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Sustainable Material Selection Criteria Framework for Environmental Building Enhancement

Abdulhafeez Ahmad M. Alwafi*

Department of Islamic Architecture, Faculty of Engineering and Islamic Architecture,
Umm Al-Qura University, Saudi Arabia
*Corresponding author: dralwafi@hotmail.com, aawafi@uqu.edu.sa

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Abstract The manufacturing and usage of building materials cause many environmental problems in the construction sector. Sustainable materials are more ecologically friendly than their traditional equivalents. However, determining the criteria for selecting building materials based on sustainability and their evaluation is complex. Consequently, the Analytic Hierarchy Process (AHP) approach was employed in this study to choose between various materials alternatives for bricks. The criteria for choosing and grading the importance level of sustainable materials were determined in the first step through literature analysis, expert perspectives, and a questionnaire survey. Through a scatter plot of mean and standard deviation values, 28 criteria were discovered and rated. The purposive sampling approach was employed in the second phase to identify specialists and professionals in material selection. They were asked to assess the various sustainability criteria and analyse and weigh the offered options. Results showed that hollow concrete blocks with a weight value of 0.5225 were a better alternative to common burnt clay bricks and burnt clay fly ash bricks. Therefore, this study created a decision-making model to assist stakeholders in selecting the materials needed to produce sustainable buildings. Consequently, the framework for analysing material selection criteria has been developed based on the suggested model. This framework may be used as a guideline for decision-makers to apply sustainable material selection criteria in order to reduce costs and increase efficiency. This study would be a benchmark for decision-makers to eliminate the unwanted cost and enhance project success by adopting SBMs in both Saudi Arabia and other developing countries.

Keywords: *sustainable building, multi-criteria, decision-making, construction*

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1. Introduction

Housing is one of the fundamental factors for judging a country's residents' quality of life and health [1]. Building services are systems that govern temperature, power, ventilation, elevators, and water supply in structures [2]. Nonetheless, demand for adequate housing exceeds supply in a changing and increasingly urbanising environment [3]. Urbanisation influences housing availability in developed and developing nations. The latter have low-wage employees who face more significant difficulties acquiring adequate housing [4]. For instance, 828 million impoverished people live in slums and low-cost housing in developing nations. By 2020, this amount is expected to reach 1.4 billion. Overall, the projected worldwide population growth for 2050 of 3.6 to 6.3 billion people means that more houses are needed to fulfil the rising demand for shelter [5].

Consequently, many nations have prioritised cost-effective residential building rules to achieve sustainable buildings concept [1]. According to UN Environment Program (UNEP)'s assessment, the construction industry can considerably contribute to the economy of any nation. The construction sector employs 5 to 10% of the workforce and contributes between 5% and 15% of GDP [6]. However, the building industry's practices have serious environmental impacts. Construction activities account for 40% of worldwide energy and greenhouse gas emissions [6]. Likewise, the sector consumes a big number of natural resources and creates a significant amount of trash [7].

Sustainable construction philosophy provides humans with eco-friendly housing facilities that efficiently use water, power, and resources [8]. Sustainable construction also helps to reduce a building's operational or maintenance costs. Additionally, it improves occupant efficiency and generates healthier cities [9]. Overall, this explanation of sustainable buildings offers solutions to environmental problems. Therefore, developing and developed countries emphasise the concept of green building [10]. Building sustainability aims to select acceptable materials while considering some environmental, social, and economic parameters [11]. These parameters guarantee that materials are energy-efficient and decrease waste and emissions to minimise a building's environmental impact. Moreover, construction materials produced with the least amount of energy contribute to the sustainability requirement. Socially, the health of those who live in such structures is improved [12].

Currently, the research emphasises the assessment stage of construction materials selection and their long-term performance. Sustainable building materials (SBMs) are ecologically friendly, high-performance materials that can help to reduce the environmental effect of buildings. When compared to non-sustainable materials, selecting SBMs is more difficult since all sustainability parameters must be addressed [11]. Thus, a multi-criteria decision model must match environmental, economic, and social factors. For example, a multiple criteria decision-making (MCDM) model has been created [13]. However, some studies have used a conceptual model and statistical tools to help decision-makers evaluate SBMs criteria [14]. In general, material selection involves numerous incompatible criteria that should be weighted to make correct and suitable judgments. Several research in the construction sector has employed the multi-criteria decision-making process. However, studies on the selection of SBM criteria with MCDM are rarely found in the literature.

Building activity has increased dramatically in the Kingdom of Saudi Arabia [15]. The government is dedicated to achieving sustainability, making them a top priority by its core beliefs. The Kingdom's Vision 2030 aligns with the SDGs for Sustainable Development. This keen vision and the accompanying diverse implementation plans serve as the foundation for supporting long-term growth targets in the national strategic plan [16]. Applicable standards for selecting sustainable building materials, on the other hand, are notably missing [17]. Therefore, managers or engineers are confronted with the difficulty of selecting the ideal material depending on its long-term advantage[15] . However, the three sustainability pillars are challenging to include in material selection. It necessitates the development of a simplified approach.

Consequently, there is an urgent need to provide some guidelines for determining the criteria for selecting sustainable building materials[18] . Thus, it is critical to creating a decision-making model that can give appropriate instruction on selecting SBMs. It will help to improve and support sustainable building materials practices. It will also encourage the development of long-term growth. Thus, this research aims to identify the criteria for choosing, prioritising, and rating SBMs.

Additionally, the study intends to develop weightage and a pairwise comparison matrix for the criterion. In the same vein, the study creates a decision-making model for selecting the best option in the Saudi Arabia building industry amongst hollow concrete bricks, ordinary burned clay bricks, and burnt clay fly ash bricks materials. Finally, it is crucial to highlight that this study focuses on alternative materials for bricks since they are the most often used materials in the construction industry and have been recommended by academic and industrial experts in the local context.

2. Literature Review

2.1. Building Sustainability

Sustainable development concerning construction is a word that defines a building's improved safety precautions, resource reduction, minimal environmental effect, enhanced aesthetics, and stakeholder satisfaction [19,20]. Environmentally conscious practitioners and scholars have paid close attention to sustainable development in various disciplines. These include economics and sociology, agriculture, construction, transportation, and design [21]. Several causes have influenced the creation of this notion, including the world's recent fast economic and urbanisation expansion, global environmental issues, rapid human population growth, and deterioration of natural resources [22,23]. In addition, building construction requires a substantial quantity of carbon, power (39 percent), and water (12 percent), as well as a significant amount of CO2 emissions (38%) [24]. The Sustainable Development Goals (SDGs) are designed to mitigate the negative consequences of these activities on human health and the environment [25]. The SDGs show how to include sustainable concepts into the construction cycle, including building construction, design, service, and maintenance. Furthermore, the SDGs encourage close collaboration among customers, designers, contractors, architects, and engineers.

