant information in multi-media formats and through internet. In addition, the system also assists the users in estimating the cost of roof element based on selected materials.

KNOWLEDGE-BASED SYSTEM FOR DECISION SUPPORT

A knowledge-based system is basically an intelligent system that can capture and replicate human expertise to solve certain problems emulating the human expert. Any knowledge-based system consists of three main components those are a user interface, knowledge base and an inference engine or a control mechanism (Mockler and Dologite, 1992). The proposed knowledge-based system, KDSMS, captures knowledge from technical literature and domain experts to build the knowledge base. It queries the knowledge base by the inference engine and provides the information to users through the user interface. The framework of KDSMS is illustrated in figure 1 and explained in the following section.

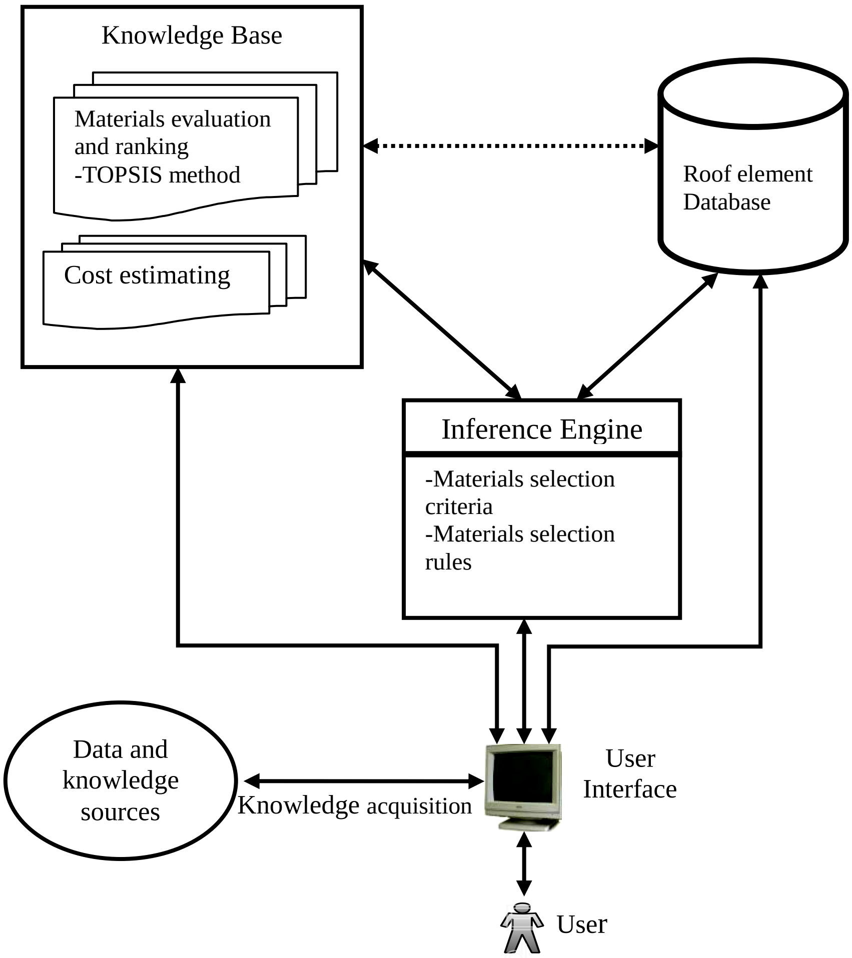

Figure 1: Framework for KDSMS

User

The potential users are the design team (architects, designers and quantity surveyors) and self builders. Expert forum comprises of the architects and quantity surveyors who have the required knowledge about building design requirements and selection of materials.

Database

The roof element database stores all information available about roofing materials of each roof sub element along with the performance characteristics that are considered to choose materials such as durability, initial cost, maintenance cost, thermal performance and sustainability among others. Data is collected from technical literature sources such as catalogues of manufacturers, data sheets, specification schedules, text books, price guide books and internet.

Knowledge base

This consists of the material selection and cost estimating processes. As selection of materials is associated with multiple criteria, a multi criteria decision making technique, TOPSIS, is incorporated to solve decision making problem (Rahman *et al.* 2008). It also contains building regulations and other selection factors that may influence the type of materials or technologies selected. It comprises of a decision support shell that can facilitate reaching a decision in selection of the optimal material by using TOPSIS. Basically, a particular solution to resolve the problem of roofing materials selection under a particular circumstance is documented in the knowledge base as knowledge. For example, under the circumstances of severe exposure category of rain and when roof slope exceeds 6m in length, interlocking tiles or slates are preferred for roof covering material.

