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Informatic Analysis and Review of Literature on the Optimum Selection of Sustainable Materials Used in Construction Projects

Dina Abouhelal[1*], Wael Kamel[1], Hesham Bassioni[1]

[1]College of Engineering and Technology, Arab Academy for Science, Technology and Maritime Transport, Alexandria, EGYPT

*Corresponding Author

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Abstract: The dramatic increase in urban population has led to rapid infrastructure development worldwide and the construction industry has become one of the most progressive sectors in the world today. As a result, the construction process and its related stages play a significant role in the environment's impact, both directly (via resource and energy consumption as well as the production of contamination and waste) and indirectly (through intense pressure on inadequate infrastructures). Consequently, there is a global drive to develop "environmental-friendly and sustainable, "green" and carbon reducing buildings". Implementing sustainability can improve the quality of our life, granting us a healthy life and promoting economic, social, and environmental circumstances. The optimal selection of sustainable building materials is acknowledged as the most fundamental way for designers to apply sustainability principles to construction projects. This Paper provides a comprehensive literature review for sustainability maximization through the material selection process. The paper performs an analysis of the previous studies related to sustainable material selection to identify the critical factors and knowledge gaps that should be considered in the material selection process. Finally, the paper concludes that the current literature in the building domain lacks a standard method that could help decision-makers select the appropriate materials by considering all factors that arise in the decision-making process to maximize sustainability in buildings. Furthermore, a need exists to fill the gap between designers and decision-makers in the sustainable construction industry for improving the selection process of sustainable building materials while at the same time looking at the accomplishment of environmental goals and meeting design and budget requirements.

Keywords: Sustainable development**,** green buildings**,** sustainable building materials**,** rating systems**,** assessment tools

1. Introduction

The energy crisis and global warming have always been significant issues for developing countries. In 2018, a special report from the Intergovernmental Panel on Climate Change (IPCC) declared that achieving a pathway compatible with limiting anthropogenic warming to 1.5˚C above pre-industrial averages would require about 45% decrease in greenhouse gas emissions by 2030 [1]. In Egypt, Buildings are responsible for about 39% of the total energy consumption, consuming 12% of potable water, nearly 68% of electricity utilization, and about 38% of the Carbon Dioxide (CO2) emissions [2]. In addition, buildings generate 25% of all ozone-depleting chlorofluorocarbons (CFC) which are released by processes to manufacture building materials and buildings air conditioners [3]. The

*Corresponding author: *dinahelal1996@gmail.com*

worldwide dilemma is how to deal with these continuous passive effects of construction activities on the environment during a project's life cycle. So, sustainable building construction has been identified as the best way to avoid resource depletion and reduce the negative environmental footprint [4].

1.1 Emergence of Green Buildings

The concept of "sustainability" or the design and construction of "green building (GB)" was introduced to set guidelines for the construction industry to limit its negative environmental impact and improve the building construction process along its life cycle [5]. "Green building is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction" [6]. According to the international residential construction community, a green building is considered a long-term strategy for reducing Life Cycle Cost (LCC) and passive environmental effects throughout its life cycle [3].

Implementing sustainability can enhance the quality of our life and thus granting us a healthy life and promoting economic, social, and environmental conditions. They are the optimal solution for reducing resource consumption, minimizing environmental damage, diminishing wastes, reducing energy loss, and increasing renewable energy use [9,11].

1.2 Sustainability Measurement Guidelines

To enhance sustainability in the construction industry, many organizations have introduced rating systems and guidelines for buildings. The first of such guidelines was the Building Research Establishment Environmental Assessment Method (BREEAM) in the UK in 1990 [10]. After that, the Leadership in Energy and Environmental Design (LEED) Green Building Rating System was developed by the U.S. Green Building Council (USGBC) in 1998. Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) was developed in Japan in 2001. GREEN STAR is a voluntary environmental rating system for buildings launched in 2003 by the Green Building Council of Australia [11]. The Green Pyramid Rating system (GPRS) was developed in Egypt to evaluate the environmental credentials of buildings [12]. The Pearl Rating System was developed by the Abu Dhabi urban planning council as part of their sustainable development initiative [13]. Moreover, there were Green Globes which consider a practical approach to green building. It is an online assessment protocol, rating system, and guidance for green building design, operation, and management. It is interactive, flexible, and affordable, and provides market recognition of a building's environmental attributes through third-party assessment [14]. Comprehensive inventories of available tools for environmental assessment methods could be found in Ding [15], the Whole Building Design Guide [16], and the World Green Building Council [17].

