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 \textit{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 \textit{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 réalité (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 Ort 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.

\[
\begin{align*}
\text{Step 1: Establish a matrix of decision} \\
\text{Step 2: Normalize a matrix of decision} \\
\text{Step 3: Normalized the weighted matrix of decision} \\
\text{Step 4: Determine the positive ideal solutions and negative ideal solutions} \\
\text{Step 5: Compute the separation measures} \\
\text{Step 6: Calculate the relative closeness coefficients} \\
\text{Step 7: Rank the final alternatives order}
\end{align*}
\]

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.

<table>
<thead>
<tr>
<th>Type of Criteria</th>
<th>Criteria</th>
<th>Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental Criteria</td>
<td>Potential for recycling and reuse</td>
<td>C1</td>
</tr>
<tr>
<td></td>
<td>Amount of waste during use</td>
<td>C2</td>
</tr>
<tr>
<td>Social-Economic Criteria</td>
<td>Cost per $m^2$</td>
<td>C3</td>
</tr>
<tr>
<td></td>
<td>Labor productivity</td>
<td>C4</td>
</tr>
<tr>
<td>Technical Criteria</td>
<td>Fire resistance</td>
<td>C5</td>
</tr>
<tr>
<td></td>
<td>Energy saving and thermal insulation</td>
<td>C6</td>
</tr>
</tbody>
</table>

### Table 2. List of investigated alternatives.

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional Block (Concrete Block)</td>
<td>ALT 1</td>
</tr>
<tr>
<td>Sandwich Block</td>
<td>ALT 2</td>
</tr>
<tr>
<td>Lightweight Concrete Panel (Sandwich Panel)</td>
<td>ALT 3</td>
</tr>
<tr>
<td>Autoclaved Aerated Concrete Panel</td>
<td>ALT 4</td>
</tr>
</tbody>
</table>

Using Fuzzy set theory, linguistic variables defined by the decision maker $D_k$, where $k = 1, ..., K$, gives a linguistic weight transformed into a Triangular Fuzzy Number (TFN) $w_{ki}$, to each criterion $i$, where $i = 1, ..., n$, and a linguistic weight transformed into TFN $x_{ij}$, to each alternative, where $j = 1, ..., m$, 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).

$$
\overline{w}_i = \left( \overline{l}_i, \overline{m}_i, \overline{u}_i \right) = \frac{1}{k} \left( w_i^1 + w_i^2 + \cdots + w_i^k \right)
$$

$$
\overline{x}_{ij} = \left( \overline{l}_{ij}, \overline{m}_{ij}, \overline{u}_{ij} \right) = \frac{1}{k} \left( x_{ij}^1 + x_{ij}^2 + \cdots + x_{ij}^k \right)
$$

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

<table>
<thead>
<tr>
<th>Linguistic variables</th>
<th>l</th>
<th>m</th>
<th>u</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Poor (VP)</td>
<td>0</td>
<td>0</td>
<td>0.2</td>
</tr>
<tr>
<td>Poor (P)</td>
<td>0</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Medium Poor (MP)</td>
<td>0.2</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>Fair (F)</td>
<td>0.4</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Medium Good (MG)</td>
<td>0.5</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>Good (G)</td>
<td>0.6</td>
<td>0.8</td>
<td>1</td>
</tr>
<tr>
<td>Very Good (VG)</td>
<td>0.8</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

#### 3.2.2 Step 2: Normalizing a matrix of decision

As shown in Eq. (3), this step uses a normalization approach for the weights $\overline{x}_{ij}$ to eliminate the different units of measurement.
\[ r_{ij} = \left( \frac{l_{ij}}{u_{ij}} - \frac{m_{ij}}{u_{ij}} + \frac{m_{ij}}{l_{ij}} \right) \]

The formation of the decision matrix depends on combining matrix \([r_{ij}]_{m \times n}\) with the vector \([\bar{w}_i]_{1 \times n}\). In this situation, \(r_{ij}\) is the normalized value of \(x_{ij}\), 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.

\[ V = [v_{ij}]_{m \times n}, \text{where } v_{ij} = r_{ij} \otimes w_i \]  

### 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.

\[ d_j^+ = \sum_i a(v_{ij}, \text{FPIS}) \]
\[ d_j^- = \sum_i a(v_{ij}, \text{FNIS}) \]

### 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).

\[ d(A, B) = \frac{1}{3} [(l_A - l_B)^2 + (m_A - m_B)^2 + (u_A - u_B)^2] \]

### 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).

\[ CC_i = \left( \frac{d_j^+}{d_j^+ + d_j^-} \right) \]

### 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 m² 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


