Selection of Materials in Construction Industry with Multi-Criteria Decision Making Models

Weng Hoe Lam, Kah Fai Liew, and Weng Siew Lam

Abstract. Construction companies play a central role in the development of a country. The construction products stimulate the growth of private physical structures and public infrastructure for many productive activities such as utilities, commerce, and services. A good material selection is an essential part that needs to be studied in order to come out with a product that is of high quality and safe to be used. As a result, material selection in the field of construction has also become an interesting topic for many researchers. Based on the previous literature, several multiple criteria decision making (MCDM) models are proposed to choose the best materials for a particular application in recent years. With multiple decision criteria, material selection is treated as an MCDM problem. According to past studies, the researchers have emphasized the integration of MCDM models to tackle complicated decision making problems. MCDM model is a good tool and has been widely proposed in various fields as MCDM models are capable to tackle the decision making problems that are taking multiple decision criteria into consideration. The intended purpose of this paper aims to provide a literature review on the material selection in the field of construction with MCDM models.

Keywords. Materials selection; multi-criteria decision making; AHP; TOPSIS; VIKOR

1 Introduction

Construction is one of the most responsive and dynamic sectors in the industry. For both underdeveloped and developed countries, the construction industry plays a significant role in accounting for a sizeable proportion in the Gross Domestic Product (GDP). In addition, the construction sector is important to generate significant casual employment in rural and urban areas. The outputs from the construction sector are quite dependent on the construction equipment. Good construction equipment is able to yield construction work of high quality, safe, and quickly. Examples of construction equipment are engines, generators, concrete mixers, backhoe loaders, and cranes. As a result, in the design process, the selection of material is one of the most prominent activities and many researchers have been attracted by...
This kind of study that is related to material selection for many years [1-4]. This is because various indispensable decision criteria involved in the selection of materials are essential to be taken into consideration. Furthermore, many alternatives that are available for the selection can also make the process of choosing the suitable alternative to become more complicated and complex. Hence, the performance of the system will deteriorate and failure or damage of an assembly will occur due to an inappropriate materials selection. Thus, material selection is considered as a multiple criteria decision making (MCDM) problem and some powerful tools or methods should be proposed to square up this problem. MCDM model is a tool that makes the decision making process to become more effective when there are conflicting, quantitative, and qualitative criteria [5]. In fact, during the decision making process, the problem parameters are quantitative and qualitative and these parameters ought to be evaluated in order to make the MCDM a comprehensive and practical evaluation strategy. As a result, various studies in the literature, the MCDM models, for example, VIKOR, Analytic Hierarchy Process (AHP), and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) are utilized to resolve decision making problems in numerous areas. As a result, this issue can be handled by MCDM models by giving a promising and optimal solution. The aim of this paper is to present a review of the application of the MCDM models in the selection of material. Past studies have shown that various common MCDM models such as AHP, VIKOR, and TOPSIS are used to apply to the material selection in the field of construction. The intended purpose of the MCDM models is to search for an optimal solution that can be utilized to resolve the decision making problems faced by the decision makers [6]. MCDM consists of establishing attributes, generating alternatives, evaluating attributes weights, assessment of alternatives, and ranking the system’s application [7]. The work is organized as follows: the next section presents the literature review. Some of the MCDM models are discussed in Section 3; and lastly, Section 4 concludes the paper.

2 Literature Review

Jahan et al. [8] completed a study on the material selection of metallic bipolar plates for polymer electrolyte fuel cells used in electric vehicles with the proposed VIKOR model. The material selection of metallic bipolar plates is based on the following criteria: easy to manufacture in low cost/high volume by automation, low mass and volume for fuel cell stack, low gas permeation, high mechanical strength, high corrosion resistance, high electrical conductivity and thermal compatibility with other components, and low material cost. These criteria are used to assess the performance of the twelve alternative materials. The available materials are 317L austenitic stainless steel, titanium (coated with nitride), AISI 436 ferritic stainless steel, aluminium (gold plated), AISI 434 ferritic stainless steel, 316L austenitic stainless steel, 310 austenitic stainless steel, A560 (50Cr–Ni), AISI 446 ferritic stainless steel, 304 austenitic stainless steel, AISI 444 ferritic stainless steel, and 316 austenitic stainless steel. The findings of the study demonstrate that 316L austenitic stainless steel is the best material for metallic bipolar plates, followed by 316 austenitic stainless steel, 317L austenitic stainless steel, AISI 446 ferritic stainless steel, and AISI 444 ferritic stainless steel. The last three rankings are obtained by 304 austenitic stainless steel, titanium (coated with nitride), and aluminium (gold plated), respectively. Throughout this study, VIKOR model is a potential MCDM model that is beneficial to the decision makers and designers for obtaining more strong decisions, especially in the applications of material selection.