Even though existing methods and tools have a long history of use, LEED has gained strong credibility among experts [14-17]. LEED has grown to become the world's most widely used green building rating system, with more than 107,500 LEED-registered and certified projects in 182 countries and territories [19].

2. Improving Green Construction Through the Selection of Building Materials

Many negative effects are caused by building materials during their extraction, manufacturing, construction, maintenance, disposal, and recycling [3]. The appropriate selection of building materials aids in reducing energy consumption in the material manufacturing process, decreasing the embodied energy of a building, reducing the environmental effects over the life cycle of the building, and preventing discomfort for air quality [20]. Various researchers have evaluated sustainable building materials based on different aims and criteria. The key goals for various research were outlined in the subsections that followed, along with the criteria for evaluating green building materials. The authors divided the purposes of selecting green materials into three parts to clarify the importance of emerging concepts of green origin and green performance to optimize sustainable material selection. Moreover, comparing green building rating systems based on the materials-related criteria and credits helped to develop the optimal selection criteria for building green materials.

2.1 Parameters Affecting Sustainable Material Selection

There are a set of parameters that affects the selection of sustainable building materials. Getting decision-makers parameters is done through reviewing benchmarking of some rating systems, previous studies, and experts' opinions. This phase aims to collect the considerable parameters used in the optimal selection of materials. Green Pyramids (Egypt), PEARL (United Arab Emirates), LEED (United States), BREEAM (United Kingdom,) and Green Globes (Canada) were selected as a different rating system for sustainable material evaluation. The five rating systems were initiated in a different context with different standards where the material is a common category for all. Each rating system has its specific categories and evaluation parameters [3].

The parameters selected from the rating systems are shown in Table 1. According to the LEED rating system, the selection of environmentally responsible materials considers material accessibility by encouraging the use of materials extracted, processed, and manufactured regionally, and, at the same time, promoting the development of regional economies. The LEED rating system also promotes the use of materials with a high recycled content, a quick renewable cycle, and minimal pollutant emissions to minimize their negative effects on the environment and the building's indoor air quality. It enhances the use of materials for which life-cycle information is available and that have environmentally, economically, and socially preferable life-cycle impacts [21]. The Parameters that are repeatedly used in different rating systems are Construction/operational waste management, recycled content/recycled materials, local/regional materials, and designing for durability and resilience. It is, also, noted that most of the rating systems are concerned with recycled materials and waste management. As such, the choice of sustainable building materials should be depended on the materials' negative environmental impacts. Reusing and recycling building materials is a crucial tactic in the implementation of sustainable practices because it reduces wastes produced during construction.

Table 1 - Parameters of material selection based on selected rating systems

No	Parameter	LEED	BREEAM	GPRS	Pearl	Green Globes
1	Storage and collection of recyclables / Building reuse	√				
2	Construction and demolition waste management	√			√	√
3	Building life cycle impact reduction	√				
4	Resource reuse / Use of salvaged materials	√		√		
5	Recycled materials	√		√	√	
6	Bio-based materials/ Rapidly renewable materials	√		√		
7	Certified wood / Treated timber elimination	√			√	
8	Locally produced materials	√		√	√	
9	Extended producer responsibility	√				
10	Environmental product declarations	√				
11	Material ingredients	√				
12	Low-emitting materials	√				
13	Building life cycle assessment	√				
14	Responsible sourcing of construction materials	√				
15	Heat island effect	√				
16	Deconstruction, assembly, and Reassembly					√
17	Designing for durability and resilience/Use of high durability materials		√	√		√
18	Materials fabricated on site			√		
19	Life cycle cost analysis (LCCA)			√		
20	Hazardous Waste Management				√	
21	Use of lightweight material			√		
22	Organic Waste Management				√	
23	Modular Pavement and Hardscape Cover				√	
24	Interior Fit-Outs (including Finishes and Furnishings)					√
25	Minimize use of Interior Materials		√			√
26	Material efficiency		√			
27	Insulation		√			
28	products Life cycle impacts		√			
29	Hard landscaping and boundary protection		√			
30	Use of prefabricated elements			√		

