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Green decoration materials selection under interior environment characteristics: A grey-correlation based hybrid MCDM method

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ABSTRACT

Materials selection, as a essential link for manufacturing enterprises, has an important driving-force to comprehensively upgrade material properties and service life, especially in building and decoration fields. To qualitatively select the optimal green decoration materials, a hybrid multi-criteria decision making (MCDM) approach integrating analytical hierarchy process (AHP) and grey correlation technique for order performance by similarity to ideal solution (GC-TOPSIS) is proposed. The weights vector of hierarchical index structure, which is established based on interior environmental characteristics, i.e., physiological comfort, psychological satisfaction and interior environmental effect, is determined by AHP. GC-TOPSIS is applied to obtain the final ranking of green decoration materials to select the optimal one. A case study, i.e., 10 kinds of solid woods, is illustrated to validate the proposed method. Additionally, a sensitivity analysis of nine experiments is carried out to monitor the robustness of solution ranking to changes. The results proved that this method furnishes an rational and efficient decision support tool for performance assessment of green decoration materials.

1. Introduction

Material selection plays a significant role in the entire design and manufacturing process for diverse engineering applications, and it has attracted many researchers in recent years [1–5]. Improper selection of materials may negatively affect the performance and service life of products, even result in enormous cost of involvement and ultimately drive towards premature component/product obsolescence [6]. Current materials selection researches can be summed up in three major issues: construct a reasonable hierarchical structure based on various principles/criteria, prioritize and assign weights to relevant criteria, and assessment process of each material alternative. As an important strategy in the industrial system, it has been applied to various fields, especially in building and decoration fields [7,8].

Rapid urbanization and economic globalization strength the rate of manufacturing and infrastructure construction, and make the construction industry become one of the fastest developing sectors in China [1]. Correspondingly, the increasing requirements for the quality of daily life, the aesthetics and comfort level of adornment space/environment for individuals put forward higher demands to the interior environment characteristics for green decoration materials. Interior environment characteristics as one of the most important properties of building decoration materials involves several aspects, i.e., the physiological comfort and satisfaction degree of material properties to individual, building physical conditions and living environment characteristics. Therefore, this paper establishes a hierarchy structure about assessment indicators/criteria focusing on interior environment characteristics, which can be applied in the assessment process of green decoration materials selection.

The process of material alternatives' evaluation is the fundamental basis for green decoration materials selection, but various selection criteria and complex relationships between them make it a challenging task. For instance, when considering interior environment characteristics, some internal criteria, e.g., visual, acoustic, tactile, olfactory, must be taken into account. Therefore, a multi-criteria decision making (MCDM) method become a useful tool to deal with this problem [9,10]. MCDM is divided into five parts: alternatives generation, criteria system building, criteria weights determination, alternatives' assess-

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ment, and application of a ranking system [11]. Each criterion is related to a target in the specific decision framework, and normalization is adopted to transform different criteria into a compatible measurement [12–14]. Technique for order performance by similarity to ideal solution (TOPSIS) approach is considered as one of the commonly used assessment approaches in the practical application. However, it has some shortcomings and drawbacks that need to be improved.

This approach evaluates material alternatives based on the distance relationship among data sequences and merely considers their location relationship among them [15]. For instance, although the index values of each alternative are different from each other, the distance between the primary alternative and positive/negative-ideal one is equal, and their alternative evaluation results are same through TOPSIS/AHP-TOPSIS method. Namely, this MCDM approach is not suitable to assess all kinds of material selection alternatives due to its measurement scale is distance. In fact, to ensure the rationalization and comprehensiveness of the final results, their evaluation not only considers the location relationship among data sequences but also employs the situation/posture changes among data sequences. Instead, grey correlation method takes the similarity of curve shape as a measurement scale, i.e., grey correlation degree, and could be applied to reveal the estimates of situation changes among data sequences [16,17]. To do so, this paper presents a grey-correlation based hybrid MCDM method to evaluate the selection problem of green decoration materials for the first time to the best knowledge of the authors. Compared with the previous researches [18–70], the contributions of this paper could be summarized as three parts: 1) based on the main service object and ergonomics of green decoration materials, a hierarchy structure about assessment criteria focusing on interior environment characteristics is established, and the weights vector of each criterion could be calculated according to AHP method; 2) owing to the defects of TOPSIS approach as described above, a grey-correlation based hybrid MCDM method is presented via a nonlinear programming which is adopted to reduce/avoid subjectivity and irrationality; 3) An empirical application of 10 kinds of solid woods is illustrated. In addition, sensitivity analysis and comparison with existing methods are performed to validate the accuracy and reliability for the proposed hybrid approach.

