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APPLICATION OF FUZZY TOPSIS FOR SELECTING MOST SUSTAINABLE BUILDING WALL MATERIAL

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Appropriate selection of construction materials is crucial for the success of any project. Poor choice of materials can lead to higher costs during construction, higher long-term operation and maintenance expenses, and endanger humans and their surrounding environment. Since the three pillars of sustainability cover the economic, social, and environmental aspects, adoption of sustainability principles in decision making will ensure selecting the optimum construction materials. This paper presents a generic model to utilize Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) principles to compare the sustainability criteria of four wall material alternatives using normalized fuzzy matrices. A case study took place in United Arab Emirates (UAE) to validate the model. Several semi-structured interviews and meetings with industry experts representing material suppliers, engineering consultants, and construction contractors took place during this research. These meetings provided six selection criteria under the three main sustainability categories, agreed-upon weight for each criteria, and evaluation of the four wall material alternatives. Results obtained from consulted experts presented Sandwich Panels as the most sustainable alternative for the case study. The developed model is generic and can be implemented on any construction project, and the alternative selection can change according to the decision-makers' opinions and preferences.

Keywords: Green building, Construction material, Multiple criteria decision making (MCDM), United Arab Emirates (UAE).

1 INTRODUCTION

Sustainability is commonly understood through its three components (the triple bottom line), which include economic, environmental, and social aspects. Sustainable project management is particularly indicated on projects that result in long lasting changes in the community and involve multiple stakeholders (Kivilä 2017). Cole *et al.* (2003) described green strategies as "building design strategies that are less environmentally and ecologically damaging than typical practice". Green Building Materials (GBMs) are recycled, ecological, health-promoting, or high performance material that cover all three pillars of sustainability. The major challenge in selecting GBM in light of the sustainability pillars is the contradicting nature of objectives. The designer needs to find an environmentally friendly material that is also easy to use and economically feasible. Hence, the consideration of all sustainability factors in GBM selection is a Multi Criteria Decision Making (MCDM) problem, requiring mathematical techniques to be solved in a scientific way (Khoshnava *et al.* 2018). MCDM techniques have been widely used by the industry and research communities for solving this type of sophisticated decision-making problem.

2 LITERATURE REVIEW

2.1 Selection of Sustainable Green Building Material

The building sector is responsible for emitting 23–40% of the world's greenhouse gases (Obafemi and Kurt 2016). One way to reduce emissions is through green building, which is defined by the Office of the Federal Environmental Executive as "the practice of: increasing the efficiency with which buildings and their construction sites use energy, water, and materials and reducing building impacts on human health and the environment throughout a building life cycle." The green building movement originated in the late nineteenth century, and has gained momentum since the early 1990s (Bartlett and Howard 2000). After celebrating the first Earth Day in April 1970, the OPEC oil embargo of 1973 truly captured the attention of the public at large through its promising "environmental movement." US Green Building Council (USGBC) formed its major green building code known as Leadership in Energy and Environmental Design (LEED) in 2000 (Scofield 2009). The LEED framework gives building owners and operators the opportunity to implement green building design, operations, construction, and maintenance practices and solutions.

In United Arab Emirates (UAE), there are great efforts underway to prioritize and develop sustainable designs throughout each individual Emirate. Abu Dhabi uses the Estidama Pearl rating system; its philosophy is similar to LEED, however it is tailored to the UAE's climate. Dubai has implemented a regulatory approach using the Dubai Green Building Regulations. There is further attention for LEED and/or Estidama certifications. By 2030, Dubai aims to reduce energy use by 30%, as well as generate at least 25% of its power from renewable sources (Small and Al Mazrooei 2016).

2.2 Multi Criteria Decision Making Techniques

Pohekar and Ramachandran (2004) suggested that MCDM approaches be used when there are multiple, usually conflicting, objectives. The MCDM approach handles quantitative and qualitative choices, combining historical data, as well as expert opinions. The main MCDM techniques include the analytical hierarchy process (AHP), elimination *et choix traduisant la realité* (ELECTRE), and technique for order of preference by similarity to ideal solution (TOPSIS). AHP breaks down difficult MCDM problem into a hierarchy structure and applies pair-wise comparisons to rank decision alternatives. Meanwhile, ELECTRE has several varieties such as ELECTRE I, II, III, and IV to allow decision makers to choose the best action. TOPSIS uses Euclidean distance to select the alternative that has the farthest distance from the negative ideal solution and the shortest distance from the positive ideal solution (Aruldoss *et al.* 2013). Fuzzy set theory is used with either AHP or TOPSIS techniques to reflect uncertainty in experts' opinions. This incorporation of fuzzy concepts leads to more reliable, applicable and effective approach for decision-making (Rezaei and Ortt 2013).