2.2 Multi-Criteria Evaluation Models for the Selection of Sustainable Materials Used in Construction Projects

The issue of choosing green materials has been studied by several scholars in many different approaches. Abeysundara et al. (2009) developed a quantitative model for selecting sustainable building materials taking into consideration environmental, economic and social assessments of materials from a life cycle perspective. The study examined five building elements which are foundations, roofs, ceilings, doors and windows, and floors. Environmental burdens associated with these elements are assessed in terms of embodied energy and environmental impacts such as global warming, acidification, and nutrient enrichment. Economic analysis was based on market prices and the affordability of materials. Market prices and the affordability of materials served as the basis for economic analysis.

Social factors that were taken into account are thermal comfort, interior (aesthetics), ability to construct quickly, strength and durability. In a matrix of environmental, economic, and social scores, two existing building cases were compared. It was found that the buildings with tile roof and floor, rubble foundation, asbestos ceiling, and timber door and windows perform better than the buildings with asbestos roof, vinyl tile floor, brick foundation, timber ceiling, and aluminium doors and windows. The matrix assists decision-makers in making multi-criteria decisions and thus helps in selecting materials for sustainable buildings [22].

Akadiri et al. (2013) produced a building material selection model based on the fuzzy extended analytical hierarchy process (FEAHP) techniques. The sustainable building materials were evaluated based on six categories including environmental impact, resource efficiency, waste minimization, life cycle cost, performance capability, and social benefit. The assessment criteria were developed by the sustainable triple bottom line (TBL) approach and the needs of building stakeholders. A questionnaire survey of building experts was conducted to evaluate the relative importance of the criteria and aggregate them into six independent assessment factors. The FEAHP was used to prioritize and assign weights to the identified criteria. To demonstrate the approach, an empirical case study of three proposed roofing element alternatives for a new building project was used. The case study results indicate that the use of the FEAHP in incorporating both objective and subjective criteria into the assessment process and improving the team decision process is desirable. The proposed model aids decision-makers to formalize and effectively solve the complicated, multi-criteria, and ambiguous perception problem of building material alternative selection [4].

Sahlol et al. (2020) developed a system dynamics model to assess the performance of building materials based on their waste generation, amount of waste sent to landfill, amount of recyclable waste, life cycle cost, and health and safety index. The developed framework's main goal is to evaluate building materials based on the identified parameters throughout their life cycle and then select the most appropriate one. The study resulted in the development of causal loop diagrams (CLDs) to identify the positive and negative relationships among all parameters as well as the presentation of the system dynamics model for estimating the performance of building materials and selecting the best one among various alternatives. To demonstrate the main features of the proposed model, a case study evaluating the performance of common building materials such as wood, concrete and steel was presented. According to the simulation results, concrete is healthier and safer than wood and steel. Ceramics is safer than linoleum. Cellulose has a minimal negative effect on the environment, so it is suitable sustainable thermal insulation material. This model could assist decision-makers in selecting appropriate building materials for construction projects [3].

