

Methods for Selecting Building Materials: A Comparative Analytical Study

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Abstract

The process of selecting building materials is one of the most important steps in architectural design. The selection process is at the core of the design process and is critical to the long-term success of an engineering project. Therefore, architects try to follow the best and most suitable methods to select building materials that match the design criteria. When selecting building materials, many criteria are related to building performance, environmental considerations, cost effectiveness, and aesthetic considerations must be taken into consideration. This research paper provides a brief overview of the methods that can be used to select building materials for architectural design. It analyzes these methods and compares them to identify the capabilities of each method and its application areas with the aim of helping architects and designers make choices that achieve the best building performance, considering criteria such as environmental impact, cost-effectiveness, and aesthetic considerations. The study results indicated that the significance of the methods for selecting building materials varies depending on the project's objectives.

Keywords: *Building Materials, Design Criteria, Architectural Design, Methods, Material Selection.*

Introduction

Building materials have been considered important and influential elements in the architectural design process throughout the ages. They have played this critical role for as long as humans have appeared on Earth. Building materials are defined as "the materials used by architects to realize their building". Building materials are necessary to the production of architecture in every era. With advances in traditional building materials and increasing knowledge of their architectural and structural properties, coupled with other environmental, economic and social factors, architecture has transcended different eras[1].

When selecting building materials, architects consider many criteria are related to cost-effectiveness, material performance and efficiency. These criterions include durability, hardness, maintainability, and resistance. Additionally, the architect seeks factors related to the aesthetics of the material and its acceptance by society, as well as minimizing negative environmental impacts [2]. Every construction project involves the selection of building materials is considered the most important step in product design. Material selection is a complex and precise task determined by the variety of building materials [3]. Selecting one material from millions is not an easy task. Traditional methods of material selection (manual selection based on the designer's material knowledge) are not effective and require a lot of time and effort. Therefore, it is necessary to identify methods that simplify the selection process [4].

The Oretical Bases

In this part, methods for selecting building materials will be explained. The process of selecting building materials falls under multi-criteria decision-making (MCDM) [4]. Therefore, the study

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will select a set of methods that can be used in the decision-making process for selecting the optimal material, which is the most common and relevant to the selection process.

Ashby Chart

The Ashby chart, established by Professor Mike Ashby in 1990, is one of the most widely used methods for initial material selection. It is a scatter chart that shows a large set of materials and their categories. Its purpose is to support the material selection process by comparing required constraints/criteria with selected materials that satisfy these constraints. The horizontal axis represents one material property, density, while the vertical axis represents another property, the elastic modulus (see FIG 1). These are numerical scales and cover a wide range, including all materials[5]. Ashby chart is superior to traditional technique, saving time and effort, and the selection process is more accurate and effective [4].

In order to select materials that meet the project requirements, a visual evaluation of the materials in the table is required. Materials within the required range are considered good. Prioritize materials based on designer preference. Materials are prioritized based on the designer's preferences. For example, priority may be given to material hardness, but cost is also a concern for the designer, so it's possible to select a material with lower strength but at a reasonable cost[4].

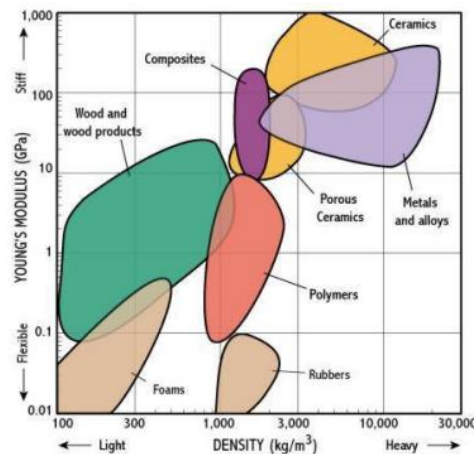


Fig. 1 Example of an Ashby diagram showing bubbles for each class of materials and each class encompassing a group of materials (Ashby, 1999)

