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SYSTEMATIC APPROACH OF SELECTING BUILDING MATERIALS USING VALUE ENGINEERING CONCEPT

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ABSTRACT

The selection of building materials from various available alternatives is a critical process that gets affected by lots of complicated factors. Every single element in the building has a specific function to perform. This necessitates a sound selection of material from the various alternatives, which normally differ in their quality, performance, and cost. To make the most valuable choice, the owner's desire is to perform the function with the maximum quality and to reduce the cost to the minimum, which is the principle of value engineering. The implementation of a value engineering process is challenging, and it needs much effort and many brainstorming sessions to be achieved. Therefore, this study will propose a concept of systematic approach to automate the value engineering process and integrate it with the decision-making process to select building materials. This process can be accelerated and facilitated by using an innovative computer technology such as building information modeling (BIM) that has been widely used in the architecture, engineering, and construction industry (AEC). In this paper, exterior walls elements will be studied as an example. A determination must be done to identify the criteria affecting the selection and how far it is related to achieving the goal of the project.

Keywords: Value, Quality, Evaluation, Building, Materials, Specification.

INTRODUCTION

World Construction Industry is one of the biggest industries in the whole world. It has come up as a basis for judging the economic condition of a certain country [1]. Locally, construction industry is considered the second biggest industry in Saudi Arabia, contributing to the development of a country where billions of dollars are being spent on different types of projects, including residential, commercial, educational, administrative, industrial, and sports buildings [2].

A tangible part of the construction project cost depends on building materials. The specified materials and the proposed construction details have an important bearing on the cost of the project [3]. Therefore, the design engineer should be always confidant about the design he/she proposes and the ideal choice he/she makes. To make the most valuable choice, the owner's desire is to perform the function with the maximum quality, and to reduce the cost to the minimum. Therefore, the following formula of value ratio is devolved by [4].

$$Value = \frac{Function + Quality}{Cost} \tag{1}$$

As for the cost factor, it is easy to compare numbers, but it is not that simple for quality. Quality must be evaluated and scored. Therefore, quality criteria must be defined and weighted. A calculation method must be developed and BIM can be adopted to facilitate data input and output. This will be the focus of the present research. A systematic approach will be proposed and building exterior walls elements will be studied as an example. The research will therefore be of a practical value to the design engineer endeavoring the process of selecting and specifying building materials. It will also be a significant step towards defining total building quality.

LITERATURE REVIEW:

Multiple Criteria Decision Making (MCDM)

International Society on Multiple Criteria Decision Making (MCDM) identified the definition of MCDM as follows: "The study of methods and procedures by which multiple and conflicting criteria can be incorporated into the decision process". All MCDM problems have the following common characteristics. Those would be summed up in the multiple objectives and attributes, in addition to the clear inconsistency between criteria and incommensurable units. The researcher should formulate his/her model preferences for the selection of the best possible compromise solution in order to resolve such Multi-Criteria Problem. The decision maker plays a crucial role in dealing with the MCDM problem, i.e., he/she cannot replace any followed method, no matter how good the other method is, neither any method itself can identify the ideal solution to a given situation. Under the best possible estimates, the decision maker can only use the method in order to enhance the basis of the effective decisions taken, furthermore, to ensure a higher quality of the decision-making process. In that regard, it should be recalled that several MCDM methods have been improved and they are extensively used.

Many researchers have deeply discussed this issue of material selection decision through many approaches in the literature. [5] have proposed an intelligent synthesis of a conjoining the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) with Analytic Hierarchy Process (AHP) to the right selection materials. After all, this method implies a great number of comparisons that become those methods impractical to solve problems with a large number of alternatives and criteria usually found in the construction industry.

[6] proposed additional alternative approaches for material selection called Optimal Scoring Method (OSM) that grants a single eligible score that can be utilized to enhance the materials classification process. Also, it grants the user the prioritization technique for a ranking-based classification of the materials even in situations where a sizeable number of materials and evaluation criteria are taken into account. Although the use of OSM must facilitate the input from decision maker, it does not grant an output of accurate results. It can only provide a wide range of material alternatives that varies according to the proposed weights. In many cases, particularly in the case that decision makers are confronted with insufficient and vague information, [7] appointed clearly that it would be appropriate to use Fuzzy approach when the modelling of human knowledge becomes totally necessary. Another situation use is when human evaluations are absolutely essential. Fuzzy set theory is approved to deal with the significant modelling problem and the adopted technique of its solution. Therefore, MCDM became one of the sections where fuzzy set theory had a wide application area.