2.3 Application of MCDM in Green Buildings

Kabak *et al.* (2014) used a fuzzy MCDM approach to analyze the Building Energy Performance Calculation Methodology (BEP-TR). Their approach categorized alternative buildings according to their overall energy performance. Akadiri *et al.* (2013) developed a model for building material selection, based on fuzzy extended analytical hierarchy process (FEAHP) techniques.

The aim was to (i) obtain assessment solutions based on sustainability principles, (ii) and prioritize weight assignment to relevant assessment criteria, which are identified based on the needs of building stakeholders and the sustainability triple bottom line approach. The model helps building designers select sustainable building materials on the basis of environmental, economic, and social factors.

3 METHODOLOGY

3.1 Selection of Fuzzy TOPSIS As MCDM Technique

Based on the literature review (Velasquez and Hester 2013) and the authors' experience, the Fuzzy TOPSIS technique was selected because it is a simple, easy to use process that deals with multiple criteria simultaneously. It can be easily understood by the involved decision-making experts. The number of alternatives does not influence the number of steps. In addition, adding fuzziness to the technique translates the uncertainty in experts' linguistic opinions into quantitative numeric values for ranking alternatives. As supported by previous research, Fuzzy TOPSIS performs better than other MCDM techniques in most decision-making problems.

3.2 Steps in Applying Fuzzy TOPSIS Technique to Select Sustainable Wall Material

The authors developed a seven-step model, based on the research by Jumarni and Zamri (2018), to apply Fuzzy TOPSIS to select most sustainable wall material as shown in Figure 1. Each of these steps is explained in detail in the following sections of this paper.

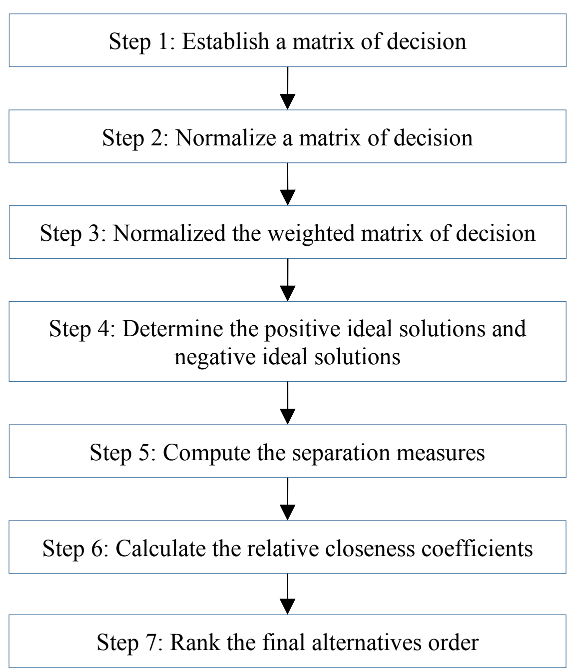

Figure 1. Steps followed to develop the research.

3.2.1 *Step 1: Establishing a matrix of decision*

The decision-making problem is formulated as finding the most suitable wall material taking into consideration the three pillars of sustainability. The technical aspect is also considered in the criteria. Three experts are selected from UAE construction industry to represent the supplier, consultant, and contractor points-of-view. After extensive literature review and meeting with the selected experts, the decision-making criteria and alternatives are shown in Tables 1 and 2.

Table 1. Decision-making criteria.

Type of Criteria	Criteria	Mark
Environmental Criteria	Potential for recycling and reuse	C1
	Amount of waste during use	C2
Social-Economic Criteria	Cost per m^2	C3
	Labor productivity	C4
Technical Criteria	Fire resistance	C5
	Energy saving and thermal insulation	C6

Table 2. List of investigated alternatives.

