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Envelope Building Material Selection for Arid Climate with a Specific Maintainability - Design Approach: A Case Study on Governmental Office Building

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Abstract: ***Cladding System is a complicated problem during the architectural design processes when building is created especially under hot climate conditions. The Multi - Criteria - Decision - Making MCDM along with the Life Cycle Cost LCC Analysis and FAST had been applied to treat the research issue. This study is a benchmark for materials selection of the building envelope based on proposed criteria and designated themes in which they are collected under specific Maintainability Theme. The study had suggested ten selected materials for the building's skin such as Metal Composite Material (MCM), Building Glass Coated, Natural Stone Panels, Wooden Panels, PVC Panels, Polyisocyanurate & Polyurethane (P&P), High Pressure Laminated (HPL) Panel, Fiber Panel and Artificial Stone Panel. The (MCDM) approach is achieved during this study, through Analytic Hierarchy Process AHP, Pairwise and VIKOR techniques. The Life Cycle Cost LCC estimation had also been engaged accordingly. After the VIKOR method, the results inclined into the Reinforced Concrete (RC) as the best among the selected ten materials. After the life cycle cost LCC evaluations, the Metal Composite Materials (MCM) or metallic came at the optimum level because of its recycling value. Delphi technique had taken a place in this research, and as Findings, the Natural Stone came first by experts' assessments. Then, the average value of the three ranking; VIKOR, LCC and Delphi had been merged to determine the best material for selection under the arid climate condition, in which the Natural Stone had appeared as the best selection, then, Artificial Stone and thirdly the Metal (MCM). On the other hand, the lowest preferences are determined for the Wood, Fiber, and PVC respectively. Finally, the results had been taken to explain the material selection issue for the Criminal Investigations Headquarter (CIH) Building in South Surra, where the cover of the selected building is Alcobond, which is one of the (MCM) category or under metallic or alloy group, in which it is presented as third preferences according to the ranking of this study. As Comprehensive results, the Natural Stone would be the optimum among the selected materials for the agent office building's envelope in Kuwait regarding to its highest score in both Maintainability Theme and Life Cycle evaluations.***

Keywords: Building Envelop, High - Performance design, Multi - Criteria - Decision - Making (MCDM), FAST, AHP, VIKOR, Material Evaluation Criteria, Life Cycle Cost (LCC).

1. Introduction

The building cover is the outer surface of a building with a special architectural touches. The function of this skin that is defined by the roof and some exterior walls including doors and some windows is exceeding the overall protection and privacy for the occupants into sustainable system that interact with the outdoor environment. The surrounding context is affecting the building envelope that has a widely meaningful applications in the field of construction. The key purpose of that envelope is to isolate the indoor atmosphere from the outside maintaining the indoor comfort zone level within specific targeted temperatures (Turgut D., 2007). The the non - load - bearing exterior walls have specific structural specifications including breaking strength, tensile and compressive abilities to protect the interior spaces against the environmental effects, solar radiation or temperature loads, wind loads, snow loads, or heavy rain loads, where all these loads form some natural forces on the building envelope. Furthermore, the architectural design including the esthetic and social factors, should also be approved (Kenney & Sams, 2017). The architectural design of the building creates the identity for the city emphasizing the belongings of heritage and history, then it is highly significant to give the building a cultural value. The aesthetic of the building is a subjective dimension but, it works as one of the main part or important factors of building architecture during the overall building evaluation in terms of its quality or performance. As known, The building envelope, which is stayed by the structural skeleton, served as a thermal buffer between the air - conditioned spaces or the enclosed inner system and the external climate in which the thermal energy is transmitted, then heating and cooling would be minimized substantially by lowering the heat flow into the building cover. It is necessary to reduce the HVAC loads in buildings by sensibly taking the care about some important parameters like orientation of the building, form, walls materials, fenestrations including windows and doors entrances, shading apparatus like canopies, and roof system. The AC loads can also be lowered by passive cooling strategies or by technology when using automated sensory systems.

Life - cycle costing (LCC) and life - cycle assessment (LCA) methods found to control how a building can work over its lifespan, through development, construction, other related services, renovation, repair, reconstruction, and destruction of the raw materials (Flager F., et., 2012). The LCC is monitored by some economic factors like cost of production and operations, as well as the cost of maintenance. The age of the building materials, and its constructions i. e., the

entire cost - cradle to grave - can be evaluated using both (LCA) and (LCC) methods.

A few studies assessed the building envelope from the life cycle aspect. The study of (Kaur S., 2020) mentioned an interactive method for estimating the effect of pollution, and its related costs to maintain the building envelope within the life cycle. Other studies such as (Bhishara, 2018) suggested applying the multi - objective optimization to the design envelope of the building taking into consideration the costs of the related impacts.

The exterior frame of the building which includes the roof, floor, walls, and windows conveys the embodied energy and their connected costs, thus plays the big role in the economic stages of construction. It is basically known that the roof floor itself carries 33% of thermal load more than the below floor, then it is important to consider treating this issue.

The LCC is an economic calculation of the competitive options for the building skin, considering the substantial ownership costs of each solution over existence thus includes the energy analysis model which is a key tool in assessing the cost - effectiveness of adopting energy conservation phases which leads to higher initial costs than other options (Corgnati S., et., 2007).

The design options for the building's envelope would include standards and designed criteria related to sustainability, maintainability, buildability along with other specific designed approach, beside the LCC that includes the initial and operational costs. Then the area of a decision - making for the selection of an appropriate building materials for the envelope is will be a critical step, where the LCC is increasing the area of the framework in this case.

The different types of exterior materials consist sometimes of small systems through air - film, double or triple façade in case of glazing, as well as the thermal braker, insulation material and thicknesses in (mm) of each components of the chosen option. The amount or concentration of the ingredients for some materials like masonry or concrete effect somehow the structural performance and environmental interaction of these blocks or panels. The concentration of cement in the reinforced concrete (RC) panels or the voids between the masonry blocks affect thermal and strength performance of these construction materials that create some important factor for study and research.