Inference engine

It uses IF-THEN production rule along with a forward-chaining reasoning mechanism to search design decision rules for selecting the appropriate combinations of materials based on the knowledge base and the database. It also helps to narrow down the search space of the database. Suppose we have the following rule,

IF Circumstances= severe rain and roof slope exceeds 6m in length and

Purpose= roof covering THEN

Material= Interlocking tiles or slates

Under this rule, the inference engine searches the database to find any data available making “this circumstance” to be satisfied and then recommends interlocking tiles or slates for roof covering material.

User interface

It interacts with the users and processes. It accepts input from users and activates the processes to produce the output to the users.

METHODOLOGY

The methodology of KDSMS model development is illustrated in figure 2 and explained below.

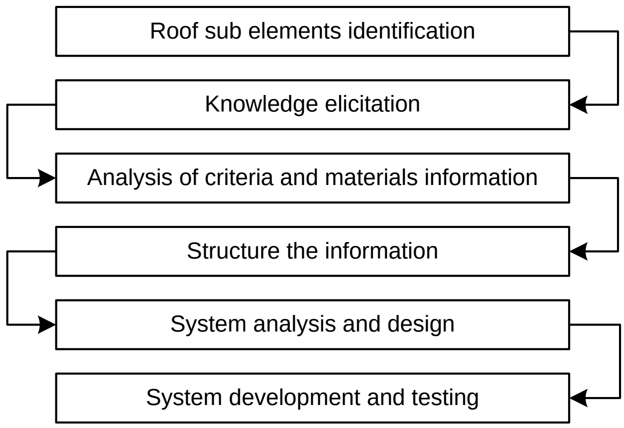

Figure 2: Methodology for KDSMS model development

Step 1: Identification of roof sub element

Roof elements and its sub elements are based on BCIS definition (BCIS 2008), as indicated in figure 3.

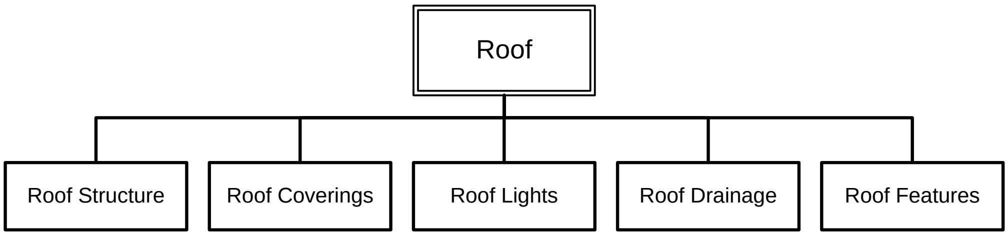

Figure 3: Roof sub elements

Step 2: Knowledge elicitation

The selection process is conceptualised from domain experts by conducting a series of structured interviews. Performance criteria are identified from literature and validated through domain experts. The performance criteria for roof insulation are considered separately as it has a significant impact on internal comfort and energy consumption. The importance weights of user criteria (client requirements) are considered as linguistic variables. It is widely acknowledged that linguistic variable is very useful to describe conventional quantitative expressions (Yong, 2006). These linguistic variables can be expressed in positive numbers as Table 1. Information on materials is collected from technical literature, catalogues and technical documents as well as manufacturers' websites.

Step 3: Analysis of criteria and materials information

Aesthetics can be an important criterion for the selection of roof coverings. As this is subjective, it is eliminated from selection criteria list for this model development. Selection criteria of each roof sub element have been considered based on the importance weights given by the domain experts. Table 2 illustrates the identified criteria and it also shows which criterion is used for which roof sub element with performance mapping for each roof sub element related to materials selection. Materials cost is estimated based on SPON price guide book. Sustainability issues are considered according to BRE green guide (Anderson *et al.* 2009).