2.2. Sustainable Criteria for Materials Selection

A comprehensive review of the literature revealed that the selection criteria for SBMs have not been established. Therefore, researchers have documented and used various classifications and interpretations of SBMs. For instance, Baharetha, et al. [26] developed a system for categorising factors for choosing sustainable construction materials. The authors suggest a three-phase evaluation of materials (pre-building, building, and post-building) that gives a more accurate estimate of a building's efficiency and life cycle. Similarly, Zhou, et al. [27] utilised the Life Cycle Assessment (LCA) technique to identify and classify sustainable materials related to mechanical, economic, and environmental criteria. However, Mathiyazhagan, et al. [28] removed mechanical variables and incorporated social criteria. This classification is consistent with the assumptions of current research that propose evaluating construction materials based on three criteria: environmental, economic, and social [18,29].

Most of the existing literature only looked at a few sustainable criteria from an environmental, economic, and social standpoint [30]. Thus, in applying the concept of sustainability to material selection, all three sustainability pillars need to be considered [11]. Subsequently, the criteria for SBMs were chosen in this study based on the recommendations of several studies [11,18,29,31]. The 28 SBMs criteria established for building material selection are shown in Table 1. Ten (10) criteria are in the environmental category, seven in the economic category, and eleven in the social category.

Table 1. Sustainable Criteria for Building Materials Selection

Environmental criteria	Economic criteria	Social criteria
E1: material impact on air quality (indoor & outdoor) [36]	EC1: operation and maintenance cost [37,38]	S1: use of local material [11, 39]
E2: recycling and reuse [40,41,42]	EC2: meeting stakeholders needs [40,43]	S2: ecological and social acceptability [44]
E3: environmental form (eco-environmentally) [44]	EC3: energy efficiency [11]	S3: social benefits and development [37]
E4: healthy interior environment [11]	EC4: investment cost [37]	S4: availability and adaptation [43]
E5: land acquisition [40]	EC5: societal costs of construction materials [40]	S5: aesthetics [40,45]
E6: water consumption [11,40]	EC6: tax contribution (e.g., imported materials-entry tax etc.) [11,46,47]	S6: resistance against natural contamination and habitat disasters [11,36]
E7: consumption of natural resources [48]	EC7: financial and economic risks [37]	S7: labour availability [49]
E8: production and transportation activities [40,48]		S8: ease of construction (buildability) [50]
E9: waste management [28,46]		S9: ease and ability to integrate with other materials [18]
E10: embodied energy within material [40,41,42]		S10: isolation of noise pollution [18]
		S11: health and safety [36, 40]

2.3. Techniques of Decision-Making

The analytical hierarchy process (AHP) is a technique that is commonly used to solve multi-criteria problems. For example, it has been utilised to evaluate buildings' sustainability [32]. In the standard process of implementing AHP, a set of alternatives and assessment criteria (value tree) hierarchies were initially identified. Subsequently, a pairwise comparison matrix of ratios is developed to evaluate the performance of each criterion (i.e. weighting) [33]. The weighting process is based on a 9-point scale, with 1 suggesting equal preference and 9 implying an absolute preference of weight/ alternative. In the second step, the pairwise comparison matrix was reduced to a set of scores that reflect the relative value of each alternative weight and output [34]. If the criteria weights and alternative scores are obtained with the method defined, the overall output of the alternative can be determined by an additive linear model [35]. The outcome is a 0 to 1 score when the weights are compatible with the criteria [34]. Few studies have applied the AHP technique on selecting sustainable building materials based on environmental, economic, and social criteria. It is shown that there is a disparity between current policy instruments, such as the life-cycle analysis (LCA), and their practical use in the environmental assessment Akadiri [51]. The study assessed the sustainability of three roofing materials, which will allow stakeholders to select sustainable building materials. However, the selected classification criteria were not based on a literature review. Besides, the research also ignored many significant parameters of sustainable building materials [51]. An AHP model for selecting the best sustainable agricultural method was likewise developed. Again, results show that the ecological criterion is essential [52].

3. Methodology

This study aims to develop a decision-making model for selecting SBMs materials to improve the sustainability of building projects. SBMs have the advantage of reducing final production costs and environmental impacts [50]. Therefore, a mixed method, which consisted of two parts, was used in this research. The first part comprised an extensive literature review of the related studies to identify the criteria for selecting SBMs, interviewing experts to refine the identified criteria, and evaluating the relative importance of the SBMs criteria through a questionnaire. In the second part, a questionnaire is based on the AHP tool structure. They were used to determine the pairwise comparison matrix. By combining the results of these parts, a decision-making model was developed to enhance the selection of sustainable building materials. An interview with experts was also conducted to explore and validate the results. Figure 1 illustrates the research flow chart for this study.

3.1. Ranking the Criteria for SBMs Selection

The SBMs criteria for materials selection were recognised from the literature. Subsequently, eight (8) experts were interviewed to refine the SBMs criteria. From the findings of the interview, four criteria were removed. Finally, 28 SBMs criteria were identified, as shown in Table 1. Secondly, the first questionnaire survey was distributed to Saudi Arabia's construction industry stakeholders. The questionnaire survey aimed to identify the importance level of the 28 SBMs criteria for material selection using a five-point Likert scale (1= least important, 5 = extremely important). The response rate was 36%, sufficient for further analysis [53]. Fifty-one (51) valid responses were subjected to ranking analysis employing a scatter plot of means and standard deviation. Based on the recommendation from the previous studies, the top three criteria, under the environmental, economic, and social categories, were chosen to develop the decision-making model [54,55].

3.2. Multi-Criteria Decision-Making Model

AHP is one of the standard methods for estimating subjective judgment during decision making. AHP was chosen for this study due to its benefits over other multi-criteria decision-making (MCDM) tools, including ISM (interpretive structural modelling), ELECTRE (elimination and choice translating algorithm), TOPSIS (a technique for order performance by comparison to ideal solution) and ANP (analytic network process). ISM, for instance, may provide the interdependent variables in the analysis with a hierarchical structure, but it is unable to examine the relative importance of each variable [56]. Other MCDM tools, such as ELECTRE and TOPSIS, have limited acceptance among scientists and professionals [57]. Likewise, ANP involves many comparison matrices, which complicates the non-expert survey process [58].

