# STUDY ON THE PRACTICE AND SELECTION OF SUSTAINABLE CONSTRUCTION MATERIALS USING FUZZY LOGIC TECHNIQUES

**KEFENE GURMESSA DESSO**

**A THESIS SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING, SCHOOL OF CIVIL ENGINEERING AND ARCHITECTURE**

**PRESENTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN CIVIL ENGINEERING (CONSTRUCTION ENGINEERING AND MANAGEMENT)**

**OFFICE OF GRADUATE STUDIES**
**ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY**

**JUNE, 2024**
**ADAMA, ETHIOPIA**

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ADVISOR: MESERET GETNET (PH.D.)

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## DECLARATION

I declare that this MSc thesis entitled "STUDY ON THE PRACTICE AND SELECTION OF SUSTAINABLE CONSTRUCTION MATERIALS USING FUZZY LOGIC TECHNIQUES" is my own original work, and has not been summited as a requirement for the award of any degree in ASTU or elsewhere. All sources of materials that are used for this thesis have been duly acknowledged through citation.

| ______________________________ | ______________________ | ______________ |
|---|---|---|
| Name of the student | Signature | Date |

## RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "**Study on the Practice and Selection of Sustainable Construction Materials Using Fuzzy Logic Techniques**" prepared under my guidance by **Kefene Gurmessa Desso**, submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Construction Engineering and Management).

Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

| | | |
|---|---|---|
| Meseret Getnet (PhD) | --------------------------- | ------------------------- |
| Main Advisor | Signature | Date |

## APPROVAL PAGE

I, the advisor of the thesis entitled "**Study on the Practice and Selection of Sustainable Construction Materials Using Fuzzy Logic Techniques**" and developed by **Kefene Gurmessa Desso**; hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Meseret Getnet (PhD) -------------------------- -------------------------

Main Advisor Signature Date

We, the undersigned, members of the Board of Examiners of the thesis by **Kefene Gurmessa Desso** have read and evaluated the thesis entitled "**Study on the Practice and Selection of Sustainable Construction Materials Using Fuzzy Logic Techniques**" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Civil Engineering (Construction Engineering and Management).

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Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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Department Head Signature Date

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School Dean Signature Date

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Postgraduate Dean Signature Date

**AKNOWLEDGMENT**

First, I would like to express my deepest appreciation to my respected advisor Dr. Meseret Getnet, for his professional assistance and continuous support throughout this study and beyond his incredible lecture courses the semesters I spent as his student.

I am very much grateful to all who have given me unreserved assistance in obtaining the information and data needed for this work. My special thanks go to the Ethiopia Construction works corporation design department and staff for their willingness to Provide me with all the necessary data and valuable information.

I would like to take this opportunity to express my heartfelt thanks to all my friends for your unreserved support and cooperation during the study.

Lastly, I would be remiss in not mentioning my family, especially my sisters Ayantu and Dabale, my wife Ebise Beleta, and my daughter Monet who has been giving me material and moral support. Without their care and love this thesis would not have been realized.

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| | |
|---|---|
| AHP | Analytical Hierarchy Process |
| BEES | Building Environmental and Economic Sustainability |
| BIM | Building Information Modeling |
| BREEAM | Building Research Establishment Environmental Assessment Method |
| CASBEE | Comprehensive Assessment System for Building Environmental Efficiency |
| ECWC | Ethiopia Construction Works corporation |
| EPM | Environmental Preference Method |
| FTOPSIS | Fuzzy Technique for Order Preference by Similarity to Ideal Situation |
| ICF | Insulation concrete framework |
| LCA | Life Cycle Assessment |
| LEED | Leadership on Energy and Environmental Design |
| LSF | Light steel frame |
| PRC | prefabricated reinforced concrete |
| RII | Relative Importance Index |
| SCM | Sustainable Construction materials |
| TRC | Tranco system |

**ABSTRACT**

*In today's world, where the need for construction projects is increasing from time to time, especially in developing countries such as Ethiopia; sustainability issues and principles were not exercised by construction professionals during the material selection process. At the initial stage, the designer considers materials he/she is familiar with which is traditional. This method of material selection often struggle to adequately account for the complexity and uncertainty inherent in sustainability assessments. This research explores the application of fuzzy logic techniques to address these challenges and enhance the decision-making process in selecting sustainable construction materials. The aim of the study is to evaluate the practice of SCM selection, identify SCM selection key indicators and develop SBM selection conceptual framework. The study used purposive sampling technique and source of data was both primary and secondary. The collected data through literature analysis, expert perspectives, and a questionnaire survey of professionals and construction industry experts has been coded and analyzed using Fuzzy logic techniques to identify the key sustainability indicators and conceptual framework model has been developed to optimize the selection of sustainable construction materials. For this purpose, 30 indicators from the three dimensions (environmental, social, and economic) identified from the literature were presented to the respondents in a structured questionnaire, and responses were collected and analyzed statically. According to the result of study the SCM selection awareness and practice is good to moderate. The study identified four key environmental indicators for measuring sustainable construction materials, and these indicators are environmental pollution, climate change, eco toxicity, and raw material extraction. Furthermore, health and safety, use of local materials, adaptability and availability, and compatibility with social identity were identified as the four key social indicators for sustainable construction materials. In addition, initial cost, operational cost, maintenance cost, and investment cost were found to be the four key economic indicators for measuring sustainable construction materials. Finally the options of structural building system are analyzed by fuzzy logic techniques and ranked from best to list as: Light steel frame (LSF), prefabricated reinforced concrete (PRC), Insulation concrete framework (ICF) and Tranco system (TRC) accordingly. The study took only views or perceptions of professionals from ECWC.*

**Keywords:** *Sustainability, Fuzzy logic, key indicators*

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background of the study

The construction sector has a huge role to play in making our world sustainable, not only because it represents a large part of our physical environment, but because it is an industry that impacts all areas of society. From energy use and pollution to providing jobs, homes and infrastructure, the building and civil engineering sector touches all of us and has a significant impact on the sustainable development of our world.

Building materials are one of the most financially and environmentally critical components of design, construction and operational phases of the infrastructure element. Through proper building material selection the sustainability of construction can be optimized. However, this aspect of building material selection is often overlooked as more emphasis is given to the structural integrity, as should be, and aesthetics, this oversight can be detrimental to the performance of the infrastructure that leads sustainability in question ; to environmental impacts (global warming, pollution, deforestation, soil erosion, and habitat destruction),social risks and economic crisis.

This building material selection is encountered on every infrastructure project small or large (Allen & Iano, 2019).This selection can be as simple as what kind of backfill material to use to as large as what kind of facade treatment to use on the exterior of the infrastructure. This selection of building materials considers a vast array of variables. As with most local designers using a conventional approach in which they select only the material they are familiar with, the variables might be easily overwhelming to take into account.

In the field of construction, sustainability is of great concern due to huge capital injunction and environmental factors coupled with societal adaptability. The issue of material selection and the factors affecting it has become one of the topics of interest for researchers around the world(Aghazadeh & Yildirim, 2024).Construction professionals and researchers are increasingly looking for sustainable solutions for buildings in a design to reduce some of the negative impacts associated with the sector such as depletion, maintenance cost, or whatever applies(Aghazadeh & Yildirim, 2024)noted that the sustainable development approach not only focuses on coexistence and friendship with the environment, but also considers economic sustainability and social adaptation, and in addition to helping the occupants of buildings and the environment, also brings the benefits of a sustainable economy.

Generally Studies on sustainable construction materials are on the rise due to with their environmental, social, and economic concerns and benefits. Construction is one of the most important sectors of the economy. The performance of construction companies and the industry at large has a direct impact on citizens' quality of life as it provides the society with the facilities needed for life (Council et al., 2009). The construction industry also underpins all other sectors of the economy by providing the infrastructure and facilities essential for the production and distribution of goods and services (Jones & Saad, 2003).The other meaningful way the construction industry affects the economy of a country is by creating jobs for millions. The construction industry's performance also directly influences regional, state, national, and international economic development(Woods, 2000) .States of construction largely determines the level of development of society and interest and level of participation of different stake holders in it: investor, customer, designer, contractor, and specialized building organizations, enterprises manufacturers of appropriate building materials, machinery and technological equipment. Thus, the construction process is influenced by many factors, which are fuzzy and/or not fully defined(Klashanov, 2018) . The decision-making process regarding the selection of sustainable materials is expressed by various indicators that the identification of these indicators can lead to positive results in advancing the goals of the construction industry while consciously and appropriately selecting materials (Mariappan et al., 2024).The selection of proper building material is of particular importance in achieving the goals of sustainable development in construction projects.

Each building affects the local and global environment through various activities during its life cycle (Mohaddes Khorassani et al., 2019). One of these activities is the selection of materials for construction. All building materials are obtained directly or indirectly from the ground and their incorrect selection may have adverse environmental effects such as depletion (E-Jahan et al., 2010). According to the World Watch Institute, the construction industry consumes 40% of the world's usage in raw stones, gravel and sand, and 25% of its virgin wood per year. Therefore, paying attention to environmental dimensions in the selection and use of materials in a construction project is one of the most important factors in sustainable development ( Cavallini et al., 2013). In addition, the use of coherent methods by considering different dimensions to select the appropriate materials is one of the basic necessities for improving the quality of the construction industry in developing countries (Al-Chaar et al., 2019).

The present thesis aims to provide a decision support framework to evaluate the main factors affecting the selection of sustainable materials in construction projects. To this end, after identifying the most important indicators affecting the selection of sustainable materials, the initial evaluation and screening of indicators have been done using statistical methods. Then, an integrated approach based on fuzzy logic analyzed decision-making method is developed to prioritize the extracted indicators. This approach is based on fuzzy analytical hierarchy process (FAHP) and fuzzy technique for order preference by similarity to ideal solution (FTOPSIS). Finally, the developed model has been implemented through a case study to select the optimal type of building material from the perspective of material selection in Construction industry.

### 1.2 Statement of the problem

The construction industry faces a critical challenge in selecting building materials that align with sustainability goals. Traditional approaches often lack the flexibility to adequately consider the multifaceted aspects of sustainability, leading to suboptimal choices. Moreover, the inherent complexity and uncertainty in assessing sustainability criteria further complicate the decision-making process.

The choice of construction materials has wide-reaching economic, environmental, and social consequence on any structure. In the field of construction, sustainability is of great concern due to huge capital injunction and its environmental impacts (resource depletion, global warming, and carbon foot print as negative impacts) coupled with societal adaptability.

Identifying and measuring the indicators for sustainable construction materials has a vital role in achieving the construction industry intended goals such as resilience, affordability& environmentally friendly and finally to address sustainable development. Knowing the key indicators for measuring sustainability of construction materials help to select the most sustainable one out of a range of options(Mehta, 2021).

Generally identifying and measuring the indicators for sustainable construction materials is relevant in placing construction material studies in the context of sustainable development.(A. Danso et al., 2019), reviewed the general and relevant available indicators for measuring sustainability of construction materials. However, there is lack of information on the most important sustainability indicators in relation with construction materials.

Though number of studies are done on the sustainable construction some of them focus on some measuring indicators either environmental or economical beside the limited tool mostly SSPS and method they follow is also not Fuzzy logic techniques, so that this study alleviate the drawbacks and forward how to select sustainable building material from potential construction materials using Fuzzy logic techniques and to develop theoretical decision making frame work. Consequently this study therefore identifies the key indicators for measuring sustainability of construction materials and develops frame work model that is used to optimize sustainability.

### 1.3 Research Questions

In order to attain the research objective, the study formulates the following specific research questions.

- What is the sustainable construction material selection practice in Ethiopia?
- What are the Key indicators of sustainability of construction materials?
- Which a comprehensive, practical and relevant sustainable construction materials selection Conceptual framework should be developed?

### 1.4Objectives

#### 1.4.1 General objective

The general objective of the study is to assess practice and select sustainable construction material using Fuzzy logic techniques.

#### 1.4.2 Specific objectives

- To evaluate the Ethiopian sustainable construction material selection practice.
- To identify the importance level of the key indicators of sustainable construction materials.
- To develop effective sustainable construction materials selection Conceptual framework.

### 1.5 Significance of the study

Despite analyzing the practice of SBM, the identification of key indicators of sustainable construction materials and ranking them, the study will propose a novel fuzzy logic-based sustainable construction material selection Frame work which examines and solves the uncertainty of decision making. Thus, the decision-making process is to choose sustainable construction materials to attain sustainable construction.

### 1.6 Scope of the Study

The scope of this research study was limited to construction materials in its sustainability concern. Participants in the study are drawn from Ethiopian Construction Works Corporation which is believed to have information and exposure to the area of interest by the researcher for it is thought the figure representative of the study concern. The information was gathered from the professionals and construction industry experts.

Due to the time and resource shortages other stakeholders of the construction industry beyond the mentioned parties are not included in this study.

### 1.7Expected outcome of the study

The research will be expected to achieve the following planned outputs:

- Assess the practices of selection of sustainable construction materials.
- Identify the key indicators of sustainable construction materials.
- Forward the effective theoretical framework for selection of sustainable construction materials.
- Leave footprint for further study for forthcoming studies concerning selection of sustainable construction material.

### 1.8 Limitation of the Study

This research tries to focus only on the selection of sustainable construction materials which is more concerned to the design phase of the project. The study is solely based on limited construction experts and architects those directly involved on design. Had the study encompass additional construction industry stakeholders and the scenario of sustainable building material selection throughout all stages of construction implementation in every dimension the output could be more viable

### 1.9 Thesis Organization

The thesis structure is presented and the specific chapter descriptions are as follows:

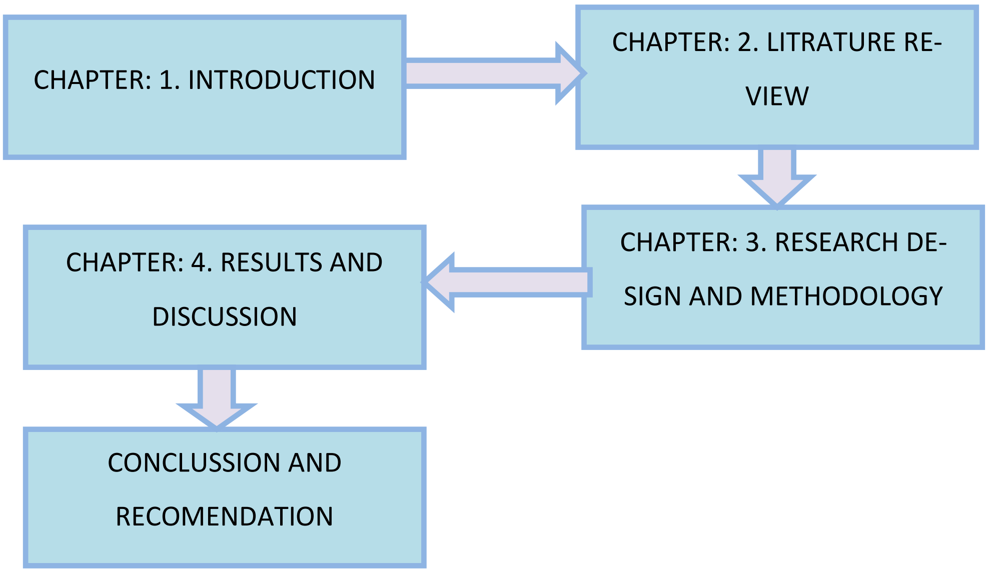



**Figure 1.1: Flow chart of organization of the paper**

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Overview of the Construction Industry

The construction industry is a sector of the economy that transforms various resources into constructed physical economic and social infrastructure necessary for socio-economic development. It embraces the process by which the said physical infrastructure are planned, designed, procured, constructed or produced, altered, repaired, maintained, and demolished. The constructed infrastructures include: Buildings, Transportation systems and facilities which are airports, harbors, highways, subways, bridges, railroads, transit systems, pipelines and transmission and power lines.

The industry comprises of organizations and persons who include companies, firms and individuals working as consultants, main contractors and sub-contractors, material and component producers, plant and equipment suppliers, builders and merchants. The industry has a close relationship with clients and financiers. The government is involved in the industry as purchaser (client), financier, regulator and operator(MUDC, 2012).

Ethiopia’s construction sector is one of the most robust in Africa. Conditions are ripe for a surge in building across the country. The updating and building of new infrastructure links, residential developments and so on is of considerable interest to the Ethiopian Government. Indeed, development of these areas features heavily in the nation’s Second Growth and Transformation Plan (GTP II).

The GTP five year plans lay out the blueprint for Ethiopia’s continued economic growth. As such, construction will play a key role towards achieving the country’s economic prosperity goals(Falcioni, 2015).

## 2.2 The concept of sustainability

The concept of sustainable development as we know it today emerged in the 1980s as a response to the destructive social and environmental effects of the prevailing approach to “economic growth”. The idea originated within the environmental movement. One of the earliest formulations of the concept of sustainable development can be found in the 1980’s World Conservation Strategy jointly presented by the UN Environment Programme, the World Wildlife Fund and the International Union for conservation of nature and natural Resources (Perdan, 2004).

For development to be sustainable, it must take account of social and ecological factors, as well as economic ones; of the living and non-living resource base; and of the long-term as well as the short-term advantages and disadvantages of alternative actions (O. P. Akadiri, 2011).

Sustainability in construction is all about following suitable practices in terms of choosing materials, their sources and construction methodologies as well as design philosophy, so as to be able to improve performance, decrease the environmental burden of the project, minimize waste and be ecologically friendlier, taking into consideration environmental, socio-economic and cultural values. All materials are ultimately derived from the bio-geo-sphere. They are everything between the take and waste and are the key to sustainability. The choice of materials for construction controls whole of life cycle impacts such as emissions, gross take, properties of wastes returned to the bio-geosphere, use of recycled wastes and their own recyclability. Materials also strongly influence lifetime energies, user comfort and durability of materials (Ghadge et al., n.d.)

For development to be sustainable, it must take account of social and ecological factors, as well as economic ones; of the living and non-living resource base; and of the long-term as well as the short-term advantages and disadvantages of alternative actions(O. P. Akadiri, 2011).

