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Developing Theoretical Sustainable Building Material Selection Framework for Ethiopia

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Abstract: The construction industry regarded as one of the pivotal aspects of achieving the objectives of sustainable development in communities. In this regard, the choice of building materials is one of the challenges in order to improve program performance with respect to sustainable development, and the use of sustainable materials is an effective step towards achieving sustainable construction. Selection of sustainable building materials represents an important strategy in the design and construction of buildings in Ethiopia. One of the principal challenges is the process of prioritizing and aggregating relevant criteria into a selection framework. Therefore, the purpose of this framework in building projects is to look at the complexity of the interactions between sustainability building materials and architects and to set up a knowledge-based decision support system. After conducting a thorough literature review, case study (BREEAM, LEED, CASBEE, LBC, and G-SEED), questionnaire, and discussion with selected experts, 27 sustainable building material selection criteria items identified based on the sustainable triple bottom line. A survey of Ethiopian architectural firms was conducted to capture their awareness of sustainable building materials. A total of 199 registered offices, based on Ethiopia's construction ministry in 2021. From among these, 51 offices chosen, as a sample size randomly. One of the study's limitations is that it excludes other stakeholders, such as the client, who may have an influence on material selection. Another drawback is that since elements are used to organize materials and components, Ratings are thus based solely on product performance within each constituent group. On the other hand, this study excluded several items. For example, "products" such as lighting, water fixtures, HVAC, and electrical fixtures are not included.

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

1. Introduction

The link between building materials and human health is progressively recognized. About 1 in 4 of the total universal deaths are assigned to environmental risk factors [1]. If they are selected well, the materials of the building can play a major role in offering a healthy indoor environment and promoting well-being for all, at all levels. On the contrary, hazardous materials (e.g. asbestos, formaldehyde, polychlorinated biphenyls (PCBs), mercury, and lead-based paint) have been found in several construction materials (e.g. insulation, cement, coatings, roofing and flooring materials) and they have the potential to damage health and cause serious diseases, reduce growth, and could create what is known as a "sick building syndrome" [2-6].

The construction industry in Ethiopia is a major driving sector for economic growth. Based on a report by the National Bank of Ethiopia [7], the construction industry in 2018 accounted for 71.4% of the nation's industrial output and expanded by 15.7% from its previous share, signifying the leading role of the construction sector. Huge government investment in infrastructure and residential building projects has made the sector create jobs and improve standards of living. Ethiopia is one of the poorest countries in the world and is struggling with serious problems. To recover from this situation, a number of significant actions must be taken. For example, local building materials (e.g. wood, sand, gravel, clay, lime, etc.) can have a significant contribution to ending some forms of poverty as well as reducing the impact of buildings on the environment. Local building materials can reduce the construction cost to its barest minimum by about 60% [8], allowing low-income individuals to get access to decent housing at a reasonable price with local technology while contributing to the reduction of poverty and building a resilient local community, which reduces the local individuals' exposure and vulnerability to extreme external environmental disasters [9].

Nowadays, an increasing variety of materials are accessible for the buildings that architects design. Material selection problems are primarily based on the material properties and on the design requirements, where the material properties are attached to those of the physical structure and the relevant structural properties of the component. To pick among this large number of materials, the architect has to take into account numerous design criteria like context, manufacturing, material aspects, and experience. In general, each material selection process is hired to fulfill a simple need, identifying the best material for a specific structure. In order to identify what the "best" material can be, it is important to understand what aspects are at play while architects are choosing materials. Moreover, to facilitate a constructive material selection process, the architects are in need of the proper information on materials (to guide them in taking decisions).

The selection of sustainable materials is one of the hardest tasks in any construction project, because several different products and materials need to be evaluated, both individually and as building components. Evaluation parameters are not consistent with product categories or different countries of origin [10].

2. Literature Review

A theoretical framework is a framework based on an existing theory in a field of inquiry. It is often "borrowed" by the researcher to build his/her own research review [11]. Concur that the theoretical framework is useful for the study of procedures. The theoretical framework offers several benefits to research work. It establishes the framework for demonstrating how a researcher defines his or her study philosophically, epistemologically, methodologically, and analytically [12]. The framework also guides a researcher's choice of research design and data analysis plan. Research findings are more meaningful and generalizable with the theoretical framework.