Figueiredo et al. (2021) presented a decision-making framework for construction professionals and researchers. The framework incorporates Life Cycle Sustainability Assessment (LCSA), Multi-Criteria Decision Analysis (MCDA), and Building Information Modelling (BIM) to select appropriate building materials. The proposed framework was developed based on Life Cycle Sustainability Assessment (LCSA) to assess the environmental, social, and economic impacts of building materials and make an appropriate choice. The Fuzzy Analytic Hierarchy Process was selected as the MCDA method within the proposed framework to contain subjectivity, uncertainty, and ambiguity within the material selection process. The Global Warming Potential (GWP), Acidification Potential (AP), and Eutrophication Potential (EP) were chosen as environmental impact categories in the study. GWP represents a measure of greenhouse gas emissions that may have negative impacts on the ecosystem and human health. The ability to increase the molecule's concentration of H^+ in the presence of water represents the acidification potential. The eutrophication potential measures excessively high levels of macronutrients, such as nitrogen and phosphorus. The impact category for the economic phases is considered in the system boundary. Finally, the impact category analyzed for the social analysis is fair salary, with Fair Wage Potential (FWP) adopted as the quantitative indicator. The framework was validated using a case study of a 36-unit residential building constructed in Rio de Janeiro, Brazil. LCSA is applied, covering the construction, operation, and end-of-life phases of the building. Different material lists were tested for the same building to determine which alternative would be the most sustainable. The framework enables construction professionals to quickly compare the alternatives [23].

Mayhoub et al. (2021) presented an evaluation framework for selecting green building façade materials based on green performance and green originality. The study identifies five primary criteria and 26 sub-criteria that could be helpful when choosing a building façade material for adhering to sustainability standards in new or renovated buildings. The evaluation framework considers LEED, BREEAM, GPRS, and Estidama rating systems as a reference to allocate credits for the relevant criteria. Based on the average scores from the four rating systems, the proposed criteria's weighted importance is determined using the Analytic Hierarchy Process (AHP). More points are gained for accreditation of green rating systems by using the proposed evaluation criteria for choosing green materials for building façades than by using the original points for materials. According to the suggested criteria, the assessed green grading systems obtain more than double the percentage of total credits. The study concluded that involving minimum levels of adverse impacts is the preferable criteria regarding the green origin concept. Sensitivity analysis results revealed that social impacts and energy efficiency significantly influence green performance more than green origin. Moreover, resource efficiency and economic impacts have more influence on green origin than green performance [24].

2.3 Optimization Models for Maximizing the Sustainability of Buildings Using LEED-Based Green Building Rating System

Many previous researchers have developed optimization models for enhancing the selection of sustainable building materials using LEED rating system as the basis for criteria evaluation. Castro-Lacouture et al. (2009) introduced a mixed integer optimization model to improve green construction decision-making through material selection. The model was developed in response to both design and budget constraints to address realistic scenarios experienced by the decision maker. The model's primary goal was to maximize the number of earned LEEDV2.2-based points by selecting the best materials and determining their extent of use. The evaluation of the performance of the candidate building was based on the environmental characteristics of the materials, such as the contribution to the heat island effect, the proportion of recycled content, and emissions of indoor materials. A case study of an 11- story office building in Colombia was presented to illustrate the model. As a result of this model, the decision-makers can obtain a detailed purchase plan that describes the materials to be used. Although this method is easy to adopt by builders due to the transparency of its requirements and the reduced data complexity, its application must consider more sophisticated assessment methods of environmental impact such as life cycle analysis (LCA) [25].

Alshamrani et al. (2012) created a Framework for selecting the suitable envelope and structure type for school buildings based on the sustainability points and LCC. The framework was developed using the Analytical hierarchy process (AHP) and the Multi-Attribute Utility Theory (MAUT), based on experts' and decision makers' opinions that were gathered using a web-based questionnaire. The selection is performed based on an evaluation of the LEED rating system and life-cycle costing techniques for typical structure and envelope-type alternatives. Several fourteen different structure and envelope types are investigated, covering steel, concrete, and wood structures, in various combinations covering both conventional and sustainable options. A Sustainability Assessment Model was developed to measure the Sustainability performance of conventional alternatives, based on the evaluation of certain LEED categories such as energy consumption, recyclability, and reuse of material, along with incorporating the Life Cycle Assessment (LCA) technique. Furthermore, The LCC Forecasting Models were created by utilizing Monte Carlo Simulation to compare the performance of conventional and sustainable school buildings. The framework provided a method that can assist governments and decision-makers in minimizing their overall expenditures on public buildings and providing the best possible structural/envelope system, while simultaneously reducing greenhouse gas emissions and minimizing the environmental impact associated with public sector buildings [26].

