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Ethiopian Institute of Architecture, Building Construction and City Development

A Study of Alternative Wall Making Materials Selection Using AHP Method

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A Study of Alternative Wall Making Materials Selection using AHP Method

Submitted by **BEHAILU WORKNEH** in Partial Fulfillment of the Requirements for The Degree Master of Science in Construction Management from, **ADDIS ABABA UNIVERSITY**, Ethiopian Institute of Architecture, Building Construction and City Development **(EiABC)**.

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ABSTRACT

Material selection is a complex and delicate task determined by the vast number of building material options. Likewise, multiple factors are often considered by the architect or building designer when evaluating the various categories of building materials. As a result, these sets of factors or variables often present tradeoffs that further complicate the decision-making process. To ease the material-selection process, this study examines the relevant factors or variables needed to develop a systematic and efficient material-selection system. Through the analysis of frequency data and results of the study, it has identified the potential factors that will impact designers' decisions in their choice of wall making alternative building materials, during the design-decision making process. The application of the criteria for the quantitative evaluation and selection of the best alternative building material, using the analytic hierarchy process model, are discussed. The developed decision support system assist designers to assess their consequences in terms of whether or not a material option is likely to be best chosen over the existing conditions. The study also investigates the existing situations in the application of alternative wall making building materials. It assesses the current materials which are being used as a wall making alternative building materials, the extent of usage and barriers to use these materials.

Keywords: *decision making process; factors or variables; selection criteria; alternative building materials; selection framework; analytical hierarchy process (AHP)*

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DECLARATION

I declare that this thesis entitled “A study of alternative wall making materials selection using AHP method.” is my original work. This thesis has not been presented for any other university and is not concurrently submitted in candidature of any other degree. To the best of my knowledge and belief, this thesis contains no material previously published or written by another person except where due reference is made.

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Acronyms

ABM	Alternative Building Material
AHP	Analytical Hierarchy Process
CFC	Chlorofluorocarbons
CR	Consistency Ratio
ELECTRE	Elimination and Choice Expressing the Reality
EPS	Expanded Polystyrine
GHG	Green House Gasses
HCFC	Hydro Chlorofluorocarbons
ISSB	Interlocking Stabilized Soil Block
MCDM	Multi Criteria Decision Making
MDCA	Multi Criteria Decision Attributes
SMART	Simple Multi-Attribute Rating Technique
SPSS	Statistical Package for the Social Sciences
TOPSIS	Technique of ranking Preferences by Similarity to the Ideal Solution

Chapter One

1. Introduction

1.1. Background

Building material is a material that is used for construction purposes. It commonly includes wood, bricks, concrete, steel, metal, cement, clay, aggregates, and so much more. The essential component of a construction project apart from its design is the materials used. Construction has always been highly related to its materials, which have been an essential component since as far back as 400 BC. Buildings and structures including bridges, roads, dams and canals have been built since pre-history. Building materials hence have a long history which is around some thousands of years (Aineias, et al., 2017). Initially, buildings were made of non-durable materials like branches, leaves and animal hides. With invention, materials like timber, stone and clay were used. Slowly came the age of concrete and bricks. Then, with the emergence of industrial revolution, came metals and steel, which was considered as a major revolution of architecture. Today, we see buildings made of concrete, bricks, wood, steel and glass (Aineias, et al., 2017).

Now, other innovative materials are continuously coming up in design & architecture. With unending research and innovative technologies, a variety of modern material alternatives have become available today. With the styles and designs on modern construction, we need materials that can maintain structural strength while reducing its impact on the environment. Modern construction materials also need to be able to adapt to various climatic conditions from freezing sub-zero temperatures to dry heat or high humidity (Ariani Mandala, 2019).

Design is the process of interpreting a new idea or a market need into a detailed information from which a product can be built. Each of its stages requires decisions about the materials from which the product is to be made and the process for making it. Normally, the design stage dictates the choice of materials. A material has its own special characteristics like its strength, cost, density, resistance to corrosion etc. A design requires a certain attribute of these characters which may be a low density, a modest cost, high strength and resistance to sea water (perhaps), and so on. Here the main task will be identifying the desired attribute profile in the design stage and then comparing it with those of real engineering materials to find the best match. This is done by, first, screening and ranking the candidates to develop a shortlist, and then looking for detailed supporting information for each shortlisted candidate, letting to end up with a final choice (Micheal, 1999).

Conventional building materials are those materials that have been traditionally used to make buildings and structures. The term "conventional" is used to describe them because these are the materials that most people use, and have done so for a long time (Joseph & Tretsiakova, 2010).

Alternative Building Materials (ABM) have different definitions by different researchers in the construction industry. There are also differences on the definitions of terminologies that are used in describing ABM. An operational definition of Alternative Building Materials could be described as building materials that are an alternative to conventional building materials in the form of total or partial substitution of the materials or its constituents for the purpose of reducing the cost, addressing environmental issues or dealing with lack of conventional materials (Marut, et al., 2020).

Buildings have same common components such as foundation, walls, floors, and roof. Different building components can be made of same or different materials. Wall in a building construction as one of the common building component, is a continuous, usually vertical structure, thin in proportion to its length and height, built to provide shelter as an external wall or divide buildings into rooms or compartments as an internal wall. The basic function of an external wall is to provide shelter against rain, wind and the daily and seasonal variations of outside temperature normal to its location, for reasonable indoor comfort (Edna, 2017).

The final choice between competing candidates will often depend on local conditions. These conditions could be availability of professionals, equipment to install the material, on the availability of local suppliers, and so forth. If the candidate of materials are not present on the local market, a systematic procedure cannot help here - the decision must instead be based on local knowledge. The material selection framework should be always adaptable to the conditions of all circumstances that it operates. It is always important to know which material is best under existing conditions (Micheal, 1999).

1.2. Statement of the Problem

Urban development is occurring in cities and rapid urbanization is underway in Ethiopia. The need of construction is high. The country's urban population was 21.2 percent in 2019, with an urbanization rate of 4.9 percent. Rapid urbanization has outpaced urban investment needs and development of infrastructure and service delivery. This has resulted in an accumulation of housing demand imbalance of about 1.2million houses (Larissa, et al., 2019). The increasing demand of housing in the country drives the industry to consider using more alternatives of building materials.

In building construction, a wide range of materials are used. A study by (Taffese & Abegaz, 2019) identified the top five most used construction materials in Ethiopian construction sector for modern constructions in urban areas; which are cement, sand, coarse aggregates, hollow concrete blocks, and reinforcement bars. These materials are known for construction based on reinforced concrete in building projects.

The existence and availability of an alternative construction material have several advantages for the construction industry. The cost of building materials and components is known to constitute about 60-70% of the cost of the buildings. This inevitably implies that high cost of building materials will make construction cost equally high (Gbadebo, 2014).With the lack of competitive construction material, when cement production goes down or price suddenly escalates, there could be no alternative solution to execute a project.

Buildings have same common components such as foundation, walls, floors, and roof. Different building components can be made of same or different materials. Wall in a building construction as one of the common building component can be made of wide range of materials. Although the relationship between the volume of a building and its wall area differs as of design, it is an important component of a building that should be researched for greater improvements, which can lead to increased total building construction efficiency.