The purpose of this research is to create a benchmark for materials selection of the building envelope on the basis of the life cycle cost and specific criteria for buildings performance that reflects its maintainability. This study is a guide for clients, owners, project directors including architects, engineers, and contractors to choose high - quality materials for the governmental office buildings in Kuwait and GCC Areas.

2. Literature Review

In façades design, the choice of constructive solutions plays a significant role (Ferreira C. et, 2021). Building envelope design is affected by a variety of determinants such as specifications for structural efficiency, environmental control, and aesthetic form. The study (Harry, 2016) proposed 14 factors defined as working criteria for building skin such as (Heat flow, Air flow, Water vapor flow, Rain penetration, Radiation control, Noise control, Fire control, Structural safety (strength and rigidity), Durability, Aesthetic, Cost, Buildability, Maintainability and Special requirements.

The Multi - Criteria - Decision - Making (MCDM) including VIKOR methods that aims to complete decision - making on existing alternatives by ranking and picking sample sets with conflicting criteria as per the study of (Mesran M., et, 2019). On the other hand, The Analytic Hierarchy Process AHP (Aziz N, et., 2016) is a method that is extensively used in decision making along with Pairwise for comparison analysis through matrix processes as per (Modanloo V., et., 2016) study.

2.1 Multi - Criteria - Decision - Making

MCDM is a logical and systematic approach for policy and decision makers to evaluate engineering systems, devices, or materials such as for cladding system as (Ferreira, et., 2021) study that had shown specific factors affect the buildings envelop. MCDM is an organized process that can be used in many fields such as management, business, urban design, and other areas.

2.2 Material Evaluation Criteria:

based on (Eltarabishi, et., 2020), is a way to program the selection where researchers could evaluate according to the cost and environmental criteria, or energy criteria versus cost criteria. On the other hand, some specialists evaluate material, including quality, performance, durability, and overall cost.

2.2.1 Fire Resistance: Designed to resist burning and withstand heat. An example of a fire - resistant material is one which is used in bunker gear worn by firefighters to protect them from the flames of a burning building

2.2.2 Water Absorption: Water absorption is known as "percentage of water saturating the body of a tile, measured under ISO 10545 - 3" determination of water absorption, apparent porosity, apparent relative density, and density.

2.2.3 Chemical Reaction: Chemical resistance refers to the ceramic surface's behavior when exposed to chemicals that corrode it to permanently penetrate it or alter its aesthetic appearance due to its composition and properties.

2.2.4 Maintainability: It measures the easiness of retaining or restoring an item to a particular condition within a given time during the maintenance performance.

2.2.5 Breaking Strength: It is an important criterion that affects the durability of the flooring. The higher breaking strength shows the higher quality of the tiles.

2.2.6 Thermal Insulation: Thermal comfort is a factor that is considered widely in the literature under comfort conditions that can even reduce the operational energy use and the cost due to that.

2.2.7 Sound Insulation: Noise reduction is a comfort criterion present in the literature. The acoustic performance of the material is given importance through this sub - theme.

2.2.8 Buildability: the amount to which a structure's design allows ease of construction, subject to the overall necessities for installing a building, including labors' skills and related preparation equipment.

2.2.9 Social - Culture: which is a restricted subjective by society is a concern since the introduction of materials is in vain if their usage is limited.

2.2.10 Aesthetic appearance: which is a flexible subjective factor that could have varying opinions among several occupants. It is a subjective aspect that could only be concluded based on surveys and opinions.

2.3 Life Cycle Cost

LCC is an important process in construction, where it is a method that abridges all the costs in the life cycle of a product that are directly assumed by one or more contributors in the product system. Based on (Stazi, F., et., 2012) research, the building envelop can be developed when LCC is concerned through solar wall project, which means LCC is part of sustainability and merged within the overall process. However, the LCC is still an estimated futuristic cost, then, there will be still a fuzzy area with less accuracy or assurance. On the Other hand, Embodied energy affects LCC based on (Jayasinghe, 2011) study, where the materials that are formed of cement and soil based alternative materials and systems will reduce the impact of energy use.

2.4 Nature and Performance of materials, it is worthy to say that the masonry structures are hugely durable and need very slight maintenance over their generations [4] comparing to wood. The Metal Composite Materials MCM is known for its high thermal conductivity.

2.5 Experts' judge and decisions during the technical interview is considered as an essential part in evaluation process and parallel in its importance to the international standards like ISO, LEED, BREEAM when assessing materials or proposing or specifying the design criteria for these materials.

3. Research Methodology

3.1 Experts technical Interviews and FAST processes: Specialists' experiences had been considered for electing criteria and creating themes. The Experts had studied and refined the 14 factors of the proposed study of (Harry, 2016) into 10 criteria, by having 8 of them typically. After that, 2 criteria had been added to the list and they are Chemical Reactions and Cultural Value of the Material. Then, the characteristics of the designed theme had been flourished after dividing the 10 selected factors into 4 categories representing the four themes as (Sustainability, Performance, Construction and Architectural Design). During the designation process, Function Analysis System Technique FAST diagram had been applied based on (Orabi 2022), to convert the selected Criteria into an illustration based on expanding the functions of "How" and "Why" within two directions along with the Critical Path as in (Figure 1,) and then, the Functional Hierarchy in (Figure 2) had been applied to order the component of Criteria and themes as it appears in (Figure 3). Finally, the criteria had been determined under specific themes as in (Table 3), and they are they are Fire Resistance, Water Absorption, Chemical Reaction, Maintenance, Breaking Strength, Thermal Insulation, Sound Insulation, Buildability, Social - Culture and Aesthetic.