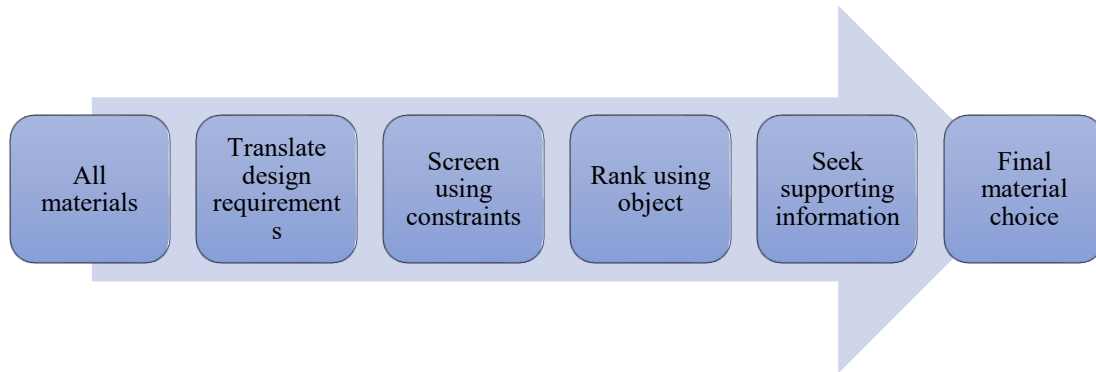
A criticism of the Ashby chart is that it only takes into account two material properties, density and elastic modulus. Notation is easily applied when the goal is simple, such as reducing weight or increasing material stiffness. However, if the goal is affected by more than one or more criterion, the property may not be able to achieve this goal and select building materials.

Cambridge Engineering Selector (CES)

The CES Selector program is a set of computer tools designed for Windows operating systems for evaluating information relevant to engineering designs. It was designed by Granta Design Ltd. and developed in collaboration with the Department of Engineering at the University of Cambridge. The program supports and enhances the teaching and learning of materials, technology, design and sustainability. It provides a comprehensive database of materials and process configurations and provides an engaging way to explore and understand the world of materials. The program can work with composite materials (hybrid materials)[7]. To achieve optimal material selection, four steps are required (see Figure 2):

- Translation step: In this stage, the design criteria that will achieve the design goals (such as cost reduction, weight reduction, or environmental impact) are identified[8].
- Screening step: In this stage, the material selection is narrowed and those that do not meet the restrictions and criteria are eliminated. This is done using a computerized database containing material properties (physical, mechanical, thermal and electrical property values)[8]

- **Ranking step:** In this stage, material metrics are presented in a material selection chart and materials with better value are identified. Ranking is achieved by defining values for density (E) and Young's modulus (ρ). Choose a larger value that satisfies this metric[8]. The result of the filtering and sorting steps is a concise list of materials classified according to quantifiable design requirements.
- **Supporting Information:** Supporting information helps narrow down the shortlist for final selection, resulting in a final match between design requirements and material properties[8].



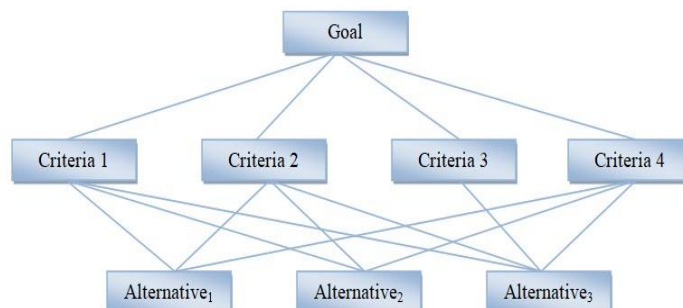
(Figure 2) The four steps of the material selection strategy (Ashby et al., 2005, p. 6)

The program CES is considered one of the most commonly used methods for selecting construction materials, as it deals with environmental, aesthetic, economic, and technical criteria for material selection. The program's database contains approximately 3000 materials. However, it does not take into consideration the availability of the material locally.

Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a multi-step method for achieving a goal, which organizes a complex ranking into a systematic hierarchical structure. It allows for the comparison of a set of complex issues that have an impact on the overall goal, considering the importance of each issue in relation to solving the problem[9]. This method is considered one of the most common and used methods for determining weights for multi-criteria problems (MCDM). It has been used as a research tool since 2000, owing to its ability to handle complex problems and make decisions in various fields, including material selection. Additionally, it can integrate both objective and subjective criteria into the decision-making process[10].