The selection of the AHP methodology in this work is due to its ability to split the complex decision problem into several hierarchical sub-problems. Each level represents each sub-problem's main criteria, sub-criteria, or parameters [56]. Besides, AHP tool can measure the objective and subjective decisions of the experts in order to achieve a consensus and to identify priority weights [59]. AHP is characterised by its usability, versatility, and coherence [60]. Relative values in AHP may be derived from an expert opinion or real assessment survey by a simple scale of 9 points.

3.2.1. Decision-Making Model Generation

This study targeted experts working in the field of construction in the Saudi Arabia's building industry. The purposive sampling method was used based on the AHP recommendation because of the availability of a limited number of experts in a particular area [61]. To compare all the criteria with their perceived importance on the nine-point scale, the respondents were provided with detailed information concerning the criteria and were asked to suggest alternatives. AHP survey was distributed to 12 experts. This part of the study was based on seven valid responses.

Therefore, the hierarchical tree was formulated from the main category (environmental, economic, and social), the top three criteria, and alternatives. The decision-making issue was broken down into a hierarchical structure [62].

The second questionnaire survey of the pairwise comparison was formulated according to the study goal, main category, top three criteria, and alternatives [63]. Experts were employed to evaluate the developed questionnaire based on a 9-point scale. From on the opinion of the experts gathered through surveys, a matrix was used to determine the main category, criteria, and the alternatives for comparison. The cumulative matrix representing all respondents' opinions was then generated using the geometric mean [33].

After that, weights were calculated for each main category of the criteria and alternatives. By solving the principal eigenvector, the maximum eigenvalue and eigenvector could be determined for instance, by adopting the uniformity of the matrix rows method [63].

Lastly, weight aggregation. During the research carried out in groups of comparative judging, the geometric mean can be combined to form the comparative judgment matrix [33].

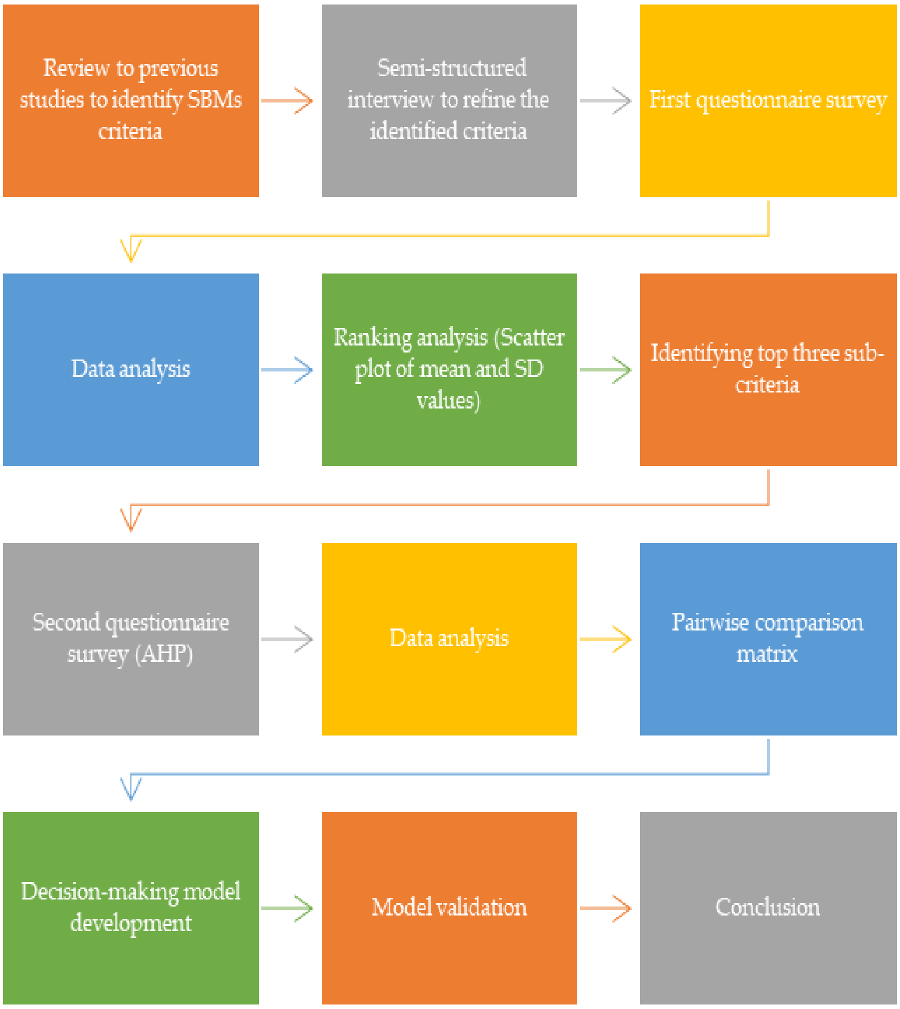


Figure 1. Research flow chart

3.2.2. Model Validation

The model has been developed during the study and validated. This validation aims to ensure systematic, thorough, and unbiased research results. Interview and questionnaire tool have been used to verify the study findings [64]. Hence, the AHP model could be deployed for possible use and adoption in the field of construction projects. The parameters for the construct validity include: comprehensiveness, structure, specificity, suitability, and applicability. Kineber, et al. [65] argued that the validation function should track the model of a domain and discuss the user's goal. To assess SBMs' application parameters [66], five experts were involved to evaluate the model's findings using Likert scale. In this study, seven questions were constructed to assess the validity adopted from the previous studies [67,68] to examine content validity (Q1, Q2), the validity of the construct (Q3, Q4), internal validity (Q5), face validity (Q6), and external validity (Q7). The seven questions to validate the results are summarised as follows:

Q1. Are the SBMs criteria for the model of supporting sustainable buildings as proposed in this study applicable?

Q2. Are the essential activities for the developed model applicable?

Q3. Is the model reasonable for identifying the sustainability pillars and building characteristics as proposed in this study?

Q4. Is the model reasonable for achieving sustainable building as proposed in this study?

Q5. Is the causality clear between the model, SBMs criteria, and essential activities as stated in this study?

Q6. Are the evaluated results presented in this study reasonable?

Q7. Can the structural model developed in the study be generalised?

