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The Percentage Result, as Well as a Critical Review of the Common Characteristics of Various Sustainable Building Material Selection Frameworks

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Abstract: There are various frameworks for selecting sustainable building materials around the globe. However, it is difficult to get literature that describes their common characteristics, so the purpose of this paper is to try to provide a general framework for architects, and designers based on the literature review only. After conducting a thorough and systematic literature review, the number of observations for each data point shown as a percentage frequency distribution, which typically represented using tables. The process of creating a percentage frequency distribution entails first determining the total number of sustainable building material selection categories (such as economic, environmental, technical, social, and so on) to be represented, then identifying sustainable building material items (subcategories) within each category based on different authors' ideas to be represented. Finally, a general framework for sustainable building material selection developed. Finally, the proposed framework, which based on the sustainable triple bottom line concept, includes three dimensions: different authors frequently select economics (72%), environment (54%), and social (36%). Alternatively, it convert into a percentage of a hundred, it will be 44.50%, 33.3%, and 22.2%, respectively. As a result, we can conclude that when a designer selects a material, it is better to consider the three critical dimensions that are economic, environmental, and social factors.

Keywords: Sustainable Building Material, Framework, Ecological Dimension, Economical Dimension, Social Dimension

1. Introduction

Sustainable construction has grown significantly in recent years, posing numerous difficulties. These difficulties include economic, technical, and environmental issues, as well as energy, technology, and building materials management systems, all of which could be caused by a lack of adequate resource and building material management. The sustainability drive is leading to a rich and complicated architectural order around the world, rather than a single universal style [1]. The built environment consumes about half of all global resource consumption, including materials, energy, water, the loss of fertile agricultural land, which is why architects must realize that construction waste pollutes our planet and endangers the health of its inhabitants [1]. Because of the extraction, processing, and transportation steps that are required to process them, choosing building materials is thought significant in sustainable design. Construction of buildings pollutes the air and water, destroys natural habitats, and depletes natural resources.

Currently, there are no universal criteria for selecting sustainable building materials these papers try to present some of their common characteristics based on their percentage frequency distribution in different works of literature.

The need for a systematic and holistic sustainable material selection method of figuring out and prioritizing applicable general sustainable selection criteria to help design crew members in the selection of building materials to be used in building projects, to look at the complexity of the interactions between sustainable building materials and architects, and to set up a knowledge-based decision support system. These theoretical criteria enable the incorporation of sustainability standards in the building material selection decision-making process. The existence of sustainable building is enhanced, thereby increasing the efficiency of the building enterprise. Like contractors and provider vendors, they can additionally be treasured for future efforts and the transfer of knowledge and information. People who live or work in sustainable buildings benefit from better indoor air quality as well as a variety of other health and wellness advantages. The local population and the environment benefit from sustainable building materials since they are free of cancer-causing chemicals and toxic contaminants. As a result, from the owner's perspective, it reduces cost and extends lifespan.

2. Literature Review

The pace of actions toward sustainable application are done is determined by decisions made by a variety of actors in the construction process, including owners, managers, designers, firms, and others [2, 3]. Many ways have been used to address the material selection problem, including multi-objective optimization, ranking methods, index-based methods, and other quantitative methods including cost benefit analysis [4].

Designers don't only design for function and use but also for practice. In architecture, the materials that shape an environment will mainly influence the user's insight of that environment. Choosing materials for an architectural project is not only about meeting technical requirements, the material's appearance and sensory behavior play an important role while designing. While selecting a material, the architect reflects performance related features, such as the material's durability but also looks into aspects that concern the user experience or sensory stimulation, such as the material's color or texture. Moreover the architect might have a certain atmosphere in mind that will be reflected through the feeling the materials evoke, as a 'formal' feeling.

3. Methodology

The percentage frequency distribution is a display of data that shows the percentage of observations that exist for each data point or group of data points. This is a particularly useful way to represent the relative frequency of survey responses and other data. The percentage of frequency distribution is often displayed as a table or as a bar or pie chart.