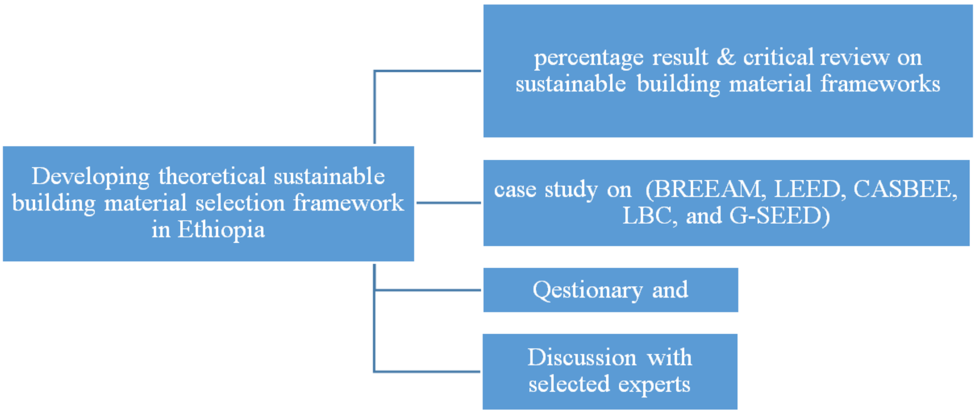

Figure 1. *Methodology.*

3. Methodology

The data display of the research is percentage frequency distribution result, which means the number of observations for each data point or cluster of data points is shown as a percentage in a percentage frequency distribution. It's a good technique to convey the relative frequency of various authors' survey responses on sustainable building material selection frameworks. Percentage frequency distributions are typically represented using tables.

There are numerous ranking systems for sustainability assessments available around the world. LBC, G-SEED, BREEAM, LEED, and CASBEE are well acknowledged approaches. Those case studies will provide as various institutional survey responses on sustainable building material selection frameworks.

A questionnaire is an instrument that is typically used for quantitative data gathering. It outlines a series of questions relating to the sustainable building materials and requires the research subjects to choose or provide responses that reflect their knowledge and experiences. To obtain the perceived importance of the criteria, a questionnaire was distributed to a large sample of Ethiopian consulting architects and designers experienced in designing buildings. "Therefore, based on the data given by Federal Democratic Republic of Ethiopia Construction Minister [13]" there are 199 consulting architects' offices registered, so based on the sample size formula,

Necessary sample size=(z-score) 2*StdDev*(1- StdDev)/ (margin of errors) 2 [14]. Therefore Population size=199, Confidence Level=90%, Margin of Error=10%.

Based on online calculation method [15], 51 offices will be selected for questionaries' randomly.

4. Result and Discussions

Formulating theoretical sustainable building material selection framework.

4.1. Climate

Ethiopia It is characterized by rugged and mountainous geography with elevations extending from 4,620m above ocean level at Mount Ras Dejen in North Gondar within the Amhara National Regional State to 110m below ocean level at the Dallol sanction within the Afar National Territorial State. Because of this variety in height, the temperature shifts from one of the world's most noteworthy yearly normals of 39°C at the Dallol Depression to the very cool Afro-montane climate at high altitudes. Because of its latitude and altitudinal contrasts, the climate system is very complex [16].

Table 1. *Ethiopian Climate (Source: [17]).*

Zone	Altitude (metres)	Rainfall (mm/year)	Average Annual temperature (oC)
Wurch (cold and moist)	3200 plus	900 - 2200	>11.5
Dega (cool and humid)	2300 - 3200	900 - 1200	17.5/16.0 - 11.5
Weyna Dega (cool sub-humid)	1500 - 2300/2400	800 - 1200	20.0 - 17.5/16.0
Kola (warm semi-arid)	500 - 1500/1800	200 - 800	27.5 - 20
Berha (hot arid)	under 500	under 200	>27.5

As the climate changes, the architecture also changes, which means building materials will definitely change. The chart below depicts that 88.2%, offices have an opportunity to design in different regions of Ethiopia. That means 88.2% have an understanding of the environmental, social, and economic status of different regions of Ethiopia. The remaining 11.8 have not gotten the opportunity to design across the region. This experience will help the architects consider the environmental, economic, and social dimensions of the country.

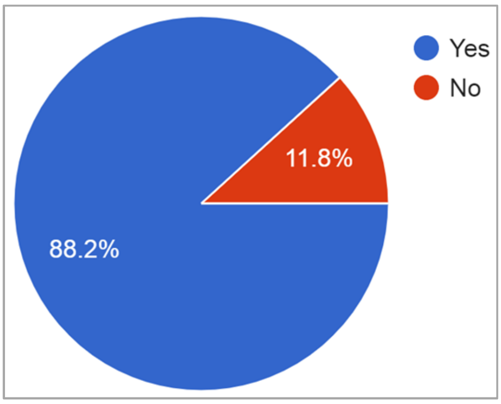

Figure 2. *Climate.*

4.2. Social, Economic and Environmental Dimensions

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.