4. Results

4.1. The Importance Level of SBMs Criteria

Reliability analysis of the internal consistency approach was initially checked to ensure that the respondents from stakeholders (clients, contractors, and consultants) provide comparable rating on the rating scale (1-5). The internal consistency is calculated to define the reliability of the defined scale using Cronbach's alpha coefficient. The reliability coefficient is more excellent on the scale parameter when the α value is closer to 1; 0.7 value is the lower acceptable limit [69]. From the analysis, all α values are greater than the 0.7, with environmental, economic, social, and all SBMs criteria rated 0.82, 0.81, 0.78, and 0.95, respectively. This indicates that the internal consistency of the SBMs criteria is excellent. Furthermore, the respondents' profiles indicated that they have experience and are aware of the selection of SBMs. This is shown in Figure 2. The respondents played a crucial role during the selection process of SBMs.

Ranking of the SBMs criteria is performed to determine the relative importance level of the sustainable criteria by using a scatter plot of mean and standard deviation values [53]. The mean score indicates the importance level among the SBMs criteria, while the standard deviation of SBMs criteria represents the agreement level among the respondents [70]. From the analysis, standard deviation scores are less or around one, which shows the respondents' consensus. Table 2 present the statistical means, standard deviations, and ranks of the SBMs criteria for materials selection.

From the scatter plot analysis of the environmental criteria, consumption of natural resources ranked as the most important among other criteria. This is followed closely by waste consumption and recycling and reuse. As for the economic criteria, "meeting stakeholders needs" ranks first and second among all criteria. Operation and maintenance cost and societal costs of construction materials are ranked second and third, respectively. According to the social criteria, use of local material is ranked first and third among all criteria. Next is rank is use of local material, followed by health and safety in the second and third level of importance, respectively. The entire criteria ranked above the lower significant levels, which is agreed with the existing literature [50].

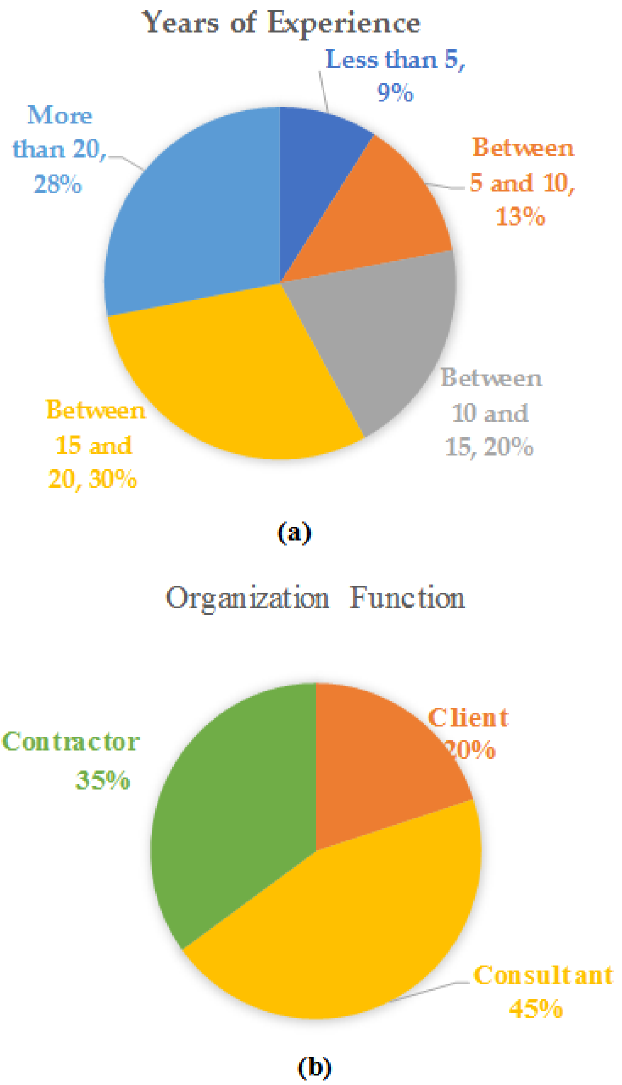


Figure 2. Respondents' profile: (a) Years of experience; (b) Organisation function

Table 2. Ranking of the criteria

Category	Criteria	Mean and standard deviation values		
		Mean	SD	Rank
Environmental	E7	3.840	0.724	1
	E9	3.745	0.815	2
	E2	3.868	0.828	3
	E4	3.443	0.834	4
	E6	3.539	0.875	5
	E1	3.457	0.895	6
	E8	4.155	0.892	7
	E10	3.649	0.973	8
	E5	3.388	1.004	9
	E3	3.608	1.033	10
Economic	EC2	3.840	0.742	1
	EC1	4.238	0.773	2
	EC5	3.553	0.779	3
	EC2	3.621	0.801	4
	EC6	3.854	0.850	5
	EC3	3.553	0.859	6
	EC7	3.964	0.885	7
Social	S1	3.690	0.750	1
	S11	3.566	0.826	2
	S2	3.608	0.835	3
	S3	3.621	0.879	4
	S10	3.498	0.879	5
	S8	3.676	0.882	6
	S6	3.498	0.893	7
	S5	3.306	0.898	8
	S4	3.457	0.909	9
	S7	3.649	0.932	10
	S9	3.265	0.948	11

4.2. Decision-Making Model

4.2.1. Participants

The survey participants are experts from the Saudi Arabia's construction industry, who have handled building projects in different organisations. Table 3 presents the respondents' profiles. About 41% of the respondents are from consulting organisations, 30% comprised client/developer stakeholders, and 29% are contractors. According to the years of experience in handling building projects, 58% of participants have between 15 to 20 years of experience, while 32% have between 10 to 15 years of experience.

4.2.2. Model Generation

Participants are requested to compare the main categories and their criteria on the three basis of sustainability (environmental, economic, and social). The participants' opinions are, then analysed through the pairwise comparison method of the AHP to determine the weight of each criterion. The consistency check is undertaken for each level and all pairwise comparison matrix is constant. The consistency ratio (CR) is acceptable if it is equal to or less than 0.1 (CR $\leq$ 0.10) [33].

The matrix of pairwise comparison for the main categories is generated and the corresponding weights are identified. Environmental criteria weights are identified by solving the pairwise comparison matrix of the experts' judgments. Among the environmental criteria, “consumption of natural resources” has the highest weight of 0.554, followed by the “recycling and reuse”, and “waste management” with weights of 0.236 and 0.210, respectively. For economic criteria, “operation and maintenance cost” has the highest weight of 0.492. “Societal costs of construction materials” and “meeting stakeholders needs” follow in rank with weights of 0.312 and 0.196, respectively.