3.2 Material Selection based on Multiple Criteria Decision Making (MCDM) Methods is a wide field that assists specialists and decision - makers to elect and rank the optimal choice based on specific factors. In this study, MCDM methods will be used to assess elevations' materials by applying the Analytical Hierarchy Process (AHP) method based on the developer (Saaty 1987), and then, taking the average values of (AHP) after experts' evaluation (A. R. Hadadian and A. Rasoulian, 2017) and finally return back to the specialists to validate the results achieving the Delphi Technique as (Grisham, 2009) study, to double - check the calculation process through Excel program. The current steps of the methodology can be explained clearly in (Figure 5).

3.3 The life Cycle Cost LCC is considered in this study for all ten materials: LCC evaluates the cost effectiveness of design decisions, quality of construction and maintenance and is considered to be a strategic process as (Stewart 2001). The costs anatomy in this case consists of initial cost, maintenance, monitoring, and repair cost, costs associated with traffic delays or reduced travel time and failure cost.

3.4 Experts' Interview and testing the proposed framework: The ten criteria had been evaluated by experts by a Likert scale as (Table 1).

Table 1: Likert scale for pair - wise comparison

Value on the Scale	Description
1	Equal importance
3	Moderate importance of one over another
5	Essential or strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values between the two adjacent judgments