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. 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.

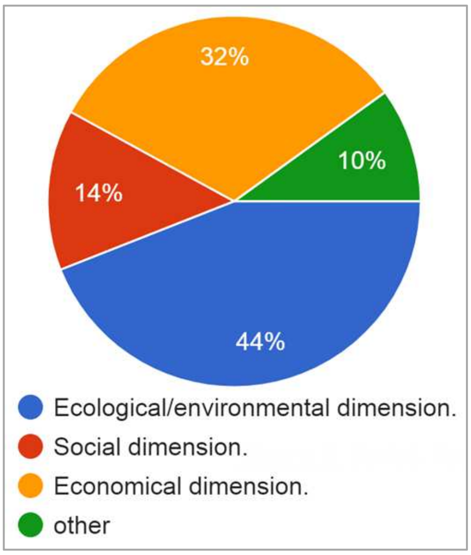

Figure 3. *Social, Economic and Environmental dimensions.*

The chart below shows that ecological or environmental dimensions have a high value of 44% in the selection of sustainable building materials in most consulting architectural offices in Ethiopia, followed by 32% in the economic dimension, 14% in the social dimension, and the remaining 10% in other dimensions. When we convert it into a percentage of a hundred for the three dimensions, it will be 49%, 35.5%, and 15.5%, respectively.

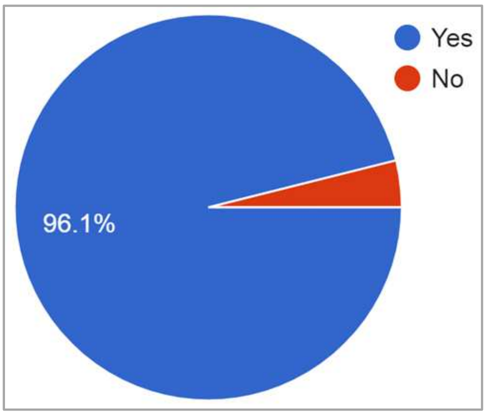

Figure 4. *Framework.*

4.3. Framework

The purpose of the sustainable building material selection framework (theoretical framework) for Ethiopia is that it provides a general or broader set of ideas; it is based on existing theory/theories in the literature that have been tested and validated by other scholars; it is in the form of a model that pivots a study; it offers a focal point for approaching; and it consists of theories that seem interrelated with their propositions deduced. So, The chart below describes that almost all (96.1%) needed a sustainable building material selection framework for Ethiopian architecture, while the remaining 3.9% didn't need the framework.

Table 2. *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	i. Availability.
			ii. Low cost technology.
			iii. Modular designs and standardized materials.
			iv. Flexibility.
			v. Recycled and reclaimed materials.
			vi. Life expectancy/service life/ span.
			vii. Weight and mass.
			viii. Constructability.
			ix. Durability.
			x. Local material/resource/manufacture.
		1.2. Cost in use	i. Maintainable
			ii. Labor supply.
			iii. Minimum-maintenance materials.
			iv. Protecting materials from destructive elements
		1.3. Recovery cost	i. Recycling potential and ease of demolition.
			ii. Reusing building materials or components.
			iii. Life cycle cost
2	Environmental dimension	2.1. Energy conservation	i. Low embodied energy.
			ii. Insulating building materials.
			iii. Deconstruction & recycling.
			iv. Low energy intensive transportation.
			v. Operational
		2.2. Ecological conservation	i. Greenhouse gases (Ozone depletion)
			ii. Carbon dioxide.
			iii. Methane Surface-level ozone.
			iv. Nitrous oxides and fluorinated.
			v. Carbon footprint.
			vi. climate
		2.3. Material & Water conservation	i. Material conservation.
			ii. Waste minimization.
			iii. Durable material.
			iv. Natural and local material.
			v. Pollution prevention.
			vi. Non-toxic material.
			vii. Water conservation.
			viii. Environmental Impact during Material Harvest/ Material Extraction.
3	Social dimension	3.1. Protecting Human health and comfort	i. Thermal comfort.
			ii. Acoustic comfort.
			iii. Aesthetics
		3.2. Protecting Physical Resources	i. Fire resistance
			ii. Water Resistant.
			iii. Resistance to decay.
			iv. Harmful chemical and Resistant.
			v. Compatibility with Social, Religious, Cultural, environment and climate.