Example of Exterior Walls Materials Evaluation Criteria:

It is normal that several solutions are usually taken into account in the selection of the best building design alternative available. These solutions should be optimally evaluated from the perspective of a number of quantitative and qualitative criteria [8]. Some researchers restrict themselves to evaluating the material alternatives according to cost and environmental criteria [9-11]. Other studies focused on evaluating energy criterion versus cost criterion in comparing alternatives [12].

On the other side, some researchers evaluate material alternatives as per various criteria including quality, performance, durability, and cost [8,13, 14]. It will be presented here a literature review of the quality criteria affecting exterior walls materials selection:

I. Wind Load Resistance

The enclosure is encountered by considerable exterior loads that must be resisted, such as (wind, weather variability, temperature range, blast, etc). But wind pressure stands as one of the more significant loads that affect the facade [15]. Winds are one of the biggest issues that must be encountered by roofs and cladding. Sometimes, hurricanes and tornadoes bring winds exceeding the designed tolerance capacity [16].

II. Thermal Insulation:

The building's exterior wall unceasingly interacts with the outside environment. Since the outside air temperature and solar radiation continuously fluctuate during the day, the outside surface temperature of the walls is seriously affected, leading to fluctuations in the heat flux passing through them to the inside. Accordingly, that may significantly change the indoor environment. Consequently, it should be given a major importance to the exterior walls design [17]. The role of walls containing thermal insulation is not limited only to create a more convenient indoor thermal environment but also ensure the energy consumption saving of the heating or air conditioning system.

The Construction Industry considers the improving of building energy efficiency and reducing building energy consumption are urgent problems. According to the composition of building energy consumption, the main factor affecting energy consumption is the thermal performance of the building exterior wall [18].

III. Weight

It is much better to exterior walls to be made of lightweight materials, to avoid any overload bearing on structural elements, particularly when the height of the story level is high, or when the exterior walls are loaded on the cantilever. Accordingly, we can reduce the structural elements volumes, as well the lightweight materials of façade should be more easy to be transported, and to ensure its more comfortable in the execution and maintenance process.

IV. Sound Transmission

As stated by [19], exterior noise may negatively affect human health. Continuous noise is a burden on our general physical well-being and our immune system. In addition, physical reactions can be triggered even at very low levels and lead to headaches, excessive irritation and sleepiness. On the basis of such findings, maximum admissible noise levels are identified for urban planning, thus it is strongly required to specify the sound insulation to be provided by the exterior wall. The purpose of this insulation requirement is to limit effectively the interior building noise level that caused by the exterior one. The essential requirements that are necessary to remedy exterior noise depend largely on the predominant exterior noise level and the permissible and actual noise levels within the building. The thermal insulation materials contained into exterior walls can either enhance or worsen the sound insulation, and that can be accomplished on basis of the system.

V. Fire Resistance:

The key issues for facades security are the preventive measures against fires, in order to prevent and delay the spread of fire, and to push heat and smoke to escape as quickly as possible. The fire protection and smoke control properties of a facade are crucial for preventive measures of fire protection and thus for the human life and property protection. A general building code is adapted to prevent fire spreading from one storey to the storey above in buildings. This code is fulfilled through providing incombustible materials [20]. Today various combustible materials are preferably used in wall assemblies to enhance energy performance, reducing water and air infiltration, in addition to ensure the flexibility of an aesthetic design. These assemblies include

Exterior Insulation Finish Systems (EIFS), metal composite claddings, high-pressure laminates, and weather resistive barriers (WRB). These exterior wall systems are typically complex assemblies of various material types and layers, sometimes including insulation layers and vertical cavities. For this reason, fire resistance of exterior walls must be evaluated.

VI. Water Penetration Resistance

Precipitation, in the form of rain, snow, sleet, hail, and humidity, they all are considered different forms of water, and water must be positively managed in the exterior walls. Water management involves water penetration and discharge. It is strictly necessary to adopt an effective technique for water management and discharge to the exterior wall, avoiding any penetration of water to the interior occupied spaces. Materials such as concrete, masonry, wood, and stone contain different levels of porosity. If these materials should be included in the exterior wall design, additional material(s) must be incorporated in conjunction with these cladding materials. Either porous materials must facilitate the water storage, which can be released to the exterior after the removal of water source, or the exterior wall system must include a combination of water impervious flashings, gutters, and drainage openings to control and discharge water to the exterior when these materials are present. All this variety of options must be evaluated due to their consequences on other criteria. [21].