The process of creating a percentage frequency distribution involves first identifying the total number of observations to be represented; then counting the total number of observations within each data point or grouping of data points; and then dividing the number of observations within each data point or grouping of data points by the total number of observations. The sum of all the percentages corresponding to each data... [5].

The process of creating a percentage frequency distribution entails first determining the total number of sustainable building material selection categories (such as economic, environmental, technical, social, and so on) to be represented, and then identifying sustainable building material items (sub categories) within each category based on different authors' ideas to be represented. Finally, frameworks for conceptual sustainable building material selection developed.

Table 1. *Main Categories that affect the sustainable building materials selection.*

No	Main Categories that affect the sustainable building materials selection.
	Factors of sustainable building material
1	1. Production requirement. 2. Economic factors. 3. Maintenance factors. [6]
2	1. Energy efficiency. 2. Resource responsibility. 3. Social/public health responsibility. 4. Economical/functional. 5. Quality of manufacturer. [7]
3	1. Environmental performances 2. Technological performances 3. Resource use performances and 4. Socio-economic performances. [8]
4	1. Physical factors. 2. Mechanical factors. 3. Life of material factors. 4. Cost and availability. 5. Codes, statutory and others. [9]
5	1. General attributes 2. Technical attributes 3. Eco-attributes 4. Aesthetics attributes. [10]
6	1. Environmental aspects. 2. economic issues 3. social factors. [11]
7	1. Mechanical Properties. 2. Economic Properties. 3. Environmental properties. [12]
8	1. Environmental criteria 2. Economic criteria. 3. Social criteria. [13]
9	1. Technical indicator, 2. Socioeconomic indicator and 3. Environmental indicator. [14]
10	1. Economic Indicator. 2. Technical Indicator 3. Environmental Indicator 4. Socio-Cultural Indicator. [15]
11	1. Technical, 2. Economic, 3. Health and Environmental, 4. Design Management, 5. Social. [16]

***Table 2.** Evaluation of Main Categories that affect the sustainable building materials selection.*

No	Categories												W%
1	Technical					√				√		√	27%
2	Economical	√	√			√	√	√	√		√	√	72%
3	Health & environment											√	9%
4	Design management											√	9%
5	Social.		√				√		√			√	36%
6	Mechanical				√			√					18%
7	Environmental			√			√	√	√	√	√		54%
8	Socio-cultural										√		9%
9	Socio-economical			√						√			18%
10	Physical				√								9%
11	Life of material				√								9%
12	Cost and availability				√								9%
13	Codes, statutory and others				√								9%
14	General attribute					√							9%
15	Aesthetic					√							9%
16	Technology			√									9%
17	Resource		√	√									18%
18	Production	√	√										18%
19	Maintenance factor	√											9%
20	Energy efficiency		√										9%

As a result of the aforementioned data, we may deduce that Economical 72%, Environmental 54%, and Social 36% attributes have a higher value. As a result, we may conclude that when a designer chooses a material, he or she shall examine the three essential dimensions of economic, environmental, and social considerations. Because the final cost of any material is the greatest limitation to any material, the economic dimensions are the most essential component in material selection from the others. Second, in a society with finite resources and substantial environmental damage, it is self-evident that a more sustainable way of life will become increasingly vital. As a result, the material's "environmental property" is crucial. The social dimension, which is far more difficult to quantify, is the final consideration when choosing a sustainable building material.

Integration of all these factors (i.e. environmental, economic and social) provides an overall picture of a material and thus, helps in selecting suitable materials or sustainable material for buildings through a multi-criteria decision-making approach.

To make such comparisons easier, a list of holistic criteria based on the sustainable triple bottom line and the needs of various project stakeholders must be established, which can better capture the potential performance of building materials and aid in the long-term development of the built environment.

