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Knowledge-based Decision Support System Quality Function Deployment (KBDSS-QFD) tool for assessment of building envelopes

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ABSTRACT

A building design team has faced several decision-making problems when assessing building envelope materials and designs for a private high-rise residential building in the early design stage. This study developed an automated fuzzy Knowledge-based Decision Support System Quality Function Deployment (KBDSS-QFD) tool to facilitate the team to mitigate such problems. A case study of the design team comprising an architect, a civil and structural (C&S) engineer and a mechanical and electrical (M&E) engineer was selected as the research design of this study. Results from the qualitative data analysis showed that the tool has the potential to mitigate the decision-making problems. The contributions of using this automated tool include not only achieving better design management but also raising the level of productivity in the construction industry.

1. Introduction

Building envelopes, as the interface between interior space and exterior environment, serve the function of weather and pollution exclusion and thermal and sound insulation [1]. Their performance affects occupant comfort and productivity, energy use and running costs, stability, durability, esthetics appeal of a building, etc. [2,3]. A thoughtful building envelope assessment can make a building work more effectively for its builders and occupants as part of stakeholders of a project and indoor environment [4]. Thus, success of the project is tied with the assessment and selection of building envelope materials and designs that can satisfy requirements of the stakeholders [5].

However, assessment of the building envelope materials and designs for high-rise residential buildings in the early design stage is not a simple task. It requires large amount of information and inputs from a design team comprising several building professionals particularly architects and engineers [2,6,7]. As a result, the assessment appears to be simultaneously affected by a number of decision-making problems; for instance, inadequate consideration of requirements, lack of communication and integration between members of a team, subjective and uncertain requirements, etc. [8,9]. These problems can cause significant adverse impacts to a project such as delays, increase in expenses, increase in manpower of a building project, poor professional relationship and poor client satisfaction [8,10].

Hence, there is a need for the design team to mitigate the decision-making problems. It was found that the use of the Quality Function Deployment (QFD) approach, fuzzy set theory and knowledge management system (KMS) shows a potential not only to facilitate decision-making processes of a design team, but also to improve quality of design solutions [7,11]. As such, in an effort to deal with the decision making problems, the main objective of this study is to develop a decision support system (DSS) by applying the QFD approach integrated with the fuzzy set theory and KMS to facilitate the design team to mitigate the decision-making problems in the early design stage. This system is named a Knowledge-Based Decision Support System QFD (KBDSS-QFD) tool.

2. Concepts of building envelope design

Building envelope design alternatives can generally be grouped into four major hypothetical types based on basic external wall materials including precast, masonry, fixed-glass and curtain walls as shown in Fig. 1 [12]. As can be seen, the systems typically comprise three fundamental material categories; namely external walls, windows and shading devices. The assessment of these building envelope materials and combinations of their designs for high-rise residential buildings involves a number of decision makers (DMs) as part of the design team from different backgrounds and requires intensive considerations related to design and construction of building envelope systems. These considerations are associated with esthetics, labor's skill sets, availability of manpower and equipment, building performance, durability, costs of a building project and so on [13,14].

In Singapore, architects from an architectural firm lead the entire building design development including building envelope design

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Fig. 1. High-rise residential buildings in Singapore.

development. In the early design stage of a private high-rise residential building project, the architects receive relevant information regarding the building envelope design development of the project from the developer/owner. The architects then develop a conceptual building envelope design with the help of the civil and structural (C&S) engineers, and mechanical and electrical (M&E) engineers from engineering consultancy firms to satisfy the requirements of the developer by providing a set of design alternatives. After that, the developer selects and finalizes the conceptual design, and this allows the architects and engineers to move on to develop schematic and detailed building envelope designs. In this regard, the design team in-charge of the assessment of the building envelope materials and designs in the early design stage consists of three main DMs; namely the architect, C&S engineer and M&E engineer.

3. Decision-making problems in the early stage design

From a pilot study conducted in Singapore in February 2012 and extensive literature reviews, six major decision-making problems faced by the architects and engineers as a team when assessing the building envelope materials and designs were found to include the following.

3.1. Inadequate consideration of requirements

Inadequate consideration of requirements in the early design stage is a major cause of poor performances of construction projects [15]. For instance, because of inadequate consideration of requirements, designers may not be able to develop a comprehensive design, which may lead to numerous adverse impacts during different project phases [16]. Singhaputtangkul et al. [5] suggested that inadequate consideration of building envelope requirements by designers tends to lead to redesigning activities, particularly when new assessment criteria have to be additionally considered. These activities can cause progress delay, project delay, increase in expenses and increase in manpower needed of a building project [10].

3.2. Inadequate consideration of possible materials and designs

The field of building envelope design and engineering is quite established, while new materials and systems are being developed on a continual basis. El-Alfy [16] and Makenya and Soronis [17] pointed out that architects and engineers typically select materials drawn from their personal collection of literature and their knowledge of what is available in the market, and frequently use short cuts based on their experience in order to save time. In addition, architects and engineers prefer to stick to familiar products, have a strong preference for certain materials and components used previously, and typically refuse to use new products unless these are unavoidable. This consequently seems to reduce a number of possible building envelope materials and design alternatives that could satisfy requirements of the stakeholders.

3.3. Lack of efficiency and consistency

Lack of efficiency and consistency is another major problem in making decisions particularly in the early design stage of the design team. This problem leads to delay, lack of confidence and participation among members of the team, and eventually affect a client's satisfaction [18,19]. There are numerous sources of this problem. One of these is an absence of an organized KMS. This issue is significant because, for instance, in cases where professionals leave the organization or the design team while the project experience continues to reside within the individual professionals, in the absence of an established and organized KMS, the professional team would face problems in designing and planning [15,20].

3.4. Lack of communication and integration between members of the team

In building design, communication and integration play a vital role in combining ideas of designers from different parties together during design processes. However, communication and integration among designers are often fraught with difficulties and are seldom linked to design outcomes. In fact, lack of communication and integration has been recognized as a crucial problem not only during the design development stage but also during the entire project development cycle. Poor communication and integration render the achievement of an optimal design difficult as well as a time-consuming process [9,21]. This problem tends to lead to unclear instructions, additional works, progress delay, project delay and poor quality of design solutions [22,23].

3.5. Subjective and uncertain requirements

Practical building design depends heavily on intuitive thinking and professional expertise that usually have a large variation of shades of gray as opposed to black and white colors [24]. Significantly, Brock [13], Lu et al. [25] and Pedrycz et al. [26] suggested that designers have faced problems in interpreting this type of requirements. In particular, under vague and uncertain circumstances especially in the early design stage, designers seem to be unable to estimate their preferences with an exact numerical input. This makes finding a balance between the subjective criteria one of the major decision-making problems encountered by most architects and engineers when assessing the building envelope materials and designs.

3.6. Disagreement among members of the team

Nutt [27] defined “decision making” as a process made up of stages carried out to set directions, identify solutions, evaluate courses of action and implement a preferred plan. The effectiveness of the group decision process has become an increasingly important organizational concern [28]. A common organizational response to this concern is to design cross-functional teams [29]. Nevertheless, these heterogeneous groups exhibit additional problems. As the