The AHP structure consists of three levels (see Figure 3), the first level contains the goal, and the second level contains the design criteria that influence the selection process, and finally, the third level contains the alternatives.



(Fig 3) General hierarchy structure of Analytic Hierarchy Process (Agarwal et al., 2014, p.22)

In evaluating each criterion within the Analytic Hierarchy Process (AHP) hierarchy and prioritizing them, a pair wise comparison matrix of ratios is developed to assess the performance of each criterion relative to one another (i.e., the prioritization). The prioritization process in AHP is based on a 9 point

scale (see Table 2), where (1) indicates equal preference, and (9) indicates an absolute preference for one over the other in terms of importance[11].

Table (2) Preference Level of factors or criteria (Saaty, 1987)

Rating Level	Verbal Judgment or Preference
9	Extremely Preferred
7	Very Strongly Preferred
5	Strongly Preferred
3	Moderately preferred
1	Equally preferred
2,4,6,8	Average values

The Analytic Hierarchy Process (AHP) is widely used in the process of selecting construction materials and determining the weights of design criteria. This is due to its capacity to decompose complicated issues into a hierarchy of smaller issues. Additionally, it can measure both objective and subjective decisions made by experts[11]. There are many computer applications for the Analytic Hierarchy Process (AHP), with Expert Choice V.11 being one of them. These applications assist in making decisions that involve multiple criteria and alternatives, making it a valuable tool in various fields, including material selection for construction projects.

Pugh Matrix

Pugh Matrix is defined as an analytical tool that produces the best concepts. It allows the list of ideas to be refined by using a matrix-based process to weigh and compare conceptual designs. It was developed by Stuart Pugh in 1990. It's also known as the Decision Matrix or Opportunity Analysis[13]. The matrix consists of rows and columns, each cell in the matrix contains the symbol +, - or S, and a concept is selected as a reference (the baseline is the option we currently have, which has the value 0 in the matrix), and all other concepts are compared to it. Based on the team's assessment, the matrix can indicate whether an alternative is "better than," "equal to," or "worse than" a reference[14](see Table 2). Pugh matrices are known for their ability to accommodate a variety of design criteria[15].

To select the best building materials using the Pugh matrix, there are several steps to follow:

- **Select a Datum:** Identify a set of design criteria and place them into the rows of the matrix. Select a range of material alternatives and place them into the columns of the matrix. Define a reference and use the criteria to compare each alternative to it. Mark with +, - or S accordingly. If the alternative is better than the current reference, it is marked with a "+". If it is worse, it is marked with "-". If they are the same, they are marked with "S"[13].
- **Ranking and Assessment:** Calculate the number of positive and negative signs in each column. Also count the "S" marks. Then add the markers -ve and +ve. Finally, a decision is made based on the results[14].

(Table 2) Pugh Matrix Model (author)

Criteria	Baseline	Alternative 1	Alternative 2	Alternative 3	Alternative 4
1	0	-	+	+	S
2	0	-	+	S	-
3	0	+	+	-	S
4	0	S	-	+	-
Total +		1	3	2	0
Total -		2	1	1	2
Total score		-1	+2	+1	-2
Rank			1 st	2 nd	

The Pugh Matrix helps to better understand the project requirements and its issues. It helps to understand the relationships between proposed options and how they lead to other decisions. It also helps determine why a particular solution is better or worse than others[14].

Value Engineering Concept (VE)

Value Engineering (VE) is an intensive and multidisciplinary activity that aims to find the best balance between product (building) performance and economic cost[16]. It is applied during the project conceptualization phase or after the completion of the general conception[17]. It is a process for improving the quality, functionality, and reducing the cost of the design process. The owner's desire is to achieve maximum quality and minimal cost[16].