New materials helped to advance engineering design over time. Today, there are more materials than ever before and the opportunities for innovation are vast. But improvement or progress is possible only if a method exists for making an informed selection. Thus, there should be a systematic method for selecting materials which leads to best matches of existing conditions and the requirements of a design (Micheal, 1999). Making decision which is based on information is a key success factor in any discipline. This is particularly important in an industry such as construction that involves immense information and knowledge management (Jato-Espino, et al., 2017). Thus, developing a framework that incorporates the main decision factors is essential for usage as an informed decision-making tool.

1.3. Research questions

- What is the current practice of using alternative wall making construction materials in Ethiopia?
- What are the parameters that need to be considered in choosing alternative wall making construction materials in Ethiopia?
- Which parameters are more influential in alternative materials selection of the Ethiopian construction industry?

1.4. Objectives

General objective

Alternative wall making materials selection using the AHP method

Specific objectives

1. Determine the current practice of using alternative wall making construction materials in Ethiopia.

2. Identify the parameters that need to be considered in selecting alternative wall building materials in the Ethiopian construction industry.

3. Apply the AHP method for selecting alternative wall making construction materials.

1.5. Significance of the study

This study is a guide to choose among alternative wall building materials in the Ethiopian construction industry. The study aims to work as an aid in the early decisions process for investors, developers and politicians when deciding between different construction materials and the conventional steel and concrete buildings. It does so by giving an overview of the main benefits and barriers that exists when constructing with alternative materials, thus mapping out which problems and opportunities that exist. The goal is to highlight the most important features concerning the economics and environmental aspects when it comes to constructing with different alternative construction materials.

The outcome of this study gives efficient set of parameters which will guide the decision support system for selection of alternative building materials for walling. These parameters will assist various construction industry players to select the most appropriate materials for wall construction of buildings from the approach of affordability, sustainability and other additional influential parameters.

Building designers who have the chance of offering more economic and eco-friendly building materials can offer solutions to their clients according to the parameters given to choose among the alternative materials in this study. The findings will help to address the knowledge gap by developing alternative building materials acceptance framework which enable the assessment of alternative materials effectively.

1.6. Research Scope

This research on a study of alternative wall making materials selection using AHP method is limited in scope to the following

- The study is limited to the construction industry of Ethiopia, specifically that of residential and commercial construction application in and around Addis Ababa city
- The study investigates only the side of contractors and consultant's perspective. Which implies end users of buildings are not included in this research since their interests can be derived from the analysis and perspectives of professionals in the construction industry.
- Among the various types of walls used in construction, this study scope is limited to external and internal non-load bearing walls.
- This study limits its scope in type of buildings on which these alternative materials could be applied. The major types of buildings this study incorporates are residential, commercial and office buildings. The research scope doesn't include buildings for special purposes like explosive storage type of buildings.

1.7. Research Limitations

Conducting a scientific research has substantial challenges and limitations while collecting and analyzing data. The research was aimed to conduct a questionnaire survey, document review, observation study and semi structured interviews. In addition, focus group discussion with key professionals is a method that can generate relevant data for the study. But due to limited time and busy schedule of key professionals, the study was unable to conduct focus group discussions. Additional research limitations include, shortage of well-organized recent and relevant data to the study subject in Ethiopia, respondent's lack of knowledge towards content of questioners, and interview generates limited data due to limited applications and experiences of ABMs.

Chapter Two

2. Literature Review

2.1. Definitions and Characteristics of Alternative Building Materials

2.1.1. Definitions of Alternative Building Materials (ABMs)

Alternative Building Materials (ABMs) are defined differently by various researchers in the building industry, and the terminologies used to describe ABM differ as well. It encompasses building and construction materials that in literature are referred to by different names such as alternative materials, local building materials, unconventional building materials, alternative residential construction materials, sustainable building materials, indigenous building materials, vernacular building materials, green building materials, environmentally responsible building materials, eco-friendly building materials, etc. (Marut, et al., 2020).

There are also different definitions according to different writers. (Opoko, 2006) defined Alternative Building Materials are manufactured or assembled in the country as opposed to imported materials which come into the country in their finished form; these materials evolved from locally available materials in the country through research and development.

(Joseph & Tretsiakova, 2010) defined ABM as those building materials that have a range of beneficial properties such as low toxicity, durability, low level of greenhouse gases (GHG) and other pollutants emissions, high recycle potential and minimal processing requirements; many of them are environmental-friendly and do not produce hazardous end products.

(Madhusudanan & Amirtham, 2015) defined ABM as those industrial and agricultural products that can be used to replace conventional building materials.

Consequently, upon these definitions, Alternative Building Materials can be defined as building materials that constitute an alternative to conventional building materials in the form of total or partial substitution of the conventional materials or its constituents for the purpose of reducing the cost, addressing environmental issues or dealing with lack of conventional materials.

2.1.2. Conventional and alternative building materials

Conventional building materials are those materials that have been traditionally used to make buildings and structures. The term "conventional" is used to describe them because these are the materials that most people use, and have done so for a long time (Joseph & Tretsiakova, 2010).

Concrete is widely used as a conventional construction material for structural frames, foundations, floors, roofs, and prefabricated elements (Pulselli, et al., 2008). The world produces more than 10 billion tons of concrete each year (Meyer, 2009). Concrete is a strong, long-lasting material with excellent mechanical properties. Despite its many advantages and widely spread use, concrete has a significant negative impact on the environment. The cement and concrete industry is estimated to contribute up to 7% of global anthropogenic CO_2 emissions, and this figure is expected to rise dramatically in the coming decades as the world's population grows (Calkins, 2009).

Alternative building materials are ecofriendly building materials that have recently gained popularity as a result of growing environmental sustainability concerns. Alternative building materials have been named so because they have evolved to be an alternative solution to the conventional building materials that have been used over centuries (Joseph & Tretsiakova, 2010).

2.1.3. Characteristics of Alternative Building materials

There are various characteristics that make ABM’s distinct from conventional building materials. The basic attributes of ABM include recycled content, low embodied energy, natural materials, energy efficiency, non-toxic or less-toxic content, reusability and recyclability (Marut, et al., 2020). ABM should be selected instead of conventional materials for new building and renovation based on the characteristics that they possessed.

(Farahzadi, 2014) identified the following qualities in eco-friendly construction materials as ABM in his research: better indoor air quality, less embodied energy, low heat transmission, low carbon dioxide (CO2) emissions, low volatile organic compounds (VOC) emissions and low toxic content. According to (Mishra & Rai, 2017) these basic characteristics are detailed as follows:

- **Indoor air quality** (**IAQ**) is the indoor and outdoor air quality of buildings and structures. IAQ is known to have an impact on building inhabitants' health, comfort, and well-being. Sick building syndrome, reduced productivity, and impaired learning in schools have all been linked to poor indoor air quality.

- **Less Embodied energy: -** is the whole amount of energy required to manufacture any goods or services, as if that energy were incorporated or 'embodied' in the product. Because energy-inputs frequently accompany greenhouse gas emissions, this idea is useful in measuring the effectiveness of energy-saving systems in buildings. Embodied energy is a way of accounting that aims to calculate the overall amount of energy required for a product's complete lifecycle. It is assessing the importance and degree of energy used into raw material extraction, transportation, manufacture, assembly, installation, disassembly, deconstruction, and/or decomposition, as well as human and secondary resources, which are parts of determining what defines this lifespan energy consumption.