Chakraborty and Chatterjee [9] carried out a study on the material selection for a specific engineering component with VIKOR, TOPSIS, and PROMETHEE models. The selection of the most appropriate materials in the engineering field is treated as an MCDM problem and this problem can be tackled by MCDM models. The purpose of this research is to determine

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The most imperative criterion for the alternative materials ranking. The criteria that are taken into consideration in the cryogenic storage tank materials selection are thermal conductivity, thermal expansion, density, Young’s modulus, yield strength, toughness index, and specific heat.

Seven materials are considered as the decision alternatives in this study, for instance, SS 301-FH, 70Cu-30Zn, Al 2024-T6, SS 310-3AH, Ti-6Al-4V, Al 5052-O, and Inconel 718.

The rankings of cryogenic storage tank materials are determined by VIKOR, TOPSIS, and PROMETHEE models. After that, the ranking performances of these three models are compared. The results reveal that VIKOR outperforms the PROMETHEE and TOPSIS models.

Banar et al. [10] applied four MCDM models, which are AHP, PROMETHEE, ELECTRE, and Analytic Network Process (ANP) models to identify the site selection of the plants. The waste of electrical and electronic equipment (WEEE) issue needs to be resolved in a faster way in order to help save natural sources, prevent environmental pollution, and decrease the consumption of energy [11-13]. There are 16 city alternatives and seven criteria taken into consideration in this evaluation. Land cost, population, existence of recycling plants, electrical and electronic equipment producers, waste management system, e-waste management system, and grants are the decision criteria that are utilized in this research. The alternatives are Istanbul, Izmir, Bursa, Kocaeli, Sakarya, Ankara, Antalya, Mersin, Eskisehir, Samsun, Konya, Kayseri, Gaziantep, Adana, Diyarbakir, and Erzurum. The major findings of this study present that Istanbul is identified as the best alternative among the four MCDM models. Istanbul achieves the first ranking for all the models. Furthermore, it is also noticed that Ankara and Izmir are placed in the top five ranking in the evaluation. Among the decision criteria, population and electrical and electronic equipment producers are treated as the most important criteria in the evaluation. This study highlights the significance of the determination of the optimum number and location of collecting points in reducing the costs of reaching the maximum amount of waste.

Rojas-Zerpa and Yusta [14] used the AHP and VIKOR models to find out the best electrical supply proposal by considering multiple criteria. In this study, the AHP model is adopted to identify the decision variables’ weights, whereas the VIKOR model is utilized to find the ranking of the power supply alternative. The alternatives that are under evaluation in this study are dispersed decentralized generation, namely DDG1 to DDG6, compact decentralized generation, namely CDG7 to CDG12, and centralized generation, namely CG13. The alternatives are evaluated by four criteria, namely environmental, economic, technical, and social criteria. According to the results of the study, the best alternative is CDG7, followed by CDG8, CDG9, CDG10, CG13, DDG4, DDG3, CDG12, DDG1, CDG11, DDG5, DDG2, and lastly DDG6. Therefore, CDGs are the best form of electrification for remote and rural areas. In this study, the hybridization of AHP and VIKOR models is able to facilitate decision making in a reliable, comprehensive, and transparent way. Hence, planners and designers can make better decisions with the aid of AHP and VIKOR models.

Liu et al. [15] have proposed a hybrid model called uncertain linguistic multi-objective optimization by ratio analysis plus full multiplicative form (UL-MULTIMOORA) and grey decision making trial and evaluation laboratory (DEMATEL) to determine the optimal location planning of electric vehicle charging stations. Electric vehicle charging stations play a central role in the development of the public charging facilities’ optimal location. The aims of this study are to determine the causal relationships and interaction levels between decision criteria with the aid of grey DEMATEL model and the ranking of the electric vehicle charging stations by using the UL-MULTIMOORA model. Moreover, the grey DEMATEL model is also employed to obtain the influential weight for each decision criterion. The decision criteria that are used to identify the best electric vehicle charging stations are service capability, traffic convenience, waste discharge, destruction degree on vegetation and water, air pollutants reduction, annual operation and maintenance cost, construction cost, and ICSTCE 2023 https://doi.org/10.1051/e3sconf/202340504015
harmonization of electric vehicle charging stations with the development planning of urban road network and power grid, and adverse impact on people’s lives.

The evaluated alternatives for electric vehicle charging stations in this study are four sites that are located in the districts of Pudong, Minhang, Baoshan, and Jiading. The four alternative sites’ ranking is as follows: Baoshan, Jiading, Minhang, and Pudong. This study is significant as the proposed integrated MCDM framework is an adequate and practical tool to tackle the problems of multifaceted electric vehicle charging stations’ site location with interdependent decision criteria.