A study by Saud (2019) used the concept of value engineering (VE) to select the building material for the building's exterior wall elements. Similarly, a study by Al Rahhal Al Orabi and Al-Gahtani (2022) for selecting floor finishing materials. To select the best building material according to the concept of value engineering, the following steps are followed:

- **Setting Evaluation Criteria:** In this step, the quality and performance criteria that affect the selection process are determined. In the value equation (see equation 1), a distinction is made between cost and quality. This includes initial cost, maintenance cost for each material, and installation cost[18].

$$\text{Value} = \frac{\text{Function+Quality}}{\text{Cost}} \quad (1)$$

- **Setting Project Goal and Function Analysis:** The selected materials must achieve the project's goals. This is done by considering criteria relevant to the functional requirements. For example, the aesthetic criteria for a hotel may be higher than for a storehouse, so materials that meet aesthetic aspects are preferred[18].
- **Criteria Weight Evaluation:** Determine the most influential criteria weights using the Analytic Hierarchy Process (AHP)[10].
- **Ranking Material Alternatives:** Next, identify the material alternatives proposed by the designer and specify their quality criteria. Subjective criteria are assessed by professionals, and objective criteria are ranked using material data and specifications. Ranking takes into account how each solution measures up to the design criteria. Each alternative is given a rank from (0-5), with Excellent (5); Very Good (4); Good (3); Average (2); Poor (1); Very Poor/Canceled (0)[18].
- **Total Quality Scores Calculation:** Calculate the total quality points for each criterion by multiplying the ranks by their corresponding weights (see equation 2). Calculate the final overall quality scores for each material option[18].

$$Q \text{ score} = W * R \quad (2)$$

W= Weights, R= Ranks

- **Value Scores Calculation:** Calculate the value for each material alternative, representing the standard material quality to cost ratio, using the following equation[18]:

$$V = Q / C \quad (3)$$

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

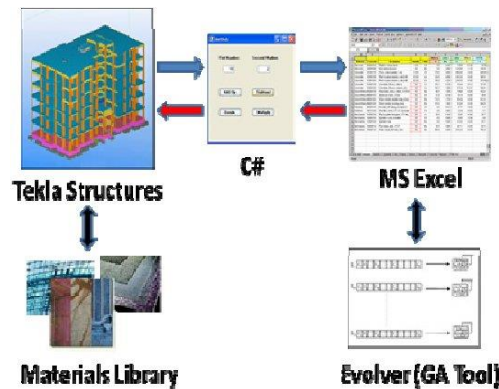
Value engineering is an effective approach for problem-solving that can lower costs while preserving or enhancing performance and quality criteria. Value engineering can help with decision-making so that the owner's money is spent most effectively while still achieving the necessary levels of functionality and quality. In order to ensure that quality, reliability, performance, and other important criteria match or exceed customer expectations, the VE process must be able to spot possibilities to reduce unnecessary expenses[17].

Building Information Modeling (BIM)

BIM is a digital tool used to improve the performance of architectural structures. It models building information for architects and designers by creating a data-rich digital model from which data can be extracted and analyzed to make decisions and enhance the proposed model[19]. BIM software has been used in numerous researches to select the best building material. The fifth dimension of the

program deals with the cost and quantities of building materials, which are considered influential factors in the selection process[10]. Users of a BIM model have access to vital engineering information and data that enhance design, design management, manufacturing, production, maintenance, and other technical building-related operations over the course of the building's life cycle[18]. Using a BIM model, users can access crucial engineering information and data that improve design, design management, manufacturing, production, maintenance, and other technical activities related to the building throughout its life cycle[18].

The study by Glaumann (2013) used a developed model (see Figure 4) for a set of software that integrates with BIM to select the final and optimal alternative, such as the "Tekla Structure" program to represent the building digitally. The C# language was used to automatically modify the BIM model based on the results of the optimization process and obtain the optimal building material[19]. The study, Al Orabi and Al-Gahtani, 2022, integrated BIM software with value engineering (VE) Dynamo to automate tasks and select the optimal building material[10].



(Figure 4) Communication between system components (Glaumann, 2013, p. 1680)

Comparing Methods for Selecting Building Materials

Understanding the project requirements and knowing the influence of important factors and criteria simplifies the problem of selecting the building material. The selection process is affected by a group of design criteria within different aspects: environmental criteria, economic criteria, technical criteria, and cultural and social criteria[20]. Therefore, in this paragraph, we will evaluate each of the aforementioned methods for selecting building materials and compare them with each other (See Table 3).