Table 2.1: Sustainable development definitions(O. P. Akadiri, 2011)

| **Authors** | **Definitions of sustainable development** |
|---|---|
| Turners, 1988 | ‘in principle, such an optimal (sustainable growth) policy would seek to maintain an “acceptable” rate of growth in per-capita real incomes without depleting the national capital asset stock or the natural environmental asset stock.’ |
| Conway, 1987 | ‘the net productivity of biomass (positive mass balance per unit area per unit time) maintained over decades to centuries.’ |
| WCED, 1987 | ‘Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.’ |
| **Interpretation of sustainable development** | |
| Mitchell, 1997 | ‘a creatively ambiguous phrase . . . an intuitively attractive but slippery concept. |
| Redclift, 1997 | ‘like motherhood, and God, it is difficult not to approve of it. At the same time, the idea of sustainable development is fraught with contradictions.’ |
| Barbier, 1987 | ‘ it is indistinguishable from the total development of society.’ |
| O’Riordan, 1995 | ‘Its very ambiguity enables it to transcend the tensions inherent in its meaning.’ |
| Mawhinney, 2001 | ‘Sustainable development appears to be an over-used, but misunderstood phrase.’ |

### 2.2.1 Building Sustainability

Sustainable development concerning construction is a word that defines a building's improved safety precautions, reduction in resource consumption, minimal environmental impact enhanced aesthetics, and stakeholder satisfaction(Alwafi, 2022b).

Sustainable construction can be viewed as a subset of sustainable development applied to the construction industry. It can be defined as “the creation and responsible management of a healthy built environment based on efficiency in resource consumption and minimal ecological principles” (Kibert, 1994). Concerns over the environment deterioration date back to ancient times but the turning point towards practical and effective actions is relatively recent. The Agenda 21 was formulated in 1992 in Rio de Janeiro, Brazil, as an international blueprint for sustainable development (development and environment). The Agenda is a comprehensive plan of action to be taken globally, nationally, regionally and locally by UN System, Governments, interest groups, businesses and the society in general. Agenda 21 provides alternatives to combat degradation of land, water, air as well as to preserve the diversity of flora and fauna. Since then all economic and social sectors including industries have made effort in order to translate and pursue sustainability within their specific contexts. As a means to set a specific sustainability agenda for the construction industry, the Habitat Agenda and CIB A21 have been established. The Agenda 21 for sustainable construction was published by the International Council for Research and Innovation in Building and Construction (CIB) in 1999. According to the main principles of this Agenda sustainable construction are : Maximization of resource reuse, Minimization of resource consumption, Use of renewable and recyclable resources, Protection of the natural environment, Creation of a healthy and non-toxic environment; and Creation of quality in built environments.

Sustainable construction embraces three main dimensions that is to say social, economic and environmental in contrast with the traditional perspective, where the main concerns were economy, utility, and durability. The social dimension addresses issues pertaining to the enhancement of people’s quality of life. The economic dimension addresses economics issues such as employment creation, competitiveness enhancement, lower operating/maintenance costs, employment creation, high quality of working environment leading to greater productivity and many others. The environmental dimension deals with the design, construction, operation/maintenance and deconstruction approaches that minimize the adverse impacts on the environment such as air emissions, waste discharges, use of water resources, land use, and others(Baloi, 2003).

Sustainable construction can be defined as a set of processes through which a profitable and competitive delivery of built assets like buildings, structures, and infrastructure are obtainable which will offer Better quality of life with: Consumer satisfaction, Flexibility to changes in future, Desirable natural and social environments and Efficient use of resources. By minimizing use of energy, water and natural resources and effective waste management, we can ensure meeting present demands without compromising the demands of future generations.

### 2.2.2 Principles of Sustainable Construction

In terms of the principle for sustainable construction, various efforts have been made to examine several definitions of sustainability in an attempt to enunciate principles to be upheld in attaining sustainable construction. Amongst the published work relating to the principles of sustainable construction are (Kilbert & Subramanian, 2010),Hill (1994), Lindle (1994), Hill and Bowen (1997), (Robbert, 1995)Graham (2000) Long (2001), DETR, (2000), Ding, (2008) and Abidin, (2010). In general, there is a consensus that the breadth of the principle of sustainable construction mirrors those of sustainable development, which is about synergistic relationships between economic, social and environmental aspects of sustainability(O. P. Akadiri, 2011).

### 2.2.3 Sustainable Building Materials

Sustainable building materials can be defined as materials with overall superior performance in terms of specified criteria. For Selection of Sustainable building materials the following criteria are commonly used: 1.Locally produced and sourced materials 2.Minimal Transport costs and environmental impact 3.Thermal efficiency 4.Occupant needs and health considerations 5. Financial viability 6. Recyclability of building materials and the demolished building after demolishing 7. Minimizing Waste and pollution generated in the manufacturing process construction materials 8. Minimizing energy consumption in the manufacturing process 9. Maximizing of renewable resources 10.Minimizing toxic emissions generated by the product 11.Minimizing maintenance costs(KALE & PATIL, n.d.).

## 2.3 The selection of sustainable building materials

It is estimated that by 2056,global economic activity will, global population will have increased by over 50%,global energy consumption will have increased nearly threefold, and global manufacturing activity will have increased at least threefold (Araújo et al., 2009)For these reasons, it is important to reduce the environmental impact of products and materials in terms of their production, rate of use and real building performance, and to optimize their longevity, either in terms of first life using or reprocessing. The pace of actions towards sustainable application depends on the awareness, knowledge as well as an understanding of the consequences of individual actions (Kamarudin, n.d.).Among these measures is the environmentally responsible approach to the selection of building materials (Anderson & Kilduff, 2009).According to Nassar*et al*. (2003)and Alibaba and Ozdeniz(2004),the selection of building materials is one of several factors that can impact the sustainability of a building project. This was also reaffirmed in the work of Treloar*etal.*(2001) and Zhou*etal.(*2009), that an appropriate choice of materials during the design process plays an important role during the life cycle of a building.

(Kibert, 2005) view sustainable material selection as one of the most difficult tasks to undertake in a building project. In part, this is because: so many different products and materials need to be evaluated, both individually and as assembled building components in addition to assessment parameters are not consistent across product categories or different countries of origin manufacturing processes lack transparency Products and materials evaluation has no universally agreed approach. Several manuals now provide guidelines for material selection. These include Doran (1992),Brantley and Brantley (1995),public technology inc.(1996)and Spiegel and meadows (1999).Spiegel and meadows (1999)note that in selecting sustainable materials, designers should aim to maximize durability, energy efficiency, recyclability, maintainability, and use of local materials to minimize the use of imported and hazardous materials, and synthetic chemicals. (Hamilton Jr, 2001)describe a strategy for the choice of sustainable building materials: design building to be efficient and to utilize as few resources as possible, specify the use of renewable and recycled sources in order to close the life-cycle loop of materials and select materials with the least environmental impact throughout their entire lifecycle(O. P. Akadiri, 2011).

The construction industry has been revealed as the fastest growing industry throughout the world due to the constant increase in urban population. This fastest growth has influenced the society for better economic and social movement and simultaneously has worsened the environmental pollution factors(Roy et al., 2019).Since sustainable construction has a direct impact on environment, economy, and society, the construction agencies are continuously trying to adopt it in their work cultures mainly in the form of sustainable design, structure, and material selection. This kind of changed scenario has drawn the focus of many researchers and consequently, several research works have been carried out on sustainable construction. As a pioneer of this concept, (Kibert, 2005)stated that "Sustainable construction is the creation and responsible management of a healthy built environment based on resource efficiency and minimization of ecological principles". Among many other sustainable construction factors, sustainable material selection plays a key role and directly affects building sustainability.

### 2.4 Sustainable Criteria for Materials Selection/Key Indicators of Sustainability

The study identified three key environmental indicators for measuring sustainable construction materials, and these indicators are human toxicity, climate change, and solid waste. Furthermore, adaptability, thermal comfort, local resources, and housing for all were identified as the four key social indicators for sustainable construction materials. In addition, maintenance cost, operational cost, initial cost, long-term savings, and life span ***costs*** were found to be the five key economic indicators for measuring sustainable construction materials. The study therefore suggests that these twelve indicators should be considered in future studies that seek to measure sustainable construction materials(Alwafi, 2022a).

Many researchers who worked on the topic have forwarded performance indicators in the selection of sustainable construction materials, which can be categorized as follows:

#### 2.4.1 Technical Indicators

(Gharehbaghi & Georgy, 2019)forwarded the following technical key performance indicators: Speed and ease of construction (TC1)implementation and operation (TC2) Maintenance capability (TC3)Lateral loads resisting (earthquake) (TC4) Integration of the texture of the material (TC5)Capability to optimize energy consumption during construction operations (TC6)Ability to store energy in the recycling process (TC7)Resistance to weathering, humidity, water and fire (TC8) Hardness, weight and structural capacity of material (TC9)Adaptation with supervisory and executive regulations and instructions (TC10)Compatibility with other material, sound insulation capability (TC11)Resistance to erosion and corrosion (TC12)Service life and durability (TC13)Easy of demolition capability (TC14).

### 2.4.2 Economic Indicators

(Khoshnava et al., 2018)forwarded the following economic key performance indicators Life-cycle cost (EC1) Material investment long-term cost (EC2) Current cost of work in the implementation phase (EC3) Initial cost of displacement and transportation (EC4) Repair and maintenance cost during the implementation and operation phase (EC5)The overhead cost of the construction phase (EC6) Cost of expert labor (EC7)Energy efficiency cost (EC8)Disposal of waste cost (EC9)Cost- effectiveness of recycling process (EC10).

### 2.4.3 Environmental Indicators

(Choudhury et al., 2023)forwarded the following environmental key performance indicators: Legal adaptation to the environment, human health and safety (NC1) Compatibility with sustainable development regulations (LCA, LEED, etc.) (NC2) Reduction of environmental pollutants (in the air, water, and soil) (NC3) Embodied energy of the material (NC4)Toxic effects on the environment and acidification potential (NC5)Air heating potential due to greenhouse gases (NC6) Minimizing the environmental impacts (ozone depletion, etc.) (NC7)Reducing the use of fossil fuels and conserving energy (NC8) Renewability and ease to disposal and recycling (NC9) Impact on climate quality (NC10) Compatibility with energy standards (NC11) Water consumption saving during operation and recycling (NC12) Environmental disposal at the end of the life of the material (NC13) Lack of excessive loss of material after the end of the life cycle (NC14) Ease of extraction of raw material from the source (NC15) Resistance in high temperature (NC16).

### 2.4.4 Socio-cultural Indicators

Compatibility with socio-cultural identity (SC1) Compatibility with ecology and the urban physical environment (SC2)Adaptation to common visual aesthetic criteria in the community (SC3)Comfort of residents and acoustic features of interior space (SC4)Preference of choice by beneficiaries (SC5)General knowledge regarding the productivity of material (SC6) Community health and the non-emission of pathogenic pollutants (SC7)Security of users and operators (SC8) Health and safety of employees (SC9)(Dinh et al., 2018)

### 2.4.5 Site and others Indicators

Compatibility with site location and geographical position (OC1)Availability of material on the site (OC2)Native material in site location (OC3)Transportation distance from the site (OC4)Adaptation to technical-proprietary building certificate (OC5)Technical experience and engineering vision of designers (OC6) Skilled and experienced labor (OC7)Crisis resistance (natural disasters in the site) (OC8)Site geometry (OC9)Up-to-date construction technology and the ability to compete with new foreign material (OC10)Spatial scale: density and spatial structure of the building (OC11)Compatibility with the site space for properly locating and warehouse management (OC12)Material accessibility on the site (OC13)(Gul & Ak, 2018)


**Figure 2.1: Sustainability Indicators**(H. Danso, 2018)

**2.5 Material Selection Method**

Several strategies for material selection problems have been developed, some of which are applicable not only to material selection but also to any design selection procedure. Although no one method is accepted as the standard approach, there are a wide variety of normally used strategies selection with computer-aided databases; performance indices or tables; decision matrices; selection with expert systems; value analysis (particularly for materials substitution); failure analysis; and cost–benefit analysis.

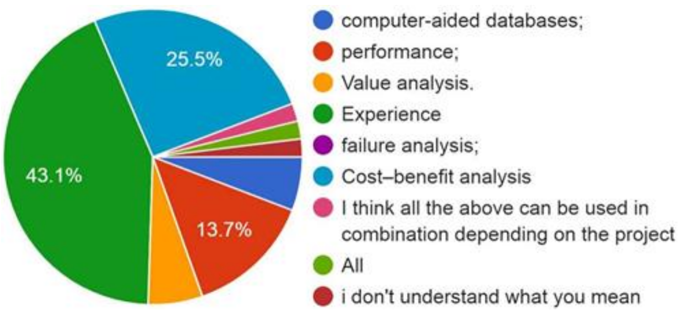



**Figure 2.2: Material selection method**(H. Danso, 2018)

The concentration of carbon dioxide was due to the burning of fossil fuels leading to global warming.In1985, researchers claimed that global warming was caused by human active ties (Kininmonth, 2003)and the first Inter governmental Panel on Climate Change (IPCC) .The subsequent report, published in1990, confirmed that there is a greenhouse effect and the increased atmospheric concentration of carbon dioxide was caused by human activities. A second IPCC followed in 1995and a third in 2001both expressed increasing confidence that greenhouse gases will cause dangerous future climate change (Ding, 2004) Figure 2.3 use consistent figure numbering throughout provides a projection of future greenhouse gas emissions of developed and developing countries. Total emissions from the developing world are expected to exceed those from the developed world by 2015.

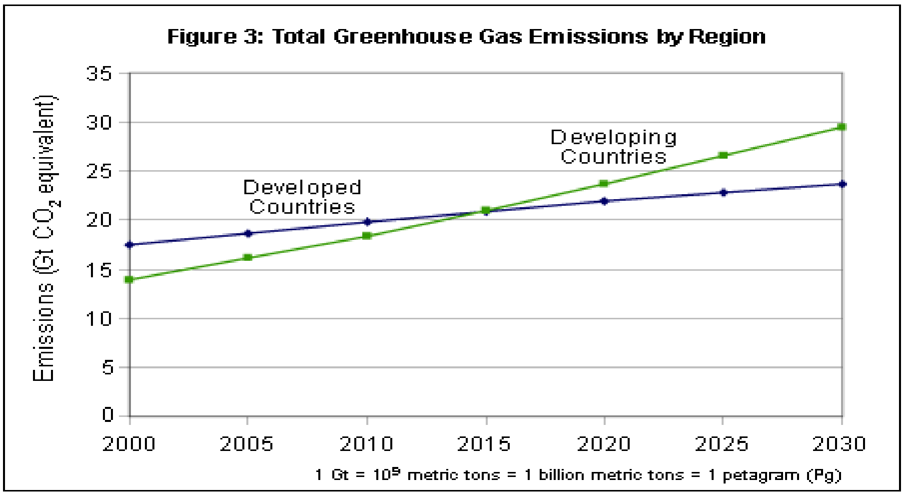



**Figure 2.3: World Greenhouse Gas Emissions by region**

**Source:** United States Environmental Protection Agency (EPA).

Apart from the increased atmospheric concentration of carbon dioxide, atmospheric concentrations of other greenhouse gases such as methane, nitrous oxide and chloro fluoro carbons are also increasing as a result of human activities(Loáiciga, 2003).According to the third IPCC in 2001, the Earth's surface temperature has increased between 0.3°C and 0.6°C during the last 150years(Loáiciga, 2003),and if no environmental pressure or controls are introduced, an increase in global mean temperature of about 2.5°Ccan be expected by the year 2100(Houghton & Organization, 2002).

The warming of the Earth's surface has a significant effect on the living creatures on Earth and as well as the structure of the atmosphere. Human health will be affected by the I creased heat stress and wide spread vector-borne diseases such as malaria (Houghton & Organization, 2002).Increasing global temperature warm sand expands the oceans, melts polar ice caps and, in turn, raises sea levels. It is estimated that there will be an average increase in sea level of about 6cm per decade for a temperature rise of between1.5to5.5°C(Falk & Brownlow, 1989).These at levels are expected to rise by about 0.5m by2100(Bala et al., 2005)The potential impacts of climate change on anthropogenic (man-made activities) systems, of anthropogenic systems on natural systems, and their subsequent influences on natural and human-induced disasters are resulted. As sea levels rise, soil erosion, flooding and storm damage to some coastal regions will follow. Ecosystems at river mouths and the quality of fresh water are also affected. Reduced snow and ice will reflect less light back into space and produce even greater warming(Langston & Shen, 2007).High concentration of carbon dioxide in the atmosphere will also affect productivity of coastal ecosystem(Langston & Shen, 2007) The high concentration of carbon dioxide in the atmosphere also increases the rate of plant loss, that is, loss of biodiversity, another environmental problem that threatens human existence(O. P. Akadiri, 2011).

## 2.6 Sustainable construction practices

Sustainable construction is considered as a way for the construction industry to move towards achieving sustainable development taking into account environmental, socio and economic issues. It is also a way to portray the construction industry's responsibility towards protecting the environment (Pitney, 1993; Spence and Mulligan, 1995; Hill and Bowen, 1997; Ofori and Chan, 1998;
Bourdeau, 1999; Ofori et al. 2000; Ding, 2008; Abidin, 2010). Within the broader context of sustainable development, construction has a prominent role. The promotion of sustainable construction practice is to pursue a balance among economic, social, and environmental performance in implementing construction projects (Shen et al. 2010). Sustainable construction practice refers to various methods in the process of implementing construction projects that involve less harm to the environment - i.e. prevention of waste production (Ruggieri et al. 2009), increased reuse of waste in the production of construction material - i.e. waste management (Asokan et al.2009; Tam, 2009), beneficial to the society, and profitable to the company (Tseng, et al. 2009; Turk, 2009; Tam and Tam, 2006; Tam et al. 2007).

The total environmental damage can be significantly reduced if the construction industry takes proper action to improve its environmental performance (Ofori and Chan, 1998; Ball, 2002) and this potential damage has to be analyzed when considering sustainable development (Bourdeau, 1999). Hill and Bowen (1997) state that sustainable construction starts at the planning stage of a building and continues throughout its life to its eventual deconstruction and recycling of resources to reduce the waste stream associated with demolition. They then describe sustainable construction as consisting of four attributes: social, economic, biophysical and technical.

These attributes form a framework for achieving sustainable construction that includes an environmental assessment during the planning and design stages of projects, and the implementation of environmental management systems. Improvements in environmental performance of buildings are often perceived as a cost burden. At the same time, because the construction industry is fragmented and because many of its products have cultural significance, the industry has been particularly slow to change and embrace environmentally friendly practices (Teo and Loosemore, 2001; Ball, 2002; Abidin, 2010). With the widespread identification and publication of environmental problems, there has been increasing pressure on the construction industry to take a more responsible attitude towards the environment.(O. P. Akadiri, 2011)

So generally characteristics of sustainable building materials are: Typically thought of as natural materials, needs low maintenance, Low energy conception, improved occupant health, comfort and increased productivity, ecologically friendly or environmentally responsible, Renewable sources and less pollutant to the environment in the production process.