3.5 Materials' selection had also been assessment by the Likert Scale as in (Table 2).

Table 2: Likert scale for level of importance

Likert Scale	Description
1	Low
2	Below Average
3	Average
4	Good
5	Excellent

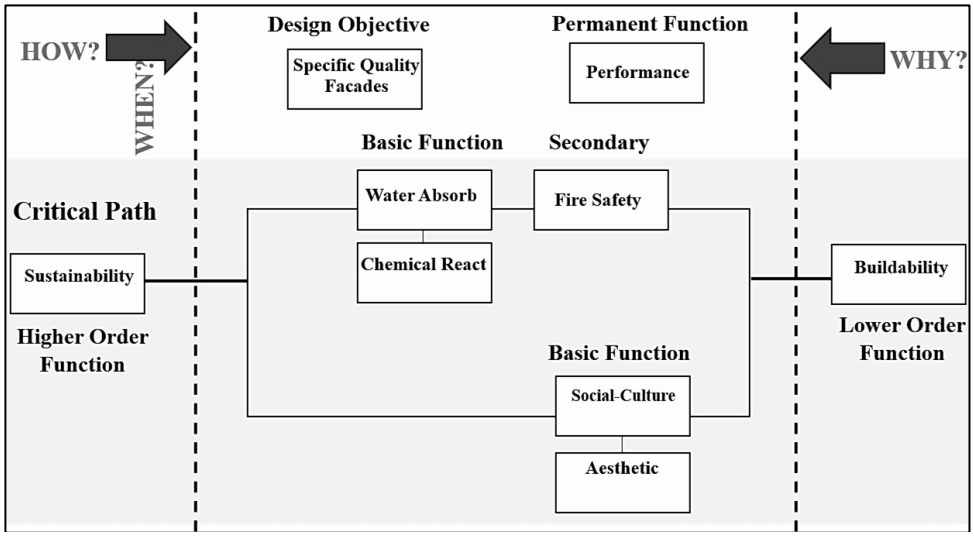

Figure 1: FAST Diagram through the Domain of the Project

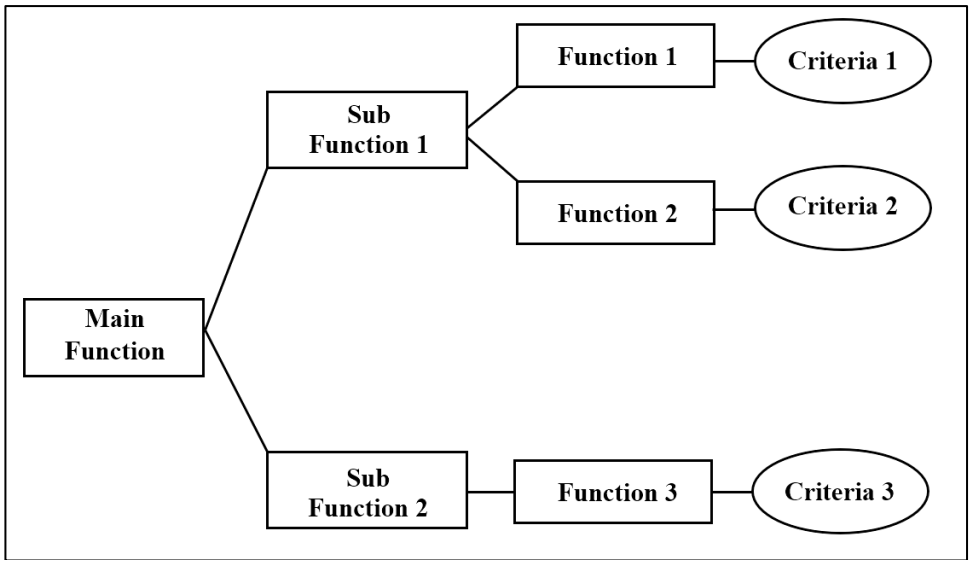

Figure 2: Main Components of FAST Diagram for the Criteria

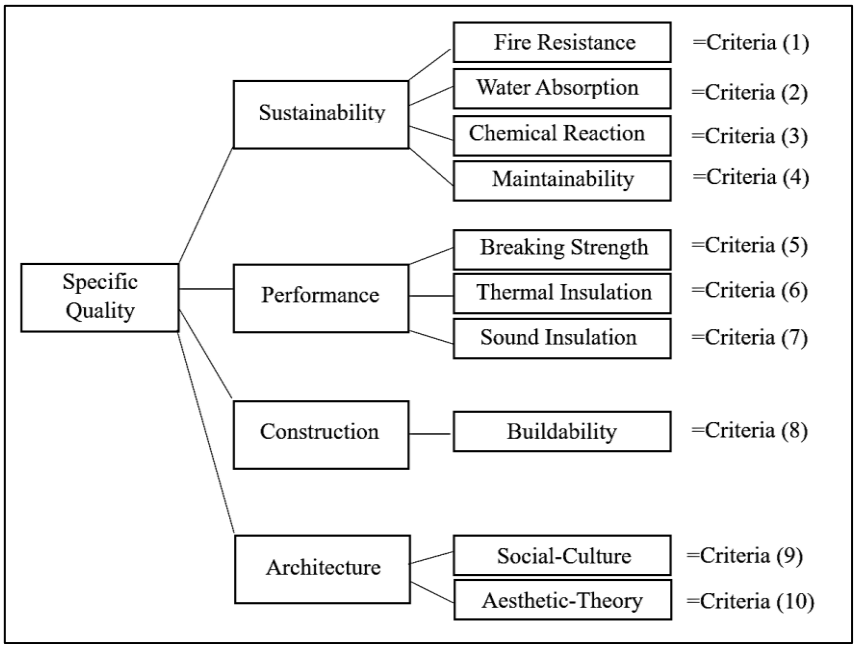

Figure 3: Hierarchy of Themes Maintainability Design Approach

Table 3: High - Quality Performance Theme

#	Sustainability Theme		
1	S1	Fire Resistance	Designed to resist burning and withstand heat. This helps the firefighters to protect the building from the flames.
2	S2	Water Absorption	Water absorption depends on porosity, relative density, and density thus will affect the size of the material which returns back to the building structure.
3	S3	Chemical Reaction	When exposed to chemicals that penetrate or alter the aesthetic appearance due to its composition and properties.
4	S4	Maintenance	The ease of retaining an item to a particular condition within a specific period during the maintenance performance.
#	Performance Theme		
5	P1	Breaking Strength	It is related to durability of the envelope. The higher breaking strength means the higher quality of that material.
6	P2	Thermal Insulation	Thermal comfort or conductivity that can even reduce the operational energy use and the cost due to that.
7	P3	Sound Insulation	Noise reduction is a comfort criterion. The acoustic performance of the material is setting an important aspect for privacy and control.
#	Construction Theme		
8	C1	Buildability	The ease of construction, related to the overall needs, such as importing materials and labors' skills for completing a building.
#	Architecture Theme		
9	A1	Social - Culture	The design expresses the belonging of the society and its traditions and originality. This criterion is also stated the identity of the society.
10	A2	Aesthetic	Aesthetic appearance is a subjective factor and varies among different opinions. It is related to color, reflectivity, texture, and sensible factors.

3.6 Pairwise with its comparison matrix had been applied to the evaluation based on (Jitesh J. Thakkar, 2021).

The methodology of this study had been summarized by using flowchart techniques as shown in (Figure 4).

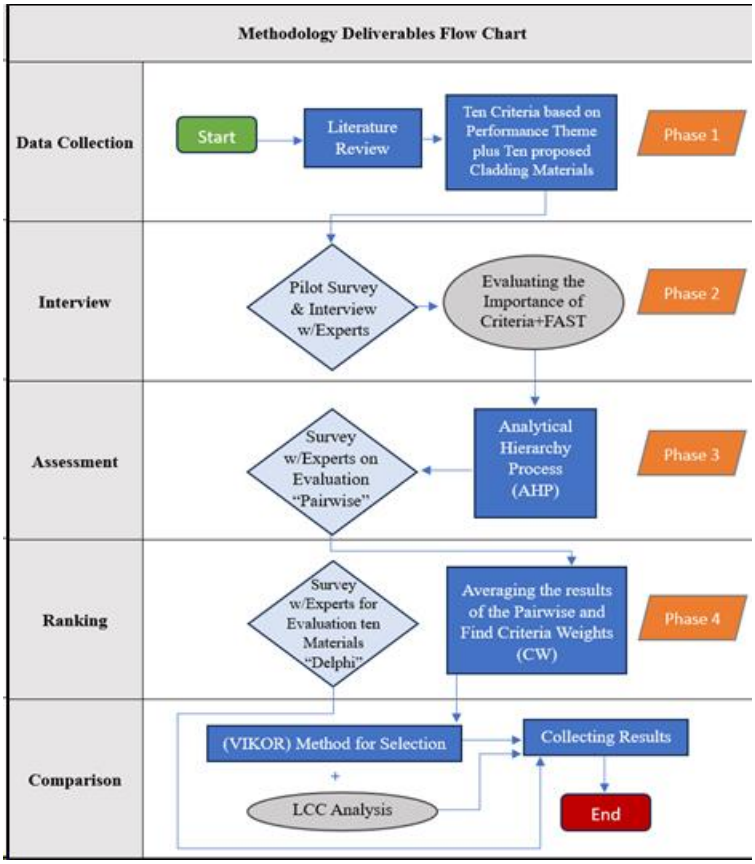

Figure 4: Methodology Deliverable Flowchart

3.7 AHP method

AHP is stands for Analytical hierarchy process (AHP) and developed by Thomas L. Saaty to be one of the most widely used MCDM methods globally (Alireza Alinezhad & Javad Khalili, 2019) due to its simplicity and adaptability with higher accuracy. The procedural steps of AHP are as follows based on

Step 1: Interview of the level of importance as in (Table 4) that referred to the Relative Index as below Table:

RI = Σw / A x N … Equation 1

Where, W: Weighting as assigned by respondent, A: Highest Weight and N: Total Number of Sample

Table 4: Range of Relative Index

Range of Relative Index	Description	Symbol
(0.8≤RI≤1)	High	H
(0.6≤RI<0.8)	High–Medium	H - M
(0.4≤RI<0.6)	Medium	M
(0.2≤RI<0.4)	Medium–Low	M - L
(0≤RI<0.2)	Low	L