Table 1: Linguistic variables for importance weights of each criterion

Linguistic variable	Values
Very High	0.30
High	0.25
Medium	0.20
Low	0.15
Very Low	0.10

Table 2: Criteria for selection of Roof sub elements

Performance criteria	RS	RC	RI	RL	RD	RF
Strength and stability	√			√	√	√
Fire resistance	√	√	√	√		
Life span	√	√	√	√	√	√
Maintenance cost	√	√	√	√	√	√
Initial cost	√	√	√	√	√	√
Life cycle cost	√	√	√	√	√	√
Sustainability	√	√	√			
Ease of installation	√	√	√	√		
Freedom from maintenance	√	√	√	√	√	√
Sound resistance		√	√	√		
Thermal performance		√	√	√		
Weather resistance		√		√	√	
Weight		√	√			
Security				√		
Thickness			√			

[RS= Roof structure, RC= Roof coverings, RI= Roof insulation

RL= Roof lights, RD= Roof drainage, RF= Roof features]

Step 4: Structure information

Material information collected from catalogues, technical booklets and other literature has been documented in Microsoft Excel Comma Separated Values (CSV) format to feed the database. The building regulations and other selection factors are identified and documented for production rules to control selection of materials. Materials cost data are recorded from SPON price guide book into Microsoft Excel CSV format.

Step 5: System analysis and design

Data modelling provides a methodology to define and analyse data requirements and activities. KDSMS uses Data flow diagrams (DFD) developed using SELECT SSADM 4.1.2 software to model business processes, information flow and relationship among roof sub elements. Figure 4 illustrates the context diagram of the proposed KDSMS. It shows what and how information is used to perform the activities. The user provides roof design requirements such as roof size, roof type and specification; and importance weights of each criterion for each roof sub element.

Then the system processes the user input to obtain the optimal material and estimate elemental cost of the selected materials.

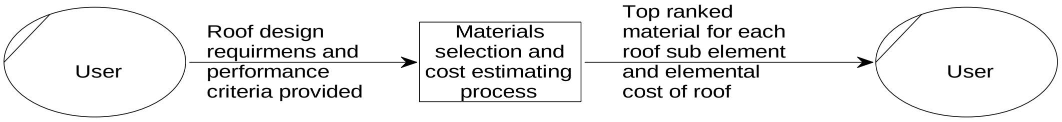

Figure 4: Context diagram of KDSMS

The level 1 DFD explains the high level processes sequentially, as it shows in Figure 5. The user provides necessary information; the material selection process retrieves material information from database, performs the operation and determines the optimal material for each roof sub element that acts as input for cost estimating process. Cost estimating process retrieves cost index to adjust cost and estimates cost for roof and provides the selected materials and elemental cost of roof to the user. Users can add new materials or update any information through the system update process.

A set of Entity relationship (E-R) diagrams have been developed in Oracle designer 10g to create conceptual and physical database for the KDSMS.

Step 6: System development and testing

The system is developed on Microsoft Windows platform with Oracle database management system. The user interface and processes are developed using Oracle Developer suite 10g. It should be noted that this stage is currently being developed.