The results showed acceptable level of awareness of sustainability (67.5% were somewhat to moderately aware), likewise, knowledge of material selection is acceptable as well (80% Good to sufficient knowledge). However, the usage of material selection tools such as LEED, BREEAM etc... Is very low. This is due to the following presumed obstacles, ranked top 3 based on their relative importance index (RII); Lack of familiarity with the technique, Lack of skills in using technique, and poorly updated programs. Another objective of the research was to identify the important criteria for building material selection. The identified criteria ranked top 3 based on their relative importance index (RII); are Material Availability, Lifecycle Cost, and Aesthetics.

The strategic framework was developed in the form of a flowchart. The developed computer program consists of multiple windows that used the 23 criteria determined in the research. The computer program evaluated the building materials based on the weights (Wi) and utilities (Uij) inputted by the user. As mentioned above the computer program uses MAUT to evaluate the building materials based on the weights and utilities inputted and gives results in a single numerical number for each building material. Then, the user has to choose the building material with the highest numerical number as it is the best material based on weights and utilities inputted for the specific project. The developed computer program will help designers in selecting the most sustainable building material based on the project's objective and client's requirements.(Berhe, 2021)

The results of correlation and regression analysis effected with the purposes of the study show that there is a direct connection and strong correlation between the GDP growth in the country and the number of large sustainable infrastructure facilities constructed and put into operation in the country.

Table2.2: GDP growth and the number of sustainable infrastructure facilities in Russia.(Mahamud, 2022)

| Year | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|
| GDP growth (%) | 97.5 | 100.3 | 101.6 | 102.3 |
| Year | 2013 | 2014 | 2015 | 2016 |
| Number of infra-structure facilities | 8 | 18 | 22 | 23 |

Construction industry plays a very important role in socio economic development of a nation especially in the developing countries, accelerating development of built environment and physical infrastructure such as roads, hospitals, schools and other basic and enhanced facilities. Despite of the global economic downfall, the global economic engagement of this industry is nearly 7.5 trillion USD, contributing 10 %- 13% of GDP. Countries the average GDP contribution is only 6-9 % of GDP. These figures show although financial involvement is much higher in the developing countries but it contributes less in GDP(Mahamud, 2022).

Several strategies for material selection problems have been developed, some of which are applicable not only to material selection but also to any design selection procedure. Although no one method is accepted as the standard approach, there are a wide variety of normally used strategies: Selection with computer-aided databases, Performance indices or table, Decision matrices, Selection with expert systems, Value analysis (particularly for materials substitution), Failure analysis and Cost–benefit analysis

Generally, in Ethiopia, the methodology of architectural design has three phases: pre-design, preliminary design, and detail design.

## 2.7 Sustainable Building Rating and Certification

The rating and certification systems and tools are intended to foster more sustainable building design, construction, operation, maintenance, and disassembly or deconstruction by promoting and making possible a better integration of environmental, societal, functional, and cost concerns with other traditional decision criteria.

These systems and tools can both be used to support the sustainable design, since they transform the sustainable goal into specific performance objectives to evaluate the overall performance. There are different perspectives in different sustainable building rating and certification approaches, but they have certain points in common. In general, these systems and tools deal, in one way or another, with the same categories of building design and life cycle performance: site, water, energy, materials, and indoor environment.

Nearly all building sustainability rating and certification methods are based in local regulations or standards, and in local conventional building solutions. The weight of each parameter and indicator in the evaluation is predefined according to local socio-cultural, environmental, and economic contexts, and therefore most of the approaches developed so far can only have reflexes at local or regional scales. However, there are a few examples of global scale methods. These kinds of methods are, above all, used at the academic level, since the requisite reference cases have to be constructed and separately assessed for each building type, which is a time consuming and expensive process.

There are three major building rating and certification systems that provide the basis for the other approaches used throughout the world: the Building Research Establishment Environmental Assessment Method (BREEAM), which was developed in the U.K., the Sustainable Building Challenge Framework (SBTool), which was developed by the collaborative work of 20 countries, and the Leadership in Energy and Environmental design (LEED), which was developed in the U.S.A(Bragança et al., 2010)

The development of assessment methods and respective tools are a challenge both for in academia and in practice. A major issue is that of managing the flows of information and knowledge between the various levels of indicator systems. A variety of sustainability assessment tools are available on the construction market, and they are widely used in environmental product declarations (e.g., BREEAM in the U.K. and LEED in the U.S.).

There are also Life-cycle assessment (LCA)-based tools available that are especially developed to address the building as whole, e.g., Eco-Quantum (Netherlands), Eco Effect (Sweden), ENVEST (U.K.), BEES (U.S.), ATHENA (Canada) and LCA House (Finland). A comparison of the contextual and methodological aspects of tools has been made before by other authors .The majority of the tools, even though they are designed to consider the whole building, including energy demand, etc., are developed based on a bottom-up approach, i.e., a combination of building materials and components sums up to a building. Tools to support decision-making, in accordance with the principles of performance-based design, have also been developed (mainly in research communities)(Bragança et al., 2010)

### 2.8 Certification Schemes for Sustainable Buildings

Certification schemes (CSs) for sustainable buildings are “environmental and management tools that aid in focusing on the construction sector and aiming at sustainability”(Giama & Papadopoulos, 2012). According to Giama and Papadopoulos (2012) traditionally, these systems have incorporated expertise and knowledge from environmental methodologies, and decision making and management tools, which have been used in other productive sectors and were therefore influenced by those. That is why the majority of the CSs is based on the concept of LCA methodology and is similar to Environmental Management Systems. Those systems also incorporate the energy audit part and extend this philosophy to more environmental issues, such as water conservation, indoor air quality, choice of materials and waste management (Berardi, 2012).Some of the most used CSs globally, based on the number of certifications accredited, are:BREEAM (Building Research Establishment Environmental Assessment Method),UK - created in 1990 by the British organization BRE (used to mean ‘Building Research Establishment’, now just the name of the organization) LEED (Leadership in Energy and Environmental Design), USA - developed in 2000 by the USGBC (US Green Building Council).HQE (High Environmental Quality), France - developed in 1994 and overviewed by the Association for High Environmental Quality. DGNB (Deutsche Gesellschaft fur Nachhaltiges Bauen), Germany - developed in 2009 by the German Sustainable Building Council and the German Government. CASBEE (Comprehensive Assessment System for Building Environmental Efficiency), Japan – launched in 2001 by the Japanese Sustainable Building Consortium. Green Globes, Canada - based on BREEAM, created in 1996; currently operated by the Building Owners and Managers Association of Canada and Energy and Environment Canada Ltd., (in the USA – by the Green Building Initiative). Green Star, Australia - developed in 2003 by the GBC of Australia, based on LEED and BREEAM.(Kudryashova et al., 2015)

## 2.9 A review of existing assessment methods

For many years, a variety of building material performance evaluation methods has been developed internationally and domestically. This is due to an increasing awareness of the need to reduce the impact of building materials on global environment and individual health (Verpoorte et al., 2005)Considerable work has gone into developing systems to measure a building material environmental performance and physical facilities over its life cycle. Separate indicators, or benchmarks based on a single criterion, have been developed to monitor aspects of building performance such as air quality and in-door comfort. Such assessments focused on related tools, mainly on building energy use, indoor climate, and many other environmental issues (Ding, 2008) Nowadays, considering that buildings present many qualities or performances which should be taken into account for a proper evaluation (Roulet et al., 1999) several evaluation methods that cover building material environmental performance more comprehensively have been introduced. In spite of this, a comprehensive assessment tool is essential to provide a thorough evaluation of building material performance against a broader spectrum of environmental criteria. In this section, some of the popular assessment methods were examined in detail and they are broadly divided into two categories, building material specific and building as whole.(O. P. Akadiri, 2011)

When a green building is built, it must be graded by a ranking system so that its efficiency and environmental impact can be assessed. The rating system has predefined criteria, which green buildings must meet in order to receive a high rating. In India, terms such as green ranking for integrated habitat evaluation (GRIHA), Leadership in energy and environment design (LEED), Indian Green Building Council (IGBC), bureau of energy efficiency (BEE) are commonly used In India.

IGBC was founded in 2001 by the Confederation of Indian Industry (CII). Earth – sustainable sites, Power – water efficiency, Fire – electricity and climate, Air – indoor environmental conditions, Sky – day light and night sky emissions are the five aspects of nature that the IGBC rating systems are focused on. In accordance with the US Green Building Council, the IGBC has established ranking schemes for virtually any kind of building. IGBC green new houses, IGBC green current buildings O and M, IGBC green residences, IGBC green classrooms, IGBC green factory buildings, IGBC green townships, IGBC green city, IGBC urban rapid transit systems, and several others are among the rating schemes. Green new buildings are rated using the IGBC green new building code, which

Consists of seven modules with specific points assigned to each, as seen in Tables 2.3 and 2.4.

Table 2.3: Product Dosage and details for 1 Acre land area(Khoshnava et al., 2018)

| Sr.no | Modules | Possible points |
|---|---|---|
| 1 | Sustainable architecture and design | 5 |
| 2 | Site selection and planning | 14 |
| 3 | Water conservation | 18 |
| 4 | Energy efficiency | 28 |
| 5 | Building materials and resources | 16 |
| 6 | Indoor environmental quality | 12 |
| 7 | Innovation and development | 7 |
| Total | | 100 |

Table 2.4: GBC green new building certification levels(Khoshnava et al., 2018)

| Rating | Points | Recognition |
|---|---|---|
| Certified | 40-49 | Best practices |
| Silver | 50-59 | Outstanding performance |
| Gold | 60-74 | National Excellence |
| Platinum | 75-100 | Global leadership |

**2.10 Sustainable Construction in Developing Countries**

Although there are many things similar design and construction considerations in developing and developed countries, there are many differences too. Here survival and political issues draw most of the policy makers attention, which puts sustainability concepts far behind of consideration. As developing countries are under construction and goes through rapid growth in this sector, introducing sustainable construction policies is of an urgent need the developing countries are different in climate, culture and economy. But they have many things in common(Du Plessis, 2002); such as main sources of foreign income (agricultural products and raw materials), Inequity of economy (dual economy), Lack of infrastructure and basic services, Rapid urbanization (with lack of fund and technology), Colonial past ( imposed certain norms, standards and bureaucratic procedures on the development), Consumes far fewer resources, and releases far less greenhouse gasses but experience immediate and visible impacts, Gender issues, Sophisticated methods of conflict resolution and reaching common agreement has grass roots ability of innovation from sustainability .

Green building is a new stage in the development of construction technologies. It is the practice of operating and erecting structures, preserving or improving their quality and internal environment to reduce the energy consumption and material resources. Nowadays, the following principal green building standards are developed: BREEAM (Building Research Establishment's Environmental Assessment Method, the United Kingdom), since 1990, has certified about 200 thousand buildings in 50 countries in nine environmental sections: Management, Health and wellbeing, Energy, Transport, Water, Materials, Waste, Land use and ecology, and Pollution. LEED (Leadership in Energy and Environmental Design, USA), since 2000, has certified about 70 thousand buildings in six sections: Sustainable sites, Energy and atmosphere, Water efficiency, Materials and Resources, Indoor environmental quality, Innovation. DGNB (Deutsche GesellschaftfürNachhaltigesBauen, Germany), since 2009, has certified about a thousand buildings; is a "second-generation" rating system, giving a more holistic evaluation of the entire life cycle of a building in terms of SD. The success of achieving green building goals depends on the professional skills and in-depth knowledge of the personnel involved. In particular, project management knowledge and skills for green construction include: Good navigation and understanding of American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards, Understanding of the energy sector standards of other countries, Awareness of the theory and practice of solving problems with CO2 and other emissions, Familiar knowledge of climatology and the modern climate doctrine as well as the ability to apply this knowledge in practice. Moreover, one must have an idea and be able to apply: Mathematical modeling for the analysis of design solutions for heating, ventilation, and air conditioning systems inside the building, Computer modeling and testing of structural strength, Life Cycle Assessment (LCA), Life-cycle cost analysis (LCCA), Building information modeling (BIM), ISO 26000 practical guide (Liu et al., 2020)

Table 2.5: Comparison between BREEAM, LEED, CASBEE, and GBI(Yadegaridehkordi et al., 2020)

| GBRSs | Country | Year | Issuer | Sustainable Categories | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Site selection | Energy efficiency | Water efficiency | Material and resources | Indoor environ- | Waste and pollution | Econom-ics | Innova-tion |
| BREEAM | UK | 1990 | Building Research Establishment Ltd | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | - |
| LEED | USA | 1994 | US Green Building Council | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | - | - |
| CASBEE | Japan | 2001 | Ministry of Land, Infrastructure, Transport and Tourism of Japan | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | - |
| GBI | Malaysia | 2009 | GBI Innovation SdnBhd | ✓ | ✓ | ✓ | ✓ | ✓ | - | - | ✓ |

Approximately 50% of all global resources are consumed by the construction industry, representing six billion tons of industrial raw materials each year. Accordingly by virtue of its size the construction industry is one of the largest users of energy, material resources and water – and it is a formidable polluter.(Windapo & Ogunsanmi, 2014)

### 2.10.1 Ethiopian Context

When we look at the current building material selection, i t is not a satisfactory one. Although there are not many studies done on building material selection in Ethiopia, a simple preliminary 3 interview survey of relevant construction stakeholders, i.e. Designers, Engineers, Architects, suggests that a lot has not been done on that front. An undue focus is bestowed on Aesthetics and Time rather than creativity and responsible building material selection.(Berhe, 2021)

### 2.10.2 Role of Construction industry in Ethiopia economy

The construction industry has important contributions to the Ethiopian economy, as demonstrated by its share in the GDP. For instance, the share of the sector in the total GDP averaged at about 5.2 percent in the period 2002/03- 2006/07 according to (Martens, 2010).The sector has registered relatively higher growth as compared to the growth of

GDP during this period. Over this period, there has been increased investment on the development and expansion of various infrastructure projects like roads, airports and residential and non-residential housing units.

During the past decade robust public and private expenditure on infrastructure and other construction works has served as a catalyst for Ethiopia's rapid economic development. The country has consistently invested more than 30% of GDP into Gross Fixed Capital Formation (GFCF) expenditure since 2010 and as a result, Ethiopia has emerged as one of the fastest growing economies in the world. The market value of the construction sector is currently estimated at more than US$7bn. According to the 2017 edition of African Economic Outlook, construction activities in Ethiopia accounted for 15.9% of GDP at current prices during the 2015/16 fiscal year(Demissie Esayas Gudeta, 2020).

### 2.11 Summary of important studies on building sustainability

Table 2.6: Summary of Study of building Sustainability

| Author | Work done |
|---|---|
| Yu and Kim | Reviews schemes of building condition to appraise the quality of indoor air that impacts on the wellbeing as well as health of occupants, considering buildings and homes to be sustainable. Asserts that the representations based on LEED and BREEAM are broadly employed globally. While the LEED representation is biased towards health and well-being, including indoor environmental quality, the focus of BREEAM is towards the efficient usage of energy. The paper advocates for a management plan on indoor air quality for the development of buildings, entailing an approval on indoor air quality while the living spaces are contemplated. Further asserts that depleted levels of emissions are required from the materials employed in new buildings. The indoor air in new building plan is as well advocated to include continuous maintenance of the systems of ventilation as well as HVAC |
| Hanke and Werner | Discusses case examples of old buildings that are recycled into libraries from Germany as well as European nations. The problems and the prospects to sustain the library buildings were elaborated upon with a focus on planning. The importance of this recycling process was emphasized to lessen the ecological foot-print of the buildings and from the perspectives of cost-effectiveness and efficiency. |
| Yung and Wang | Advance and builds up a representation to appraise the sustainability of a building from the lens of building information modeling technique coupled with its permissible know-how. The span of sustainability entails production of materials, operation, demolition, disposal, construction and maintenance. All these are the life-cycle elements |

| | |
|---|---|
| | of a building and the approach may be as well described as life-cycle based. |
| Bartolini | Discusses policies, which could cause a movement of the world economy to a largely sustainable direction. The focus of discussion was on a largely politically sustainable group of put forward idea towards green pursuits preferable to the existing pursuits. |
| Hopkinson and Gwilliam | Elaborates on the operations of a group of trainers that adopts evidence-rooted method to build up and offer programmers (training) on sustainability with target on professional in built environment in Wales. The approach tackles the buildup of stall requirement that entails the training anticipation in the confines of the sector, view from short, middle and long ranges in planning. The advantages of the implementation of the structure to the Wales region are elaborated from the viewpoint of policy appraisal. |
| Oduyemi and Okoroh | Reviews diverse research approaches from the survey of literature, paying keen attention to the advantages and problems failed by the building information modeling (BIM) with reference to software application. Treated a case application in design to appraise diverse scenarios on a put-forward manifold-application building. It was stated that the software offers information required to improve design as well as the accomplishment of buildings. |
| Fadeyi | Elaborates on the function on the function of building information modeling (BIM) to lessen the fragmentation within the profession, involving professionals, considered for all the phases of building delivery with evidence obtained from the academic literature. Assets that BIM offers a repository which permits straightforward opportunity to and interfaces with information as well as knowledge considered in real-time. Concludes the BIM offers a structure for professionals to operate in a joint circumstance in all phases of delivery of building services. |
| Gupta et al. | Applies an appraisal method to neigh in u- use of energy against data from environmental accomplishment from building situated in England that are planned to operate at elevated sustainability thresholds as well as depleted heating requirement. It was found that despite that the two buildings attained evaluated rates of air permeability, they experienced common concerns associated with weak documentation regarding the as-built drawings, challenges relevant to direction and weak handover, challenges relating to joining novel know-how, poor sub-meter calibration and weak controls of windows. |
| Saldana-Marquez et al. | Reveals the outcome of the appraisal conducted, by means of worldwide known BSRS, that is Building sustainability rating systems, on varied housing schemes developed within the frame work of the BSRS. The adopted approach implemented a normalization scheme because of the complication they offer in conducting a compar- |

| | |
|---|---|
| | ative examination was discussed. A case examination was contributed that reflects that buildings built up using the funding program for housing solutions (FPHS) attained depleted assessment values with respect to the BSRS. The challenge was in the substantial weakness of materials, efficiency of energy, quality of the indoor environment, as well as management. It was concluded from the research that a number of concerns with the FPHS assessment procedure work against the joining of sustainable features of the Mexican social housing scheme. |
| Shukla et al. | Establishes the idea of sustainable building and the function that the application of building and the function that the application of building integrated photovoltaic (BTP) schemes plays to sustain structures. The validity of idea was tested using countries in the southern part of Asia as examples. A comprehensive survey of the application of the above mention scheme for the southern Asia countries together with the problems and barriers that the BIP scheme pose were elaborated upon. |
| Soliman et al. | Discussed the spread of building coverage in geographical terms based on non-linear joint influence representation. The outcome was show cased in terms of unrestricted access data that evaluates the geographical spreading focusing on predictions, standard deviation and mean. The research was noted to offer quantitative insights concerning the models employed for prediction. |
| Fuentes cortes and Flores Tlacuahuac | Tackles the sizing problems of establishing the most advantageous sizing coupled with the choice of the commonest know-how for water supply and energy considering buildings that are sustainable. The solution was attained by manifold-objective and manifold situation joint integer non-linear optimization technique. An attractive feature of the presented model is that it permits the user to establish the wishes of the designer rooted in a pre-established weight to attain the tradeoff results employing a route of dimensional analysis. |
| Kamaliel. | Examine the sustainability accomplishment of modular buildings for the lens of lifecycle. The appropriate measures for sustainability were hinged on accomplishment factors based on unit buildings, built and ordered. The advanced representation was used in practice with convincing data using unit building from Canada. The research serves good purposes for practicing construction experts from the methodical structure proposed. |