Step 2: The comparisons among the themes and the sub - themes are carried out as pairs forming square matrices (n×n) A= [a_{ij}], such that:
$a_{ij}=1/a_{ji}$ and $a_{ii}=1$ for each i, j=1…n … Equation 2

Step 3: The equation for priority vector w is such that:

$Aw=\lambda_{max}$ w … Equation 3

Step 4: Where λmax is the principal Eigenvalue of A; Then the Consistency Index (CI) is calculated using

$CI = (\lambda_{max} - n) / (n - 1)$ … Equation 4

Step 5: Finally, the Consistency Ratio (CR) is computed

CR = CI/RI … Equation 5

Where RI values are shown as the below Table:

Table 5: RI values with the size of the matrix

Matrix Size	1	2	3	4	5	6	7	8	9	10
Random Index	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

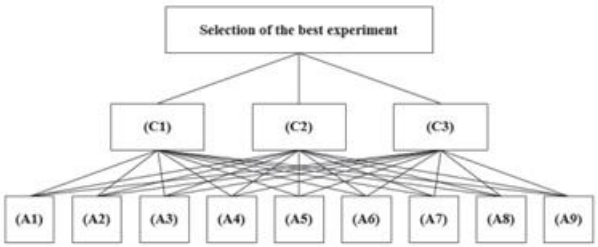

Figure 5: AHP Method

3.8 VIKOR

The VIKOR methods were developed in 1998 by Opricovic. It works based on the best solution obtained from the closest ideal solution, and it is one of multi - criteria optimization and compromise solution. The VIKOR procedures can be summarized within the following steps based on (Alireza Alinezhad & Javad Khalili, 2019):

Step 1: *To find best and worst attributes defines as: and*

$$S^- = \max_i S_i \qquad S^* = \min_i S_i$$ *... Equation 6*

Step 2: *To find best and worst attributes defines as:*

$$R^- = \max_i R_i \qquad R^* = \min_i R_i$$ *... Equation 7*

Step 3: *To find S index defines as:*

$$S_i = \sum_{j}^{m} \left(W_j * \frac{X_i^+ - X_{ij}}{X_i^+ - X_i^-} \right)$$ *... Equation 8*

Step4: *To find R index defines as:*

$$R_i = \max_j \left(W_j * \frac{X_i^+ - X_{ij}}{X_i^+ - X_i^-} \right)$$ *... Equation 9*

Step 5: *To find Q_i defines as: where; (v=0.5)*

$$Q_i = \upsilon * \frac{S_i - S^*}{S^- - S^*} + (1 - \upsilon) * \frac{R_i - R^*}{R^- - R^*}$$ *... Equation 10*

Step 6: *Acceptable Advantage C1*: *Q (A2) - Q (A1) ≥ DQ*, where; *DQ ≥ 1/ (j - 1):* j=No. of Alternatives *... Equation 11 where A1 is Alternative 1 and where A2 is Alternative 2*

Step 7: *Acceptable Stability in Decision Making C2: Alt. (A1) is the best ranked by S or/and R ... Equation 12*

Step 8: if one of the conditions C1 or C2 is not satisfied, then a set of compromise solutions is proposed. Such as:

- *Alternatives 1, 2; (A1) and (A2) if only condition C2 is not satisfied, or*
- *Alternatives (A1), (A2), ..., (Aj) if only condition C1 is not satisfied; and Aj is determined by the Equation 13: Q (Aj) - Q (A1) < DQ for maximum j (the positions of these alternatives are in closeness).*

3.9 LCC Analysis

The equation of LCC is defined as the following based on (Sujeeva S, et., 2002) study, the anatomy of life cycle cost can be obtained as the following equation:

$$C_{lifecycle} = C_{initial} + C_{repair} + C_{user} + C_{failure}$$ *... Equation 14*

$C_{initial}$: Preliminary design cost, startup, material cost and labor cost like supervisors, skilled and unskilled.
C_{repair}: based on (Thoft - Christensen, 2000) the cost can be defined as, functional cost C_1 ($t_{r,\ i}$), fixed - repair cost C_2 ($t_{r,\ i}$), and unit dependent - repair cost C_3 ($t_{r,\ i}$) and can be collected as: /

$$C_{maintenance}(t_{r,i}) = C_1(t_{r,i}) + C_2(t_{r,i}) + C_3(t_{r,i})$$ *... Equation 15*

Then, the Cost of Maintenance would be engaged into Repair Cost as the following where the assumed repair cost discounted to the initial time (t=0) is the sum total of the single repair cost:

$$C_{repair} = \sum_{i=1}^{n} \left(1 - P_f(t_{r,i})\right) C_{maintenance}(t_{r,i}) \frac{1}{(1+r)^{t_{r,i}}}$$

... Equation 16

where (n = number of failures at LCC) and P_f is the informed failure probability at each repair time.
C_{user}: during initial restoration and during the next periodic examination, maintenance, or repair:

$$C_{user} = \sum_{i=1}^{n} C_{user}(t_{r,i}) \frac{1}{(1+r)^{t_{r,i}}}$$

... Equation 17

$C_{failure}$: Failure cost based on two studies (Von Neumann and Morgenston 1944) and (Val and Stewart 2004) could be formulated as:

$$C_F(T) = \frac{c_F}{(1+r)^t}$$

... Equation 18

where C_F is the cost of failure set at the time of decision making, t, the time of failure and r the discount rate, thus, $C_{F(T)}$ is a discrete random variable which at failure time ti assumes different values, ci as:

$$c_i = \frac{c_F}{(1+r)^{t_i}}$$

... Equation 19

with probabilities of occurrence pi, for a single structure, which can fail only once during T years of service, and when C_F is anticipated the same for all failure modes, then the expected cost of failure is calculated according to (Stewart et al., 2004) as:

$$E[C_F(T)] = \sum_{i=1}^{M} p_i c_i$$

... Equation 20

where M is number of points in time at which the possibility of failure occurrence. The failure during its service life the probability distribution of the cost of failure with considering the discount rate is:

$$f(C_F) = \begin{cases} P_f(t_i) - P_f(t_{i-1}) & C_F = \frac{c_F}{(1+r)^{t_i}} \\ 1 - P_f(t_M) & C_F = 0 \end{cases}$$

... Equation 21

where $P_f(t_i)$ is cumulative probability of failure at time t_i (i=1, 2, 3…, M), M the number of point in time at which failure may occur, $t_0 = 0$ and t_M denotes the latest possible time of failure. It is assumed that repair of a failed material occurs after the material is inspected. The time between inspections, where $\Delta t = t_i - t_i - 1$.