Table 3. Respondents' profile

Variable	Category	%
Years of experience	Between 5 and 10	10
	Between 10 and 15	32
	Between 15 and 20	58
Organisation function	Client	30
	Consultant	41
	Contractor	29

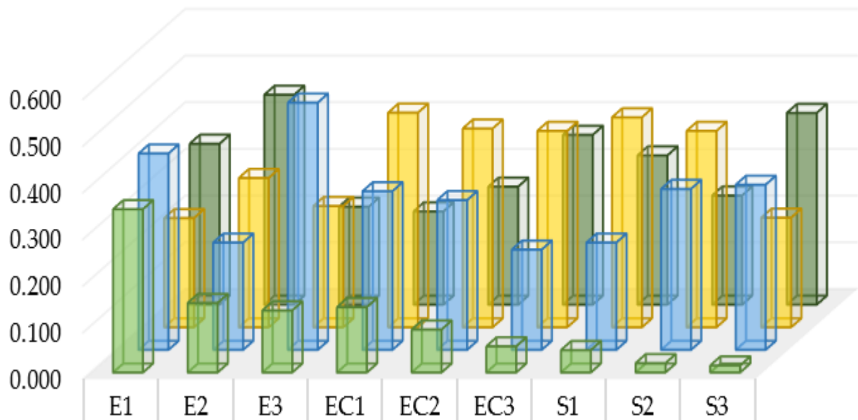
Regarding the social criteria, “ecological and social acceptability” exhibits the highest weight (0.583). it is followed by use of local material (0.236), and “health and safety” (0.181). Table 4 summarises the weight and global weight (GW) of the mentioned criteria.

Experts' opinions are utilised to develop the decision-making model for supporting SBMs to achieve sustainable buildings through materials selection, they were asked to evaluate and compare the criteria of SBMs concerning the provided alternatives. Hollow concrete blocks (a1), common burnt clay bricks (a2), and burnt clay fly ash bricks (a3) were provided as alternative materials to be evaluated. The aggregation of the final weight of each alternative is evaluated considering its global weight, as shown in Figure 3.

According to the environmental criteria, it is observed that the hollow concrete blocks (a1), has the highest priority weight in terms of consumption of natural resources (0.421) and recycling and reuse (0.530) as compared with other alternatives. However, burnt clay fly ash bricks (a3) weights more critical than (a1) in terms of waste management with a weight value of 0.450. It indicates that (a1) cannot be easily recycled and used.

Table 4. Weights and global weights of criteria

Category	Weight main perspective	Criteria	Weight	Global Weight
Environmental	0.632	E1: consumption of natural resources	0.554	0.350
		E2: waste management	0.236	0.149
		E3: recycling and reuse	0.210	0.133
Economic	0.285	EC1: meeting stakeholders needs	0.492	0.140
		EC2: operation and maintenance cost	0.321	0.092
		EC3: societal costs of construction materials	0.196	0.056
Social	0.083	S1: use of local material	0.583	0.048
		S2: health and safety	0.236	0.020
		S3: ecological and social acceptability	0.181	0.015



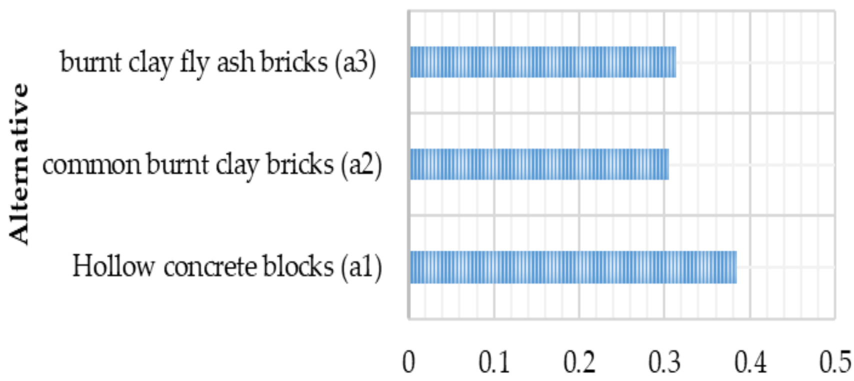
	E1	E2	E3	EC1	EC2	EC3	S1	S2	S3
Global Weight	0.350	0.149	0.133	0.140	0.092	0.056	0.048	0.020	0.015
a1	0.421	0.230	0.530	0.340	0.321	0.215	0.230	0.345	0.354
a2	0.234	0.320	0.260	0.460	0.426	0.421	0.450	0.421	0.235
a3	0.345	0.450	0.210	0.200	0.253	0.364	0.320	0.234	0.411

Figure 3. The priority weight of the alternatives with respect to SBMs criteria

Under the economic criteria, the calculated priority index shows that (a2) has the highest priority in terms of "meeting stakeholders needs" and "operation and maintenance cost" with weight values of 0.460 and 0.426, respectively. One potential explanation is that (a2) has the lower cost compared to other alternatives. Besides, (a2) is weighted as more critical than other alternatives in terms of societal costs of construction materials with a weight value of 0.421. This findings are in line with a previous study conducted in the Indian building industry [28].

In the social category, (a2) ranked higher than (a1 & a3) under the criterion of use of local materials and health and safety with a weight value of 0.450 and 0.421, respectively. It suggests that (a2) is more suitable in the local context by using the local materials. According to the criteria of ecological and social acceptability (weight = 0.411). The hollow concrete blocks is slightly important than common burnt clay bricks.

To decide between the alternatives, the sum of the final weight is calculated. Figure 4 presents the final aggregation values of the provided alternative materials for selecting the most sustainable building bricks. From the experts, hollow concrete blocks (a1) display a weight value (W) of 0.385 as compared to (a2) (0.305) and (a3) (0.314). Therefore, concrete bricks material is deemed better alternative to achieving a sustainable building in the local context. It is noteworthy that the manufacture of cement requires tremendous energy and contributes massive quantities of carbon dioxide to the air [71]. However, it is possible to improve the durability and efficiency of concrete by using other waste materials. These are referred to as the Supplementary Cementitious Materials (SCMs). They can be used to reduce the quantity of cement required and improve the efficiency of sustainability performance [72].



	Hollow concrete blocks (a1)	common burnt clay bricks (a2)	burnt clay fly ash bricks (a3)
Series1	0.385	0.305	0.314

priority weight

Figure 4. The aggregation value of the alternatives' priority

4.3. Validation

The developed model was validated using the survey method of the questionnaire for the interview. All interested parties (contractors, clients, and consultants) were notified that they would be involved in the validation process. The purpose of validation is to examine and address various scientific questions relating to the theory of the selection process of SBMs for future construction use and acceptance. Following the recommendation from Yiu [66] five parameters for validating the entire validity of the study: 1) content validity, 2) construct validity, 3) internal validity, 4) face validity, and 5) external validity. The purposive sampling was applied when a small number of experts are present in a given field [61]. The respondents were evaluated and the criteria involved the relationship between the variables and the objectives during the validation process. The assessment of validity has been based on the content and not the number of respondents [73]. Five experts were involved in discussing results for the developed model, and their evaluation found that, concerning five aspects of validity, the parameters of the developed model from this study were acceptable [74]. The participants were experts from the Saudi Arabia building industry, as shown in Table 5.