(source: S. Hendiani, M. Bagherpour,2019)

### 2.12 Preliminaries of Fuzzy Logic Theory

Fuzzy logic has emerged as a potential computation intelligence mechanism to represent the multiple-criterion decision-making framework. Perceived as a generalization of the deterministic logic, this technique commenced by Zadeh has been widely studied and applied for mathematical modeling of multivariate logic design with imprecise human reasoning and experiences. Several parameters with diverse units, dynamic range of continuous values and implicit uncertainties can be expressed through the fuzzy logic process. Based on the notion of non-binary intermediate logic, the linguistic constructs such as low, medium, high, many, few, tall, short, etc. deal with the approximate reasoning and data ambiguity concepts. These variables are described by specific type of functions depicting the relative graded membership of each linguistic term. The stated membership functions map each linguistic variable to a value between 0 and 1, determining the degree of belongingness of a certain crisp system variable to the associated fuzzy linguistic variable on a steady scale from 0 to 1. These variables take values from the fuzzy set specified by the range of points within the universe of discourse for the fuzzy variable(H. Danso, 2018b)

(Zadeh, 1965) introduced Fuzzy set theory in order to make decisions for problems dealing with vagueness, subjectivity and impreciseness. The fuzziness comes into play when the judgment is not well defined and does not have proper boundary/limit. In fuzzy set theory, each element is assigned with a membership value to determine the degree to which the element belongs to a fuzzy set ranging from 0 to 1. The concept of quantitative evaluation using linguistic terms is subjective in nature and involves vagueness. For this, the fuzzy set theory captures and resolves the ambiguity involved in the judgment. The fuzzy set denoted by 'A' is defined by mA(x): X! [0, 1] on the universe of discourse, where each element of 'x' is well-defined to a membership value mA(x) between 0 and 1 (If mA(x) ¼0 the element x does not belong to set A and when mA(x) ¼1, the element x absolutely belongs to set A). Since there does not exist absolute membership values, generally, subjectivity is assessed based on the context. In the present study, the trapezoidal fuzzy number is preferred to handle the subjectivity of the decision-maker(Reddy et al., 2022)

Fuzzy logic provides a highly effective solution to the problem, given fuzzy or incomplete information. It allows you to design multivariable regulators with Supervisory functions are not based on mathematical methods, and on the basis of experimental data and experience of other researchers. The verbal description of the construction management process, including the ambiguity and randomness of both external and internal factors is the block description of the control system construction. Logical-linguistic model allows to develop and to find the optimum option of the construction management system (Klashanov, 2018). Measuring the feasibility performance of sustainable building design from the perspective of adaptive fuzzy control system which models different attributes associated with the resource efficiency and environment quality is a scarce methodology on literature review.

Because of the imprecise and ambiguous data coupled with the optimal design and operation of green buildings, fuzzy reasoning mechanism apparently constitutes a convenient tool for the initial design stages of sustainable and smart buildings. The advantages of the deployed MIMO fuzzy system are the coherent and analytical modeling of the developed sustainable structure, contemplating various dimensions influencing the performance of green building design. Moreover, it facilitates the decision-making implementation that emulates the human reasoning paradigm. This multivariable Mamdani-type fuzzy logic controller determines the set of optimal output parameters assessing the performance analysis of autonomous sustainable development. The nonlinear MIMO fuzzy control process operates in a self-organizing decentralized way for exploiting the fuzzy rule base and making corresponding inferences.(H. Danso, 2018)

### 2.12.1 FUZZY TOPSIS Method

The technique called fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Situation) can be used to evaluate multiple alternatives against the selected criteria. In the TOPSIS approach an alternative that is nearest to the Fuzzy Positive Ideal Solution (FPIS) and farthest from the Fuzzy Negative Ideal Solution (FNIS) is chosen as optimal. An FPIS is composed of the best performance values for each alternative whereas the FNIS consists of the worst performance values.

### 2.12.2 Summary of researches that used fuzzy logic and decision making approaches for modeling sustainability.

Table 2.7: Summary of Fuzzy Logic Researches

| Researcher | Methodology | Application Area |
|---|---|---|
| Rajak and Vinodh (2015) | Fuzzy logic | Social sustainability in manufacturing organizations |
| Qorri et al. (2018) | Multi-criteria analysis | Sustainability in supply chains |
| Bandeira et al. (2018) | Fuzzy logic | Sustainability in urban freight transportation |
| Tsao et al. (2018) | Fuzzy multi-objective programming | Sustainability in supply chain networks |
| Kiani Mavi and Standing (2018) | Fuzzy DEMATEL-ANP | Sustainable project management in construction |
| Djekic et al. (2018) | Fuzzy logic | Sustainability of transportation in the dairy industry |
| Pislaru et al. (2019) | Fuzzy logic | Corporate sustainability performance |
| Kumar and Anbanandam (2019) | Fuzzy logic | Social sustainability in freight transportation |
| Present Study | Fuzzy logic | Social sustainability in constructions |

## 2.13 Research Gap

Although researches have been done centered around material selection with sustainability as a driving concept, the conducted researches were focused mainly on European and Asian countries. Most of them focused in only a certain aspects of sustainability concern especially environmental issue. The methodology of the conducted researches were mainly concerned with identifying criteria for material selection while others went even further by using various techniques (MCA, MCDM etc...) to evaluate these identified criteria. Therefore, on the back of these aforementioned research gaps, conducting this research was deemed appropriate because, no evidence was found in the extensive literature survey (more than 100 literatures) and scholar's research database that similar research to this thesis work was conducted in Ethiopia.(Habenom, 2017) research on statistics of studies of titles of Ethiopian construction industry proves that a study concerning sustainability issue is insignificant. Since construction material selection is crucial in achieving sustainable construction and vary significantly with changing geographical location, local designers and consultants cannot logically use these foreign identified criteria in Ethiopia. In addition to the geographical location gap, this thesis work goes further in that after identifying and evaluating the criteria, a Fuzzy Logic analysis is proposed to facilitate and reliable decision making framework in the selection process.

## CHAPTER THREE

## RESEARCH DESIGN AND METHODOLOGY

### 3.1 Introduction

Research is the systematic method consisting of enunciating the problem, formulating a hypothesis, collecting the facts or data, analyzing the facts and reaching certain conclusions either in the form of solutions towards the concerned problem or in certain generalizations for some theoretical formulation (Kothari 2004). Therefore research methodology is a way which brings all the research processes together and leads the researcher to accomplish the objectives of the study.

Accordingly the purpose of this section is to present research methodology in this thesis work and provides information about the research strategy, the research design and methodology, target population, sample size determination formula, data sources, data collection instruments and measurements and analysis methods used in the study.

### 3.2 Study Design and approach

A research design is the arrangement of conditions for collection and analysis of data in a manner that aims to combine relevance to the research purpose with the time frame and scope of the project in procedure. In fact, the research design is the conceptual structure within which research has been conducted; it constitutes the blueprint for the collection, measurement and analysis of data (Kothari, 2004).

Based on the research goal, this research can be categorized under applied research. This is because the results of the research analyses are meant to be applied instead of solely enriching the knowledge base; based on research objectives, it is both a descriptive and exploratory research. The reason it could be under these two categories is because the research has both aspects. It has abundant descriptions of its topics of consideration, wherever it is deemed necessary, while it also critically explores topics that need to be analyzed, explained, and put in perspective.

The research method selected for this study comprised of both qualitative and quantitative approaches. This has been shown in the development of the questionnaire that has been drafted based on the recommendation of the literature review and then refined and tuned through qualitative semi-structured interviews.

The questionnaires were developed based on the literature review to verify the practice of sustainable building material selection, factors of sustainable construction materials and how to make decision on sustainable construction material selection. The second stage has been tested with experienced professionals in order to find out the shortcomings and the ambiguities in the first draft of the questionnaire. Qualitative data was obtained through administration of questionnaires using 5 point Likert's scale to measure the key indicators of sustainability of construction materials.

In the final stage, the modified questionnaires were distributed among ECWC design teams, and customers of ECWC including clients, suppliers …. The expected sector participants are Construction project developers, construction project consultants, contractors and experts in the area of study. Moreover, adequate number of professionals with an average experience of 4 years in the construction industry including having experience in project formulation, project design at least on two projects has been interviewed. Consequently, the responsive data were statistically analyzed in pursuit of an answer to the research question. Additional questions to account opinions and general back ground of the respondents to address the main questions, to be asked in this review are whether the points covered in the questionnaire are sufficient, clear and relevant to evaluate the experience and selection of sustainable construction materials in design of construction projects. From the feedback, some adjustments has introduced to enhance clarity and to assure consistency in pursuit of appropriate results and conclusions.

Therefore, a fuzzy multi-criteria decision model was used in a case study to cover the main purpose of this paper, which is to develop a decision support model for the selection of sustainable materials in mass housing construction projects.

Finally, the results have been presented and interpretation as well as discussion has followed on the research findings. Consequently conclusions have been drawn and recommendations have also forwarded.

In this study, a questionnaire survey method was used to collect the opinions and views of experts following extensive literature review. As a result it is qualitative-quantitative combination that follows the following four phases:

Phase 1: Identification of indicators affecting the selection of sustainable construction materials

Phase 2: Initial screening and selecting of key indicators for sustainable construction materials

Phase 3: Development of framework as a decision support system/model

Phase 4: Validation of proposed decision making framework.

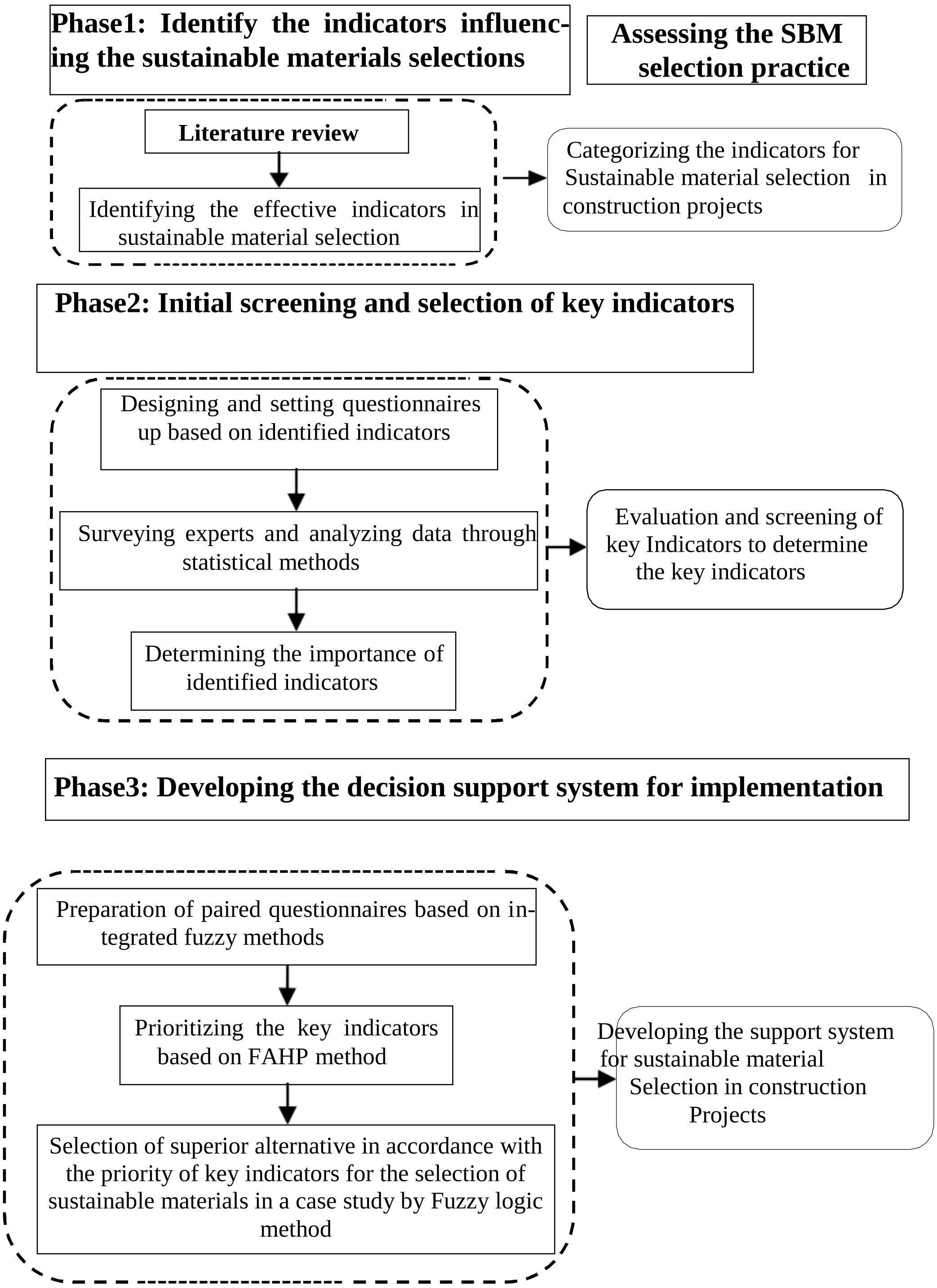



**Figure 3.1: Research design flow chart(**Yildirim & Aghazadeh, 2021)

### 3.3 Population of the study

Target population is said to be a specified group of people or object for which questions can be asked or observed made to develop required data structures and information. Therefore, for this study the target population of the study will be experts belonging to construction industry (the ECWC project development design team and the customers of the corporation). It includes academicians, researchers, designers, and architects, consultant those directly involved on project development and management center.

Accordingly ECWC project development and management center, construction design Department; there are20 Building design team members, 16 Transportation design team members, 14 Water design team members, 14 BIM team members, 4 central laboratory, 6 Project formulation and 2 project appraisal team members, professionally Civil Engineers, Material engineers, Hydrologists, Architects, Structural Engineers, Highway Engineers, Geologists, Economists at project development and management center. A total 76 respondents were incorporated in this study to analyze their opinion on construction material sustainability.

### 3.4 Sampling

The sample design employed for this research is non-probability sampling which is Purposive sampling technique. According to Saunder (2009), in non-probability sampling, the probability of each case being selected from the population is not known.

#### 3.4.1 Sample Size Determination

The term population refers to the aggregate or totality of all the objects, subjects, or members that conform to a set of specifications. In quantitative studies, the researcher identifies the 76 population to be studied during the planning phase. A smaller population can be studied more extensively at a fixed cost than a larger population, so it is important to decide what population is really of critical importance (Joro, 2015).

At the time of this study, a total of 76 ECWC’s project development center design department staff members who are believed to have sufficient work exposure and qualifications on the study concern were drawn by purposive sampling technique. These staff serves in project feasibility study of project development, formulation, appraisal and design of all kinds of construction projects in Ethiopia Construction Work Corporation in Ethiopia and other neighboring countries. The selection of the respondents was carried out in consultation with the managers of work unit/department of the Corporation.

In this paper, the respondents were selected purposively on the bases of the following criteria or requirements:

(i) The respondent should have at least a BSc. in construction engineering and related fields from a known institution

(ii) The respondent should have knowledge of construction materials and their properties

(iii) The respondent shall have an experience in construction projects. Accordingly, 76 respondents were identified. The following Table 3.1 shows the selected respondents along with their numbers.

Table 3.1: The identified population

| No. | Respondents | Numbers of population |
|---|---|---|
| 1 | Transportation design | 16 |
| 2 | Building design | 20 |
| 3 | Water design | 14 |
| 4 | BIM | 14 |
| 5 | Project formulation | 6 |
| 6 | Project appraisal | 2 |
| 7 | Central laboratory | 4 |
| Total number of population | | 76 |

Since the primary focus of this study is the selection of sustainable construction materials, the researcher determined the sample size based on the formula from Akanni et al. (2008) cited in Saleh(2014,p 43) which will be adopted in the calculation of the sample size as follows:

Sample size= $\eta$=100/ [1 + (n'/ N)]

Where,

$\eta$ = sample size

n' = sample size from infinite population = $S^2/V^2$

N = total estimated population;

The V = standard error of the sampling distribution = 0.05,

S2 is the variance of the population elements and V is a standard error of sampling population. (Usually S = 0.5 and V = 0.05)

Hence, the sample size for 20 building design,

$\eta$ = 100 / [1 + (100 / 20)] = 17 samples

This means that the questionnaire should be distributed to16 building team in order to achieve 95% confidence level

The sample size for 16 transportation team,

$\eta$ = 100 / [1 + (100 / 16)] = 14 transportation team.

The sample size for 14 water design.

$\eta$ = 100 / [1 + (100 /14)] = 12 sample

The sample size for 14 BIM team,

$\eta = 100 / [1 + (100 /14)] = 12$ sample

The sample size for 6 project formulation

$\eta = 100 / [1 + (100 /6)] = 6$ sample

The sample size for 2 project appraisal

$\eta = 100 / [1 + (100 /2)] = 2$ sample

The sample size for 4 central laboratories,

$\eta = 100 / [1 + (100 /4)] = 4$ sample

Therefore, according to the above calculation a total of 67questionnaires were distributed to collect relevant data with regard to the research purpose.