(Table 3) Methods for Selecting Building Materials (Author)

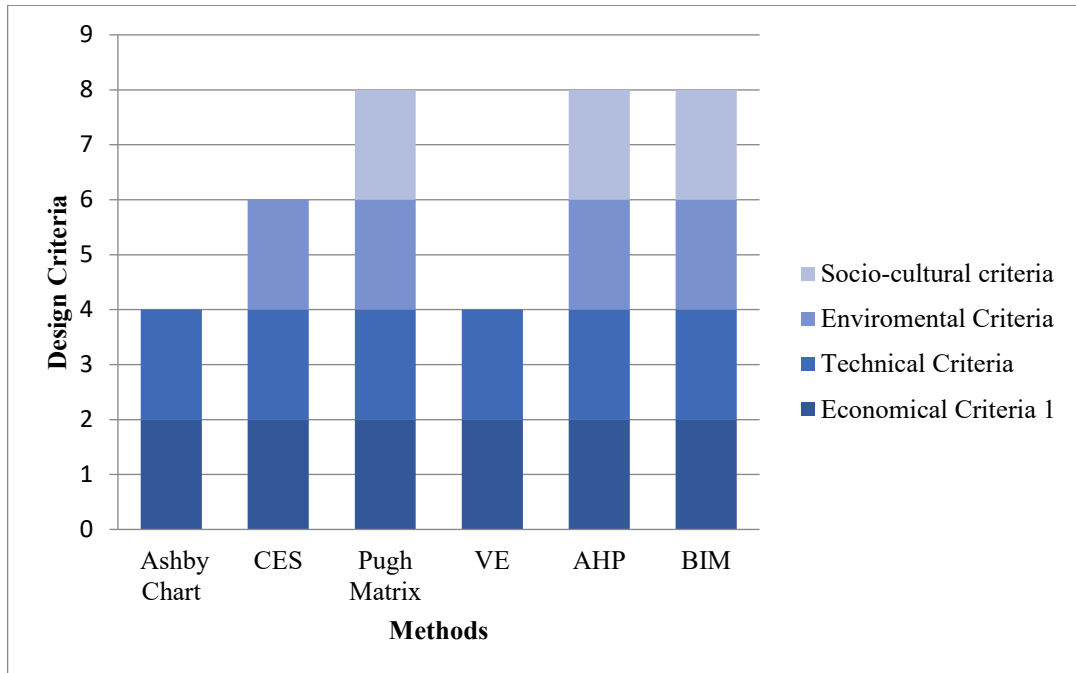
#	Method / Tool	Advantages	Defects	The criteria that it's deal with
	Ashby Chart	<ul style="list-style-type: none"> The chart classifies a variety of materials. Material selection involves simple math. 	<ul style="list-style-type: none"> Material selection based on density and Young's modulus. One criterion per selection process. 	<ul style="list-style-type: none"> Economic criteria Technical criteria
	Cambridge Engineering Selector (CES)	<ul style="list-style-type: none"> The program classifies materials and provides a selection process. A database of approximately 3000 materials is provided. Select materials at different stages (production, use, and disposal). Performance predictions help designers meet criteria. 	<ul style="list-style-type: none"> Failure to consider whether the material is available locally. A complex program that requires prior training to use correctly. 	<ul style="list-style-type: none"> Economic criteria Technical criteria Environmental criteria