Tian et al. [16] completed a study on the selection of green decoration materials under interior environment characteristics. Material selection is important in the manufacturing process for a wide range of applications of engineering. The hybrid MCDM models that are adopted by the researchers in this study are AHP and grey correlation TOPSIS (GC-TOPSIS). There is a total of 10 material alternatives are investigated in this research. The available green decoration materials are Picea jezoensis var.microsperma, Pinus koraiensis, Betula platyphylla, Abies nephrolepis, Larix gmelini, Quercus mongolica, Pinus sylvestris var. mongolica, Juglans mandshurica, Fraxinus mandshuric, and Pterocarpus santalinus. The green performance of these alternatives is measured based on six crucial decision criteria, such as architectural physics, olfactory, tactile, acoustic, visual, and living body. AHP model in this research is to identify the weights of each decision criterion, whereas the GC-TOPSIS model is to determine the distance closeness index and the similarity closeness index. The results of this study show that Pterocarpus santalinus achieves the highest similarity closeness index (0.6522), followed by Fraxinus mandshuric (0.5239), Pinus koraiensis (0.5156), Pinus sylvestris var. mongolica (0.4996), and Larix gmelini (0.4674). In this study, Betula platyphylla obtains the last ranking with a similarity closeness index of 0.2952. This study concludes that grey correlation based hybrid MCDM model is an accurate and effective tool to carry out green decoration materials selection.

Ozcan et al. [17] did a study on the main equipment groups for maintenance planning in hydroelectric power plants by using AHP-TOPSIS model. AHP model is adopted to obtain the evaluation criteria’ weights. On the other hand, the ranking of the most critical equipment of the power plant is identified by TOPSIS model. In this study, nine criteria have been considered in the evaluation of the equipment of the power plants. These criteria included fault shooting time, dynamic or electrical property of equipment, static, availability of measuring equipment, possible consequences, failure period, additional work requirement, maintenance pre-conditions, warehouse backup, and detectability of failure. This study found that possible consequences and maintenance pre-conditions are the two most significant criteria with the highest weights. In this research, turbine, generator, disconnector, intake structure, butterfly valve, main power transformer, brake system, relay, wicket gate, cooling water structure, compressed oil tank, excitation transformer, speed governor, and circuit breaker are the equipment of the power plant that is considered for the evaluation. Based on the results, in terms of power plant, the most critical equipment is found as disconnectors, generators, and turbines.

Kumar [18] applied the TOPSIS model to do the material selection for the hybrid bio-composites of glass fiber/reinforced with thermoset polymers. TOPSIS model is utilized to determine the ranking of the hybrid bio-composite. There is a total of eight hybrid bio-composites are evaluated by considering the significant decision criteria. The decision criteria included tensile strength, flexural strength, hardness, density, and water absorption. The decision criteria’ weights are obtained by the entropy method. The findings of this study present that each hybrid bio-composite is able to obtain a closeness index. The hybrid bio-composites in this research are D1, D2, D3, D4, D5, D6, D7, and D8. The ranking is given to the hybrid bio-composites based on their closeness index. D3 achieves the highest closeness index among the hybrid bio-composites, followed by D2, D4, D7, D8, D6, D1, and
3 Multi-Criteria Decision Making Models

3.1 Analytic Hierarchy Process (AHP)

AHP model is utilized to decompose the complex decision making problem into a hierarchical structure with three different levels or components. The first level is referring to the objective of the study, followed by the decision criteria, and lastly decision alternatives. AHP model is capable to analyze the priorities of decision criteria according to the decision makers’ judgements through the pairwise comparison matrix. Hence, AHP model does not require additional tools to get the weights of the criteria. After that, the final result generated by the AHP model is a set of relative importance priorities between all the studied alternatives. In short, the optimal solution is achieved based on the degree of importance of alternatives and criteria. The AHP model is described as follows:

Step 1: Determine the objective of the study, decision alternatives, and decision criteria.

Step 2: Compare the decision criteria in pairwise by using Saaty’s scale.

Step 3: Construct the pairwise comparison matrix (PCM) after obtaining the pairwise comparison between the decision criteria. The PCM is presented below.

\[
\begin{bmatrix}
c & c & \cdots & c_m \\
c & c & \cdots & c_m \\
\vdots & \vdots & \ddots & \vdots \\
c_m & c_m & \cdots & c_m \\
\end{bmatrix}
\]

where \(m\) denotes the number of decision criteria.

Step 4: Normalize the PCM by taking the mean of each row in the PCM to obtain the decision criteria’s weight score.

Step 5: Repeat steps 2 to 4 to obtain the weight score of the decision alternatives.

Step 6: Compute the overall weight score for each decision alternative (\(FDW\)) by using the weight score of the decision alternatives and decision criteria.