Alternatives	Mark
Traditional Block (Concrete Block)	ALT 1
Sandwich Block	ALT 2
Lightweight Concrete Panel (Sandwich Panel)	ALT 3
Autoclaved Aerated Concrete Panel	ALT 4

Using Fuzzy set theory, linguistic variables defined by the decision maker D_k, where $k = 1, \ldots, K$, gives a linguistic weight transformed into a Triangular Fuzzy Number (TFN) w_{ki}, to each criterion i, where $i = 1, \ldots, n$, and a linguistic weight transformed into TFN x_{kij}, to each alternative, where $j = 1, \ldots, m$, with respect to each criterion i. In the current study, the alternatives are the available sustainable wall material. The weights are then aggregated according to the Eqs. (1) and (2) (Hamdan *et al.* 2017).

$$\overline{w_i} = \left(\overline{l_i}, \overline{m_i}, \overline{u_i}\right) = \frac{1}{k}\left(w_i^1 + w_i^2 + \cdots + w_i^k\right) \tag{1}$$

$$\overline{x_{ij}} = \left(\overline{l_{ij}}, \overline{m_{ij}}, \overline{u_{ij}}\right) = \frac{1}{k}\left(x_{ij}^1 + x_{ij}^2 + \cdots + x_{ij}^k\right) \tag{2}$$

Table 3. Linguistic variables for rating of variables and criteria.

Linguistic variables	l	m	u
Very Poor (VP)	0	0	0.2
Poor (P)	0	0.2	0.4
Medium Poor (MP)	0.2	0.4	0.5
Fair (F)	0.4	0.5	0.5
Medium Good (MG)	0.5	0.6	0.8
Good (G)	0.6	0.8	1
Very Good (VG)	0.8	1	1

3.2.2 *Step 2: Normalizing a matrix of decision*

As shown in Eq. (3), this step uses a normalization approach for the weights $\bar{x}_{ij}$ to eliminate the different units of measurement.

$$r_{ij,} = \left(\frac{\overline{l_{ij}}}{u_j}, \frac{\overline{m_{ij}}}{u_j}, \frac{\overline{u_{ij}}}{u_j}\right) \quad (3)$$

The formation of the decision matrix depends on combining matrix $[r_{ij}]_{mxn}$ with the vector $[\overline{w}_i]_{1xn}$. In this situation, r_{ij} is the normalized value of $\bar{x}_{ij}$, knowing that $u_j = \max_i u_{ij}$ and $l_j = \min_i l_{ij}$.

3.2.3 *Step 3: Normalizing the weighted matrix of decision*

The following Eq. (4) shows how we multiply each alternative weight by each criterion weight to attain the weighted normalized fuzzy decision matrix.

$$V = [v_{ij}]_{m\,x\,n}, where\ v_{ij} = r_{ij} \otimes w_i \quad (4)$$

3.2.4 *Step 4: Defining Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS)*

Here, we identify the fuzzy positive ideal solution (FPIS), as well as the fuzzy negative ideal solution (FNIS). Knowing that the normalized values of V_{ij} are from 0 to 1, we deduce that the FPIS is (1,1,1), and the FNIS is (0,0,0). Eqs. (5) and (6) show how these values are used to calculate the distance from the positive ideal (d_j^+) and the negative ideal (d_j^-) solutions for each alternative.

$$d_j^+ = \sum_i^n d(v_{ij}, FPIS) \quad (5)$$

$$d_j^- = \sum_i^n d(v_{ij}, FNIS) \quad (6)$$

3.2.5 *Step 5: Compute the separation measures*

Distance between $A = (l_A, m_A, u_A)$ and $B = (l_B, m_B, u_B)$ is calculated using Eq. (7).

$$d(A,B) = \sqrt{\frac{1}{3}[(I_A - I_B)^2 + (m_A - m_B)^2 + (u_A - u_B)^2]} \quad (7)$$

3.2.6 *Step 6: Calculate the relative closeness coefficients*

The closeness coefficient CC_i is defined to determine the ranking order of all alternatives. The index CC_i indicates that the alternative is close to the FPIS (d_j^+) and far from the FNIS (d_j^-). The closeness coefficient of each evaluated alternative is calculated using Eq. (8).

$$CC_i = \left(\frac{d_i^+}{d_i^+ + d_i^-}\right) \quad (8)$$

3.2.7 *Step 7: Ranking of alternatives*

The rating from decision makers are aggregated, and the closeness coefficients for the alternatives are 0.4606, 0.4847, 0.5357 and 0.5067 respectively. Hence, alternative 3, Lightweight Concrete Panel, is found to be the most sustainable wall material as per the developed Fuzzy TOPSIS model.