VII. Aesthetic

To large extent, exterior walls are estimated as the most significantly distinct and notable artistic feature of a building. They are the most inevitable and recognizable elements of a building. They involve a key role as a carriage for architectural impact. In many projects, the aesthetic criterion involves the crucial role in the façade material selection. Also, the façade cost may be increased dramatically as per its aesthetical appearance.

VIII. Maintainability and Durability

All enclosures seriously need a good maintenance to maximize their service life—ranging from cleaning the glass and metal surfaces to repair of materials or replacement. [22] defines the maintainability as ‘the probability of restoring a failed item to operational effectiveness state within a given period of time if the repair process is performed in accordance with prescribed procedures.’ This, in turn, can be paraphrased as ‘The probability of repair in a given time’. To distinguish between Maintainability and Durability term, [23] defines Durability as ‘the ability of a product to perform its required function over a lengthy period under normal conditions of use without excessive expenditure on maintenance or repair’.

Building Information Modeling (BIM)

Building Information Modeling (BIM) is defined as a model-based technology linked with a database of project information that can be accessed, manipulated, and retrieved for construction estimation, scheduling, and project management. The approach of this building design can enhance higher productivity and improved quality, securing project delivery time at minimum cost [24]. In fact, through a BIM model, the user can take out the geometric data and other relevant necessary data for design enhancement, such as procurement, fabrication construction, maintenance, plus any other activities and technical tasks related to the building during its lifecycle [25]. Additionally, BIM tools also grant a proper platform to implement additional features for performance assessment to a building model [26]. BIM is truly advantageous due to its smart functionality to share and distribute the technical data between several stakeholders during all stages of a project ranging from the predesign phase to the operation phase. In one of BIM software such as Autodesk Revit, it grants share "Application Programming Interface" (API) that enhances the possible efficiency to integrate external applications into Revit. Accordingly, Revit ensures the capacity for applying any external features to a BIM model.
Furthermore, depending on the database, various dimensions of the BIM approach can be distinguished, 3D, 4D, 5D, … nD. Each dimension refers to specific type of data (Cost, Scheduling, Sustainability … etc.). [27]. These extension dimensions used to enhance the fully

automation of the model during the project life cycle of the project. This research can be developed to establish a new BIM dimension related to the value engineering.

THE PROPOSED APPROACH

The goal of the proposed approach is to select the most valued material. As shown in (Fig. 2), the proposed approach flowchart defines the required inputs and the selected methods. Then, it goes through the evaluation process. finally, it will be linked with the BIM Model to facilitate data input and automate the calculation process accordingly. More detailed explanations are followed below.