Table 5. Respondents' profile

c	Category	%
Years of experience	Between 10 and 15	38
	Between 15 and 20	62
Organisation function	Client	40
	Consultant	48
	Contractor	12

The results of the suggested seven (7) validation questions are summarised in Figure 5. The content validity is a non-statistical tool for assessing the conflicting importance and meaning within the definition by deciding whether the research material is fact and satisfactorily real [75]. From the analysis, the mean values for Q1 and Q2 are 4.10 and 4.50, respectively, which indicated the applicability of SBMs criteria and the model for supporting materials selection. Concerning the construct validity, which aims to determine the suitability of using theoretical concepts that compare the results and stated study goals [76]. The mean scores for Q3 and Q4 are 3.90 and 4.10, respectively. These values have indicated that the model is suitable. Meanwhile, the respondents have been also confirmed the internal validity of the causality concept and the derivability of data connexons to avoid unclear theoretical frameworks and shortcomings in data processing and inaccurate data analysis [77]. Moreover, the face validity of the study findings requires that non-researchers should reach an agreement on the results [64]. This validation was appropriate by the respondents with a mean value of 3.90. Lastly, the participants show a positive response in the external validation, which involves testing the inference theory and determining whether the study findings can be generalised [77]. Likewise, also showed their interest in developing the multi-criteria decision model.

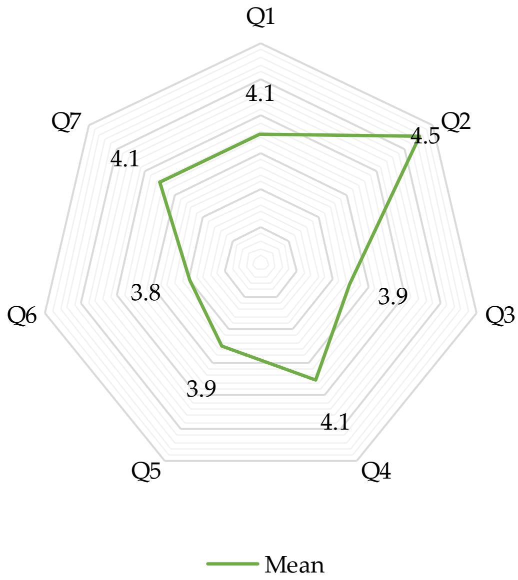


Figure 5. Score values of the model validation

The validation assessment is indeed reasonable. Additionally, the structured and generic structural model has been developed in this study. The input from all respondents confirms the model's description, purpose, and performance. Therefore, it is very relevant to stakeholders and the building industry. Likewise, it can help the building industry and the model suitability for interacting with sustainable building challenges by materials selection. A general evaluation of the application variable of the model was also given to the respondents. The analysis showed that the structure proposed from the model is significant but does not typically cover most deals for construction. The input also implied that the criteria suggested, and the model covered the area of green buildings. Effective use of the model can also lead to an unforeseen increase in the sustainability of the Saudi Arabia building industry cultivate the credibility of the construction industry. Stakeholders, including engineers, project managers, firms, quantity inspection firms, etc., may also properly introduce the model parameters. This model would assist stakeholders during the materials selection process to achieve sustainability goals. Finally, the positive outcome of (1) validity of contents, (2) validity of constructs, (3) internal validity, (4) face validity, and (5) external validity was approved by respondents.

5. Discussion

5.1. Decision-Making Model for Sustainable Material Selection Criteria

The selection of SBMs represents an essential strategy in the design and construction of building projects [78]. Meanwhile, the identification of assessment criteria is challenging based on the concepts and principles of green alignment with sustainable development and the process of prioritisation and aggregation into a framework [79]. To achieve building projects sustainability, strategies that give a clear perspective of selecting acceptable materials while considering various environmental, social, and economic criteria are required [80]. Therefore, this study offers a multi-criteria decision-making model which could support stakeholders during materials selection.

Based on the developed decision-making model results, it was perceived that specific criterion are influencing the sustainable building materials selection to achieve sustainability. The results from Table 4 shows that the significance of environmental and economic criteria is greater than the social criteria. Possible reason is that the natural resources are needed to fulfil the expanding urban needs. Thus, large amounts of resources are used in the environment. Almusaed, et al. [81] argued that adverse environmental impacts are critical for climatic changes from the last decade. Moreover, CFCs are released into the environment during the preparation of hazardous compounds [54] Therefore it is getting increasingly difficult to manage the environment sustainably while meeting urban needs. Here, sustainability arises, which is critical to meeting existing and future demands through resource management. Furthermore, using environmentally friendly materials lowers the release of hazardous gases into the atmosphere from buildings [82].

Hence, environmental criteria should be considered during materials selection. Meanwhile, the importance of economic and social criteria comes after the environmental criteria. Current findings agreed with previous studies in the related field [18]. This observation shows that the environmental criteria considered necessary concerning the other criteria within the local context.

The proposed model also shows that consumption of natural resources and waste management criteria is essential to consider while selecting the material. Gluch, et al. [83] contended that the corporations encourage waste management and environmental acts as important materials selecting actions. These findings were followed by the potential for recycling and reuse of materials criteria. Akadiri, et al. [84] argued that materials capability for recycling and reuse positively contributes to resources efficiency.

The analysis of the economic criteria shows that meeting stakeholders needs is the top priority in materials selection (Figure 4). The choice of appropriate green material for building should meet the user's satisfaction, since stakeholder satisfaction is required during materials selection [54]. Based on Mathiyazhagan, et al. [85], materials are significant to satisfy the users' needs. Additionally, operation and maintenance cost criteria are ranked as second priority. The selection of appropriate green materials for constructing on a site is an investment mode. Thus, no maintenance expenditures for materials are necessary during climatic changes [86]. According to the social category, using local materials positively influence the social aspect from the materials selection view. Because of a developing understanding of its ramifications, this criteria is frequently connected with job development [87]. Besides, health and safety are also considered important during the selection process. By providing a clean and safe working environment, site safety boosts social life [88].