4. Different Sustainable Building Material Selection Frameworks

***Table 3.** Sustainable building material selection framework (Source: [7]).*

Comparative environmental parameters				
	1. Building exterior category	Synder- crete	Arch precast	American cellular
1. Energy efficiency	2. Energy efficiency use	2	3	3
	3. Use of renewable source of energy	3	3	3
	4. Transportation	1	4	3
2. Resource responsibility	5. Min need for other material	2	4	3
	6. Maintenance requirement	3	3	3
	7. Durability (life expectancy)	3	3	3
	8. Efficient use of resource material	2	4	3
	9. Recycled content	1	5	1
	10. Recyclable	4	4	4
3. Social/public health responsibility	11. Harmful chemical in production	3	3	3
	12. Reduction of gasses	3	3	3
	13. Worker or institute health	4	4	4
	14. Building occupant health	3	3	3
4. Economical/functional	15. Cost effectiveness	2	2	2
	16. Availability	3	3	3
	17. Acceptability	2	2	2

Comparative environmental parameters				
5. Quality of manufacturer	18. Local resource	4	4	4
	19. Local manufacture	4	4	4
	20. Environment	2	4	3
Total		153	183	165

Note 1, excellent 2, good 3, fair 4, poor 5, very poor.

Table 4. *Sustainable building material selection framework (Source: [8]).*

Environmental Performance	Technological Performance	Resource Use Performance	Socio-Economic Performance
1. Impacts on Air Quality a. Carbon Dioxide b. Hydrocarbons	1. Durability	1. Energy a. Embodied b. Operational c. Efficiency d. Distributional	1. Occupant Health/Indoor Env'l Quality a. VOC Outgassing b. Toxicity c. Susceptibility to bio contamination Appropriateness for:
2. Impacts on Water Quality	2. Service Life	2. Degree of Processing Source Reduction Materials.	d. Scale
3. Impacts during Harvest Processing Impacts	3. Maintainability	a. Renewable	e. Climate f. Culture
4. Assimilability Scarceness	4. Strength	b. Recyclability	g. Site
5. Impacts on Soil Quality		c. Reusability d. Renewability	2. Economics: a. Contribution to Economic Development.
6. Ozone Depletion Potential	5. Constructability	e. Local/Transport f. Distance g. Packaging Requirements	b. Cost c. Labor Skill Requirements d. Labor Amount Requirements

Table 5. *Sustainable building material selection framework (Source: [13]).*

Main category	criteria	Sub criteria
1. Environmental criteria	1.1. Energy consumption	i. Energy consumption in production and execution stage ii. Energy consumption during building life
	1.2. Compatibility	i. Compatibility with natural environment and climate ii. Compatibility with built environment
	1.3. Waste	i. Material waste ii. Resources waste iii. Energy waste
	1.4. Recycle criteria	i. Material recycle ii. The application of renewable material
	1.5. Pollution criteria	i. The amount of pollution in production and execution stage ii. The amount of pollution in maintenance and consumption stage iii. The amount of pollution in destruction stage
	1.6. Resources consumption	i. Materials consumption ii. Water consumption
2. Economic criteria	2.1. Cost	i. Costs of resources and materials ii. Labor costs iii. Maintenance costs iv. Renovation and destruction costs
	2.2. Investment criteria	i. Investment return ii. Initial investment iii. Exchange amount
	2.3. Time	Construction time
	2.4. Execution issues	i. Durability ii. Constructability iii. Continuity of execution stages iv. flexibility v. Material and equipment availability
3. Social criteria	3.1. Social issues	i. Social participation ii. Social disturbance
	3.2. Labor market	i. Labor availability ii. Influencing labor market
	3.4. Safety and health	i. Work safety ii. Occupants health
	3.5. Design and architecture issues	i. Individualization and social identity ii. Physical space and performance iii. Aesthetics and architectural issues