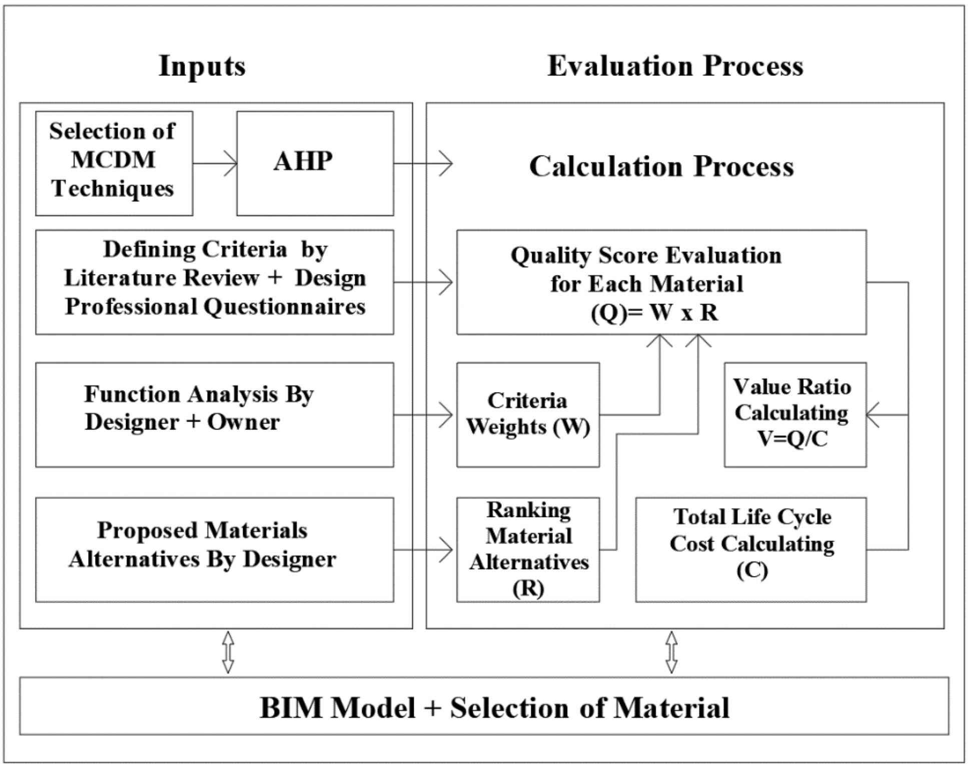

Fig. 2: The Proposed Systematic Approach of Material Selection

Selection of MCDM Techniques.

Prior to the selection of MCDM techniques, it is essential to describe the current problem correctly: Evaluating materials for exterior wall. It is affected by multiple criteria that need to be weighted in a consistent way that handles the correlations between criteria. Also, Decision makers usually include client who needs an easy way to weight.
A comprehensive review table (Table 1) of MCDM Techniques is introduced by [28]. It shows the features of each MCDM technique. In this research, the decision-making problem of evaluation building materials requires a consistent and easy way that handle correlations. Thus, according to the table, the appropriate options will be AHP, and ANP. Moreover, as it is not complex problem, thus the selection of the proposed approach will be for AHP method.

Table1: Comprehensive review of MCDM techniques.

MCDM Methods	Consider Uncertainty	Incorporate Preferences	Comprehensive	Handle interdependencies	Easy to use	Individual Assessment	Effective	Handle Complex Problems	Based on Similarity	Self-learning	Consistent	Expandable	Measure Efficiency	Handle imprecise data	Handle various criteria units	Ranking of Alternatives	Weighting of Coefficients	Simple computation	Handle correlation
MAUT (Keeney, 1977)	✓	✓	✓													✓		✓	
AHP (Saaty, 1980)		✓			✓						✓					✓	✓		✓
ANP (Saaty and Brady, 2009)		✓		✓	✓			✓			✓	✓				✓	✓		✓
FT (Zadeh, 1965)	✓		✓			✓	✓	✓		✓	✓			✓					
CBR (Daengdej et al., 1999)					✓				✓	✓		✓		✓					
DEA (Charnes et al., 1978)				✓				✓					✓			✓	✓		✓
TOPSIS (Hwang and Yoon, 1981)					✓			✓	✓		✓					✓		✓	
Pugh Matrix		✓					✓	✓	✓		✓		✓	✓	✓	✓		✓	
SMART (Olson, 1996)	✓	✓	✓		✓												✓		
GP (Charnes and Cooper, 1961)			✓		✓			✓			✓	✓						✓	
SAW (Zionts and Wallenius, 1983)					✓											✓	✓	✓	
ELECTRE (Roy, 1968)	✓	✓												✓		✓			
PROMETHEE (Brans and Vincke, 1985)		✓	✓		✓			✓						✓		✓	✓		✓

Setting Evaluation Criteria:

In this step, quality and performance criteria that affect the process of evaluating and selecting various types of material must be plainly stated. In addition, the literature review and the investigations of professional engineers may be used. Cost-related criteria, including initial and life cycle cost, will not be stated in this step, since the cost is separated from quality in the value formula (Equation 1). To simplify the evaluation process, the unrelated criteria, should be eliminated.

Setting Project Goal and Function Analysis:

The selected building materials must achieve the project goal. Therefore, the owner and the design team must state the project goal and functions in the early stage of the project. Goals are essential to know the “what” and the “why” of the design. Additionally, function analysis is an essential part of the value engineering process. Material criteria cannot be weighted if the function analysis of the project is not fairly defined. For example, the weight of the esthetical criterion for a hotel building is higher than a warehouse building so the material that has more esthetical rank will be preferred.