Table 3.2: The identified respondents

| No. | Respondents | Numbers of respondents |
|---|---|---|
| 1 | Transportation design | 14 |
| 2 | Building design | 17 |
| 3 | Water design | 12 |
| 4 | BIM team | 12 |
| 5 | Project formulation | 6 |
| 6 | Project appraisal | 2 |
| 7 | Central laboratory | 4 |
| Total number of respondents | | 67 |

### 3.4.2 Validity Check

The weights of the criteria and sub criteria were determined by using the matrix concept and certain mathematical computations on the bases of experts' ideas. The criteria and sub criteria were prioritized on the bases of their weights and the consistency ratio were computed.

CR = CI/RCI.

And, CI is computed as

$CI = \lambda \max - n/ n - 1$. Where, RCI (random consistency index) is the consistency index of a randomly generated pairwise comparison matrix. RCI depends on the number of elements being compared (i.e., size of pairwise comparison matrix) and takes on the following values in Table below. Here, CR = consistency ratio, CI = consistency index, $\lambda$ max = average Eigenvalue of the consolidated matrix, n =number of criteria or sub criteria in a consolidated matrix, and RCI = Random consistency index. The results are consistent if the consistency ratio (CR) is greater than 0.10.

### 3.4.3 Questionnaire Design

Data was collected using a structured questionnaire adopted from a research into a similar topic. The questionnaire for this thesis was motivated by structured questionnaire designed by Akadiri, (2011). The questionnaire design was undertaken to determine the opinion of contractors, consultants and academics regarding the sustainable building material selection practices and the factors & their respective weights that are (if any) considered in the design and planning process.(Berhe, 2021)

## 3.5 Study variables

In a study focusing on the selection of sustainable construction materials using fuzzy logic techniques, the research variables can be categorized into three main types: independent variables, dependent variables, and control variables.

Accordingly, independent variables are sustainability criteria those used to evaluate the sustainability of construction materials; such as environmental pollution, eco toxicity, climate change, health and safety, compatibility, initial cost, etc. Fuzzy logic parameters such as membership functions and fuzzy logic operations are considered as independent variables. Material suitability and selection outcome are known as dependent variables. Whereas external factors such as cost constraints, regulatory requirements and stake holder preferences, environmental context and technological constraints are control variables.

In addition to indicated study variables three basic dimensions of sustainability factors are identified from extensive literature review and professionals and design expert's preliminary interview. These dimensions are namely environmental indicators, social indicators and economic indicators each of which have further detail list of indicators. Environmental dimension have 14 indicators, social dimension have 10 indicators and economic dimension have 6 indicators.

## 3.6 Research Flow Chart

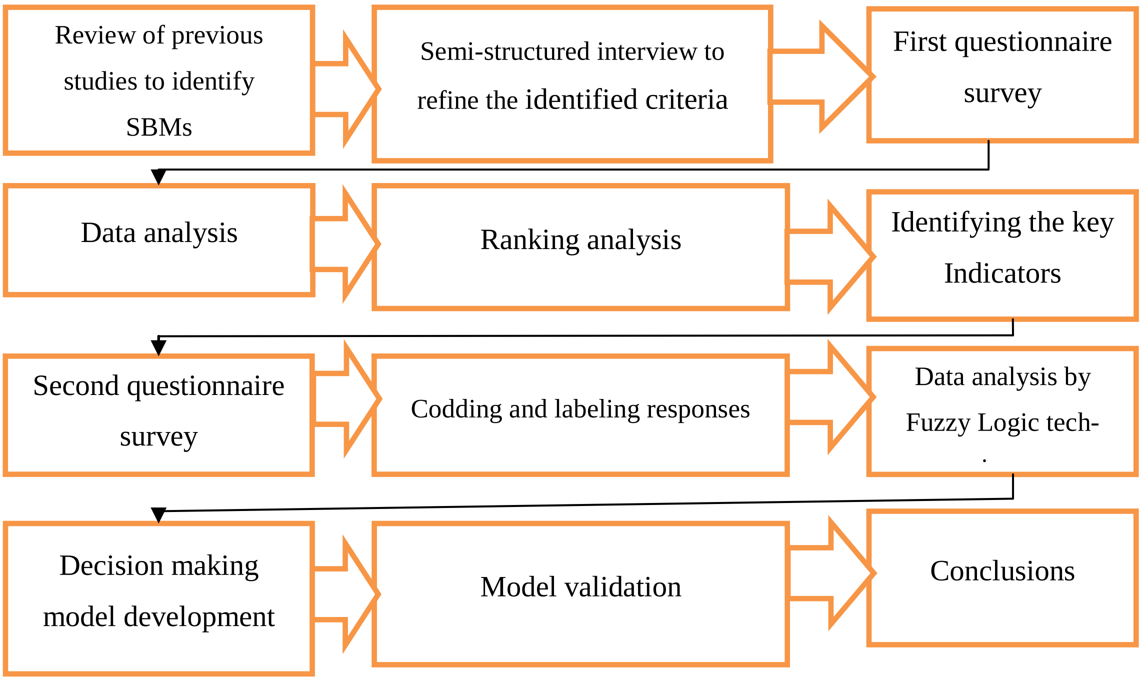



**Figure 3.2: Research flow chart**

## 3.7Proposed Framework

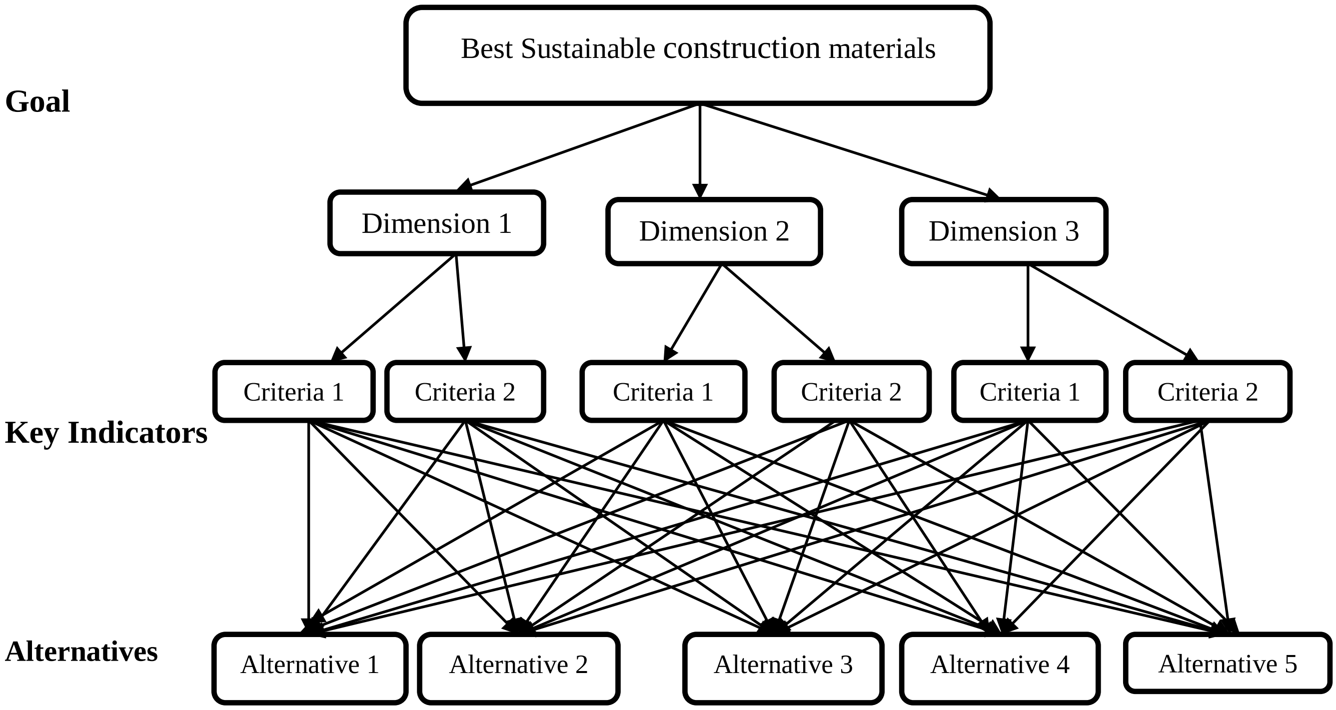



**Figure 3.3: Hierarchy of proposed frame work**

## 3.8 Data Collection

The data was collected from primary and secondary sources. A primary data source includes a questionnaire, interview and observation while secondary data sources include journals and internet sources.

**Primary Data:** Primary data will be collected through different data collection methods.

It has been gathered through interview and questionnaire which have been prepared and administered based on literature review related to the subject of the study. Questionnaires: Standardized Questionnaires (Close-ended and Open-ended questionnaires) will be distributed to all respondents using Likert's five rating scale to respond accordingly.

Interview: The research done with qualitative research tools that allow exact exploring the excellences and attitudes of the people. The interview is used in order to achieve the respondents own viewpoint in Sustainable construction materials and how it is selected, and perceived in their daily life in the projects.

Observation: Observation was used for the research assessing the routine and interactional design selection of sustainable construction materials on the projects. This is a way of witnessing what and how, for example, managers and supervisors deal with the employees or how the perceive, understand and use in practice.

To use the realistic scenario to select the optimal sustainable construction material and to make decision making model case study in a mass housing construction project by the company is done.

**Secondary Data Collection:** Secondary data sources were used to analyze the situation to put the study in the context of the Ethiopia sustainable construction material selection trends with respect to global trends. A desk study was conducted from secondary data obtained from reports, books, journals, designs, schedules, contractual documents and other legal documents.

### 3.9 Data Analysis

The collected data have been coded and analyzed using Fuzzy logic techniques to identify the key sustainability indicators and to optimize the selection of sustainable construction materials.

Research design used for this study was that of a survey which relied on a questionnaire to generate data for the analysis. The questionnaire was developed, pretested to a sample of three experts in construction materials, and then modifications were made to obtain a more efficient instrument. Then after; the structured questionnaires data analyzed statistically to make ranking for sustainability key indicators. Based on key indicators ranking the sustainable construction material selection frame work will be developed.

#### 3.9.1 Relative importance index

The relative importance index method (RII) is a statistical method of the determining owners, consultants, and contractors perceptions of the relative importance of the identified effective factors, which is used for ranking the different important factors. As this survey, there will be designation to identify the relative importance of the factor to sustainability of construction materials. The RII is to determine the relative ranking of the factors, mean values are transformed to importance indices based on the formula:

$$\mathrm{RII} = \sum_{i=1}^{i=5} (\mathrm{Wi} * \mathrm{Xi}) / \sum_{i=1}^{i=5} (\mathrm{Xi})$$

Where:

$X_i$ is the frequency of the $i^{th}$ respondent and $W_i$ is the weight assigned to each variable by the $i^{th}$ respondent, which is equal to 1, 2, 3, 4 and 5. The RII values vary from 0 to 1(other than zero). A higher value of RII indicates the higher importance of the parameters and conversely, a lower value of RII indicates that the parameter is less important.

To analyses the data from the gathered information, have RII value ranging $0<RII \leq 1$. The RII value close to 1 has highest important effect factor, and RII value close to 0 has the least important effect factors. After analyzing the data, variables prioritized the most affecting factors and presenting the results by using different methods; like graphs, charts and tables. In order to answer research objectives, study the analysis results, discussion of the results is compared by using the RII values.

Finally, conclusions will be drawn regarding to the selection of sustainable construction materials and their remedial measures forwarded based on the findings of the study and reviewed literature.

### 3.10 Ethical considerations

The research is free from any political consideration; it is based on the academic perception. The researcher also assuring that the names of respondents will not be revealed in the study and this research is informed to the consent participants. Finally, the researcher took appropriate measures to ensure the research would cause no physical or psychological harm to research participants. As a general rule, therefore, the study did not raise any ethical concerns.

### 3.11 Validation

The model has been developed during the study and validated. This validation aims to ensure systematic, thorough, and unbiased research results. To assess SBMs' application parameters, experts will involve evaluating the model's findings using Likert scale. In this study, nine questions will be constructed to assess the validity .The nine questions to validate the results are summarized as follows:

Q1. Can the model accurately and precisely select a sustainable construction material?
Q2. Are the SBMs criteria for the model of supporting sustainable construction as proposed in this study applicable?
Q3. What is relevance of the model in construction Industry?

Q4. Is the model reasonable for achieving sustainable construction as proposed in this study?
Q5. Would you say the model is simple, clear and easy to understand to the intended users?
Q6. Can the structural model developed in the study be generalized?
Q7. Does the model address an important problem in sustainable material evaluation and selection?
Q8. Would you say the model is capable of assisting architects and designers in the selection of Sustainable materials for construction projects?
Q9. What is your opinion on the description of the model and it's lay out?
Additionally open ended question are used to ensure the validation of the framework model as follows.
Q1. In your opinion, are there any other important criteria that were not considered?
If yes, please list these criteria that ought to have been considered.

Q2. In your opinion, are there any further matters of importance which ought to be included in the model or considered?
If your answer is yes, please specify:

Q3. Please provide any other general comments that you have on the model or suggestions for improvement (continue on a separate sheet if necessary)

Finally based on the statistical analysis of the result the validity of the model be assured.

The reliability of the questionnaires statistics was calculated using Cronbach's Alpha. Cronbach's alpha was used to assess the reliability, or internal consistency, of a set of scale or test items. In most social science research situations the general rule of thumb is that a Cronbach's alpha. As shown in Table 3.3 below, reliability of items was tested by SPSS 22 and Cronbach's Alpha resulted 0.818. So, the coefficient alpha 0.70 or higher is considered to be acceptable.

Table 3:3: Cronbach's alpha for questionnaires reliability checking factors

| | | No of response | % | Cronbach's | N |
|---|---|---|---|---|---|
| Cases | Valid | 67 | 89.55 | 0.90 | 76 |
| | Excluded | 7 | 9.21 | | |
| | Total | 76 | 100 | | |

### 3.12 Data quality assurance

The data will be checked to be more accurate. However, if there is an error or inconsistence on the data, Pilot studies should be performed for both qualitative and quantitative studies. The importance of the pilot study will save time, resources and ignore frustrations. Additionally the following are important note: Adequate training for data collectors, sufficient payment for data collectors and Proceeding with appropriate checks after data collection.

A pilot study was conducted to refine the methodology and test instrument such as questionnaires before administrating final phase. A questionnaire was tested on potential respondents, academic lecturers, and second year MSc. CEM students or my friends to make the data collecting instrument objective, relevant, suitable to the problem and reliability. Issues raised by these pilot respondents were corrected and questionnaires were refined. Besides, proper detection by my advisor was also taken to ensure validity of the instruments. Finally, the improved version of the questionnaires were printed, duplicated and dispatched.

# CHAPTER FOUR

# RESULTS AND DISCUSSIONS

## 4.1 Introduction

Data collected through different techniques were analyzed in this chapter. In the analysis, sixty seven (67) questionnaires were distributed to ECWC project development design professionals', experts and researchers. Out of the total number of questioners distributed sixty one (61) were successfully completed, returned and used for the study. The response rate was approximately 91.05 % of the total questionnaires distributed. The researcher was also conducted interviews with each concerned design Department team leaders of the ECWC project development and management center. Accordingly, the presentation, analysis and interpretation of the interviews and questionnaires were done simultaneously whereby the findings obtained from the interviews were presented in parallel by substantiating against the results obtained from the questionnaires. Additionally to suit it to real scenario case study is incorporated to develop decision making frame work. In order to analyze the research results Fuzzy logic analysis was used. Descriptive measures of each questions response and an interview conducted with results presented in the following sections.

## 4.2 Questionnaire survey response rate and respondent profile

The questionnaire was distributed to ECWC project development design professionals', experts and researchers. Before analyzing the questionnaires, returned questionnaires were checked for their reliability and the valid responses shown in Table 4.1 and Figure 4.2 were analyzed.

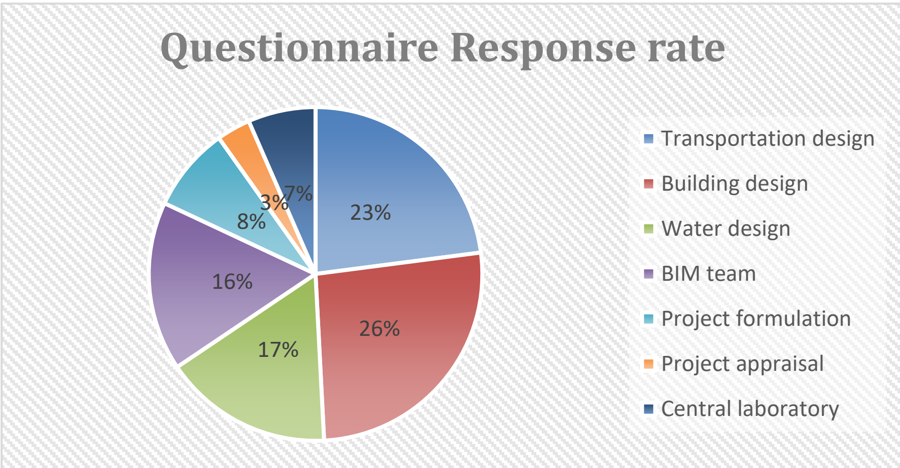
### 4.2.1 Response Rate

A total of 67 Questionnaires were distributed to respondents who are participating in ECWC project development and management center and 61 questionnaires were filled completely and returned. The remaining 6 questionnaires were not returned in which the 2 of the respondents were assigned on duty for field work without filling the questionnaire on the next day and the remaining 4 are due to the reluctance of the respondents.

Table 4.1: Questionnaire distribution and response rate

| Respondents From | Questionnaire distributed | Questionnaire responded | Response rate |
|---|---|---|---|
| Transportation design | 14 | 14 | 100.00% |
| Building design | 17 | 16 | 94.14% |
| Water design | 12 | 10 | 83.33% |
| BIM team | 12 | 10 | 83.33% |
| Project formulation | 6 | 5 | 83.33% |
| Project appraisal | 2 | 2 | 100.00% |
| Central laboratory | 4 | 4 | 100.00% |
| Total | 67 | 61 | 91.05% |

**Source: Survey result, 2024**




**Source: Survey result, 2024**

**Figure 4.1: Questionnaire Response Rate**

### 4.2.2 Respondent's Background

The study tried to determine the demographic data in the following variables as indicated the below table.