- **Heat transfer: -** Heat transfer, in general, refers to the flow of heat (thermal energy) as a result of temperature differences, as well as the subsequent temperature distribution and changes. When phase change material is used on walls, it is expected to reduce the heat rate by storing energy during the phase change process. When the ambient temperature is low, the stored energy is released. Discharging and charging cycles can be used with temperature changes between noon and evening.

- **Volatile organic compounds** (**VOC**) are organic chemicals that have a high vapour pressure at room temperature. High vapor pressure correlates with a low boiling point, which is associated to the number of the sample's molecules in the surrounding air. VOCs (volatile organic compounds) are a class of chemicals found in many of the materials we use to construct and maintain our homes. These chemicals are released or "off-gas" into the indoor air we breathe once they are in our houses. They may or may not be odor able, and odor is not a reliable signal of health risk.

- **Low toxic content** Toxic substance is any liquid, solid or gas, which when introduced into the water supply creates, or may create a danger to health and well being of the consumer.

Non-toxic materials are those that are free of substances that could cause harm to the user's health.

The following features of ABM materials, were referred in the study of (Luis & Tormenta, 1999) as a high-performance building materials.

1. They benefit the occupants of a building in the following ways:
    a) Chemical emissions that are low or non-existent, which can lead to poor indoor air quality;
    b) Are free of very hazardous chemicals;
    c) Are durable.
2. They conserve resources in the following ways
    a) Recycled content (both pre- and post-consumer);
    b) Can be easily re-used (in whole or in parts); and
    c) They can be easily recycled (preferably in closed-loop recycling systems).

3. They have far-reaching, global consequences, particularly materials that:

    a) do not contain CFCs, HCFCs, (Chlorofluorocarbons or hydro chlorofluorocarbons) or other ozone-depleting substances;
    b) come from sustainable harvesting practices;
    c) come from local resources and manufacturers;
    d) have low embodied energy; and
    e) Are derived from renewable resources.

In addition, in their book “Appropriate Building Materials” (Stulz & Mukerji, 1993) list nine factors that determine the appropriateness of an Alternative Building Material:

a) Locally produced;
b) Whether cheap, abundant and renewable or not;
c) Location of the production factory and the machines and equipment required;
d) Energy requirements for the production, and the amount of waste and pollution caused;
e) Climatic acceptability and appropriateness;
f) Safety against hazards;

g) Whether its technology can be easily transferred to the local workers; (h) Possibility of repairs and replacements with local means;
h) Social acceptability.

ABM are distinct as they are sustainable unlike the conventional building materials (Moreal, et al., 2001). ABM are generally lower in embodied energy and toxicity than man-made materials. They require less processing and are less damaging to the environment (Moreal, et al., 2001). When locally found building materials are incorporated into building products, the products become more sustainable (Marut, et al., 2020). (Hema, 2012)opined that ABM should be selected on the bases that they are found locally or regionally which will lead to reduction in transportation cost.

2.2. Characteristics & Types of Wall Construction

Wall is a continuous, usually vertical structure, thin in proportion to its length and height, constructed to provide shelter as an external wall or divide buildings into rooms as an internal wall. It is a structure and a surface that defines an area, carries a load, provides security, shelter, or soundproofing, and is aesthetically pleasing.

2.2.1. Functions of walls in a building

The importance and functions of wall depends upon the type of structure which is to be erected, the situation of the building in terms of both macro and micro environment and the use for which the building is intended. According to (Adedeji, et al., 2011), some major functions and characteristics of wall in a binding are indicated as follows:

- **Strength and stability:** A wall should be strong enough to support the imposed load without deforming excessively. The strength of a wall is depends on the material's strength and the thickness of the wall (Adedeji, 2002)
- **Weather exclusion:** It is extremely important to keep weather out of a building and the internal environment should remain constant.
- **Thermal insulation:** Heat is transferred from a hotter to a cooler environment (conduction). Insulation can be used to reduce heat loss from external walls; the range of thermal conductivity of various engineering materials varies greatly (Otiki, 2004).

- **Durability:** External wall materials must be resistant to the damaging effects of the climate, such as erosion, pollution, rain, chemical and solar radiation (Platts, 1997).
- **Sound Insulation:** Noise is defined as an unwanted, extremely loud sound that can be harmful to one's health, irritating, and cause concentration loss. As a result, sound travels less in airtight medium. Walls do not allow the direct passage of successive air pressure through the material. Electric lighting and power outlets, water pipes, telephone and television outlets, and other services, must pass through or be fixed to the wall. As a result, the wall's material must be able to accommodate them without loss of strength.
- **Attachment:** Cupboards, shelves, and other storage units can all be hung on wall (Adedeji, et al., 2011).

2.2.2. Types of Walls in a building

A. Load bearing walls

A load-bearing wall is a part of structural component. It supports a house's weight from the roof and upper floors all the way down to the foundation. On the upper floors, it supports structural members such as beams, slabs, and walls. It's made to support a vertical load. Load-bearing walls are also responsible for their own weight. Examples of common types of load bearing walls are precast concrete wall, retaining wall, masonry wall, stone wall (Somaieh, et al., 2015).

B. Non-load bearing walls

A non-load bearing wall does not assist the structure in standing up and only supports itself. It is not capable of supporting roof loads above the floor. The majority of the time, they are interior walls that divide a structure into rooms. They're made of lighter materials. Any non-load bearing walls can be removed without compromising the building's structural integrity. They are not responsible of the property's gravitational support. Examples of common types of non-load bearing walls are hollow concrete block, brick walls, solid concrete block (Jayeshkumar, et al., 2016)

C. Shear walls

It's a framed wall which is designed to resist lateral forces. The use of a shear wall is critical, particularly in large and high-rise structures. Concrete or masonry are commonly used in its construction. It has a strong structural system that can withstand earthquakes. It is symmetrically located to minimize the negative effects of a twist. The shear wall doesn't reveal any stability problem (Venkta, 2014).

D. Partition walls

Partition wall is used to act as a barrier between spaces of buildings. It can be solid, made of brick or stone. It is secured to the floor, ceiling, and walls. They strong enough to support their own weight. It is impact resistant, is stable and strong to support wall fixtures, works as a sound barrier and is fire resistant (Qian & Cong, 2018).

Wall systems can also be classified as external and internal walls

E. External Walls

An exterior wall forms part of a building envelope which separates the accommodation inside from that of outside. The prime function of an external wall is to provide shelter against wind, rain and the daily and seasonal variations outside temperature normal to its location, for reasonable indoor comfort. External walls can be built as both load bearing and non-load bearing walls (Jayeshkumar, et al., 2016).

F. Internal Walls

The primary function of internal walls is to divide up the space inside a building. This is important for creation of different rooms. Much of plumbing and electrical wiring is hidden inside internal walls. Depending on what they are made of, these walls can also act as load bearing to help maintain structural integrity or non-load bearing partition walls (Jayeshkumar, et al., 2016).

2.3. The concept of sustainability in the choice of building construction martials

The concept of "sustainability," first defined in the Brundtland Report, published in 1989 by the United Nations World Commission on Environment and Development, has been placed in the center of a several studies and practices (Mustafa Yilmaz & Adem Bkis, 2015). In the context of sustainable development, sustainability has been defined as "meeting the needs and aspirations of the present without compromising the ability of future generations to meet their own needs and aspirations". It is related to quality of life in a community whether the economic, social, and environmental systems that make up the community provide a healthy, productive, and meaningful life for all present and future residents (O. Canarslan & Elias-Ozkan, 2010).