In a nutshell, the selection of materials among numerous alternative materials in the construction industry is a difficulty, which leads to unpleasant conditions that affect building industry stakeholders. Therefore, this presented decision-making model can be used by stakeholders during materials selection, which will act as a platform for materials selection in the building industry.

5.2. The Proposed Sustainable Material Selection Criteria Implementation Framework

This section describes the recommended framework for material selection criteria implementation in the building industry, which was developed based on the validation of these criteria using the aforementioned model, as shown in Figure 6. A framework, according to the Oxford definition, is “an integrated structure to aid or support.” The conceptual framework accepts a troublesome situation as rational. It controls generalisation (concepts) derived from specific problem-related functions. A conceptual framework composed of assertions that link abstract notions to empirical facts is simply a less traditional sort of theory [89]. To account for abstract events that arise under comparable settings, conceptual frameworks and sustainable material selection criteria are established [89]. By connecting theory to reality, they provide a relationship that many academics overlook, but which Lewin clearly articulated: 'Nothing is more real than a good theory [90]. According to the suggested framework's definition, a causal network is a graph that represents the variables in a naturalistic model. This AHP diagram will serve as the conceptual framework's basis [91]. The significant criteria based on the suggested AHP model are presented. As a result, these requirements must be met before sustainable material selection criteria may be effectively implemented in the building sector. As a consequence, the findings of the AHP analysis revealed three (3) major components for the implementation of sustainable material selection criteria, which are as follows:

5.2.1. Environmental

The first component addressed variables that directly contribute to the “Environmental,” such as the influence of materials on air quality, a healthy interior environment, waste management, and manufacturing and transportation operations. The construction sector has a significant impact on our environment [8]. Because construction materials have an influence on the environment, environmental requirements are becoming increasingly important.

“The building industry is struggling to adopt sustainable practices and seeking new strategies” [10]. Environmental factors are vital for supporting design decisions and material selection, and they should complement broader strategy sustainability goals. A building's sustainability can be accomplished based on the environmental standards specified for material selection. However, the utilization of appropriate natural resources and raw materials would be beneficial in achieving environmental goals [55]. The construction sector is widely acknowledged as one of the largest users of energy, resulting in enormous environmental concerns [4].

Moreover, it was said that specialized resources are limited, and leftover stockpiles should be managed with care [56]. The construction sector is regarded as a big user of natural resources. As a result, environmentally friendly construction materials greatly minimise the impact of wasteful use of natural resources.

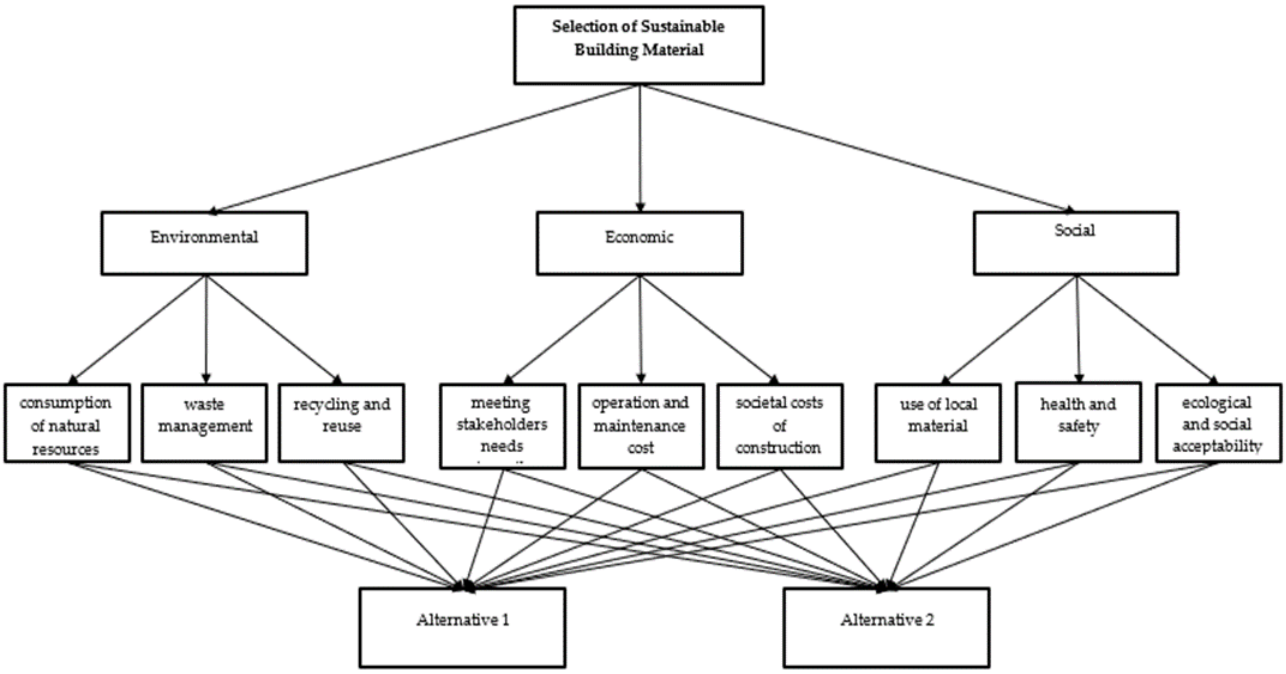


Figure 6. Sustainable material selection criteria implementation framework

5.2.2. Economic

The variable directly contributing to the "Economic" was provided in the second component. As a result, this group presented variables such as operation and maintenance costs, financial and economic risks, the societal cost of materials, and investment cost, which aid stakeholders in decision making during the material selection process while taking the concept of life cycle cost and the project's budget into account. Due to the growing demand for environmentally friendly structures, stakeholders are focusing on early assessment of the financial sustainability of construction projects. Improving construction cost efficiency is significant to all stakeholders [57].

The building industry's sustainability philosophy is to encourage maximum output while incurring the fewest financial expenditures [58]. The budget for building projects is regarded as an important factor [59]. It is crucial to emphasize, however, that the quality of life is a fundamental focus of the green building evaluation, leading to long-term economic development [60]. Comfort and convenience are two characteristics of life quality represented by good relationships to nature. As a result, in order to accomplish the sustainable economic goals, the life quality of materials should be addressed. This component's variables include meeting the demands of stakeholders and material life expectancy.

5.2.3. Social

The "Social" component is connected with resistance to natural contamination and habitat catastrophes, noise pollution isolation, and simplicity of building. One component of building design is the pursuit of balance while meeting several performance targets. The performance definition provides a logical foundation for planning and construction that is dynamic and responsive to changes and advancements [36]. A structure that does not value system interface and performance capability may result in incompatibility, malfunctions, and obsolescence risk.