**Respondent's Education Level and Experience in Construction projects.**

In Table 4.2 below, from the total of 61 respondents of all organizations, 1.64% (1) held PhD. Degree, 26.23% (16) held MSc. Degree, 65.57 %( 40) held BSc. Degree and 6.56 % (4) were held Diploma. Also, out of 61 professionals 29.51% (18) respondents have experienced less than five years in construction projects, 50.82% (31) of the respondents have experienced between 6-10 years, 18.03% (11) of the respondents have experienced between 11-15 years, 1.64% (1) of the respondents have experienced above 16-20 years.

Table 4.2: Educational Level and Experience of Respondents

| Level of Education & Experience of Employees | | Design Team | | Project Formulation & Appraisal Team | | BIM | | Central Laboratory | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Freq. | % | Freq. | % | Freq. | % | Freq. | % | Freq. | % |
| Edu. Level | PHD | 1 | 2.50 | - | - | - | - | - | - | 1 | 1.64 |
| | MSc. Degree | 8 | 20.00 | 3 | 42.86 | 2 | 20.00 | 3 | 75.00 | 16 | 26.23 |
| | BSc. Degree | 29 | 72.50 | 3 | 42.86 | 8 | 80.00 | - | - | 40 | 65.57 |
| | Diploma | 2 | 5.00 | 1 | 14.29 | - | - | 1 | 25.00 | 4 | 6.56 |
| Experience | 1-5 years | 12 | 30.00 | 1 | 14.29 | 4 | 40.00 | 1 | 25.00 | 18 | 29.51 |
| | 6-10 years | 20 | 50.00 | 3 | 42.86 | 6 | 60.00 | 2 | 50.00 | 31 | 50.82 |
| | 11-15 years | 7 | 17.50 | 3 | 42.86 | - | - | 1 | 25.00 | 11 | 18.03 |
| | 16-20 years | 1 | 2.50 | - | - | - | - | - | - | 1 | 1.64 |
| | 21-30 years | - | - | - | - | - | - | - | - | - | - |

**Source: Survey result, 2024**

### 4.3 Analysis of questionnaire on sustainable construction material selection practices

Although there are not many studies done on construction material selection in Ethiopia, some studies showed that the consideration of sustainability issues on construction material selection is not satisfactory.

Reviewed literatures showed in Ethiopia acceptable level of awareness of sustainability (67.5% were somewhat to moderately aware), likewise, knowledge of material selection is acceptable as well (80% Good to sufficient knowledge). However, the usage of material selection tools such as LEED, BREEAM etc... Is very low.

Furthermore, this study discusses the awareness and practices of SBM selection based on stakeholder’s response.

Table 4.3: The importance level based on RII

| RII value | RII %value | Intensity |
|---|---|---|
| 0.8–1 | 80–100 | Good(G) |
| 0.6–0.8 | 60–80 | Good to Moderate (G-M) |
| 0.4–0.6 | 40–60 | Moderate (M) |
| 0.2–0.4 | 20–40 | Moderate to Poor (M-P) |
| 0.0–0.2 | 0–20 | Poor(P) |

Sustainable construction material selection practice questionnaire's responses are analyzed carefully by filtering them depending on the questions core objectives about like SBM selection practice, personal knowledge and understanding on the issue and the implementation of sustainability measuring tools in projects so far. Each questionnaire response organized and their corresponding RII values are computed and average of the same concern are calculated. Finally summarization is given based on the computed results as follows.

Table 4.4: Sustainable construction material practices Responses

| **Sustainable construction material practices** | | | |
|---|---|---|---|
| No | **SBM Awareness and practices** | RII | RII % |
| 1 | Implementation of sustainability standard in your company | 0.71 | 70.82 |
| 2 | Availability of training and seminars in sustainability concern | 0.66 | 66.23 |
| 3 | Extent of consideration of sustainability in projects | 0.70 | 69.51 |
| 4 | Availability of organization sustainability personal | 0.62 | 61.64 |
| 5 | Your level of knowledge and understanding of sustainable construction materials. | 0.78 | 78.03 |
| 6 | Sustainability assessment is an important issue in construction project. | 0.85 | 85.25 |
| 7 | Overall rate of projects you've handled involving sustainability consideration. | 0.73 | 72.79 |
| 8 | Having obtained the ISO 14001 certification | 0.83 | 83.28 |
| 9 | Please indicate your level of awareness of sustainability issues in building construction. | 0.78 | 77.70 |
| 10 | Having obtained the code for sustainable homes standard | 0.68 | 68.20 |
| 11 | Material specification should include sustainability considerations. | 0.83 | 83.28 |
| Average total | | 0.74 | 74.25 |
| Average of SCM selection practice | | 0.70 | 69.78 |
| Average of SCM selection knowledge | | 0.82 | 82.19 |
| Average of SCM selection standards | | 0.76 | 75.74 |

**Source: Survey result, 2024**

The study response revealed that the selection of sustainable construction material awareness and practice is generally good to moderate level which has an average RII% of 74.25% for it is [60,80]. The investigation indicates that the SCM knowledge is good

(82.19 %) that lie in [80,100]; which is in a better level than the practice (69.78%), however implementation of sustainable material selection standards & codes look good to moderate (75.74%).

### 4.4 Analysis of questionnaire of sustainable construction materials key indicators

In the present study, the responses from the initial questionnaires were obtained based on the Likert scale. Thus, it is not very desirable to use parametric methods to assess the preferences of the respondents (Siegel and Castellan, 1988). Therefore, the relative importance index (RII) method was used to determine and filter the initial relative importance of the indicators. RII is a non-parametric filtering technique that is widely used by construction management researchers to analyse the original responses of the structured questionnaires with regular attitude assessment (Kometa et al., 1994; Wariset al., 2014; Tayeh et al., 2020). When the Likert scale is used to assess the importance of the questionnaire parameters, the value of RII for each parameter can be determined according to equation (1) (Olomolaiye et al., 1987; Chan and Harris, 1989):

$$\mathrm{RII} = \sum_{i=1}^{i=5} (\mathrm{Wi} * \mathrm{Xi}) / 5 \sum_{i=1}^{i=5} (\mathrm{Xi})$$

Where,

xi is the frequency of the $i^{th}$ respondent and wi is the weight assigned to each variable by the $i^{th}$ respondent, which is equal to 1, 2, 3, 4 and 5. The RII values vary from 0 to 1(other than zero). A higher value of RII indicates the higher importance of the parameters and conversely, a lower value of RII indicates that the parameter is less important. In general, the comparison of RII with the corresponding importance level can be made using the transfer matrix presented by Chen et al. (2010), as shown in Table 4.5.

Table 4.5: The importance level based on RII

| RII value | RII %value | Importance |
|---|---|---|
| 0.8–1 | 80–100 | High (H) |
| 0.6–0.8 | 60–80 | High-medium (H-M) |
| 0.4–0.6 | 40–60 | Medium (M) |
| 0.2–0.4 | 20–40 | Medium-low (M-L) |
| 0.0–0.2 | 0–20 | Low (L) |

### 4.4.1 Environmental key indicators

Table 4.6: Environmental indicators analysis

| **Environmental indicators** | | | RANK | | |
|---|---|---|---|---|---|
| No | Code | Statements | RII | Environmental rank | overall |
| 1 | EN1 | Climate change | 0.803 | 2 | 2 |
| 2 | EN2 | Ozone layer depletion | 0.738 | 8 | 9 |
| 3 | EN3 | Water consumption | 0.741 | 7 | 8 |
| 4 | EN4 | Embodied energy | 0.744 | 6 | 7 |
| 5 | EN5 | Acidification | 0.685 | 10 | 19 |
| 6 | EN6 | Waste generation | 0.751 | 5 | 6 |
| 7 | EN7 | Environmental pollution | 0.820 | 1 | 1 |
| 8 | EN8 | Eco toxicity | 0.767 | 3 | 4 |
| 9 | EN9 | Fossil fuel depletion | 0.685 | 10 | 19 |
| 10 | EN10 | Raw material extraction | 0.757 | 4 | 5 |
| 11 | EN11 | Distribution and transportation | 0.725 | 9 | 11 |
| 12 | EN12 | Photochemical oxidation | 0.659 | 12 | 24 |
| 13 | EN13 | Land acquisition | 0.751 | 5 | 6 |
| 14 | EN14 | GHG emission | 0.675 | 11 | 21 |

**Source: Survey result, 2024**

As indicated on the table 4.6 above from identified 14 list of environmental key indicators by using their relative importance index (RII) value ranked as environmental pollution(EN7) take first and climate change (EN1), eco toxicity (EN8), raw material extraction (EN10), Waste generation (EN6), Land acquisition (EN13), embodied energy (EN4), water consumption (EN3), Ozone layer depletion (EN2), Distribution and transportation (EN11), Acidification (EN5), Fossil fuel depletion (EN9), GHG emission (EN14), and Photochemical oxidation (EN12) from highest to least respectively. That means environmental pollution (EN7) is the most and photochemical oxidation (EN12) is the least level of impact on sustainability.

#### 4.4.2Social key indicators

Table 4.7: Social indicators analysis

| Social indicators | | | RANK | | |
|---|---|---|---|---|---|
| No | Code | Statements | RII | Social | overall |
| 1 | SC1 | Compatibility with social identity | 0.731 | 3 | 10 |
| 2 | SC2 | Aesthetic quality | 0.721 | 4 | 12 |
| 3 | SC3 | Comfort of residents and beneficiaries | 0.715 | 6 | 14 |
| 4 | SC4 | Employment and participation | 0.718 | 5 | 13 |
| 5 | SC5 | Housing for all | 0.695 | 9 | 18 |
| 6 | SC6 | Adaptability and availability | 0.731 | 3 | 10 |
| 7 | SC7 | Accessibility | 0.702 | 8 | 17 |
| 8 | SC8 | Use of local materials | 0.757 | 2 | 5 |
| 9 | SC9 | Thermal comfort | 0.708 | 7 | 15 |
| 10 | SC10 | Health and safety | 0.790 | 1 | 3 |

**Source: Survey result, 2024**

As it is seen in the table 4.7 above from screened 10 number of social key indicators by using their relative importance index (RII) values the top ranked indicators are: Health and safety (SC10),Use of local materials (SC8),Adaptability and availability (SC6),Compatibility with social identity (SC1),Aesthetic quality (SC2),Employment and participation (SC4),Comfort of residents and beneficiaries (SC3),Thermal comfort (SC9),Accessibility (SC7) and Housing for all (SC5) are listed from higher to least impact respectively. It implies Health and safety (SC10) is the most and Housing for all (SC5) is the least level of impact on sustainability.

### 4.4.3 Economical key indicators

Table 4.8: Economic indicators analysis

| **Economic indicators** | | | RANK | | |
|---|---|---|---|---|---|
| No | Code | Statements | RII | Economic | Overall |
| 1 | EC1 | Initial cost | 0.790 | 1 | 3 |
| 2 | EC2 | Maintenance cost | 0.741 | 3 | 8 |
| 3 | EC3 | Operational cost | 0.744 | 2 | 7 |
| 4 | EC4 | Jobs and prosperity | 0.682 | 5 | 20 |
| 5 | EC5 | Investment cost | 0.705 | 4 | 16 |
| 6 | EC6 | Renovation and destruction cost | 0.672 | 6 | 22 |

**Source: Survey result, 2024**

From the result of table 4.8 the rank of identified economic key indicators: Initial cost (EC1), Operational cost (EC3), Maintenance cost (EC2), Investment cost (EC5), Jobs and prosperity (EC4) and finally Renovation and destruction cost (EC6) ranked from most to least based on their RII values.

The results of this research revealed that environmental aspects take first rank; social and economic key indicators follows as second and third consecutively.

### 4.5 Analysis of Interviews

The interview adopted in this research is dependent on the purpose of the objective to be achieved. Semi-structured qualitative interview was adopted, as earlier stated. Three construction sites were selected for the qualitative part of this study. The interview was conducted with randomly selected professionals (site engineers, Project managers and office Engineers who have had also participated in questionnaire on each construction site. These professionals were directly involved in the fieldwork with other construction employees and are adequately aware of sustainable building material selection in project design and construction. The interview questions were arranged as shown in appendix-2 form question 1 to 7 denoted as (Q1, Q2…and Q7) based on the research objectives and the respondents' suggestion were arranged in table 4.9 below.

The above interview questions were tried to address the interviewees. Their respondents reply also had tried to be concluded in below table from view point of the contractors, consultants and Employers.

Table 4.9: Summary of interview Analysis

| No | Interview Questions | Summary of Interview responses |
|---|---|---|
| 1 | From your experience, to what extent you consider sustainability concern in material selection? | Though the concept is considered in feasibility study there is limited application during design beyond using and repeating conventional materials as if it is trend. |
| 2 | What are the main factors/indicators used for selection sustainable building materials? | Environmental impact, Resource efficiency, Recyclability & Reuse, Durability, Energy efficiency, Energy efficiency, Eco friendly, Economic, Availability, Social & Quality. |
| 3 | List the indicators of sustainable building materials from most to less. | 1. Environmental impact, 2.Resource efficiency, 3.Durability & maximum service life, 4. Recyclability & reuse, 5. Health & well being |
| 4 | At which stage of construction the sustainability issues need more attention? | In all construction phase the sustainability concern matters; however at planning & design stage is critical because it governs all stages of activities. |
| 5 | List down the most sustainable building materials (for structural element) do you think with their hierarchy. | -prefabricated reinforced concrete, light steel structure , On site casted reinforced concrete, |
| 6 | In your experience, which measurement method/standard is most commonly used during project? | -ISO Integrated management system, ISO 9001: 2015 Quality management systems, ISO 14001:2015 Environmental management system and ISO 45001:2018 Health & safety management systems certified. |
| 7 | To insure the sustainability of building materials what is your recommendation? | -To use locally available materials<br>-To use environmentally friendly materials<br>-Re use materials<br>Each and every construction firm has to comply with sustainability in terms of all sustainability dimensions starting from project planning & design throughout its operation further by implementing local and global standard documents and specifications on each and every phase of project. |

**Source: Survey result, 2024**

Interview and open ended questionnaire's respondents' responses reviewed and summarized as follows.

According to the result from the interview there is better knowledge and understanding of SCM concern that it is measured in terms of environmental, social and economic dimensions; so that SCM has to choose for their environmental compatibility, renewability, recycled, energy efficiency, durability, resource efficiency, ecofriendly, and shall be durable, strong, accessible, reusable, and affordable.

Environmental concern comes first and then social, economic and others follow accordingly. To optimize SCM selection it needs attention; especially at planning and design stage of construction is vital. According to respondents' response the prioritized sustainable structural member is reinforced concrete especially if it is prefabricated one it is better than any of today's material.

Finally since Sustainability has abroad concept each and every construction stakeholders has to comply with it in terms of environment, energy, resource efficiency, and others throughout all stages of construction especially in design phase.

**4.6 Analysis of Case study**

By applying the steps of Fuzzy logic techniques, materials were ranked through a questionnaire. To this end, a decision-making group was formed which consisted of three experts of construction project design and material experts. Detailed discussion on every criterion of alternative materials has been conducted. This process can be conducted for all groups of construction materials specifically structural system, such as Column, Beam, Slab, Footing Pads etc.

In this study, the decision-making process is developed for assessing five types of structural element construction systems used in building construction; Light Steel Frame (LSF), Prefabricated Reinforced Concrete System (PRC), and Insulation Concrete framework (ICF), 3D Sandwich Panels (3DP), and the Tronco System (TRC) were proposed. The criteria with a positive performance are demonstrated by (+), and vice versa, the sign (−) indicates criteria with negative performance.

As described earlier, after transforming the linguistic terms into Fuzzy numbers (see Table 4.10), the Fuzzy numbers should be normalized. The weighted normalized form of experts' judgments was obtained by multiplying the weight of each criterion to the normalized performance as presented in Table 4.15.

Subsequently, FPIS and FNIS were determined based on indicated equations, Table 4.16 demonstrates the results of this step. Afterward, by calculating the Euclidean distance from FPIS for all materials, the relative closeness of each alternative was determined (Table 4.17). In the next step the final ranking of each option with respect to the relative closeness is determined and results are given in Table 4.17. According to the results, the light steel frame (LSF) is the finest option for structural construction in terms of sustainability of construction. Even though it is used for a building with a limited number of floors it is advantageous over the others in resistance to earthquakes due to its light weight without need for traditional and heavy materials, Environmental friendliness, flexibility, high durability, dimensional stability, and being stiff sections. Moreover, due to the uniform distribution of forces throughout the building, the system is recognized as a highly safe system. Prefabricated reinforced concrete system (PRC) is also another option proposed for structural system with its own advantages and drawbacks. Since concrete parts are prefabricated, there are no considerable dimensional and proportional limitations in the architectural design of this system. However it is characterized by its fast and easy implementation and, thus, short duration between investment and operation. In addition, short execution time and cost as well as high service life are among the advantages of this system. The third proposed sustainable construction system is insulation concrete framework (ICF). Earthquake resistance, acoustic and thermal insulation, low construction costs, lack of architectural form limitations, long durability and service life, easy operation of the building, integration into other systems, and fast execution, the possibility of implementation in different seasons of the year, formwork independence, allowing for embedding ducts and pipes in the walls, and easy transportation are among the advantages of ICF system. Tronco system (TRC) is the fourth proposed system that consists of simple frames with cold-rolled metal elements. This system is usually applicable in low-rise buildings. During operation and implementation of this system, the door frames, windows, and electrical and mechanical elements are installed within predetermined spaces. Since the empty spaces within pipes, walls, and ceiling are filled by EPS panels, this system is the best choice in terms of energy saving and light weight. Considering the advantages, this system resembles the LSF system but is constructed and implemented in a different and more expensive way. Lastly 3D sandwich panels are also another alternative found. It is a suitable and effective system that can significantly simplify the building construction process. The system is characterized by lightness, strength, integrity, insulation, and fast and easy implementation, which make the system fully compliant with safety and other relevant standards. The advantages of this structural system include reduced weight, structural rigidity and limited displacement, decreased prime cost, reduced spaces occupied by walls, rapid implementation, and easy installation of electrical and mechanical ducts, etc.

The distance from the normalized weighted matrix of an alternative (Ai) to the corresponding FPIS & FNIS is evaluated.

$di+= \sum_{j=1}^{n} d(aij, aj+)$ ; i=1, 2, 3… k

$di-= \sum_{j=1}^{n} d(aij, aj-)$ ; i=1, 2, 3…..k

Compute the Closeness Coefficient (CCi) for each alternative (Ai).