The international community makes states, establishments, institutions, and the business world, as well as non-governmental organizations and other stakeholders, to adapt environmental and energy policies that support economic development while not endangering natural life. Sustainable environmental policies in the construction sector, which is widely responsible for the consumption of natural resources and pollution, have resulted in eco-friendly and smart buildings. Sustainability aims to ensure that future generations will be able to exist by protecting the natural and built environment, as well as human and natural resource continuity (Osso, et al., 1996).People require a lot of buildings to sustain their lives during civilization. In the process of construction, operation, and maintenance as well as destruction of these facilities, they cause lots of environmental issues. Buildings use a lot of energy and natural resources, and they contribute to climate change by affecting air and water quality in cities (Mustafa Yilmaz & Adem Bkis, 2015).

The built environment consumes roughly half of all global resources, including materials, energy, water, and the loss of agricultural land. The building industry is a large consumer of raw materials, and the types and quantities of raw materials extracted, as well as how they are processed, have direct environmental consequences. Buildings necessitate not only energy, but also materials for construction, which require energy for production and transportation (Pearce, 1998). The ideal situation would be to construct buildings with natural sustainable materials collected on site; and also that are able to generate their own energy from renewable sources, such as solar or wind, and manage their own waste (O. Canarslan & Elias-Ozkan, 2010).

Typical buildings consume more resources than are necessary, have a negative impact on the environment, and produce a lot of waste. The majority of the environmental effects are caused by the energy used in manufacturing and the emission of harmful substances during surface treatment. As a result, sustainable architecture encourages the use of energy and materials that do not harm the environment (O. Canarslan & Elias-Ozkan, 2010). The following criteria takes supreme importance in this regard: minimizing material waste, ensuring long-term use, selecting materials with low environmental impact, and designing buildings so that they can be easily maintained, refurbished, and deconstructed (Kohler & Chini, 2005). Reduced energy consumption, the use of environmentally friendly materials, and reduced waste and pollution are all included in sustainable design. Hence, in order to design sustainable buildings, selection of appropriate building materials becomes very important (O. Canarslan & Elias-Ozkan, 2010).

2.4. The development of building material selection support tools

Empirical research validates that studies on building material support tools or systems have continued to develop in size and specification (Trusty W.B, 2010). In attempts to achieve greater degree of ability in the material-selection process, and facilitate a constructive material selection process, most studies have generated schematics of basic material selection factors or variables for assessing the performance metrics of a variety of building materials or products.

According to a survey conducted by (Flórez, et al., 2009) a number of studies on the attributes of building materials have been conducted, indicating the use of objective and subjective measures in defining the performance metrics of building materials or products. These studies provide lists of material section variables believed to contribute to the performance quality of building materials or products.

A study by (Rahman, et al., 2008) developed a multi-criteria decision-making model (MCDM) that takes into account the performance criteria of new technologies or materials, allowing decision-makers to solve complex problems associated with material selection. The system objective, however, was to create a knowledge-based model that took into account the life-cycle of materials and technologies while being as cost-effective as possible. Similarly in another study, (Kesteren, et al., 2005) presented a material-selection consideration model in which the designer considers product personality, use, function, material characteristics, shape, and manufacturing processes. Also study by (Ljungberg, 2007) developed an integrated system to assess material performance based on factors such as trend braking, low reparability, safety, and user satisfaction.

The article by (Cagan & Vogel, 2002) suggested six categories of factors or variables that account to material value or performance such as emotion (sensuality, power, and sense of adventure), aesthetic (visual, tactile, and auditory), product identity (personality, sense of impact, and social), ergonomics (ease of use, safety, and comfort), core technology (enabling and reliable), and quality (durability).

According to another study (Chueh & Kao, 2004) performance, features, reliability, conformance, durability, serviceability, aesthetics, tangibles, assurance, empathy, value, involvement and responsiveness are demonstrated as the major dimensions of product quality factors. Their study however, supports consumer perception as a major contributing factor in determining material choice and performance.

A model is developed by (Abeysundara, et al., 2009) for quantitative analysis of a range of sustainable building materials, based on environmental (embodied energy), economic (market prices and cost), and social variables (thermal comfort, aesthetics, ability to construct quickly, strength and durability). However, the results of their analysis revealed that environmental parameters were given precedence over social and economic factors in the decision-making process.

In addition to the ones presented here, several related studies have attempted to apply modern information technologies to problems like quantitative analysis of local building materials in the material evaluation and selection process. Although no practical model was conceived, these studies suggested the use of multi-criteria decision-making methodology for the assessment of the decision-making process in selecting local building materials. Their activities, however, tended to emphasize renewable materials and energy sources, low-polluting materials, a concern for buildings' overall lifetime impacts (both occupation and construction impacts).

Given the key insights from the presented studies and reviewed literature, (Ogunkah & Yang, 2012) presented the following literature gap in their study.

- In the design-decision-making process, there is a gap between awareness and implementation of sustainable practices in the selection of local and recycled building materials.
- Locally produced and recycled building materials are yet to become main features in design and construction.
- Each set of material selection tools or systems available, has evolved to meet its particular values and priorities

- Without considering the key influential factors or variables, technology push (i.e., technological-led solution) is insufficient to determine or justify the effectiveness of a building material or product.
- The weighting system is still being considered as a viable option for determining the effectiveness and suitability of material options.
- The majority of studies do not directly incorporate social or cultural criteria into the decision-making process, but rather do so indirectly through technical or economic criteria.
- The majority of existing models still only consider a few factors or variables when choosing local and recycled building materials or products, resulting in structures that are vulnerable, fragile, and difficult to maintain.
- Developing a material-selection system that aids decision makers in selecting locally sourced or recycled building materials by taking into account all of the factors that come into play during the decision-making process will quicken or make necessary the use of locally sourced or recycled building materials in mainstream design and construction.

Many efforts to bridge the existing knowledge gap identified regarding to material selection, have been initiated (Fernandez, 2006). There is reasonable evidence to suggest the need for a multi-factorial assessment toolkit with proficient design-decision making capabilities for locally sourced and recycled building materials, given the lack of an appropriate support tool to assist potential beneficiaries (such as designers, architects, and material specifiers). The purpose of a framework is to solve and eliminate complex issues associated with material selection. The goal is to give designers a better understanding of the consequences of their decisions during the material selection process (Ogunkah & Yang, 2012).

2.5. The need for Adoption of ABMs for Walling

2.5.1. World Wide Application of Wall Making ABMs

Currently the need for usage of ABM throughout the world is highly related to sustainability requirements. Buildings are the largest consumers of energy and emitters of greenhouse gases in both developed and developing countries. Buildings alone account for up to 50% of carbon dioxide emissions in continental Europe. As a result, immediate changes are required in the areas of energy saving, emissions control, material production and application, renewable resource use, and building material recycling and reuse. Furthermore, due to growing environmental concerns, the development of new eco-friendly building materials and practices is critical. (Joseph & Tretsiakova, 2010).