		<ul style="list-style-type: none"> • Determine environmental impact and select sustainable materials. • Provide cost estimates. 		
	Analytic Hierarchy Process (AHP)	<ul style="list-style-type: none"> • Select relies on evaluating and comparing alternatives and criteria. • Consider both subjective and objective criteria. • Handle a large number of criteria simultaneously. • Compare material options for the best choice. • Improve team collaboration through group assessments. • Consistency reduces irrational decisions. • Selection involves mathematical operations and supporting software. 	<ul style="list-style-type: none"> • The results may be biased and subjective. • Pairwise comparisons in the selection process are time-consuming. • It is difficult to use in large projects due to extensive data requirements. • Difficulty in determining weights for pairwise criterion comparisons. 	<ul style="list-style-type: none"> • Economic criteria • Technical criteria • Environmental criteria • Socio-cultural criteria
	Pugh Matrix	<ul style="list-style-type: none"> • The choice depends on an evaluation of alternatives and criteria. • Improve material alternatives. • Consider both subjective and objective criteria. • It handles a large number of criteria simultaneously. • Compare material options for the best choice. • Improve team collaboration through group assessments. • Reduce construction costs to mitigate budget risk. 	<ul style="list-style-type: none"> • The results may be biased and subjective. 	<ul style="list-style-type: none"> • Economic criteria • Technical criteria • Environmental criteria • Socio-cultural criteria
	Value Engineering (VE)	<ul style="list-style-type: none"> • Reduce build costs to reduce budget risk. • Minimize resource waste and increase project efficiency. • Select materials balancing cost and performance. 	<ul style="list-style-type: none"> • Cost reduction can compromise material durability and quality. • Initial cost savings may result in higher maintenance costs or greater 	<ul style="list-style-type: none"> • Economic criteria • Technical criteria

			<p>environmental impact.</p> <ul style="list-style-type: none"> • The resulting building prioritizes function and economy over aesthetics. 	
	<p>Building Information Modeling (BIM)</p>	<ul style="list-style-type: none"> • Digitally represents buildings and material suitability. • Numerical data improves the model. • Integrates with other selection-supporting software. • Allows you to set a project budget. 	<ul style="list-style-type: none"> • The cost is high, especially for small projects with a specific budget. • A time-consuming and complex process that requires significant effort 	<ul style="list-style-type: none"> • Economic criteria • Technical criteria • Environmental criteria • Socio-cultural criteria

From the preceding discussion, we notice there are differences in the method of applying the aforementioned mechanisms for selecting building materials. The Ashby Chart relies on a graphical representation of material properties like density and Young's modulus, and through this chart, the material that meets only one criterion (cost or durability) is selected. It cannot satisfy more than one criterion in each selection process. As for the CES software, it is an enhanced model of the Ashby chart but relies on a vast database for its selection. It can meet a set of criteria for a single selection process. The Analytic Hierarchy Process (AHP) relies on a set of key criteria, which may include a set of sub-criteria, prioritizing them to select materials from a set of proposed alternatives by a team of experts through assigning weights to the criteria. On the other hand, the Pugh Matrix relies on a set of predefined criteria for a specific material alternative and compares it to the reference (baseline), making the selection based on a set of predetermined calculations by the specialized team. Value Engineering (VE) depends on achieving the lowest cost and ensuring the best quality, meeting only these two criteria in each selection process, with the selection process carried out through a series of simple calculations. Finally, the BIM program also makes use of a data management system and a digital representation of the building, which can help with material selection by visualizing, evaluating, and simulating different material alternatives.

There are some methods that deal with all the design criteria affecting the selection process of the appropriate building material, such as the Pugh Matrix method, the Analytical Hierarchy Process (AHP), and Building Information Modeling (BIM). There are some methods that limit the selection process to only two criteria's, such as the Ashby chart and Value Engineering (VE) (see Figure 5).



(Figure 5) The relationship between methods of selecting building materials and design criteria (author)

Conclusion

In this research paper, various methods for selecting construction materials were highlighted, aiming to assist designers and architects in choosing the most suitable approach based on specific project requirements, available data, and constraints. The study revealed that there is no single universally superior method for selection over others. Therefore, practitioners should leverage the strengths of each specified method and compare them with the project requirements.

However, it can be considered that the Analytical Hierarchy Process (AHP) and the Pugh matrix are among the methods that most effectively meet all the criteria. Nevertheless, the selection process may involve some subjectivity. Regarding building information modeling (BIM), it is regarded as one of the most precise methods in the selection process, but its application takes a longer time compared to other methods due to the need for integration with other software. Regarding other methods, such as the Ashby chart, CES selector, and value engineering (VE), they address specific design criteria, but they do not encompass all design criteria. Therefore, the method chosen depends on the project's goals for application.

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