Table 6. *Sustainable building material selection framework (Source: [14]).*

Environmental criteria	Social-economic criteria	Technical criteria
1: potential for recycling and reuse	1: disposal cost	1: maintainability
2: availability of environmentally sound disposal options	2: health and safety	2: ease of construction (buildability)
3: impact of material on air quality	3: maintenance cost	3: resistance to decay
4: ozone depletion potential	4: aesthetics	4: fire resistance
5: environmental impact during material harvest	5: use of local material	5: life expectancy of material (e.g. strength, durability, etc.)
6: zero or low toxicity	6: initial acquisition cost	6: energy saving and thermal insulation
7: environmental statutory compliance	7: labor availability	
8: minimize pollution – e.g. air, land		
9: amount of likely wastage in use of material		
10: method of raw material extraction		
11: embodied energy within material		

Table 7. *Sustainable building material selection framework (Source: [15]).*

Criteria	Sub-criteria	Subsidiary Criteria	
1. Economic Indicator	1.1. Material & Construction Cost (including labor & equipment costs) 1.2. Transportation Cost 1.3. Service & Maintenance Cost 1.4. Overhead Cost 1.5. Energy Cost (during operation) 1.6. Market value		
2. Technical Indicator	2.1. Weight 2.2. Chemical Resistant 2.3. Water Resistant 2.4. Fire Resistance 2.5. Strength 2.6. Life Expectancy		
3. Environmental Indicator	3.1. Consumption of Energy & Resources	i. Embodied Energy ii. Loss Factor iii. Energy Saving & Thermal Insulation iv. Water Use	
	3.2. Human Comfort & Health	i. Safety During Construction	Fire Immunity Shock Immunity
		ii. Indoor Air Quality iii. Human Health	cancer (non cancer)
	3.3. Environmental Impacts	Acoustic Quality Of Interiors, Environmental Impacts Global Warming, Ozone Depletion, Acidification, Photo-Chemical Smog Eutrophication (pollution), Land Occupation, Recycling/Reusing Potential, Air pollutants, Ecological Toxicity.	
4. Socio-Cultural Indicator	3.4. Social, Religious And Cultural Identity 3.5. Aesthetics 3.6. Labor Availability 3.7. Designer's Knowledge		

Table 8. *Sustainable building material selection framework (Source: [16]).*

Sustainable building material criteria				
Technical	**Cost/economy**	**Health/environment**	**Design management**	**Socio-cultural/aesthetical**
1. Weight and mass 2. Structural 3. Severability 4. Acoustic 5. properties 6. Thermal conductivity 7. Durability 8. Material fixing. 9. Maintenance 10. level 11. Reusability 12. Life span	1. Life cycle cost 2. Embodied energy cost 3. Affordability 4. Labor cost 5. Construction cost 6. Transport cost 7. Maintenance cost 8. Market interest 9. The cost of returning to the initial condition (initial cost)	1. Made from renewable sources 2. Safety of people during construction and installation. 3. Pollution 4. Change in natural habitat. 5. Consumption of non-renewable resources.	1. Creativity. 2. Availability. 3. Experience. 4. Design limitation. 5. Consultancy. 6. Climate information. 7. Owners view. 8. Location.	1. Compatibility with cultural and religious traditions. 2. Compatibility with aesthetics traditions. 3. Sensorial factors. 4. Protect ecological character.