4. Case Study

The envelope of the building is affected by the surrounding environment. Kuwait is located at hyper arid desert climate that is highly variable with recurrent extremes. The climate is marked by four distinct seasons, with long, hot, and dry summers and short winters (World Bank). The longitude and latitude of Kuwait lies within 47° 57' 57.923" East and 29° 13' 18.856" North (Metrological). Maximum daily temperatures can reach 45°C during summer in which there is no rainfall. As a Justification for this research, this study is applied on a Criminal Investigations Headquarter Building, as a specific case to generalize it for other agency buildings in Kuwait. The building is defined as a governmental office building under the ministry of interior and located at the ministries area at South Surra area and close to Kuwait Airport area with 46m height above the mean sea level (World Bank). The importance of this is study is to find the appropriate cladding material based on specific criteria that are suitable for the weather of this region and social life and expresses at the same time the high - performance and maintainability. The target for this study is to test and validate the efficiency of the current material which is alcobond – a metal composite material if it is a best choice for the deliverable project, in which it was completed in 2022 and consisted of 5 stories on a plot of 30, 000 sqm and construction cost of 121 million dollars (SSH Int.) The purpose of this study is to create a benchmark for electing the cladding materials at such agency office buildings in Kuwait to achieve the highest performance.

Figure 6: Project Aerial and Perspective Views

4.1 Apply the Designed Criteria and Research Tools on the Case Study

The AHP, Pairwise matrix and VIKOR methods along with LCC calculations had been applied on the selected governmental office building in Kuwait, and the results came as the following:

4.2 Results and Discussion

4.1 The results and analysis of expert's survey carried out as the following tables, where experts show the highest importance (8 points/10) for S1, P1 and P2 in which they are Fire Resistance, Breaking Strength, and Thermal Insulation, respectively. The second importance (7 points/10) for S2 and S3; Water Absorption and Chemical Reaction. The Aesthetic of Architectural Design in which it is a subjective criteria came at the tail of experts' evaluation with (4 Points/10).

Table 6: The level of importance of identified themes after averaging the approximating the evaluation results

1	S1	8
2	S2	7
3	S3	7
4	S4	6
5	P1	8
6	P2	8
7	P3	6
8	C1	6
9	A1	6
10	A2	4

4.2 The results and analysis of the developed framework in comparing materials by the experts as the below: the Likert scale is used for evaluation the ten materials respect to the ten criteria, where (1/5) shows the minimum value and described as Low. (5/5) shows the maximum value and described as Excellent.

Table 7: Testing of the developed framework in comparing materials after averaging the approximating the evaluation results

		1	2	3	4	5	6	7	8	9	10
		S1	S2	S3	S4	P1	P2	P3	C1	A1	A2
1	Metal	3	5	4	3	4	3	2	5	2	2
2	Glass	4	5	4	3	3	2	2	4	3	4
3	N.Stone	5	4	4	4	5	4	4	3	5	5
4	Wood	2	2	2	3	3	3	3	3	3	4
5	PVC	3	4	4	3	3	3	3	4	2	2
6	P&P	3	5	4	4	3	5	4	4	2	2
7	HPL	4	4	4	4	4	4	4	4	3	3
8	Fiber	3	3	3	4	3	4	4	4	2	2
9	A.Stone	4	4	4	4	4	4	4	4	4	4
10	RC	4	4	4	3	5	4	4	4	4	4

4.3 Criteria Weights had been extracted as in the below Schedule. After that the VIKOR processes in Table 9 were achieved by using the Criteria Weights from Table 8. Then Tables 10 and 11, is a complementary processes of VIKOR techniques.

Table 8: Finding Criteria Weights after AHP - Pairwise Comparison

	CW1	CW2	CW3	CW4	CW5	CW6	CW7	CW8	CW9	CW10
CW	1.700	1.200	1.200	0.950	1.700	1.700	0.950	0.950	0.950	0.441
Criteria	S1	S2	S3	S4	P1	P2	P3	C1	A1	A2

Table 9: Integrating CW to apply VIKOR

	CW1	CW2	CW3	CW4	CW5	CW6	CW7	CW8	CW9	CW10
CW	1.700	1.200	1.200	0.950	1.700	1.700	0.950	0.950	0.950	0.441
Material	S1	S2	S3	S4	P1	P2	P3	C1	A1	A2
Metal	3	5	4	3	4	3	2	5	2	2
Glass	4	5	4	3	3	2	2	4	3	4
N.Stone	5	4	4	4	5	4	4	3	5	5
Wood	2	2	2	3	3	3	3	3	3	4
PVC	3	4	4	3	3	3	3	4	2	2
P&P	3	5	4	4	3	5	4	4	2	2
HPL	4	4	4	4	4	4	4	4	3	3
Fiber	3	3	3	4	3	4	4	4	2	2
A.Stone	4	4	4	4	4	4	4	4	4	4
RC	4	4	4	3	5	4	4	4	4	4

Table 10: Finding best and Worst Xi to apply VIKOR

CW	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Best Xi+	**5**	**5**	**4**	**4**	**5**	**5**	**4**	**5**	**5**	**5**
Worst Xi-	**2**	**2**	**2**	**3**	**3**	**2**	**2**	**3**	**2**	**2**