Table 3. *"List of material-related criteria organized by the three sustainable dimensions" The table below shows the results of various case studies (BREEAM, LEED, CASBEE, LBC, and G-SEED).*

Dimensions	Indicators	Keywords		Sub tot	Total Point
			Toxic	6	
		Pollution	Run-off	3	
	Ecology		light	1	
		Heat Island		2	
		Ecological Area		1	
	Energy	Energy Performance		11	
Environmental		Reuse		6	51
		Recycle		6	
		Reduce Construction Waste		4	
	Resource	Reduce Using Material		3	
		Assessment		1	
		Embodied CO2, LCCO2		4	
		LCA		3	
	LCC			1	
Economic	Durability and Adaptation			8	13
	Local Economy	Regional Materials		4	
	Justice	Responsibility		5	
		Transparent Information		6	
			Air	6	
		Indoor	Sound	7	
		Comfort	Thermal	3	
Social	Wellbeing			2	39
		Outdoor Comfort		1	
		Aesthetic/Psychological	Visual	2	
		Easy Maintenance		1	
	Diversity	Locality and Harmony		6	
	IDP			3	3

Table 4. *The percentage result of a case study (BREEAM, LEED, CASBEE, LBC, and G-SEED), a questioner, and a literature review based on the three sustainable dimensions.*

	Dimensions	Case study (BREEAM, LEED, CASBEE, LBC, and G-SEED) %	percentage result & critical review on sustainable building material frameworks	Questionnaires %	Total /300%
1	Environmental	51%	33.3%	49%	44
2	Economic	13%	44.5%	35.5%	31
3	Social	39%	22.2%	15.5%	25

Table 5. *A theoretical framework of sustainable building materials for Ethiopia.*

	Dimensions	Categories	Item included	Total point
		Ecology	Ecological Area	
			Carbon footprint.	
			Energy Performance	
		Energy	Low embodied energy.	
			Operational energy	
1	Environmental dimension		Natural material	44
			Environmental Impact During Material Harvest/ Material Extraction.	
		Resource conservation	Reuse	
			Recycle potential	
			Reduce Construction Waste	
		LCC (life cycle coast)	Life cycle cost analysis	
		Local Economy	Local material. Availability	
			Modular designs and standardized materials	
			Flexibility.	
2	Economical dimension		Weight and mass.	31
		Material techniques	Durability	
			Constructability.	
			maintainable	
			Ease of demolition.	

	Dimensions	Categories	Item included	Total point
3	Social dimension	Indoor & Outdoor Comfort	Thermal comfort. Acoustic comfort. Aesthetics	25
		Protecting Physical Resources	Fire resistance. Water Resistant. Resistance to decay. Harmful chemical and Resistant. Compatibility with Social, Religious, Cultural.	
4	Innovative material design		Innovative of new sustainable building material	10
5				Total=110

Table 6. *Rating benchmarks.*

No	Point	Certification
1	35-45	Certified
2	46-60	bronze
3	61-70	Silver
4	71-85	Gold
5	86+	Platinum

5. Conclusion

Based on the sustainable triple bottom line, a total of 27 items were identified, with eight criteria highlighted at the category level. All the criteria derived from a thorough literature review, case study (BREEAM, LEED, CASBEE, LBC, and G-SEED), questionnaire, and discussion with selected experts in the use of sustainable materials for building projects.

Some criteria may better capture the sustainability of building materials than others. In terms of the environmental dimension, there are three categories: ecology, energy, and resource conservation. Ecological area and carbon footprint items were included in the ecology category. Energy performance, low embodied energy, and operational energy items were all included in the energy category. Natural materials, environmental impact during material collection and extraction, reuse, recycle potential, and reducing building waste considered in resource conservation. In terms of the economic dimension, there are three groups: LCC (life cycle coast), local economy, and material techniques. There is one item in the LCC categories: life cycle cost analysis.

Local material and availability items are included from the local economy, and modular designs and standardized materials, flexibility, weight and mass, durability, constructability, maintainability, and ease of demolition are included from material approaches. Indoor and outdoor comfort, as well as the protection of physical resources, are two categories in the social dimension. Thermal comfort, acoustic comfort, and aesthetics are some of the indoor and outdoor comfort categories. Fire resistance, water resistance, decay resistance, and resistance to toxic chemicals and aromas, as well as compatibility with social, religious, and cultural norms, are included in the protection of physical resources. Finally, the item included in this framework is innovative new sustainable building materials.

Conflict of Interest

The authors declare that there is no conflict of interest.

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