Frolez and Castro-Lacouture (2013) presented a mixed integer optimization model to aid in the selection of appropriate building materials and design parameters for buildings. To best achieve the multiple objectives, the suggested model integrates objective and subjective aspects. The author considered design, budget, and the number of points achieved under LEED rating system account for objective factors, whereas subjective factors comprehend user-based perceptions. The study's goal is to quantify the assessment of sustainability based on visuals and provide designers with information about perceived values. Credits in the proposed model were based on those credits in the existing LEED 2009 version for new construction and major renovations rating system that are related to material selection. The heat island effect, recycled content, regional distance from the manufacturer to the project, renewable cycle, wood certification, and emissions of indoor air contaminants were the sustainable characteristics examined in the study. The assessment of subjective factors of sustainability involves making a comparison of the visual sample against a series of criteria. The decision-maker is first shown a graphic representation of a sustainable material as part of the process. The visual information retrieved by the decision maker is then compared to a set of criteria to determine the level of sustainability of a material. A case study of an 11-story office building with an area of 6000 m2 was presented to illustrate how objective and subjective factors influence the material selection decision-making process. This approach may help designers select the right materials by considering not only budget, design, and LEED constraints but also information about perceived values [27].

Abdallah and El-Rayes (2016) presented a multi-objective optimization model using the LEED-EB V3 rating system as a tool to assess the environmental criteria. The goal of the optimization model was to find the best trade-offs between the three sustainability goals of limiting a building's negative environmental impact, minimizing the cost of building upgrades, and increasing the number of LEED points that an existing structure may achieve (LEED-EB). The proposed model's calculations were carried out utilizing a non-dominated sorting genetic algorithm (NSGAII). (NSGAII). The effectiveness of the model was assessed using a case study of an actual public building, and the findings showed how the established model was uniquely and practically capable of producing the best trade-offs among the three optimization targets indicated earlier. The proposed model could help building owners and facility managers in their ongoing efforts to achieve green building certification and to enhance the use of cost-effective green upgrade measures in existing buildings. The created optimization methodology is restricted to improving existing buildings' fixtures and equipment, setting up renewable energy systems, controlling the solid waste, and applying LEED-EB credit categories [28].

Marzouk and Azab (2018) presented a system dynamic model to provide the decision-makers in governmental authorities with an analytical tool to assist them in selecting the best building materials alternatives that satisfy the sustainability of the environmental and economic performances of low-income housing (LIH) buildings. The economic performance of buildings was assessed in this study by assessing the LCC of LIH projects, taking into consideration initial cost and operation costs. The Environmental aspects were evaluated by the material selection area in LEED V3 for new construction and major renovations. Only, five credits are chosen to track the impact of material characteristics on the assessments which are the reuse of materials, recycled content, regional materials, rapidly renewable materials, and certified wood. The proposed model was developed by formulating the System Dynamics (SD) model with the STELLA software package. The proposed model is capable of considering the dynamic nature and interactions among major variables affecting the assessment of economic and environmental performances of selected green materials [29].