Table 11: Results of the three first materials of ten

CW	1.700	1.200	1.200	0.950	1.700	1.700	0.950	0.950	0.950	0.441	Si	Ri
Materials	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	SUM	Max
Metal	0.850	0.100	0.450	0.380	0.944	1.082	0.950	0.000	0.950	0.373	6.079	1.082
Glass	0.567	0.000	0.150	0.950	1.700	1.700	0.950	0.543	0.518	0.170	7.247	1.700
N.Stone	0.000	0.300	0.000	0.000	0.189	0.155	0.000	0.950	0.000	0.000	1.593	0.950
Wood	1.700	1.200	1.200	0.380	1.511	0.927	0.543	0.950	0.691	0.170	9.272	1.700
PVC	1.275	0.200	0.300	0.380	1.511	1.236	0.814	0.271	0.864	0.441	7.293	1.511
P&P	1.133	0.100	0.450	0.190	1.700	0.000	0.136	0.136	0.864	0.441	5.149	1.700
HPL	0.708	0.300	0.450	0.190	0.944	0.309	0.136	0.407	0.691	0.339	4.475	0.944
Fiber	0.992	0.700	0.600	0.190	1.700	0.464	0.136	0.543	0.777	0.373	6.474	1.700
A.Stone	0.283	0.300	0.300	0.190	0.756	0.309	0.136	0.271	0.259	0.170	2.974	0.756
RC	0.283	0.400	0.300	0.380	0.000	0.309	0.136	0.136	0.345	0.204	2.493	0.400
									Min	S* R*	1.593	0.400
									Max	S- R-	9.272	1.700

4.4 The Table 12 below shows an Advance VIKOR step before finalizing its Procedures.

Table 12: Collecting Criteria Weights CW for VIKOR Procedure

		Si	Ri	Qi	Rank
#	Material	SUM	Max		
1	Metal	6.08	1.08	0.55	5
2	Glass	7.25	1.70	0.87	9
3	N.Stone	1.59	0.95	0.21	2
4	Wood	9.27	1.70	1.00	10
5	PVC	7.29	1.51	0.80	7
6	P&P	5.15	1.70	0.73	6
7	HPL	4.47	0.94	0.40	4
8	Fiber	6.47	1.70	0.82	8
9	A.Stone	2.97	0.76	0.23	3
10	RC	2.49	0.40	0.06	1
Min	S* R*	1.59	0.40	0.06	
Max	S- R-	9.27	1.70	1.00	

From the above Table, Q (A1) is first Rank as order but still Not the best "Natural Stone". The same thing for Q (A2), it is the second Ranking in order "Reinforced Concrete (RC) " between the results but Not the second one as materials preferences. Then, after applying the VIKOR methods from Step.1 to Step.8, we find that C1 and C2 conditions are accepted and Reinforced Concrete (RC) is best alternative which takes the lowest value (0.06), and the Natural Stone comes second with a value (0.21), then Artificial Stone comes third (0.23), and so on until reaching the last material which is wood (1.00) at level 10.

4.6 The Consistency Pairwise Matrix results came as the following: the below table and by using previous equations 1 - 5, the Consistency Index (CI) is calculated as 0.015 and where the Random Index (RI) from the previous table is 1.49 at n=10, then Consistency Ratio (CR) is 0.01, in which it is below 0.1, so it is accepted based on (Saaty 1987).

Table 13: A Process for Deriving the CI and CR values as an important validation Step

	S1=8	S2=7	S3=7	S4=6	P1=8	P2=8	P3=6	C1=6	A1=6	A2=4	SUM	Avg	S/A
S1=8	1.70	1.20	1.20	1.90	1.70	1.70	1.90	1.90	1.90	1.76	16.86	1.70	9.92
S2=7	1.70	1.20	1.20	0.95	1.70	1.70	0.95	0.95	0.95	1.32	12.62	1.20	10.52
S3=7	1.70	1.20	1.20	0.95	1.70	1.70	0.95	0.95	0.95	1.32	12.62	1.20	10.52
S4=6	0.85	1.20	1.20	0.95	0.85	0.85	0.95	0.95	0.95	0.88	9.63	0.95	10.14
P1=8	1.70	1.20	1.20	1.90	1.70	1.70	1.90	1.90	1.90	1.76	16.86	1.70	9.92
P2=8	1.70	1.20	1.20	1.90	1.70	1.70	1.90	1.90	1.90	1.76	16.86	1.70	9.92
P3=6	0.85	1.20	1.20	0.95	0.85	0.85	0.95	0.95	0.95	0.88	9.63	0.95	10.14
C1=6	0.85	1.20	1.20	0.95	0.85	0.85	0.95	0.95	0.95	0.88	9.63	0.95	10.14
A1=6	0.85	1.20	1.20	0.95	0.85	0.85	0.95	0.95	0.95	0.88	9.63	0.95	10.14
A2=4	0.43	0.40	0.40	0.48	0.43	0.43	0.48	0.48	0.48	0.44	4.41	0.44	10.00
													10.13

4.7 The LCC is calculated for the ten materials as the following for 20 - Years:

The ranking of the best materials after LCC analysis is shown as below, where all prices are Normalized:

Table 14: LCC in KD/Kg for ten materials and Ranking the best LCC materials among the selected ones

Material	Metal	Glass	N.Stone	Wood	PVC	P&P	HPL	Fiber	A.Stone	RC
LCC Kuwaiti Fils/Kg ~ 20Yrs	1650	55	105	95	25	40	15	30	45	1
LCC KD/Kg ~ 20Yrs	1.650	0.055	0.105	0.095	0.025	0.040	0.015	0.030	0.045	0.001
Ranking	1	4	2	3	8	6	9	7	5	10

4.8 The Final Decision after combining Criteria Comparison of VIKOR and LCC Analysis

The average ranking for the ten materials comes as the following table:

Table 15: Merging both results of VIKOR Criteria and LCC together into one

Ranking / Material	Metal	Glass	N.Stone	Wood	PVC	P&P	HPL	Fiber	A.Stone	RC
MCDM-VIKOR	5	9	2	10	7	6	4	8	3	1
LCC (KD/Kg) ~ 20Yrs	1	4	2	3	8	6	9	7	5	10
Averge of both Rankings	3.0	6.5	2.0	6.5	7.5	6.0	6.5	7.5	4.0	5.5
Final Ranking	2	5	1	7	10	4	8	9	3	6

4.9 Using Delphi Techniques evaluating and averaging the results of ten materials from the experts as below where (1 of 5) shows the worst value and (5 of 5) shows the best among others as in Table 16. After that, the results were divided into 3 bands based on their scores as in Table 17, where the Natural Stone, RC and Artificial Stone came in the first band and as first choice.

Table 16: Results after Delphi Methods

Material	Expert 1	Expert 2	Expert 3	Expert 4	Avg.	Ranking
Metal	2	3	3	3	2.75	3
Glass	3	3	4	3	3.25	2
N.Stone	4	4	5	4	4.25	1
Wood	1	2	2	2	1.75	4
PVC	2	2	1	3	2.00	3
P&P	3	3	3	4	3.25	2
HPL	3	3	3	3	3.00	2
Fiber	4	1	2	3	2.50	3
A.Stone	4	4	4	4	4.00	1
RC	5	5	4	5	4.75	1

Table 17: Results after dividing the scores into three bands for Ranking after Delphi Methods

Materials			Avg. Interva	Ranking
N.Stone	RC	A.Stone	4 - 4.75	1
Glass	P&P	HPL	3 - 3.75	2
Metal	PVC	Fiber	2 - 2.75	3
Wood			1 - 1.75	4

4.10 The final step was achieved after collecting all three ranking of VIKOR, LCC and Delphi as it appears in Table 18 below, where Natural Stone get the highest score. After that, the ten materials had been divided into 3 preferences groups (High or Best Choice, Middle Choice and Low or Worst Choice) as it is illustrated in Table 19.

Table 18: Comparison between both Ranking in Tables 16 and 14

Ranking / Material	Metal	Glass	N.Stone	Wood	PVC	P&P	HPL	Fiber	A.Stone	RC
Ranking of VIKOR+LCC	2	5	1	7	10	4	8	9	3	6
Ranking of Delphi	3	2	1	4	3	2	2	3	1	1
Averaging the Ranking	2.5	3.5	1	5.5	6.5	3	5	6	2	3.5
Final of Avg. Ranking	3	5	1	7	9	4	6	8	2	5

Table 19: The three variant Groups for Choice

Best		Middle		Worst	
Materials	Ranking	Materials	Ranking	Materials	Ranking
N.Stone	1	P&P	4	Wood	7
A.Stone	2	Glass+RC	5	Fiber	8
Metal	3	HPL	6	PVC	9

The summary of the three groups had been abbreviated into one best group, which is a benchmark in this study which can aid architects, engineers, and contractors for materials selection of the building envelope.

Table 20: Final Ranking – Best Group for Choice

Best	
Materials	Ranking
N.Stone	1
A.Stone	2
Metal	3

5. Conclusion and Recommendation

This study investigated for ten maintainability designed criteria along with the life cycle cost LCC for ten external façade materials applied to the building elevations in Kuwait. A governmental office building had been selected to be taken as a case study to apply these criteria. The selected building was presented as an arbitrary model of agent office building in hot and arid climate condition, not only in Kuwat but also at the Arabian regions. The life cycle cost had been determined theoretically for 20 - years as a mid - period lifespan for the selected materials, taking into consideration, the initial, operational, maintenance, and salvage costs. The analysis for the results came within two comparisons, the first one when AHP, Pairwise and VIKOR techniques had been applied as MCDM procedures upon the selected materials and criteria, and second for the LCC. The outcome after the calculations indicated that the optimum material after VIKOR procedure is Reinforced Concrete panels RC, including the Glass - fiber Reinforced Concrete GRC. The study outcome also showed the best material after LCC estimation, which is the MCM including Metallic, Alloy, Alcobond and similar materials. In parallel to that process, Delphi technique had considered of this study, and the results had tended to Natural stone as the best choice for claddings. After that, Delphi, VIKOR and LCC methods had been combined together by averaging their ranking results to obtain the final ranking. After the overall evaluations, the final results were divided the ten materials into three chosen groups. The first group had the best preferences and involves three materials as Natural Stone which came first, then artificial stone, then metal (MCM). The second group was in middle of preferences and included the polyisocyanurate and polyurethane (P&P), then Reinforced Concrete and Glass, then the High Pressure Laminated (HPL). The third group came with minimum preferences and involved Wood, Fiber Materials and Polyvinyl Chloride (PVC). At the end, the study recommended using the Natural Stone as the best elected materials for the agent office building in Kuwait and similar area with arid climate, thus after the calculations and strict evaluations.

6. Limitation of the Study

The first important issue lies when dealing with the International Standards where the Climate is complicated and differs from location to another, then applying same standards or criteria is somehow difficult. The second issue is the reliability of the specialists and experts to evaluate correctly. On the other hand, the accuracy of the life cycle cost (LCC) 's input data would form some obstacles in this research. The condition of the market, different labors wages and overhead with installation arrangement related to materials, sub - contractors and inflation, psychology of the market like offers and demands are different dimensions and causes that limit this study, i. e., it was a tough step when estimating the costs anatomy and related ones to deliver the Life Cycle Cost (LCC).

7. Future Studies

To Apply the same methods and processes on other Governmental buildings at Kingdome of Saudi Arabia (KSA) and other Arabian Gulf Countries to compare and analyze the results under the similar conditions of climate, size of the project, and cladding materials of the envelop.

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