Table 9. *Evaluating the Content or items of sustainable building materials.*

Evaluating the Content or items of sustainable building materials								
	content or items of sustainable building material	**Reilly, 1997**	**Pearce, 1998**	**Hossein et al., 2012)**	**(Akadiri & Olomolaiye, 2012).**	**Mahmoudkelaye, et al., 2018).**	**Ebrahim, et al., 2019**	**W%**
Environmental dimension								
1	Ecological					√	√	33%
2	Environmental/impact	√				√		33%
3	Recycling (cost) and Reuse		√	√	√	√	√	83%
4	Renewable	√	√				√	50%
5	Consumption of non-renewable resources.						√	16%
6	Site/Location.		√				√	33%
7	Disposal/Waste			√	√			33%
8	Air quality		√		√			33%
9	Water Quality		√					16%
10	Soil Quality		√					16%
11	Ozone depletion/global warming	√	√		√	√		50%
12	Environmental Impact During Material Harvest/Material Extraction		√		√			33%
13	Climate		√				√	33%
14	Toxicity		√	√	√			50%
15	VOC Outgassing		√					16%
16	Environmental Statutory				√			16%
17	Pollution			√	√	√	√	66%
18	Energy	√	√	√	√	√	√	100%
Economical Dimension								
19	Initial cost				√		√	33%
20	Overhead Cost					√		16%
21	Life cycle cost						√	16%
22	maintainable and M. cost	√	√	√	√	√	√	100%
23	disposal cost				√			16%
24	Recycling (cost)	√						16%
25	local material/resource/manufacture	√	√	√	√	√		83%
26	Availability/Acceptability	√		√			√	50%
27	Flexibility			√				16%
28	Durability/Strength	√	√	√		√	√	83%
29	Market interest/value			√			√	33%
30	ease of construction/Constructability		√	√	√			50%
31	Structural severability						√	16%
32	Weight and mass					√	√	33%
33	Material/Construction cost					√	√	33%
34	Transportation/Distance or cost	√	√			√	√	66%
35	Energy Cost					√		16%
36	Cost effectiveness/Affordability	√					√	33%
37	life expectancy/service life/span		√		√	√	√	66%
38	Packaging Requirements		√					16%
39	Renovation and destruction costs			√				16%
40	Construction time			√				16%
Social Dimension								
41	Thermal insulation/conductivity				√		√	33%
42	Acoustic properties					√	√	33%
43	fire resistance				√	√		33%
44	Resistance to decay				√			16%
45	Water Resistant					√		16%
46	Enviromental Health and safety for workers, indoor and outdoor	√	√	√	√	√	√	100%
47	Harmful chemical and Resistant	√				√		33%
48	Compatibility with Social, Religious, Cultural, environment and climate		√	√		√	√	66%
49	Labor availability, Skill, Experience & cost		√	√	√	√	√	83%
50	Designer's Knowledge/limitation					√	√	33%
51	Aesthetics			√	√	√	√	66%
52	Social participation & disturbance			√				16%
53	Investment (return or Initial) criteria			√				16%
54	Creativity						√	16%

Energy, maintainability and maintenance costs, as well as worker health and safety, interior and outdoor environments, are all important considerations for sustainable construction materials, as shown in the chart above (which is 100%). The next most important factor in the selection is the cost of recycling and reuse, as well as local material/resource/manufacture, durability/strength, labor availability, skill, experience, and cost (83%). Pollution, transportation/distance or expense, life expectancy/service life/span, social, religious, cultural, environmental, and climate compatibility, and aesthetics are the third (66%). Renewable, Ozone depletion/global warming, Toxicity, Availability/Acceptability, and simplicity of construction/constructability are the fourth option for selecting sustainable building materials (50%). Ecological, Environmental/Impact, Site/Location, Disposal/Waste, Air quality, Environmental Impact during Material Harvest/Extraction, Climate, Initial cos, Market interest/value, Weight and mass, Material/Construction cost, Cost effectiveness/Affordability, Thermal insulation/conductivity, acoustic properties, fire resistance, hazardous chemical and resistant materials, and designer knowledge/limitations (33%).