4 CONCLUSION

In this study, Fuzzy TOPSIS is used as MCDM technique for selecting the optimum sustainable wall building material. The selected technique proved efficient in handling contradicting nature of sustainability objectives and incorporating linguistic preferences of experts. A generic model is developed using environmental (potential for recycling and amount of wastage during construction), socio-economic (cost per m^2 and labor productivity) and technical (fire resistance and thermal insulation) criteria. Traditional block, sandwich block, lightweight concrete panel, and AAC panel were considered as alternatives. A case study with experts from UAE construction industry took place to validate the model. The case study revealed that lightweight concrete panel is the most sustainable alternative for building wall material. The developed model is generic and can be applied to any construction site to reflect decision-makers' opinions and preferences.

References

Akadiri, P. O., Olomolaiye, P. O., and Chinyio, E. A., *Multi-Criteria Evaluation Model for the Selection of Sustainable Materials for Building Projects*, Automation in Construction, 30(3), 113-125, March, 2013.

Aruldoss, M., Lakshmi, T. M., and Venkatesan, *A Survey on Multi Criteria Decision Making Methods and Its Applications*, American Journal of Information Systems, 1(1), 31-43, January, 2013.

Bartlett, E., and Howard, N., *Informing the Decision Makers On the Cost and Value of Green Building*, Building Research and Information, 28(5-6), 315-324, 2000.

Cole, R. J., and Lorch, R., *Introduction: Knowledge, Values and Building Design*, Wiley, 2003.

Hamdan, S., and Cheaitou, A., *Supplier Selection and Order Allocation with Green Criteria: An MCDM and Multi-Objective Optimization Approach*, Computers and Operations Research, 81(5), 282-304, May, 2017.

Jumarni, R., and Zamri, N., *A New Concept of Fuzzy TOPSIS and Fuzzy Logic in a Multi-Criteria Decision*, Third International Conference on Soft Computing and Data Mining, 161-170, Johor, Malaysia, 2018.

Kabak, M., Köse, E., Kırılmaz, O., and Burmaoğlu, S., *A Fuzzy Multi-Criteria Decision Making Approach to Assess Building Energy Performance*, Energy and Buildings, 72(4), 382-389, April, 2014.

Khoshnava, S. M., Rostami, R., Valipour, A., Ismail, M., and Rahmat, A. R., *Rank of Green Building Material Criteria Based on the Three Pillars of Sustainability Using the Hybrid Multi Criteria Decision Making Method*, Journal of Cleaner Production, 137(1), 82-99, February, 2018.

Kivilä, J., Martinsuo, M., and Vuorinen, L., *Sustainable Project Management Through Project Control in Infrastructure Projects*, International Journal of Project Management, 35(6), 1167-1183, Aug, 2017.

Obafemi, A. O., and Kurt, S., *Environmental Impacts of Adobe as a Building Material: The North Cyprus Traditional Building Case*, Case Studies in Construction Materials, 4(6), 32-41, June, 2016.

Pohekar, S. D., and Ramachandran, M., *Application of Multi-Criteria Decision Making to Sustainable Energy Planning—A Review*, Renewable and Sustainable Energy Reviews, 8(4), 365-381, August, 2004.

Rezaei, J. and Ortt, R., *Supplier Segmentation Using Fuzzy Logic*, Industrial Marketing Management, 42(4), 507-517, May, 2013.

Scofield, J. H., *Do LEED-Certified Buildings Save Energy? Not Really…*, Energy and Buildings, 41(12), 1386-1390, December, 2009.

Small, E. P., and Al Mazrooei, M., *Evaluation of Construction-Specific Provisions of Sustainable Design Codes and Standards in the United Arab Emirates*. Procedia Engineering, 145, 1021-1028, 2016.

Velasquez, M., and Hester, P. T., *An Analysis of Multi-Criteria Decision Making Methods,* International Journal of Operations Research, 10(2), 56-66, February, 2013.