Kumar et al. (2018) presented a multi-objective optimization model to help decision-makers in sustainable construction in selecting optimum building materials for their projects. The model focuses on the trade-off between time, cost, and sustainability represented in the LEED MR credits. It was developed as a multi-objective optimization tool based on LEED v3 for new construction. The MR LEED credits which have been considered in the model were Recycled Content, regional materials, and rapidly renewable materials. Two validation case studies were introduced to validate the GA optimization model. Data collection and analysis of the case study were conducted on a LEED-certified project as the case study. The analyzed data was run on the code created in Python using the GA optimization model, to find the near-optimal solution based on the user-defined priorities. The second validation case study was introduced to check the reliability of the optimization model and check for coherence in results when applying the optimization model to various types of projects. The optimization model resulting from this research is beneficial to different stakeholders in the construction industry. It can reduce the workload of LEED consultants exponentially, by providing them with material options to use based on the important factors provided by the owners [30].

Marzouk (2020) developed a mixed integer optimization model to help architects, designers, and owner representatives choose building materials at the design stage while taking costs and risks into their account. The model was created as a simulation optimization tool for new buildings using LEED V3. The environmental aspects of construction materials, such as their contribution to the heat island effect, percentage of recycled content, and emissions of indoor pollutants, were taken into consideration in the evaluation process. The created model enabled the cost analysis of various design alternatives using both deterministic and probabilistic methods. It also finds the least expensive way to earn LEED credits as well as the risks connected to material quantities and unit costs. To demonstrate how to use the suggested tool, a case study of an Egyptian office construction project was presented. In the case study under consideration, an integrated Fuzzy Monte Carlo Simulation (FMCS) analysis was done to take the hazards of utilizing novel materials into account. By incorporating the proposed model into the LEED rating system for new construction, it can capture the cost uncertainty of building materials and assess the cost and sustainability performance of various building materials [31].

As per reviewing the literature, there are some critical gaps in the decision supporting systems related to sustainable material selection. Table 2 summarizes the different assessment criteria of green building materials that were carried out by the previous studies.

3. Critical Knowledge Gaps in Previous Studies

The comprehensive literature review revealed some critical knowledge gaps:

- Most developed decision-making methods to date do not include all the material-related credits in their criteria consideration. Much of the decision-making process surrounding sustainable material selection is based on material reusing, recycling content, regional and rapidly renewable materials, and certified woods. Additional decision-making models should be developed to maximize the environmental benefits. Further criteria can be investigated such as the embodied energy and CO2 emissions of building materials, the contribution to the heat island effect, life cycle assessment of sustainable materials, and the consideration of the emittance of building materials and its effect on the indoor air quality.
- Furthermore, a critical consideration in the development of material selection decision-making is the material's life cycle costing. previous studies didn't consider both LCC and environmental performance as objective functions that can be optimized simultaneously. They are often limited to the evaluation of criteria related to the environment.
- Previous research efforts didn't take into account the effect of the uncertainty costs associated with building systems on the economic and environmental performances of the building.
- Moreover, no study proposes optimization methods for multiple objectives in the process of selection of sustainable building materials using LEED v4.1 under the rating system of Building Design and Construction (BD+C) so far. Also, the majority of the material selection optimization models are applicable for the buildings under the category of new construction and major renovation such as residential buildings and office buildings. There is a need to the consideration of other construction project types, like Schools, Healthcare, Hospitality, etc.…, since each type has its requirements.
- There is a gap between the awareness and implementation of sustainable practices in the choice of sustainable building materials in the design decision-making process [32].

- Despite the spreading of advanced computing tools in several operations, the need of selecting sustainable building materials is still impeded by several parameters and there is a need for creating a dynamic model of parameters [33].
- There is a gap in integrating all dimensions of sustainability.