Step 7: Compute the PCM’s consistency ratio (\(CR\)). The formula of \(CR\) is demonstrated below.

\[
CI = \frac{CI}{RI} \\
CR = \frac{CI}{RI}
\]

where \(RI\) denotes the random index and \(CI\) denotes the consistency index.

The result of the study is reliable if \(CR\) is less than 0.10. This implies that the PCM is consistent.

3.2 Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS model is applied to compare and sort the ranking of the alternatives based on the separation distance from the ideal solution. The best alternative is to seek to have the least separation distance from the best ideal solution and the longest separation distance to the worst ideal solution. The merits of the TOPSIS model are simple and the steps of the model are ICSTCE 2023
The steps of the TOPSIS model are depicted below.

Step 1: Construct a decision matrix $\mathbf{P}_{ij}^{n \times m}$

$$
\mathbf{P}_{ij}^{n \times m} = \begin{bmatrix}
\mathbf{p}_{11} & \mathbf{p}_{12} & \cdots & \mathbf{p}_{1m} \\
\mathbf{p}_{21} & \mathbf{p}_{22} & \cdots & \mathbf{p}_{2m} \\
\vdots & \vdots & \ddots & \vdots \\
\mathbf{p}_{n1} & \mathbf{p}_{n2} & \cdots & \mathbf{p}_{nm}
\end{bmatrix}
$$

where $n$ denotes the number of decision alternatives and $m$ denotes the number of decision criteria.

Step 2: Determine a normalized decision matrix $\mathbf{P}_{ijr}^{n \times m}$

$$
\mathbf{P}_{ijr}^{n \times m} = \frac{\mathbf{P}_{ij}}{\sqrt{\sum_{i=1}^{n} \mathbf{P}_{ij}^2}}
$$

Step 3: Find the weighted normalized decision matrix $\mathbf{P}_{ijv}^{n \times m}$ by the multiplication of $\mathbf{P}_{ijr}^{n \times m}$ and the weights of the decision criteria $\mathbf{w}_j$.

$$
\mathbf{P}_{ijv}^{n \times m} = \mathbf{P}_{ijr}^{n \times m} \times \mathbf{w}_j
$$

Step 4: Identify the best ideal solution $\mathbf{D}^+$ and the worst ideal solution $\mathbf{D}^-$ for each decision criterion.

$$
\mathbf{d}_i^{-} = \frac{\sqrt{\sum_{j=1}^{m} \mathbf{v}_j - \mathbf{D}^-}}{\sqrt{\sum_{j=1}^{m} \mathbf{v}_j - \mathbf{D}^+}}
$$

$$
\mathbf{C}_i = \frac{\mathbf{d}_i^{-}}{\mathbf{d}_i^{-} + \mathbf{d}_i^{+}}
$$

Step 5: Compute the relative closeness to the ideal solution for the alternatives $\mathbf{C}_i$.

3.3 VlseKriterijuska Optimizacija I Komoromisno Resenje (VIKOR)

$$
\mathbf{P}_{ij}^{n \times m} = \begin{bmatrix}
\mathbf{p}_{11} & \mathbf{p}_{12} & \cdots & \mathbf{p}_{1m} \\
\mathbf{p}_{21} & \mathbf{p}_{22} & \cdots & \mathbf{p}_{2m} \\
\vdots & \vdots & \ddots & \vdots \\
\mathbf{p}_{n1} & \mathbf{p}_{n2} & \cdots & \mathbf{p}_{nm}
\end{bmatrix}
$$
Step 2: Identify the best and worst values of criterion.

Step 3: Determine the evaluation value of criterion for alternative .

The normalized decision matrix is depicted below.

\[ S_j = \frac{w_j (p_j - p_\theta)}{p_j - p_\theta} \]

\[ R_j = \frac{w_j (p_j - p_\theta)}{p_j - p_\theta} \]

\[ Q_i = \frac{v}{S_i - S_i} + \frac{v}{R_i - R_i} \]

where denotes the weight of criterion.

Step 4: Compute the utility, regret, and VIKOR indices values.

\[ w \] is the weight for the strategy “majority of criteria”.

The strategy could be compromised when \( 0.5 = 0.5 \).

\[ \sum_{j=1}^{m} w_j (p_j - p_\theta) \]

4 Conclusion

In conclusion, the construction process needs raw materials or inputs from other industries and production factors including labour, capital, and land. As a result, material selections in the construction field need to be carried out comprehensively in order to obtain an ideal alternative by considering the multiple decision criteria. MCDM is a popular and well-known model that is used to resolve decision making problems that are involved multiple criteria. MCDM models are competent in proving the appropriate and optimal solution based on the situation given. According to the previous study, the present MCDM models are sufficiently flexible to resolve the complex multiple attribute decision making problems such as optimization of material selection. Furthermore, future work can be proposed by implementing more and more hybrid models or new models in order to tackle the optimization of material selection problems in a more effective and efficient way.

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