In order to combat global warming and the resulting climate change, sustainability principles have now become mandatory. Several countries' governments have put in place policies aimed at controlling and improving the current state of the construction industry. The major actions include reducing energy consumption in buildings, making better use of natural resources, and tightening emission controls. All of these measures should be implemented in a systematic manner when selecting materials for environmentally friendly buildings and construction projects (Calkins, 2009).

2.5.2. The Need and Extent of ABMs Adoption in the Ethiopian Construction Industry

In Ethiopia high population growth related housing inadequacy in urban areas is a major problem. The need for housing is increasing while construction material costs also increasing. A challenge facing the Ethiopian society is thus to give a growing population opportunity to obtain decent, sustainable and affordable housing (Bihon, 2012).

The *chikka* house (wood structure and earth and straw filling) is the most common design and is found almost everywhere in the country. Though, many other building cultures coexist, ranging from **l**oad bearing stone masonry walls structures with earthen mortar in the north of the country, to bamboo structures and thatch walls in the south and demountable wood and fibre mats houses of the nomadic peoples in the desert areas of Somali and Afar. Round houses (*tukuls*) and thatch roofs are very common throughout Ethiopia, but corrugated galvanized iron (CGI) sheet roofs are becoming ubiquitous with the shapes of the houses progressively adopting a rectangular plan (Bihon, 2012).

In cities, constructions built with reinforced concrete structure, cement blocks or fired bricks are becoming more and more common. Multi-story condominiums are progressing thanks to public initiatives and are gradually substituting *chikka* and CGI sheets houses. Ethiopia has a great need for improvement and development. To fulfil this situation, a number of important measures must be taken. One is to give the Ethiopian people the opportunity to get better housing. The need for this can be identified over large parts of the country; both rural and urban. This need has to be seen in relation to the large, general problems which are facing the country. Of these problems, a high population growth, an increasing deforestation and an uncontrolled urbanization process can be regarded as the most serious (Hjort & Widen, 2015).

In Ethiopia, housing inadequacy is largely felt at the level of low and middle income and more so with continuous rise in cost of construction at all levels. This necessitates the use of appropriate and cost effective materials & technologies in house construction. Because the leading type of housing construction system in Ethiopia which is conventional system couldn't be compatible with increasing rate of housing provide and this created a negative impact on housing construction such as long time construction, rising cost, material wastage, high embedded energy and so on (Kebede, 2013).

As the study of Shimeles Kebede indicates, introduction and application of alternative construction materials & technology such as agro stone, stabilized soil blocks (Chemically stabilized soil block and cement stabilized soil block), hydra foam, fly ash brick/blocks, stone colored roofing, pre cast panels are not new in Ethiopia. These materials have the potential for increasing the housing stock, and also it is the most important that can reduce the housing cost to a reasonable rate in the case of Ethiopia.

2.6. Factors to Consider in Choosing Among Alternative Construction Materials

The vast number of building material options makes material selection a difficult and delicate task. Multiple factors are often considered by the architect when evaluating the various categories of building materials during the material selection process. As a result, these sets of factors or variables frequently present tradeoffs, further complicating the decision-making process. Several studies now claim that using locally sourced and recycled building materials reduces CO_2 emissions, produces healthier buildings, and strengthens the local economy (Kibert, 2008).

Selected criteria to choose among alternative building materials should consider all dimensions of parameters that influence decisions in local existing conditions. Available wide range of materials have their own characteristics on which a designer decision depends on. Different studies presented the influential parameters that needs to be considered in choosing among construction materials.

A study by (Aghazadeh & Hassan, 2019) examines the most important criterion for selection of martials in construction projects. After extensive evaluations and research, criterions are presented in the form of template. Main material selection criteria are categorized in five groups (1) technical, (2) economic, (3) health and environmental, (4) design management, (5) social. In each area/groups the relevant sub- criteria are presented.

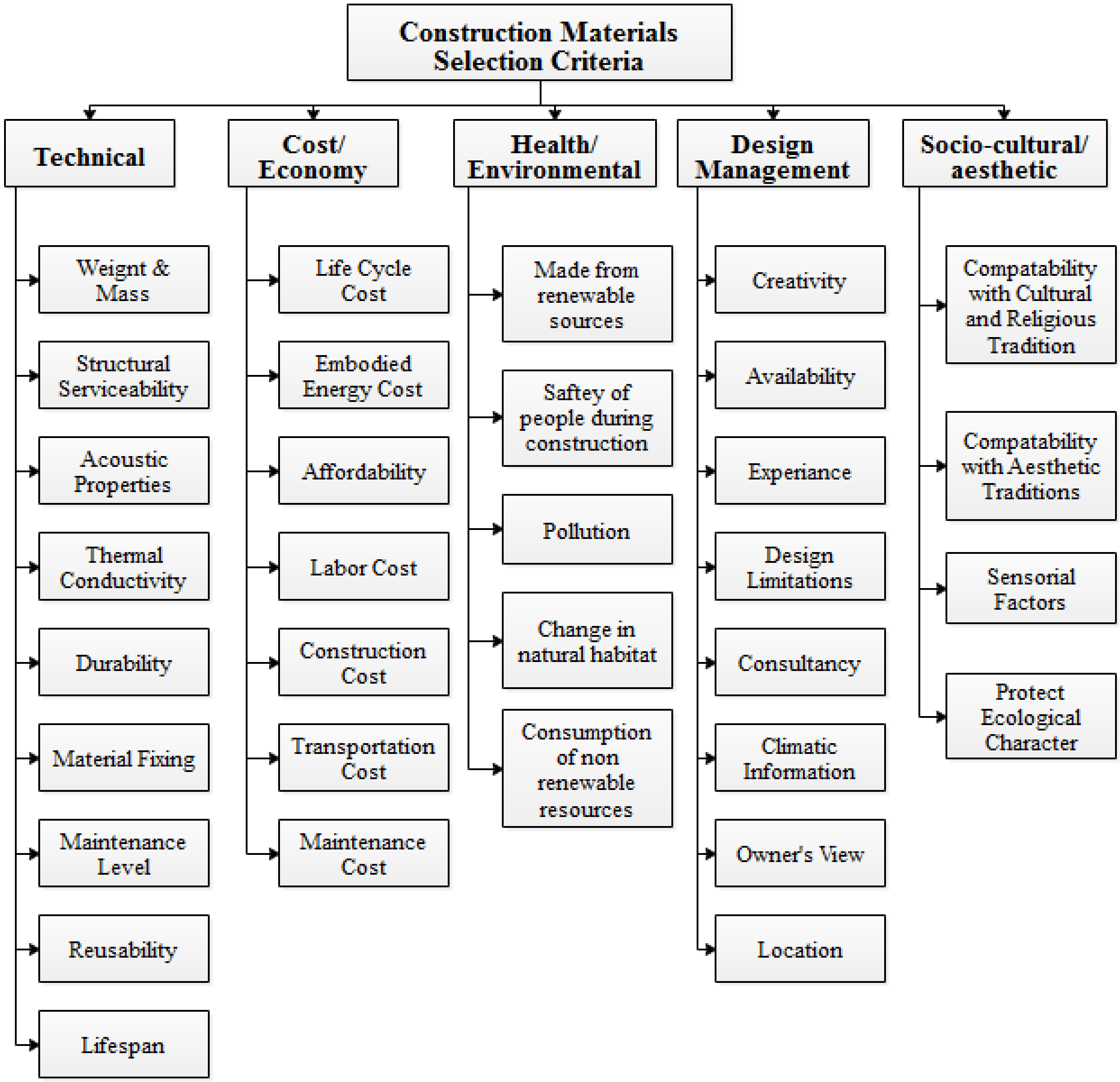

Figure 2. 1: Construction materials selection criteria

Source: (Aghazadeh & Hassan, 2019)