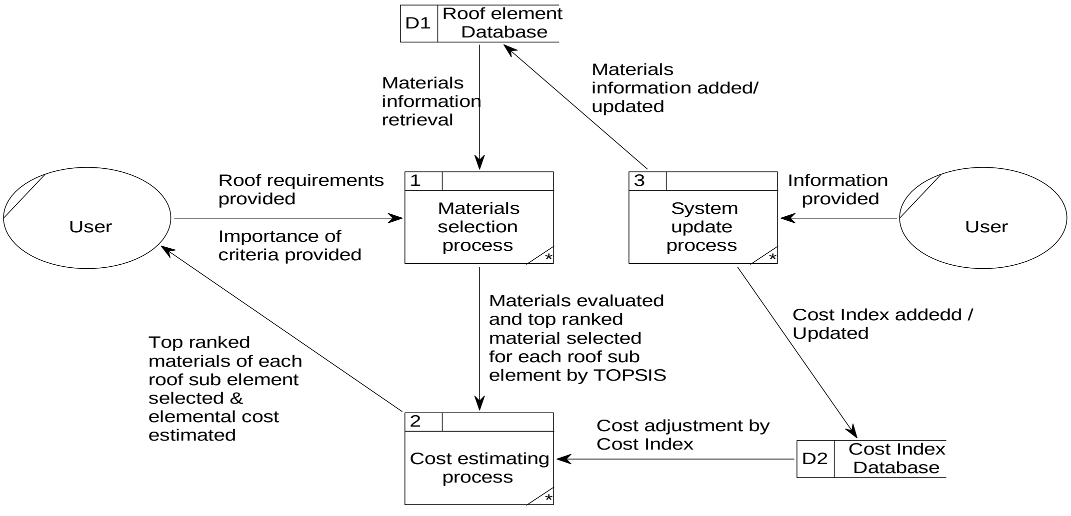

Figure 5: Level 1 data flow diagram of KDSMS

DISCUSSION

The problem of knowledge acquisition is one of the major obstacles of this system. Hence, knowledge is elicited from extensive review of technical literature and a forum of domain experts. The domain experts are chosen among architects and quantity surveyors from industry and academia. Experts from industry enabled the capture of the materials selection procedures that are used in practice. Necessary information on materials are collected from product catalogues and fed into the database to build up the decision support system. This information can also be obtained from contractors or previous similar projects. Because of the non-availability of structured format for material information, it will take a great deal of effort to feed data to the database in practice.

In the KDSMS, users provide information such as roof area, roof type (flat/pitched), and degree of pitch as design specification and importance weights of criteria for each roof sub element as inputs. Since importance weights of criteria vary from user to user, the system prompts the user a set of default weights for the level of importance attached to the criteria in order to select the required materials. Linguistic variables are used for importance weights of criteria. The system retrieves materials information from materials database. Importance weights of criteria and performance characteristics of materials are used for evaluation and ranking the materials; and TOPSIS method is used to perform the multi criteria decision making operation. The top ranked materials of each sub element along with design specification are provided as input for cost estimating process. BCIS standard form of cost analysis is adopted for cost estimating process. Cost of each material is calculated from SPON price book; tender index and location factor are used to adjust the cost for the specific time and location. Top ranked materials and elemental cost of roof are the output of this system. If the users do not wish to consider any of the roof sub element or other criteria, it can be ignored. The system will use default values in such instances. The system facilitates the users to maintain the database by adding or updating materials information and cost data so that new materials is stored and database is updated.

Multiple criteria decision making is an effective technique to select optimal material in a knowledge-based system because it can evaluate and synthesise multiple criteria simultaneously. An optimal material is quantified by its performance that is assessed by defined requirements. The appropriate material is one that is the most favourable for the given requirements. The requirements are considered as selection criteria of materials. In order to select the appropriate material, it needs to consider multiple criteria simultaneously. The proposed KDSMS model facilitates to consider multiple criteria and asses the performance of materials by ranking them. Hence, KDSMS provides a plausible methodology for roofing materials selection.

CONCLUSION

This research presents the knowledge-based decision support system for roofing materials selection (KDSMS). This system also estimates cost for the selected materials and provides all information related to selected materials through a multi-media interface. Appropriate materials are always preferred not only for environmental reasons but also for cost effectiveness. Energy cost may be reduced by using proper insulating materials. In order to select higher quality materials, multitude of information needs to be considered simultaneously. New innovative materials and technologies are frequently introduced to the market, but may not be used due to lack of information and experience. Therefore, building (house) designers are often confronted with the problem of information overload and pressures on innovative and sustainable design. This research hypothesised the use of a knowledge-based system to overcome this problem. If information related to new materials along with the performance characteristics is stored in a knowledge-based system, it is possible to efficiently retrieve the details of appropriate materials and its performance when required. Several research projects have attempted to develop knowledge-based systems solutions to this problem but none have been initiated in roofing materials selection within the housing design domain. There is no evidence of the use of multi criteria decision making techniques to resolve this problem. This research fills this gap and proposes a knowledge-based model as the decision making tool. This system (KDSMS) helps to select appropriate materials that contribute to reduce energy cost and carbon footprint. This system incorporates TOPSIS to solve multi criteria decision making problem while facilitating the update of its database. It estimates elemental cost of roof based on BCIS standard form of cost analysis. The KDSMS exemplifies the use of multi-criteria decision making techniques for material selection, optimisation of requirements and estimating. The KDSMS data model and concept can be effectively expanded to cover all elements of a building facilitating the effective use of innovative building materials and technologies. As data acquisition is one of the most complicated tasks of this system, further research is required to simplify the structure of information requirements that can facilitate efficient and convenient build up of a large database for the decision support system.

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