Criteria Weight Evaluation

As the criteria are not equally important, it must be weighted in some way that matches the project goal. [29] stated that there are many researchers who don't give attention to the difficulty in estimating the criteria weights and they suppose that all decision makers understand the meaning of criteria. The decision for choosing the appropriate weighting method is significant in solving any MCDM problems. As noted above, the selected MCDM for this research is AHP which uses the pairwise weighting method. Furthermore, the function analysis must be integrated with the criteria weight. Therefore, the criteria will be assigned to the Function Analysis System Technique (FAST) diagram. Each criterion will be attached to its relevant function. Some criteria may be relevant to more than one function. After criteria integration, all criteria must be evaluated with the assigned weights. Weights will be given at each level of the diagram.

Ranking Material Alternatives:

After defining all criteria and giving them their respective weights, the materials alternatives that have been nominated by the designer must be identified and their quality criteria shall be recognized. Therefore, this will require a full survey for data to measure each criterion. Sources include manufacturer's information, manuals, catalogs, information available from contractors, special consultants, and other literature. [30]. If the criterion is not able to be measured, the design professional will give the rank according to his/her experience. For example, the criterion of wall thermal resistance seems easy to be measured and can be obtained from its factory, or according to performance tests. On the other hand, the esthetic of a wall is perceived as an unmeasurable criterion, because it cannot be measured in a straightforward manner. In conclusion, objective criteria will be ranked according to the material data and specifications whereas subjective criteria will be ranked according to design professional expertise. The ranking takes into consideration how each alternative compares with the criteria. Ranks are as follows: excellent (5); very good (4); good (3); fair (2), poor (1), null (0). After ranking all criteria, the rank matrix should be normalized. Linear Scale Transformation, Max Method (LSTMM) will be adopted [31].

Total Quality Scores Calculation

To calculate total quality scores for each criterion, the ranks will be multiplied by the corresponding weight of the criterion, and the resulting total quality scores will be established for each material alternative. A numerical example in Table 2 is provided to explain the calculation clearly.

Table 2- Total quality scores numerical example

Criteria	Weights	Aluminum Cladding Ranks	Stone Finish Ranks	Paint Finish Ranks
C1: Wind Load Resistance	20%	0.80	0.60	1.00
C2: Esthetic	30%	1.00	0.80	0.60
C3: Thermal Insulation	50%	1.00	1.00	0.90
Q Scores= W * R		0.96	0.86	0.83

Value Scores Calculation

The most flawless choice will be the material which has the maximum score and the least life cycle cost. Then, initial and maintenance cost per unit of each material must be given by factories or contractors. Initial cost must include material and its installation cost. Then, the cost will be normalized. Finally, the value ratio for each material alternative is the ratio of the material normalized quality score to the material normalized cost. For more clarification a numerical example in Table 3 is provided. It shows that although the paint finish material is the lowest quality, it is the highest value and it should be selected.

$$V = Q/C \qquad (2)$$

V= Material value
Q = Material quality score
C = Material normalized cost

Table 3- Material values numerical example

Criteria	Aluminum Cladding Ranks	Stone Finish Ranks	Paint Finish Ranks
Q - Material quality score	0.96	0.86	0.83
C - Material normalized cost	1.00	0.86	0.45
V - Material value	0.96	1.00	1.84

Linking Evaluation Process with the BIM Model

It will be more value if the proposed approach integrated with the BIM model. To achieve that, all studied material types with their properties and criteria values must be embedded in BIM model. The evaluation process must be linked these data with BIM model via the API platform. Once material type is selected, it will automatically calculate the criteria scores, the quantity, and the total cost. This will help the decision maker to note the impact of their choices instantly.

CONCLUSION

Selecting building materials has a direct impact on the project value. Value engineering is a process to improve the quality and functionality and to reduce the cost. This paper proposed a concept of systematic approach to facilitate the material selection with the maximum value. A literature review of the related studies was presented. As an example of the materials, exterior walls materials were selected. The criteria affecting the selection of exterior walls materials were explored. Analytical Hierarchy Process (AHP) was selected as the suitable Multi Criteria Decision Making (MCDM) technique to deal with the material selection. Moreover, an appropriate weighting approach was produced to make sure that the functionality of the project is integrated. Furthermore, the paper proposed to integrate Building Information Modeling (BIM) to automate the process. Finally, a small numerical example was provided to select the most valued material between three alternatives. Only three criteria were considered. It demonstrated that the right decision cannot be judged merely by considering the quality or the cost with connection of Building Function. The right decision considers the value that guaranty the highest ratio of the quality/function to the cost and these process should follow systematic automated approach.

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