Table 2 - Sustainable material selection literature criteria consideration

Author(s)	Purpose of Research		Material selection consideration			Level of study			Methodology	Case Study application	Limitations	Ref.
	Optimization	Analysis	Economic	Environmental	Social	Element	System	Building				
Castro-Lacouture et al. (2009)	√			- Contribution to the heat island effect -Proportion of recycled content -Emissions of indoor pollutants				√	Mixed Integer Linear Programming	11-story office building in Colombia	- The study didn't consider the effect of the economic and social factors due to the assessment of sustainable building materials.	[25]
Abeysundara et al. (2009)		√	-Market prices and the affordability of materials	-Embodied energy and environmental impacts such as global warming, acidification, and nutrient enrichment	-Thermal comfort. -Interior (aesthetics) - Ability to construct quickly - Strength and durability	√			Matrix analysis	Two existing building cases in Sri Lanka	-This study is applicable for selecting sustainable building materials for the existing buildings in Sri Lanka. -The impact on "land use" is not addressed. This may be useful for overall assessment. - Only five building elements, viz., foundations, roofs, ceilings, doors and windows, and floors are analyzed. Other building elements could be investigated with other building types.	[22]
Alshamrani (2012)	√		-Life cycle cost •Initial cost •Running cost •Environmental impact cost •Salvage value	-Energy consumption - Recyclability -Reuse of material -Life cycle assessment				√	Analytical hierarchy process (AHP) and the Multi Attribute Utility Theory (MAUT)	New school building in Canada	- The study is appliable for conventional and sustainable school buildings only. Other building types could be investigated as its building has its own requirements. - The evaluation of building materials was based on limited criteria. Future sustainable criteria could be used for enhancing the material selection.	[26]

Table 2 - Sustainable material selection literature criteria consideration (Cont.)

Author(s)	Purpose of Research		Material selection consideration			Level of study			Methodology	Case Study application	Limitations	Ref.
	Optimization	Analysis	Economic	Environmental	Social	Element	System	Building				
Akadiri et al. (2013)		√	-life cycle cost • Initial cost • Maintenance cost • Disposal cost	-Zero /low toxicity -Ozone depletion -Minimize pollution -Impact on air quality -resource efficiency - waste minimization - performance capability	-Use of Local materials -Aesthetics -Health and safety -Material availability	√			fuzzy extended analytical hierarchy process (FEAHP) techniques	Empirical case study for new building project	-The study is applicable for selecting sustainable building materials for roofing elements. Further building elements could be investigated.	[4]
Florez & Castro-Lacouture (2013)	√		-Initial cost	-Recycled content -Place of origin -VOC content -Renewable period -Forest certification -Urea-formaldehyde -Reflectance index -Subjective properties of sustainable materials				√	Mixed Integer Linear Programming	11-story office building in Colombia	- The study didn't take into consideration the effect of the material's LCC in the evaluation process. -The assessment of sustainable materials was based on LEED - New Construction v3 (2009). Future studies could use the latest versions of LEED.	[27]
Marzouk et al., (2013)	√		-Initial cost	-Reuse of materials -Recycled content -Regional materials -Rapidly renewable materials -Certified wood				√	ACO + System Dynamics	2-floor residential building (villa)	-The research can be expanded to encompass different types of construction, taking into consideration the different combination of materials.	[34]
Abdallah & El-Rayes (2016)	√		-Initial cost	-Energy efficiency -Material recycling -Waste reduction			√		NSGA-II	Existing public building	-The model is applicable for upgrading the existing structures only.	[28]
Marzouk & Azab (2017)		√	-Life cycle cost • Initial cost • Operation cost • Replacement cost • Salvage value	-Reuse of materials -Recycled content -Regional materials -Rapidly renewable materials -Certified wood				√	System Dynamics (SD)	low-income housing (LIH) building in Badr City, Egypt	-The scope of this research can be extended in the use of other criteria such as social aspects. - Life-Cycle Assessment could enhance the selection process on the different stages of LIH buildings.	[35]

Table 2 - Sustainable material selection literature criteria consideration (Cont.)