Table 2. 1: Key factors in choosing materials

Source: (Aghazadeh & Hassan, 2019)

1. Extraction and Manufacture	**A. Impact of extraction:** noise, visual pollution air pollution, water pollution, chemical emission, release of co_2, damage, ecosystems, water use, energy use.
	B. Energy and resource use: The total energy used in the extraction, production, transportation and construction of a building material is the embodied energy of that material. As high consumers of energy, buildings have a significant impact on our environment.
	C. Byproducts and emissions: The process of the production of building materials can cause pollution and emissions of co2 and other greenhouse gases.
2. Sourcing	**A. Material sources:** The source of materials must be considered to keep transport costs and resultant emissions to a minimum.
	B. Availability: Long delivery time cause project hold-ups and cost and energy losses.
	C. Cost: Includes the initial cost of purchase and the lifecycle costs of materials. Lice cycle costs include maintenance, replacement, demolition and disposal.
	D. Transport to site: The further materials must be transported, the greater the financial costs and emissions.
3. Construction/ Installation	**A. Health and safety during construction/ installation:** Some materials such as solvents and chemicals release VOCs, and materials that release dust and other airborne pollutants may be harmful to people during installation or application.
	B. Ease of Construction/installation: Complicated installations with close tolerances can result in with greater wage or even rework being required.
	C. Adaptability: The more adaptable a material, the less waste will result from changing needs or tastes.
4. Performance	**A. Health and safety during the life of the building**: Materials should generally be selected to minimize adverse effects to occupants.
	B. Structural capability: Materials must be selected or designed for their ability to support the loads imposed by the building over the whole life of the building.
	C. Durability: A highly durable material reduces maintenance or replacement requirements & it also must be appropriate to the expected life of the building.

	D. Maintenance: Materials with higher maintenance requirements are likely to have lower initial costs but they will also have higher whole life cycle costs.
	E. Thermal performance: Material selection must contribute to good thermal performance and reduced energy demand by including insulation and thermal mass in the building.
	F. Moisture resistance: Some materials have a natural moisture resistance while others must be fully protected from moisture.
	G. Material deterioration: Some materials deteriorate rapidly in moist environment, generally due to the growth of corrosion
5. Waste disposal/ recycling/ reuse	**A. Reuse:** Materials that can be reused after the useful life of the building will reduce the need of new materials to be produced in the future.
	B. Recycling: Materials that can be recycled will reduce the need for new materials to be produced, and the energy required to reconstitute materials is generally less than required for new production.
	C. Waste disposal: The impact of the disposal of materials at the end of their service life must be considered.

Source: (Aghazadeh & Hassan, 2019)

Another related study by (Ogunkah & Yang, 2012) investigated information to identify key influential factors to address the decisions for making effective material choices. In the study, a semi-structured questionnaire survey was deployed to targeted experienced experts in their respective countries in the UK, USA and China, by using an online survey tool and through administered mode (using telephone interviews). The study collected information regarding material selection factors or variables that will influence architects or designer decisions in their choice of materials from a range of options. As a result, the study presented a framework that lists the various categories of factors which are identified to affect the selection of local and recycled building materials.

According to the study of (Ogunkah & Yang, 2012), their research resulted in lists of material-selection factors or variables that contribute to the performance, quality and acceptance of building materials. The factors or variables chosen are grouped in to six categories which are (1) general or site (2) economic (3) socio-cultural (4) environmental (5) sensorial (6) technical or functional factors. These criteria/ factors/selection parameters are presented in the following table.

Table 2. 2: Factors affecting choice of building material

Source: (Ogunkah & Yang, 2012)

1. General/ Site Factors

- G1 Location
- G2 Distance
- G3 Availability of Materials
- G4 User's Choice
- G5 Experience
- G6 Creativity
- G7 Material Type
- G8 Site Layout
- G9 Regional Setting/ Geographic information
- G10 Space Usage
- G11 Site Access
- G12 Building Structure
- G13 Scale

2. Cost/Economic Factors

- C1 Life-cycle cost
- C2 Material embodied energy
- C3 Economic Status
- C4 Affordability
- C5 Labor cost
- C6 Energy efficiency

3. Socio-Cultural Factors

- SC1 Compatibility with Cultural and Aesthetics traditions
- SC2 Communal identity and Setting
- SC3 Cultural implications of materials
- SC4 Family structure
- SC5 Owner's View
- SC6 Designers' knowledge of the region

4. Environmental/ Health Factors

- E1 Environmental Compatibility
- E2 Waste prevention
- E3 Safety and Health of User
- E4 Habitat Disruption
- E5 Degree of pesticide treatment
- E6 Climate
- E7 Total environmental impact

5. Sensorial Factors

- S1 Appearance
- S2 Texture
- S3 Color
- S4 Temperature
- S5 Acoustics
- S6 Odor
- S7 Thickness
- S8 Roughness
- S9 Fineness

6. Technical Factors

- T1 Reusability
- T2 Demount ability
- T3 Maintenance level
- T4 Ability to accommodate movement
- T5 Technical skills
- T6 Material fixing
- T7 Fire resistance
- T8 Heat resistance
- T9 Water resistance
- T10 Scratch resistance
- T11 Weather resistance
- T12 Chemical resistance
- T13 Weight and mass of material
- T14 Strength
- T15 Durability

2.7. Decision making tool to choose among building materials

The selection of building materials is regarded as a multi-criteria decision-making problem (MCDM). MCDM is also referred to as multiple criteria decision analysis (MCDA) or multi-attribute decision analysis (MADA). MCDM is the study of methods and procedures concerning about multiple conflicting criteria that can be formally incorporated into the management planning process. It could be categorized into single decision and group decision making problems. In MCDM problems, defining the criteria is an important element of the structuring process (Scheubreina R & Ziontsb S, 2006).

There are different MCDM methods, such as analytic hierarchy process (AHP), technique of ranking preferences by similarity to the ideal solution (TOPSIS), elimination and choice expressing the reality (ELECTRE) and simple multi-attribute rating technique (SMART) are widely used techniques that have been adopted to solve MCDM problems in construction industry (Sazzadur, et al., 2018).

The analytic hierarchy process (AHP) method, conceptualized by (Saaty T.L, 1994), is one of the most popular MCDM methods. The purpose of MCDM is to select the best alternative from a set of competitive alternatives and evaluate it with a set of criteria. The AHP method can be successfully applied to analyze qualitative data quantitatively. It transforms a complex and multi-criteria problem into a structured hierarchy. The AHP requires minimal mathematical calculations and is the only methodology that can consider consistency in decision-making. In addition, it has been applied in construction industry to select suppliers & construction method (Dongmin Lee, et al., 2020).

The study of (Saaty T.L, 1994), describe AHP method as a multiple step analytical process of judgment, which synthesizes a complex arrangement into a systematic hierarchical structure. It allows a set of complex issues that have an impact on an overall objective to be compared with the importance of each issue relative to its impact on the solution of the problem. It is designed to cope with the intuitive, the rational, and the irrational when making multi-objective, multi-criterion and multi-actor decisions exactly the decision-making situation found with material selection. Furthermore, it can easily be understood and applied by decision makers saddled with building material selection process (Dongmin Lee, et al., 2020).