$CCi = di^{-} / (di^{-}+di^{+})$

Based on the Closeness Coefficient (CCi), the geometric distance of alternative from FPIS and FNIS, the priority of the alternatives is determined.

In the distributive mode, the distance between the different alternatives from the d*i*+ and *di*– with respect to each sub-criteria show the importance that the experts have allocated to dominate each alternative in comparisons with other alternatives under that sub-criteria. For example, the results of the d*i*+ and d*i*– according to Table 4.16 and Table 4.17 show that regarding the NC7, the LSF has the shortest distance from the PIS and the farthest distance from the NIS, respectively. Therefore, LSF can be considered as the most optimal system according to item NC7. This result can be interpreted for other alternatives in each item. In ideal mode, the proximity of the alternatives to the positive and NIS can be determined in terms of closeness coefficient (*CCi*) by considering the effect of all effective parameters in the selection of sustainable materials. The *CCi* results and the final ranking of the alternatives presented in Table 4.17. The results show that LSF, PRC, ICF systems have more final similarity to the ideal alternative, respectively. In other words, these systems are more effective than the identified sub-criteria in order to implement the new construction system in terms of sustainable materials in the project.

Table 4.10: Linguistic variables for rating of variables and criteria.

| Verbal | TFN | Fuzzy Value |
|---|---|---|
| Very low(VL) | 1 | (1,1,3) |
| Low(L) | 2 | (1,3,5) |
| Medium(M) | 3 | (3,5,7) |
| High(H) | 4 | (5,7,9) |
| Very high(VH) | 5 | (7,9,9) |

Table 4.11: Linguistic variables of experts response of Environmental indicators

| Criteria | 3DP | TRC | ICF | PRC | LSF |
|---|---|---|---|---|---|
| EN7 | (5,7,9) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) |
| EN1 | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) |
| EN8 | (5,7,9) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) |
| EN10 | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) |

Table 4.12: Linguistic variables of experts response of Social indicators

| Criteria | 3DP | TRC | ICF | PRC | LSF |
|---|---|---|---|---|---|
| SC10 | (5,7,9) | (5,7,9) | (3,5,7) | (5,7,9) | (3,5,7) |
| SC8 | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) |
| SC6 | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) |
| SC1 | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) |

Table 4.13: Linguistic variables of experts response of Economic indicators

| Criteria | 3DP | TRC | ICF | PRC | LSF |
|---|---|---|---|---|---|
| EC1 | (5,7,9) | (5,7,9) | (5,7,9) | (3,5,7) | (3,5,7) |
| EC3 | (3,5,7) | (5,7,9) | (3,5,7) | (5,7,9) | (3,5,7) |
| EC2 | (5,7,9) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) |
| EC5 | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) | (3,5,7) |

Table 4.14: Normalized Aggregated Fuzzy Decision Matrix FOR ALTERNATIVE

Environmental indicators

| 3DP | TRC | ICF | PRC | LSF |
|---|---|---|---|---|
| (0.33,0.43,0.6) | (0.43,0.6,1) | (0.43,0.6,1) | (0.43,0.6,1) | (0.43,0.6,1) |
| (0.43,0.6,1) | (0.43,0.6,1) | (0.43,0.6,1) | (0.43,0.6,1) | (0.43,0.6,1) |
| (0.33,0.43,0.6) | (0.43,0.6,1) | (0.43,0.6,1) | (0.43,0.6,1) | (0.43,0.6,1) |
| (0.43,0.6,1) | (0.43,0.6,1) | (0.43,0.6,1) | (0.43,0.6,1) | (0.43,0.6,1) |

Social Indicators

| 3DP | TRC | ICF | PRC | LSF |
|---|---|---|---|---|
| (0.56,0.78,1) | (0.56,0.78,1) | (0.33,0.56,0.78) | (0.56,0.78,1) | (0.33,0.56,0.78) |
| (0.43,0.71,1) | (0.43,0.71,1) | (0.43,0.71,1) | (0.43,0.71,1) | (0.43,0.71,1) |
| (0.43,0.71,1) | (0.43,0.71,1) | (0.43,0.71,1) | (0.43,0.71,1) | (0.43,0.71,1) |
| (0.43,0.71,1) | (0.43,0.71,1) | (0.43,0.71,1) | (0.43,0.71,1) | (0.43,0.71,1) |

Economic Indicators

| 3DP | TRC | ICF | PRC | LSF |
|---|---|---|---|---|
| (0.33,0.43,0.6) | (0.33,0.43,0.6) | (0.33,0.43,0.6) | (0.43,0.6,1) | (0.43,0.6,1) |
| (0.43,0.6,1) | (0.33,0.43,0.6) | (0.43,0.6,1) | (0.33,0.43,0.6) | (0.43,0.6,1) |
| (0.33,0.43,0.6) | (0.43,0.6,1) | (0.43,0.6,1) | (0.43,0.6,1) | (0.43,0.6,1) |
| (0.43,0.6,1) | (0.43,0.6,1) | (0.43,0.6,1) | (0.43,0.6,1) | (0.43,0.6,1) |

Table 4.15: Weighted Normalized Fuzzy Decision matrix

Environmental Indicators

| Criteria | 3DP | TRC | ICF | PRC | LSF |
|---|---|---|---|---|---|
| EN7 | (0.99,2.32,5.4) | (1.29,3.24,9) | (1.29,3.24,9) | (1.29,3.24,9) | (1.29,3.24,9) |
| EN1 | (1.29,3,7) | (1.29,3,7) | (1.29,3,7) | (1.29,3,7) | (1.29,3,7) |
| EN8 | (0.99,2.32,5.4) | (1.29,3.24,9) | (1.29,3.24,9) | (1.29,3.24,9) | (1.29,3.24,9) |
| EN10 | (1.29,3,7) | (1.29,3,7) | (1.29,3,7) | (1.29,3,7) | (1.29,3,7) |

Social Indicators

| Criteria | 3DP | TRC | ICF | PRC | LSF |
|---|---|---|---|---|---|
| SC10 | (2.8,4.84,9) | (2.8,4.84,9) | (1.65,3.47,7.02) | (2.8,4.84,9) | (1.65,3.47,7.02) |
| SC8 | (1.29,3.55,7) | (1.29,3.55,7) | (1.29,3.55,7) | (1.29,3.55,7) | (1.29,3.55,7) |
| SC6 | (1.29,3.55,7) | (1.29,3.55,7) | (1.29,3.55,7) | (1.29,3.55,7) | (1.29,3.55,7) |
| SC1 | (1.29,3.55,7) | (1.29,3.55,7) | (1.29,3.55,7) | (1.29,3.55,7) | (1.29,3.55,7) |

Economic Indicators

| Criteria | 3DP | TRC | ICF | PRC | LSF |
|---|---|---|---|---|---|
| EC1 | (1.65,2.67,5.4) | (1.65,2.67,5.4) | (1.65,2.67,5.4) | (2.15,3.72,9) | (2.15,3.72,9) |
| EC3 | (1.29,3.48,9) | (0.99,2.5,5.4) | (1.29,3.48,9) | (0.99,2.5,5.4) | (1.29,3.48,9) |
| EC2 | (1.65,2.32,5.4) | (2.15,3.24,9) | (2.15,3.24,9) | (2.15,3.24,9) | (2.15,3.24,9) |
| EC5 | (1.29,3,7) | (1.29,3,7) | (1.29,3,7) | (1.29,3,7) | (1.29,3,7) |

Table 4.16 The $d^+$ and $d^-$ for alternatives

| Item | | $d^+$ | | | | | $d^-$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 3DP | TRC | ICF | PRC | LSF | 3DP | TRC | ICF | PRC | LSF |
| Environmental dimension | EN7 | 6.37 | 5.56 | 5.56 | 5.56 | 5.56 | 2.66 | 4.81 | 4.81 | 4.81 | 4.81 |
| | EN1 | 4.02 | 4.02 | 4.02 | 4.02 | 4.02 | 3.44 | 3.44 | 3.44 | 3.44 | 3.44 |
| | EN8 | 6.37 | 5.56 | 5.56 | 5.56 | 5.56 | 2.66 | 4.81 | 4.81 | 4.81 | 4.81 |
| | EN10 | 4.02 | 4.02 | 4.02 | 4.02 | 4.02 | 3.44 | 3.44 | 3.44 | 3.44 | 3.44 |
| Social dimension | SC10 | 4.31 | 4.31 | 5.43 | 4.31 | 5.43 | 4.67 | 4.67 | 3.27 | 4.67 | 3.27 |
| | SC8 | 3.85 | 3.85 | 3.85 | 3.85 | 3.85 | 3.55 | 3.55 | 3.55 | 3.55 | 3.55 |
| | SC6 | 3.85 | 3.85 | 3.85 | 3.85 | 3.85 | 3.55 | 3.55 | 3.55 | 3.55 | 3.55 |
| | SC1 | 3.85 | 3.85 | 3.85 | 3.85 | 3.85 | 3.55 | 3.55 | 3.55 | 3.55 | 3.55 |
| Economic dimension | EC1 | 5.97 | 5.97 | 5.97 | 4.99 | 4.99 | 2.24 | 2.24 | 2.24 | 4.42 | 4.42 |
| | EC3 | 5.47 | 6.31 | 5.47 | 6.31 | 5.47 | 4.85 | 2.69 | 4.85 | 2.69 | 4.85 |
| | EC2 | 6.1 | 5.17 | 5.17 | 5.17 | 5.17 | 2.24 | 4.35 | 4.35 | 4.35 | 4.35 |
| | EC5 | 4.02 | 4.02 | 4.02 | 4.02 | 4.02 | 3.44 | 3.44 | 3.44 | 3.44 | 3.44 |
| Sum total | | 58.2 | 56.49 | 56.77 | 55.51 | 55.79 | 40.29 | 44.54 | 45.3 | 46.72 | 47.48 |

Table 4.17 Closeness coefficients and ranking

| Criteria | 3DP | TRC | ICF | PRC | LSF |
|---|---|---|---|---|---|
| $d^+$ | 58.2 | 56.49 | 56.77 | 55.51 | 55.79 |
| $d^-$ | 40.29 | 44.54 | 45.3 | 46.72 | 47.48 |
| CCi | 0.409 | 0.441 | 0.444 | 0.457 | 0.460 |
| Rank | 5 | 4 | 3 | 2 | 1 |

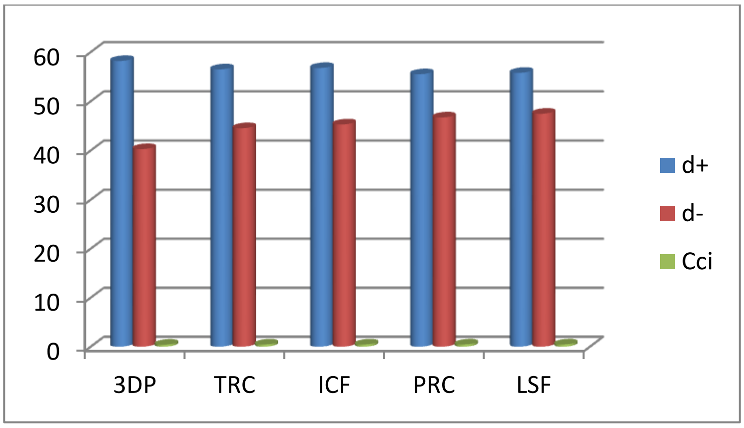



**Figure 4.2: Alternatives Closeness coefficients**

**4.7 Selection of SCM Conceptual Frame work development System**

As mentioned before, the present study is an executive attempt to develop a decision making support model for selecting the optimal structural system. Next, the selected structural system was utilized to execute the structural frames used in mass-housing projects, while taking into account compatibility with the sustainable material selection procedures. Several structural systems with specific advantages and disadvantages were proposed for this purpose. According to the initial opinion of the employer of a mass construction project, five types of new structural systems known as the Light Steel Frame (LSF), Prefabricated Reinforced Concrete System (PRC), and Insulation Concrete framework (ICF), 3D Sandwich Panels (3DP), and the Tronco System (TRC) were proposed to the project contractor for constructing the building. The basic specifications and the executive form of the proposed structural systems are presented in Figure 3 and Table 3, respectively.

Table 4.18: Summary of interview Analysis

| Structural Systems | Information |
|---|---|
| Light Steel Frame (LSF) | LSFs are used to construct buildings with a limited number of floors (usually up to 5 floors). LSF is composed of cold-rolled steel sheets to provide stability. The foundation thickness is very small in this system due to the small loads applied on the building; the system is highly resistance to earthquakes due to its light weight without need for traditional and heavy materials. Moreover, due to the uniform distribution of forces throughout the building, the system is recognized as a highly safe system. Environmental friendliness, flexibility, high durability, dimensional stability, and stiff sections are the main advantages of this system. |
| Prefabricated Reinforced Concrete (PRC) | In this system, the concrete parts that are prefabricated according to the maps are transported from the factory to the construction site. Since concrete parts are prefabricated, there are no considerable dimensional and proportional limitations in the architectural design of this system. The system is characterized by its fast and easy implementation and, thus, short duration between investment and operation. In addition, short execution time and cost as well as high service life are among the advantages of this system. |
| Insulating Concrete Framework (ICF) | This system consists of reinforced concrete as the load-bearing component and expanded polystyrene (EPS) panels as concrete formwork and thermal insulators. Earthquake resistance, acoustic and thermal insulation, low construction costs, lack of architectural form limitations, long durability and service life, easy operation of the building, integration into other systems, and fast execution, the possibility of implementation in different seasons of the year, formwork independence, allowing for embedding ducts and pipes in the walls, and easy transportation are among the advantages of this system. |
| 3D Sandwich Panels (3DP) | The 3DP is a suitable and effective system that can significantly simplify the building construction process. The system is characterized by lightness, strength, integrity, insulation, and fast and easy implementation, which make the system fully compliant with safety and other relevant standards.<br>The advantages of this structural system include reduced weight, structural rigidity and limited displacement, decreased prime cost, reduced spaces occupied by walls, rapid implementation, and easy installation of electrical and mechanical ducts, etc. |
| Tronco System (TRC) | TRC consists of simple frames with cold-rolled metal elements. This system is usually applicable in low-rise buildings. During operation and implementation of this system, the door frames, windows, and electrical and mechanical elements are installed within predetermined spaces. Since the empty spaces within pipes, walls, and ceiling are filled by EPS panels, this system is the best choice in terms of energy saving and light weight. Considering the advantages, this system resembles the LSF system but is constructed and implemented in a different and more expensive way. |

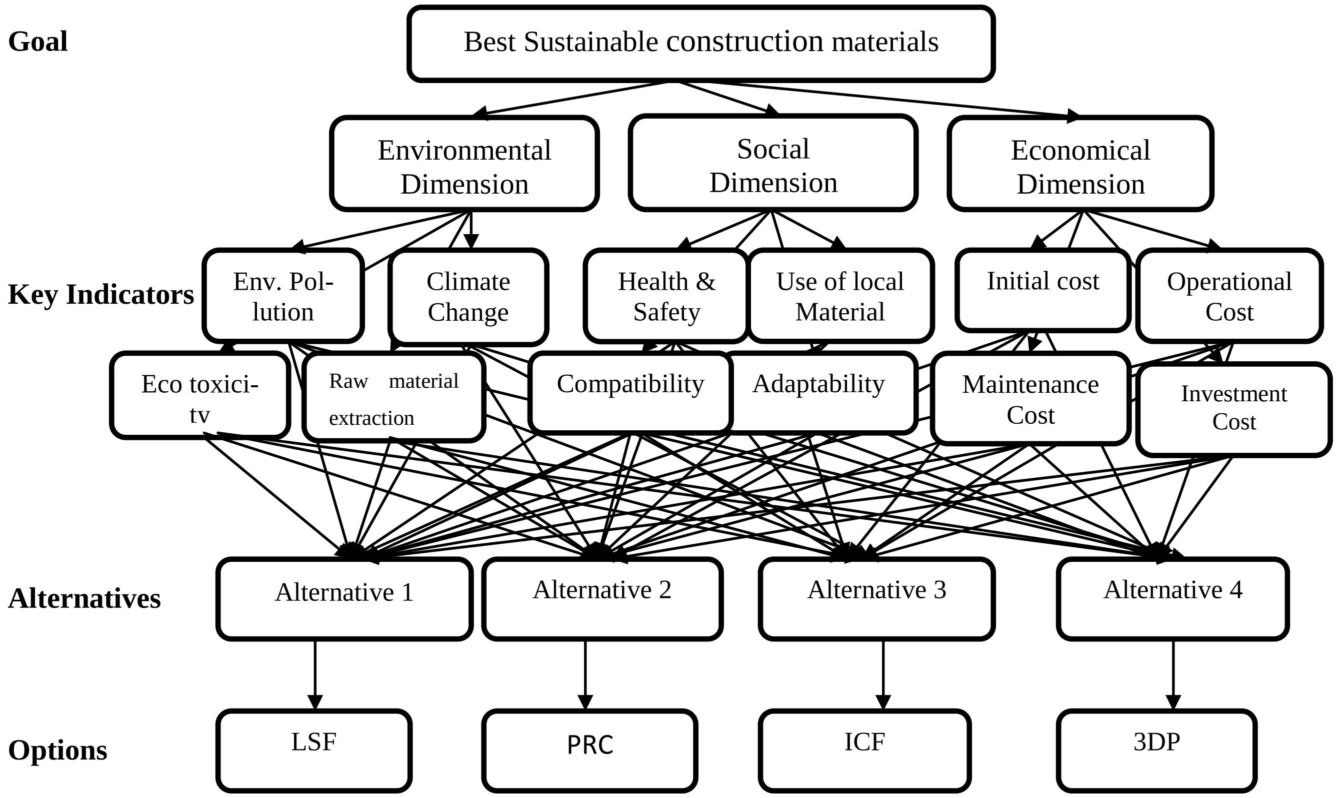



**Figure 4.3: SCM selection Conceptual Frame work**

After screening the sustainability dimensions through intensive literature review and the concerned expert's suggestion, the key indicators of each sustainability dimension are further and ranked by RII values accordingly. Hence three sustainability dimensions namely environmental, social and economic indicators are identified. Based on prescreening 14 key indicators from environmental, 10 indicators from social and 6 indicators from economic are listed. Finally the rank of each key indicators are found by statistical analysis; calculating relative importance index (RII) values and correlated to existing scenario by combining to experts response and fuzzy logic techniques analysis.