Author(s)	Purpose of Research		Material selection consideration			Level of study			Methodology	Case Study application	Limitations	Ref.
	Optimization	Analysis	Economic	Environmental	Social	Element	System	Building				
Marzouk et al., (2018)	√		-Life cycle cost • Initial cost • Operation cost • Replacement cost • Salvage value	-Reuse of materials -Recycled content -Regional materials -Rapidly renewable materials -Certified wood				√	NSGA-II	University in Saudi Arabia	-This research considers only the material and resources category of LEED (2009) for evaluating sustainable building materials. Other critical sustainable factors could be investigated such as Life Cycle Sustainability Assessment.	[29]
Kumar et al., (2018)	√		-Initial cost	-Recycled content -Regional materials -Rapidly renewable materials				√	GA optimization	Fire station project & Health and Medical Center (HMC), in Fort Collins, Colorado	-This research considers LEED version 2009 for credits' calculation, even though the latest version for LEED is V4.1. -The selection of building materials was based on limited environmental properties.	[30]
Sahlol et al. (2020)		√	-life cycle cost • Initial cost • Running costs • Replacement cost • End of life cost	-Waste generation -Amount of waste sent to landfill -Amount of recyclable waste -Health and safety index		√			System dynamics	New construction project	- Although the model achieved practical results, Future studies may find the new interrelations between parameters to select building materials on a high accurate level.	[3]
Marzouk (2020)	√		-Initial cost	-The heat island effect -Recycled content -Regional distance from the manufacturer to the project -Renewable cycle -Wood certification -Emissions of indoor air contaminants				√	Mixed Integer Linear Programming	Office building project in Egypt	-The model is applicable for selecting optimum building materials to office building projects based on selected criteria on LEED (2009) rating system. Further criteria can be investigated such as the use of raw materials and the effect of carbon dioxide emissions. -Further studies can cover the recent editions of rating systems such as LEED V4-US, BREEAM-UK, and GPRS-Egypt.	[31]

Table 2 - Sustainable material selection literature criteria consideration (Cont.)

	Purpose of Research		Material selection consideration			Level of study						
Author(s)	Optimization	Analysis	Economic	Environmental	Social	Element	System	Building	Methodology	Case Study application	Limitations	Ref.
Figueiredo et al. (2021)		√	-Impact category	-Global Warming Potential (GWP) - Acidification Potential (AP) -Eutrophication Potential (EP)	-Fair salary, with Fair Wage Potential			√	Fuzzy Analytic Hierarchy Process	36-unit residential building constructed in Rio de Janeiro, Brazil	-In this research, the project was modeled for a proposed building, which brings certain limitations to the study compared to a real construction project, such as the impossibility of collecting data from the region's inhabitants and the need to make some assumptions on the construction methods used. Furter studies are needed to explore the use of the proposed framework in real buildings, identifying effective ways to weigh the various impacts and accurately measure the qualitative aspects.	[23]
Mayhoub et al. (2021)		√	-Life Cycle Cost -Low Embodied Energy cost.	-Regional materials -Recycled content -Reusable or recyclable, Renewable sources -Durability -Minimum levels of adverse impacts -Low Embodied carbon -Low-Emitting Materials -Low or non-toxic content	-Aesthetics -Certified materials -Thermal performance -Effect on occupant -Thermal comfort -Effect on Acoustics -Ease of implementation		√		Analytic Hierarchy Process (AHP)		The model is applicable for evaluating the origin and green performance of building façade using AHP method. The model can be further extended to assess the building materials performance of other building elements (i.e., flooring and roofs) or to the whole building not only its façade. Moreover, the decision will be complex when determining the relationships among the sustainable criteria using AHP as several criteria are not based on numerical analysis, so other techniques (e.g., ANP) could be used in future works.	[24]

4. Conclusions

The construction industry has a major negative effect on the environment. Selecting sustainable building materials is a serious task that should be done at the early stage of the project. This paper has presented a comprehensive literature review for improving sustainable construction through the material selection process. Many approaches to the material selection problem have been developed, including multi-objective optimization, ranking methods, index-based methods, and other quantitative methods like cost-benefit analysis. Although many approximations to the material selection problem have been proposed in the previous literature, there are many critical factors were not considered. Additional decision-making models should be developed to maximize the environmental benefits. Thus, a need exists to fill the gap between designers and decision-makers in the sustainable construction industry for improving the selection process of sustainable building materials while at the same time looking at the accomplishment of environmental goals and meeting design and budget requirements.

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