The application of AHP to a decision problem involves four steps. In structuring of the decision problem into a hierarchical model, material selection problem is defined, objective is identified, criteria and attributes that must be satisfied to objective are recognized. Objective is at first level, criteria is at second level, attributes are at third level, and decision alternatives are at fourth level in hierarchical structure of the problem (Peter, et al., 2012).

Chapter Three

3. Methodology

3.1. Introduction

3.1.1. Overview of the study Area

The overall aim of this research is to determine the acceptance criteria of alternative building materials for walling and to develop material selection method for the Ethiopian construction industry. There are several reasons why one construction material could be chosen over other materials. There could be several findings that may show non- applicability of a material due to local contexts. The outcomes of these study include prioritizing the critical construction material selection factors and to prepare a method for selection of best suitable material.

This research on wall making building material selection aims to develop a set of useful knowledge bases and structured 'selection' systems that will serve as the basis for evaluating building materials in terms of their suitability considering several useful parameters, during the design process of a building project. The research will also investigate the current application, practice and extent of using alternative wall making construction materials in and around Addis Ababa, Ethiopia.

3.1.2. Research Design

The main focus of the research design is the way the research questions could be answered through realistic methodology, data collection, data analysis and conclusion that determine the finding of the study. In order to collect the data needed to address the above-mentioned points in the statement of the problems, the researcher adopted a descriptive survey design. Suitable clusters of research approaches are considered in this 'material selection' research which includes exploratory literature reviews, field observations, series of questionnaire surveys and knowledge-mining interviews.

Since this research is concerned with developing a method of material-selection for alternative wall making materials, which entails gathering information from a wide range of sources, the study upholds and adopts a combination of both quantitative and qualitative methods of data-collection. A quantitative research is one of an objective approach which usually requires to record the opinion, belief and attitude of the respondents in different degree that can be measured with numbers. On the other hand, qualitative research is a subjective approach of discussing and observing peoples in their language and environment respectively (Naoum, 2007). Therefore, the methodological approach used in undertaking this research was a mixed approach.

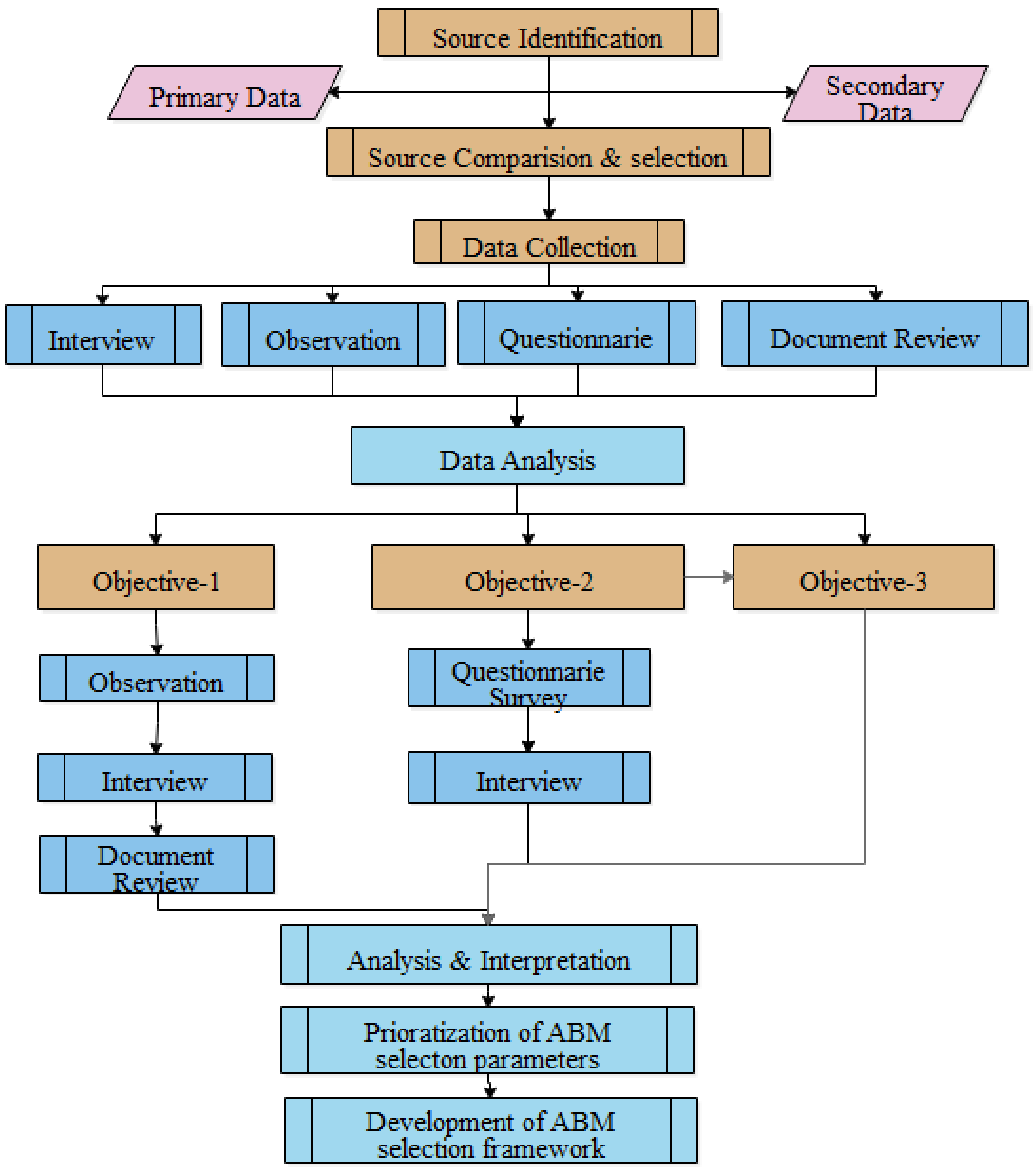

Figure 3. 1: The research design framework

3.2. Data collection methods and tools

In this research, both primary and secondary data were used in an attempt to solve the problems and address its objectives. The primary data were sourced from various individuals, professionals and organizations. Observations, semi-structured interviews and questionnaire surveys are sources of primary data and exploratory document review is used as a secondary data. Data collecting and gathering adequate information related to the essential factors or variables that will influence decisions of material selection process is performed. This is achieved by conducting both quantitative and qualitative methods of survey with qualified construction experts using semi-structured questionnaire and interviews.

3.2.1. Interview

In developing the conceptual framework, the knowledge of domain experts is captured through semi-structured interviews. A semi-structured interview is one in which the interviewer only asks a few predetermined questions and the rest of the questions are not planned in advance. Interview method is adopted for the research in order to get professionals and individuals perception and lived experience towards the usage of different construction materials in the construction industry. This includes representatives form contractors, consultants and real estate developers. Generally, the interview data collection system is used to answer the first and second of the objectives in this research. Which are answering the current trends in the Ethiopian construction industry in using ABMs; and helps to identify and prioritize the key local parameters that helps in selecting among alternative wall making materials.