5. Result

Table 10. *General sustainable building material selection framework.*

General sustainable building material selection frame work.			
No	**Dimensions**	**Categories**	**Item included**
1	Economical dimension	1.1. Initial cost	a. Availability. b. Low cost technology. c. Modular designs and standardized materials. d. Flexibility. e. Recycled and reclaimed materials. f. Life expectancy/service life/span. g. Weight and mass. h. Constructability. i. Durability. j. Local material/resource/manufacture.
		1.2. Cost in use	a. Maintainable. b. Labor supply. c. Minimum-maintenance materials. d. Protecting materials from destructive elements
		1.3. Recovery cost	a. Recycling potential and ease of demolition. b. Reusing building materials or components. c. Life cycle cost
2	Environmental dimension	2.1. Energy conservation	a. Low embodied energy. b. Insulating building materials. c. Deconstruction & recycling. d. Low energy intensive transportation. e. Operational
		2.2. Ecological conservation	a. Greenhouse gases (Ozone depletion) b. Carbon dioxide. c. Methane Surface-level ozone. d. Nitrous oxides and fluorinated. e. Carbon footprint. f. climate
		2.3. Material & Water conservation	a. Material conservation. b. Waste minimization. c. Durable material. d. Natural and local material. e. Pollution prevention. f. Non-toxic material. g. Water conservation. h. Environmental Impact during Material Harvest/Material Extraction.
3	Social dimension	3.1. Protecting Human health and comfort	a. Thermal comfort. b. Acoustic comfort. c. Aesthetics
		3.2. Protecting Physical Resources	a. Fire resistance. b. Water Resistant. c. Resistance to decay. d. Harmful chemical and Resistant. e. Compatibility with Social, Religious, Cultural, environment and climate.

The general sustainable building material selection framework based on the sustainable triple bottom line, a total of 44 items were identified, with eight criteria highlighted at the category level. All the criteria were derived from a thorough literature review only.

6. Conclusion

Numerous studies are seeking to answer the problem of material selection, currently there is no universal definition of "sustainable building materials." As a result, sustainable building materials are those that are resource and energy efficient in the manufacturing process, and they should emit less pollution and have no negative health effects. As a result, the design criteria for sustainable building materials are classified into the following categories.

To begin with, sustainable building materials should be ecologically friendly and reduce environmental threats without emitting pollutants or other emissions that have an impact on human health and comfort over their whole life cycle. Buildings have a substantial environmental impact due to emissions and resource and energy use. Renewable energy sources, rather than non-renewable energy sources, are used to make sustainable building materials. They should also be sustainable throughout their whole life cycle and consume less energy during production. Natural building materials with low energy consumption and low maintenance costs are commonly used in sustainable building, and they should be easily removed and recyclable upon demolition. Initial and recurring energy use are included in the embodied energy consumption of building materials. The former refers to the energy consumed during the construction phase, while the latter refers to the energy consumed during the operating phase, which includes material replacement, repair, and maintenance procedures during the course of the effective life cycle. However, the energy consumption of building materials is linked to construction energy and transportation energy during on-site construction, as well as the embodied energy consumption of raw materials recycling and building materials processing. The amount of energy in building materials varies depending on the type of energy used, the technology used, and the production procedures used, and it varies from region to region and manufacturer to manufacturer. Low maintenance requirements could be addressed by extending the life cycle of buildings through design durability or by repairing existing building materials.

Second, there is mounting evidence that using sustainable building materials pays off for building owners, operators, and occupants. Energy, water, maintenance/repair, and other running costs are often lower in sustainable buildings. The economic attribute is the most important factor to consider when choosing a material. Purchase price, processing price, transportation price, recycling/disposal price, life cycle cost, energy cost, renovation and destruction costs, and so on are all factors in economic property.

Third, the social benefits of sustainable building materials are linked to increased quality of life, health, and happiness. These advantages can be enjoyed on a variety of levels, including buildings, communities, and society as a whole. Indoor environments now have a significant impact on users' health, well-being, and performance. Building materials, in particular formaldehyde and other volatile organic compounds (VOCs) generated by building materials, are obviously major factors in defining indoor air quality, with serious negative impacts on human health, comfort, and productivity. Pollutant-containing materials can have negative consequences throughout their life cycle, impacting employees during production, building occupants during usage, and generating pollution during recycling and terminal treatment. As a result, sustainable building materials are those that emit few or no carcinogens, do not regenerate noxious compounds or irritants, and have no detrimental influence on the structure or the environment.

Conflict of Interest

The authors declare that there is no conflict of interest.

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