### 4.7.1 Validation of SCM selection Conceptual Framework model

Table 4.19: SCM Selection Framework model validation

| Validation questions | | RII | RII% |
|---|---|---|---|
| **No** | **Statements** | | |
| 1 | Can the model accurately and precisely select a sustainable construction material? | 0.77 | **77** |
| 2 | Are the SCMs criteria for the model of supporting sustainable constructions as proposed in this study applicable? | 0.81 | **81** |
| 3 | The relevance of the model in construction Industry? | 0.81 | **81** |
| 4 | Is the model reasonable for achieving sustainable construction as proposed in this study? | 0.63 | **63** |
| 5 | Would you say the model is simple, clear and easy to understand to the intended users? | 0.71 | **71** |
| 6 | Can the structural model developed in the study be generalized? | 0.76 | **76** |
| 7 | Does the model address an important problem in sustainable material evaluation and selection? | 0.84 | **84** |
| 8 | Would you say the model is capable of assisting architects and designers in the selection of Sustainable construction materials? | 0.70 | **70** |
| 9 | What is your opinion on the description of the model and it's lay out? | 0.81 | **81** |
| | **Average RII** | **0.76** | **76** |

As illustrated in Table 4.19 above, the model or the SCM selection or decision making framework has been approved and validated by ten purposively selected construction professionals, Engineers and Managers. As a result, nine variables asked and the respondents agreed as, "The proposed framework is clear, specific, understandable and applicable; so that it assists architectures and designers to select proper construction material that optimize sustainability", "The model has no more ambiguity and no any other suggestion, or modification needed."

### 4.8 Summary of results and discussion

In this research, 67 questionnaires were distributed to ECWC (contractors, consultants, and other experts) from which 61 valid responses were collected from them which comprises a total response rate of 91.05%. Table 4.1 shows that the response rate of the respondents for distributed questionnaires.

The research identifies 30 sub criteria which were categorized under 3 main criteria (dimensions).

The criteria were selected after conducting interviews with experts in the construction industry and reading previous related literature studies. The following Table 4.6, 4.7 and Table 4.7 shows the three most important criteria and sub criteria for the selection of sustainable material for construction work.

The aim of this paper was to identify the practice of sustainable construction material selection, key indicators for measuring sustainable construction materials and to list prioritized list of sustainable structural system. Accordingly the sustainable material selection consideration is shown satisfactory to good.  This study was based on the three main dimensions of sustainable development, which are environmental, social, and economic from intensive literature review. The study adopted 30 indicators from the literature out of which the respondents identified twelve (12) as key indicators for measuring sustainable construction materials. From the scatter plot analysis of the environmental criteria, environmental pollution ranked as the most important among other criteria. This is followed closely by climate change, eco toxicity and raw material extraction. As for the social criteria, “health & safety” ranks first among all criteria. Use of local materials, compatibility with social identity and adaptability& availability were identified as the proceeding key social indicators for sustainable building materials respectively. According to the economic criteria, initial cost is ranked first among all economic criteria. Operational cost, maintenance cost and investment cost were found to be the following rank key economic indicators for measuring sustainable construction materials. Finally the options of structural building system are analyzed by fuzzy logic techniques and ranked from best to least as: Light steel frame (LSF), prefabricated reinforced concrete (PRC), Insulation concrete framework (ICF) and Tranco system (TRC) accordingly. Fuzzy logic analysis leads to SCM decision framework development which has been validated by experienced experts and professionals.

## CONCLUSIONS AND RECOMMENDATIONS

After analyzing the data acquired through primary and secondary sources, key findings have been presented in the previous chapter. This chapter presents the overall conclusions and recommendations drawn based on the findings of the research.

### Conclusions

This section forwards the conclusions of this research based on the major findings stated in the previous chapter, data analysis and discussion, a brief conclusion are summarized to the findings and finally helpful recommendation for the research problems will also be forwarded.

The study response revealed that the selection of sustainable construction material awareness and practice is generally good to moderate level; whereas the SCM knowledge is in a better level than the practice and implementation of sustainable material selection standards & codes.

Based on the results of intensive literature review and experts opinion, 30 indicators were identified as the parameters effective in the selection of sustainable materials and categorized into three general dimensions, namely: Environmental Indicators, Social Indicators and Economic Indicators. Under each dimensions key indicators are identified and ranked accordingly.

The environmental key indicators by using their relative importance index (RII) value ranked as environmental pollution(EN7) take first and climate change (EN1), eco toxicity (EN8), raw material extraction (EN10), Waste generation (EN6), Land acquisition (EN13), embodied energy (EN4), water consumption (EN3), Ozone layer depletion (EN2), Distribution and transportation (EN11), Acidification (EN5), Fossil fuel depletion (EN9), GHG emission (EN14), and Photochemical oxidation (EN12) from highest to least respectively.

The social key indicators by using their relative importance index (RII) values the top ranked indicators are: Health and safety (SC10),Use of local materials (SC8),Adaptability and availability (SC6),Compatibility with social identity (SC1),Aesthetic quality (SC2),Employment and participation (SC4),Comfort of residents and beneficiaries (SC3),Thermal comfort (SC9),Accessibility (SC7) and Housing for all (SC5) are listed from higher to least impact respectively.

Economic key indicators: Initial cost (EC1), Operational cost (EC3), Maintenance cost (EC2), Investment cost (EC5), Jobs and prosperity (EC4) and finally Renovation and destruction cost (EC6) ranked from most to least based on their RII values.

The results of this research revealed that environmental aspects take first rank; social and economic key indicators follows as second and third consecutively.

Finally, the results of selecting the superior alternative structural system in terms of compatibility with the sustainable material selection criteria or FTOPSIS method showed that LSF, ICF, 3DP systems are more similar to the ideal option, respectively.

**Recommendations**

The finding exposed that sustainable construction material selection practice has been undermined and inadequately practiced in building projects. The insufficient studies on the sustainable material issue indicate in addition to lack of implementation of sustainable standards and measuring tools seek remedial measure to optimize sustainability. Since sustainability is all about goal of sustainable development in broad concentrations should be given to the identified important SCM factors and the impacts they could have on the success of the project and the continuity of construction firms.

Based on the findings and conclusions made from the study, the following recommendations can be forwarded to the project stakeholders i.e. contractors, consultants, employers and regulatory bodies in construction projects.

- Every construction firm has to comply with sustainability standards and codes and practice sustainability systems & specifications starting from planning through all construction phases.
- Stakeholders should maintain effective training, guidelines, and manuals for sustainable development at general and sustainable construction material selection in particular.
- Researchers and material experts have to find solution for sustainable construction material by developing innovative systems & mechanism to insure sustainability.
- The government should support the construction firms who are trying to apply sustainable construction material optimization practice.
- Construction firms should have sustainable construction structure and specific professional personals for the duty.
- Construction firms should have guidelines, standards, and specifications that foster sustainability.
- Study on the sustainable construction in general and sustainable construction material in particular should be appreciated in construction industry and institutions.
- Serious attitude change among architects and designers should be fostered in decision making for sustainable material selection at design and planning phase.

**Future Works and Implications/Future research areas**

- Beyond selection of sustainable construction materials for sustainable construction there should be studies that incorporate advanced construction materials to optimize sustainability.
- This study is that the scope of research is limited to the project development and formulation in the ECWC so that future studies can incorporate a large scale of construction industry stakeholders.
- The developed model has only been implemented to select the structural construction system for buildings therefore, future studies, can implement the model to select different construction materials.

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## APPENDICES

### Appendix I- A PRELIMINARY QUESTIONAIRE

Adama Science and Technology University
Department of Civil Engineering,
School of Civil Engineering and Architecture
Stream of Construction Engineering and Management

**Dear respondent,**

**A PRELIMINARY QUESTIONAIRE FOR THE SELECTION OF SUSTAINABLE CONSTRUCTION MATERIALS**

The aim of this questionnaire is to gather and assess experts' opinions on the key indicators of sustainable construction materials selection, which is intended for assisting architects and designers in evaluating and selecting sustainable construction materials for projects. This is to incorporate missed information which is significant to this study and to omit if irrelevant information that ought to be omitted in addressing the decision problem con-fronting designers on SCM selection.

Your genuine and complete responses are highly helpful to make the findings of the study reliable. I would like to thank you in advance for your valued and kind consideration.

**Section A: Background of Respondent**

Name of Respondents (Optional):…………………………………………………………..

Profession:…………………………………………………………………………………..

Qualification:……………………………………………………………………………….

**Section B: Questionnaires on key indicators of sustainable construction materials**

Q1. Are there any sustainability indicators that you consider irrelevant and should be omitted? If there list them.

Q2. Are there any other sustainability indicators you think could be considered? If there list them.

Q3. Please provide any other general comments that you have on the work so far for improvement (continue on a separate sheet if necessary).

Thank you very much for your time！

**Appendix II- MAIN QUESTIONAIRE**


Adama Science and Technology University
Department of Civil Engineering,
School of Civil Engineering and Architecture
Stream of Construction Engineering and Management


**Dear respondent,**

Thank you very much for your willingness to take time to respond to this research questionnaire. The study is being conducted by a postgraduate student at Adama Science and Technology University, Department of Civil Engineering, and Degree of Master's in Construction Engineering and Management. It is all about questions pertaining to **"Selection of Sustainable Construction Materials Using Fuzzy Logic Techniques."**

The participation is fully on voluntary basis and your accurate and frank responses are imperative for the successful accomplishment of the study.

Please be assured that your responses will be treated in a strictly confidential manner and the result will be used only for the purpose of this research, presented only at aggregate level without focusing on individual company.

Kindly, therefore, please return the questionnaire up on completing each item appropriately.

**Thank you in advance for your Time and cooperation!**

Respectfully!


**Kefene Gurmessa Desso**
Mob: +251994919077
*Email: nugusagurmu04@gmail.com*

**Questionnaire survey**

Title of Research Study: **Selection of Sustainable Construction Materials Using Fuzzy Logic Techniques**. I kindly request you to indicate your answer to each question by filling in the space provided or by ticking (√) in the correct answer as appropriate.

***Part 1: General Information***

What is your Organization status in the firm?

Contractor ☐ consultant ☐ Employer ☐ other_____________

Educational Background

PhD ☐ MSc. ☐ BSc. ☐ Diploma ☐ Advanced diploma ☐ other ______

Tota work Experience__________________________Years

Current Position:______________________________________

Head of Department ☐ Team leader☐

Project manager ☐ Office Engineer ☐ Site Engineer ☐

Resident Engineer ☐ Surveyor ☐ orman Other___☐______

***Part 2: Awareness and practice of sustainable construction material in construction projects.***

Please try to fill the questionnaires provided below based on the level of Agreement you have on the sustainable construction material practices in your company by making (√) in the space provided. (**5** = Strongly Agree; **4** = Agree; **3** = Neutral; **2** = Disagree; and **1** = Strongly Disagree).

| **Sustainable construction material practices** | | **Intensity** | | | | |
|---|---|---|---|---|---|---|
| No | **SCM Awareness and practices** | 1 | 2 | 3 | 4 | 5 |
| 1 | Implementation of sustainability standard in your company | | | | | |
| 2 | Availability of training and seminars in sustainability concern | | | | | |
| 3 | Extent of consideration of sustainability in projects | | | | | |
| 4 | Availability of organization sustainability personal | | | | | |
| 5 | Your level of knowledge and understanding of sustainable building materials. | | | | | |
| 6 | Sustainability assessment is an important issue in building project | | | | | |
| 7 | Overall rate of projects you've handled involving sustainability consideration | | | | | |
| 8 | Having obtained the ISO 14001 certification | | | | | |
| 9 | Please indicate your level of awareness of sustainability issues in building construction | | | | | |
| 10 | Having obtained the code for sustainable homes standard | | | | | |
| 11 | Material specification should include sustainability considerations | | | | | |

**Part 3: Sustainable construction materials key indicators**

Please indicate the extent of your agreement or disagreement with the following statements about environmental issues in building design and construction (Please tick (√)box as appropriate).

**A. Environmental indicators** (**5** = Very high; **4** = High; **3** = Moderate; **2** = Low; and **1** = Very low).

| **Environmental indicators** | | **Level of Impact** | | | | |
|---|---|---|---|---|---|---|
| No | Statements | 1 | 2 | 3 | 4 | 5 |
| 1 | Climate change | | | | | |
| 2 | Ozone layer depletion | | | | | |
| 3 | Water consumption | | | | | |
| 4 | Embodied energy | | | | | |
| 5 | Acidification | | | | | |
| 6 | Waste generation | | | | | |
| 7 | Environmental pollution | | | | | |
| 8 | Eco toxicity | | | | | |
| 9 | Fossil fuel depletion | | | | | |
| 10 | Raw material extraction | | | | | |
| 11 | Distribution and transportation | | | | | |
| 12 | Photochemical oxidation | | | | | |
| 13 | Land acquisition | | | | | |
| 14 | GHG emission | | | | | |

**B. Social indicators** (**5** = Very high; **4** = High; **3** = Moderate; **2** = Low; and **1** = Very low).

| **Social indicators** | | **Level of Impact** | | | | |
|---|---|---|---|---|---|---|
| No | Statements | 1 | 2 | 3 | 4 | 5 |
| 1 | Compatibility with social identity | | | | | |
| 2 | Aesthetic quality | | | | | |
| 3 | Comfort of residents and beneficiaries | | | | | |
| 4 | Employment and participation | | | | | |
| 5 | Housing for all | | | | | |
| 6 | Adaptability and availability | | | | | |
| 7 | Accessibility | | | | | |
| 8 | Use of local materials | | | | | |
| 9 | Thermal comfort | | | | | |
| 10 | Health and safety | | | | | |

**C. Economic indicators** (**5** = Very high; **4** = High; **3** = Moderate; **2** = Low; and **1** = Very low).

| **Economic indicators** | | **Level of Impact** | | | | |
|---|---|---|---|---|---|---|
| No | Statements | 1 | 2 | 3 | 4 | 5 |
| 1 | Initial cost | | | | | |
| 2 | Maintenance cost | | | | | |
| 3 | Operational cost | | | | | |
| 4 | Jobs and prosperity | | | | | |
| 5 | Investment cost | | | | | |
| 6 | Renovation and destruction cost | | | | | |

***Thank you in advance for your time concern!***

## Interview

**Interviews Questions**

1. From your experience, to what extent you consider sustainability concern in material selection?

2. What are the main factors/indicators used for selection sustainable construction materials?

3. List the indicators of sustainable construction materials from most to less.

4. At which stage of construction the sustainability issue need more attention?

5. List down the most sustainable construction materials (for structural element) do you think with their hierarchy.

6. In your experience, which measurement method/standard is most commonly used during project?

______________________________________________________________________________

7. To insure the sustainability of construction materials what is your recommendation?

______________________________________________________________________________

***Thank you!!!!!***

**Appendix III- VALIDATION QUESTIONAIRE**

Adama Science and Technology University
Department of Civil Engineering,
School of Civil Engineering and Architecture
Stream of Construction Engineering and Management

**Dear respondent,**

**A QUESTIONAIRE FOR VALIDATING A MODEL FOR THE SELECTION OF SUSTAINABLE CONSTRUCTION MATERIALS**

The aim of this questionnaire is to gather and assess experts' opinions on the attached model, which is intended for assisting architects and designers in evaluating and selecting sustainable construction materials for projects. This is meant for validating the proposed model as to its significance to the industry, workability in practice and adequacy in addressing the decision problem confronting designers on SCM selection.

The questionnaire is in three (3) parts. Section A seeks to collect information on your background; Sections B and C ask for your opinions or comments closed and open ended questions of the model, respectively. There are no correct or incorrect responses, only your much- needed opinion. I kindly request you to indicate your answer to each question by filling your response in space provided or by ticking (√) in the correct answer as appropriate. I would like to thank you in advance for your valued and kind consideration.

If you would like any further information about the research, please let me know.

Respectfully!

**Section A: Background of Respondent**

Name of Respondents (Optional):………………………………………………

Profession:………………………………………………………………..

Qualification: ……………………………………………………………….

**Section B: General Impression on the model (Please tick√ as appropriate)/closed – ended questionnaires/**

Please try to fill the questionnaires provided below based on the level of Agreement you have on the validity of model for the selection of sustainable construction materials by making (√) in the space provided. (7 = To a large extent; 6 = To a moderate extent; 5 = To some extent; 4 = To a small extent; 3 = Not at all; 2 = Not relevant; and 1 = I don't know).

| No | Questions on validity of model for selection of SCM | Level of impact | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1 | Can the model accurately and precisely select a sustainable construction material? | | | | | | | |
| 2 | Are the SCMs criteria for the model of supporting sustainable construction as proposed in this study applicable? | | | | | | | |
| 3 | The relevance of the model in construction Industry? | | | | | | | |
| 4 | Is the model reasonable for achieving sustainable construction as proposed in this study? | | | | | | | |
| 5 | Would you say the model is simple, clear and easy to understand to the intended users? | | | | | | | |
| 6 | Can the structural model developed in the study be generalized? | | | | | | | |
| 7 | Does the model address an important problem in sustainable material evaluation and selection? | | | | | | | |
| 8 | Would you say the model is capable of assisting architects and designers in the selection of Sustainable construction materials? | | | | | | | |
| 9 | What is your opinion on the description of the model and it's lay out? | | | | | | | |

**Section C: Impression on the model's techniques/open-ended questionnaires/**

Q1. In your opinion, are there any other important criteria that were not considered?
If yes, please list these criteria that ought to have been considered.

Q2. In your opinion, are there any further matters of importance which ought to be included in the model or considered?
If your answer is yes, please specify:

Q3. Please provide any other general comments that you have on the model or suggestions for improvement (continue on a separate sheet if necessary)

Thank you very much for your time!

**Appendix IV- FEEDBACK FORM**

**Feedback Form**

1. How many minutes did it take you to complete the Questionnaire?
 ………………..minutes
2. Did you find any questions ambiguous or difficult to answer?

Yes ☐
No ☐
Can’t Say ☐

3. If you answered ‘Yes’ above, can you please list those questions here or specify their numerical order?
…………………………………………………………………………………………………
…………………………………………………………..
4. Are there any specific questions that you consider irrelevant and should be omitted from the Questionnaire?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
….
5. Are there any other issues that you think could be considered in the Questionnaire? (Please give details below).
…………………………………………………………………………………………………
………………………………………………………………………

**NB: Confidentiality and anonymity are guaranteed!**