"The maintenance and risks of a possible decline in the income are arising from the loss of tenants, which adversely affect the building's financial viability" [37]. As a result, it is critical to think about the performance requirements for construction materials. Stakeholders accomplish the aim of performance capability by identifying performance criteria during the material selection process.

Furthermore, consideration of societal benefits throughout the material selection process is critical. Social factors are several techniques that may be used to achieve sustainable construction projects. For promoting the use of local materials, a distinct value must be considered. Using building health and safety helps to fulfil sustainability, which decreases injuries and accidents during and after the construction process, resulting in lower insurance costs for construction businesses [61]. As a result, social benefits criteria are used to accomplish building sustainability.

5.3. Managerial Implications

The rearrangement of sustainable material selection criteria can be beneficial for developing a "framework" that stakeholders, such as project owners and contractors, can utilise to implement a sustainable approach more successfully in their projects. Furthermore, this reorganisation can serve as a model for developing a beneficial framework for the successful transformation of construction participants through sustainable stages. The framework "will contribute to Saudi Arabia's goal of establishing a stable, sustainable, and competitive economy." Furthermore, the "framework" produced from this study can, to a large extent, support the deployment of a sustainable strategy in other developing nations where building projects are implemented in a similar manner [92]. This is especially important in underdeveloped nations, which face several constraints, such as incurring exorbitant fees to address environmental challenges [93]. As a result, a sustainable approach can give these nations with chances to include sustainability into building project design methods [94,95]. Nevertheless, this study makes a substantial contribution in the following specific aspects, all of which have important consequences for the construction industry:

It provides a database of the sustainable material selection criteria implementation and related aspects in order to determine their competitiveness and global market survival via sustainable integration.

It assists owners, consultants, and contractors in reviewing and selecting sustainable material criteria for implementation in order to maximise the planning, economy, and consistency of construction projects.

It demonstrates scientific evidence that might help Saudi Arabia and other developing countries adopt sustainability.

The majority of building sustainability and sustainability research has focused on industrialised countries (the United Kingdom, the United States, Hong Kong, and Australia) as well as other countries like as Malaysia, China, and Saudi Arabia. As a result, there is no study on sustainability implementation in the Saudi construction sector and only a few studies on adopting sustainable material selection criteria in a developing nation. As a result, our research has effectively linked sustainable material selection criterion adoption to the Saudi building sector. This lays a solid foundation for exploring the practise of sustainability in improving the dependability of local building projects and closing the knowledge gap.

This study provides a helpful tool for decision-makers to use in the unbiased creation of sustainable material selection criteria. For the first time, the prediction technique for AHP is provided in this paper to examine the Sustainable material selection criterion in the building sector. As a result, this technique has the potential to be game-changing in construction projects, particularly in poor nations. Despite the fact that the study was conducted in Saudi Arabia, it is expected that this paradigm shift results in comparable conditions and limits in other developing nations.

The outcomes of this study can help to adopt sustainable material selection criteria in Saudi Arabia building projects. Our findings give a knowledge of the goals of implementing sustainable material selection criteria, which include reducing needless costs and allocating appropriate costs to each project. As a result, by designing and following the intended strategies, all involved parties may focus on the project's purpose in terms of expenditure, time, and efficiency. Ultimately, establishing a high level of sustainability in a project has a good influence. The findings of this study also give a guideline or a benchmark for decreasing difficulties related with project execution. Overrun expenses, project completion, and ambiguous requirements were among them.

Furthermore, this research gives owners or employers with insight into how to use sustainable material selection criteria to improve the success of their projects.

5.4. Theoretical Implications

While the notion of developing a sustainable concept is not new, [96], it seems to play an ever more vital role in several enterprises [97]. The suggested prioritisation model includes a need for the adoption of sustainable material selection criteria, particularly in the field of sustainable residential building. The proposed AHP model is used in this study to identify the Sustainable material selection criteria. These criteria can help overcome the present challenges to successfully adopting a sustainable material selection strategy in the Saudi Arabia building sector. As a result of this research, the gap between practise and theory of sustainable material selection criteria will be narrowed. To the best of our knowledge, no research has been conducted to examine the Sustainable material selection criterion in the Saudi Arabia building sector. To begin, this study empirically analyses the important Sustainable material selection criteria that might assist in the implementation of sustainability in the building sector. This conclusion lays the groundwork for future research on the Sustainable material selection criterion in developing nations by scholars, notably in the field of construction management. To that purpose, the theoretical components of this research provide a mathematical framework for creating sustainable material selection criteria that may be employed effectively in Saudi Arabia and other developing countries. The components of the sustainable material selection criterion in the Saudi construction sector have been compared using the unique AHP model. As a result, this work provides a way to help policymakers who are interns implement sustainable material selection criteria impartially.

6. Conclusions

Saudi Arabia has faced tremendous challenges in providing quality building structures and executing large-scale building projects like many other developed countries. To alleviate this condition, SBMs criteria for materials selection should be introduced. Therefore, it forms the prime objective of this study. A total of 28 SBMs criteria have been identified from the literature and experts interviews were conducted. The research resolves and harmonizes conflicting SBM criteria on three sustainability pillars (environmental, economic, and social). It proposed a hybrid MCDM methodology. A scatter plot has been used to rank the SBMs criteria, and the top three criteria from the main categories of environmental, economic, social criteria have been selected to develop the decision-making model. Among the environmental criteria, consumption of natural resources ranked as the first priority, followed by waste management and recycling and reuse. Under the economic criteria, meeting stakeholders needs, operation and maintenance cost, and societal costs of construction materials emerged as the top three criteria. Similarly, under the social category, use of local material, health and safety, and ecological and social acceptability are ranked as the top criteria. Seven (7) experts are involved in developing the decision-making model to weight the main categories, criteria, and alternative materials. Based on the final normalised matrix, hollow concrete brick (a1) is better alternative material to achieve sustainable buildings.

This research contributes to knowledge in this field by providing essential inputs for researchers to improve their understanding of the SBMs criteria for selecting materials and lays a good foundation for further research on the criteria for selecting SBMs. Additionally, this study provides stakeholders with SBMs criteria and a decision-making model for supporting sustainable building materials.

A major limitation of this study is that the scope of research is limited to the stakeholders in the Saudi Arabia's building industry. Similarly, the developed model has only been implemented to select the bricks materials for buildings. Therefore, future studies, can implement the model to select different building materials. Lastly, another decision-making method may be used to enhance the accuracy of the assessment.

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