The structure of this research can be summarized as follows: Section 2 makes a summing up of the literature review. The solution method, i.e., a grey-correlation based hybrid MCDM method, is presented in Section 3. The verification of an empirical case about 10 kinds of solid woods, the comparison of the previous researches, and the sensitivity analysis on variations of criteria weights are presented to demonstrate the new decision framework in Section 4. Section 5 provides a statement about the conclusions and further research topics.

2. Literature review

Materials selection is normally treated as a typical MCDM problem, because of the lack of accurate and formal measurement rules/criteria or programs. Therefore, the assessment process of alternatives is largely established on the basis of reliable experiences from related experts rather than numerical or simulation methods [18–21]. In the literature, many previous researches have explored and proposed various contexts/approaches to carry out the researches of material selection issue, and the adopted impact criteria are social, technical, environmental or economic field [22–26]. Many researches as cases are shown in Table 1 to reveal the particularity of the hierarchy structure about assessment criteria for different material types. However, for different types of materials, the emphasis point should also be distinct. Take this paper as an example, the main service object about green decoration materials is households or work offices. In short, the overall feelings of persons who live/work in the internal environment occupy a large proportion in the selection process for green decoration materials. Therefore, considering interior environment characteristics in the assessment process has an great significance on meeting manufacturing, industrial or practical needs in building field, and contributes to green building standards formulation [27–30].

An overview of main material selection methodologies by the previous researchers is revealed briefly in this section. Overall, this MCDM methods could be summarized into two types: 1) synthetical evaluation methods, e.g., ELimination and Choice Expressing the REality (ELECTRE) [31], TOPSIS [45,46], AHP [30], Vlse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR) [47], Decision Making and Evaluation Laboratory (DEMATEL) [48], grey correlation (GC) [49,50], best-worst method (BWM) [51]; and 2) approaches on the basis of life cycle assessment (LCA) [52]. Additionally, some integrated methods have been successfully presented and applied to deal with the shortcomings of single one. For instance, Liu et al. [20] propose a hybrid MCDM method integrating DEMATEL-based ANP (Analytical network process) and modified VIKOR to improve the reliability of the optimization results, which can help engineering designers to deal with the lack of the interrelated relationships analysis among each criterion in material selection process. Peter et al. [53] applied an integrated approach that combines fuzzy extended AHP and fuzzy synthetic extent analysis method to obtain the ultimate rank/priority of each criterion. Shanian and Savadogo [54] present a material selection problem of highly sensitive components via using MCDM method. In addition, owing to the drawbacks of uncertainty, fuzzy theory and 2-Tuple theory are been coupled in the assessment process [55,56].

The review of the literature illustrates that although there are many effective assess-levels/approaches to deal with the issue of material selection. Nevertheless, some aspects still be overlooked, e.g., interior environment characteristics, which have a significant impact on the assessment process for green decoration materials, is rarely considered; TOPSIS approach as a commonly used decision support tool is not appropriate to evaluate all kinds of material alternatives because its measurement scale is distance. Therefore, a hybrid evaluation approach integrating AHP and GC-TOPSIS is proposed to help fill the gap. The weights vector of hierarchical index structure, which is established based on interior environmental characteristics, i.e., physiological comfort, psychological satisfaction and interior environmental effect, is determined by AHP approach. GC-TOPSIS is applied to obtain the final ranking of green decoration materials to select the optimal one.

3. A grey-correlation based hybrid MCDM method

In this section, a grey-correlation based hybrid MCDM method integrating AHP, GC and TOPSIS is proposed for multi-criteria optimization in complex systems. After generating decoration material alternatives and identifying the material selection criteria system, AHP is applied to determine the weights vector of hierarchy structure about assessment indicators/criteria focus on interior environment characteristics; GC-TOPSIS is adopted to select the optimal material alternative based on integrated closeness index. The proposed comprehensive approach is illustrated step by step as below.

3.1. AHP approach

AHP, introduced by Saaty [71], reveals the principle to obtain the relative importance/weights of several clusters of indexes/criteria to lay the foundation for MCDM problems. A hierarchical structure including different levels and various indexes/criteria, which was formulated based on the characteristics of certain events, could be categorized into three layer, i.e., the target one, the rule one, and the index one [72]. The pair-wise comparison matrix (PWCM) was structured by related experts with reliable experience based on the fundamental scale of comparison values as shown in Table A1, thus calculating the corresponding preference/weight of each decision