3.2.2. Document analysis

Document analysis helps in understanding the current usage of ABM in the Ethiopian construction industry which is the first objective of the study. Materials which are widely being used in the country and opportunities and barriers in using ABMs could be reviewed from different articles or journal papers. Additionally, a wide range of useful parameters were reviewed from document analysis that should be considered in choosing among building construction materials.

3.2.3. Questionnaire survey

The research used a questionnaire survey mainly to prioritize the parameters that influence the decision-making process to choose ABMs. The survey tool is designed comprising questions based on the background analysis and literature review. Questions are prepared in the questionnaire with different options to be answered which helps in the quantitative analysis. To collect qualitative information and gain in depth and better understanding of knowledge on the subject, participants are provided a blank space to give additional information in the subject matters.

The structure of the questionnaire is divided into three sections, with each section grouping related questions under precise headings. The first section (section A) of the questionnaire require participants' personal details including job title, level of education and their experience in the local construction. These questions ascertain respondents level of experience in the study area. The second section (section B) is focused on assessing current building material usage status. This section provides an opportunity for respondents to give their views for the presented questions on a five-point Likert-scale format from the highest (5 = Strongly Agree (high value answer); to 1 = Strongly Disagree (low value answer)). The final section (section C) is used to rank the important parameters which are common in choosing among wall making materials. In this section 36 important wall making material selection parameters are chosen by the researcher based on literature review & interview responses. Respondents are provided with a 5 point Likert scale format to express the importance of each selection parameter.

3.3. Research Technique

This paper proposes a building material selection framework based on the analytical hierarchy process (AHP) techniques. Assessment criteria are identified based on the need of building stakeholders. A questionnaire survey of building experts is conducted to assess the relative importance of the criteria to aggregate or categorize them into independent assessment factors. The AHP is used to prioritize and assign important weightings for the identified criteria. The proposed framework provides guidance to building designers in selecting sustainable wall building materials.

This material selection model framework needs three decisive data to recommend decisions. It creates a hierarchy using the **goal, decision criteria** and **decision alternatives**, and sorts the various alternatives according to their relative importance. The aim in AHP is to choose the most suitable and important alternative, by making an arrangement from the most important to the least.

3.3.1. Bases for selecting AHP

AHP provides a well-tested multi-attribute decision analysis (MADA) method that allows building analysts to consider multiple, sometimes conflicting attributes of alternatives when making decisions (Saaty T.L, 1994). Since this research is concerned with developing a material selection framework with which has many levels of decisions with complex dimensions, AHP was chosen for the following strengths:

- Ability to assist in the decision-making process when a large number of interrelated and often conflicting factors are present, to enable trade-offs among them;
- Ability to allow for subjective judgment, with intuition playing an important role in deciding on the best alternative;
- Possesses an effective attribute weighting process of pairwise comparisons;
- Ability to incorporate hierarchical descriptions of attributes, which helps to keep the number of pairwise comparisons manageable.
- Its combination of flexibility and ease of use has allowed it to be used in a wide range of practical MADA problems.

3.4. Data Analysis

3.4.1. Questionnaire data analysis

In this research, ordinal scales were used for the level of measurements of the questionnaire survey. Ordinal scale is a ranking or a rating data that normally uses integers in ascending or descending order. The numbers (1,2,3,4,5) are assigned to indicate level of importance. In ascending order number 1 represents lower importance to 5 highly important. The data analysis of the questionnaire survey is done by using SPSS software and the Microsoft excel.

3.4.2. Interview analysis

Interview data analysis is generally performed through the trend analysis system in this research. Trend analysis in interview is performed by collecting information to spot a pattern through frequency data. Thus, it's is used to generalize and present respondent's responses.

3.4.3. Decision Analysis using the Analytical Hierarchy Process (AHP)

Multi-attribute decision analysis (MADA) methods are used in situations where a decision maker must choose or rank a limited number of options based on two or more relevant variables or attributes (Saaty T.L, 1994). AHP is a MADA method that belongs to the "additive weighting methods" category (Saaty T.L, 1994).

With AHP, the score of an alternative is equal to the weighted sum of its preference ratings (cardinal score), where the weights are the important weights associated with each attribute (Chen, et al., 1992). The cardinal scores for each alternative can be used to rank, screen, or select an alternative material/product that best suits a specific spatial function or the entire building. There are five basic AHP elements that are common to all MADA problems, can be identified and presented as follows:

A. Structuring of the Decision Problem into a Hierarchical Model

MADA problems involve analysis of a finite and generally small set of discrete and predetermined alternatives. Decision factors are organized in a hierarchy type structure to decompose the complexity. The highest level of the structure will be occupied by the problem's primary goal (e.g., selecting a set of local/recycled building materials), followed by "sets of factors" organized in several more hierarchy levels (Saaty T.L, 1994). Depending on the nature of the problem, these, in turn, are directly affected by all of the criteria in the set located one level lower (e.g., life cycle cost may be affected by production cost, maintenance cost, transportation cost, replacement cost, and so on). AHP hierarchy level alternatives will be connected to all of the leaf attributes potentially affecting their evaluation.

B. Making pairwise comparisons

It is difficult for decision makers to accurately determine cardinal importance weights for a set of attributes at the same time (Chen, et al., 1992). As the number of attributes increases, better results are obtained when the problem is converted to a series of pairwise comparisons. Once the interrelationships between attributes (decision factors) are mapped by the hierarchy, relative weights of the attributes are determined by comparing them in pairs, separately for each set in the hierarchy. In this case the decision maker expresses his opinion regarding the relative importance with pairwise comparison using nine-point system ranging from 1(the two choice options are equally preferred) to 9 (one choice option is extremely preferred over the other). When two attributes are compared, the following will be determined:

1) which attribute (factor/variable) is more important or has a greater influence on the attribute one level higher in the hierarchy; and
2) The intensity of importance (e.g., weak, strong, absolute).

C. Relative weight calculations

Using the outcome of the pair-wise comparison process, the overall score of the alternatives is obtained by multiplying the local priority vector of the alternatives with respect to each leaf attribute by the inclusive priority vector of that leaf attribute, and summing the products.

D. Aggregation of relative weights

After calculating the relative weights for each set of attributes at each level of the hierarchy and generating the corresponding local priority vectors, the overall score of each alternative factor/variable, which represents the preference of one alternative over another, is obtained.

E. Consistency ratio

The "Consistency Ratio" (CR) is a tool for controlling that pair-wise comparisons are consistent. Because one of the benefits of AHP is its ability to allow subjective judgment, and because intuition plays a big role in deciding which option is best, absolute consistency in the pair-wise comparison procedure shouldn't be expected (Saaty T.L, 1994). “Absolute consistency” means, for example, that if x is two times more important than y, and y is three times more important than z, then x should be six times more important than z.

3.4.4. The functional process of the various stages of the proposed framework

Stage 1: Defining the objective/task: Selecting the Building Element

The process of evaluating and selecting materials usually begins with the definition of the overall goal or task. This stage of the process will begin with the definition of decision objectives, followed by the selection of a preferred building element, which is wall in this study.

Stage 2: Identifying alternatives to be rated

Based on the structure of the decision objectives, the next step is to identify a set of locally sourced or recycled building material alternatives for the selected building element.

Stage 3: Identifying key influential factors/variables

Following the identification of a set of locally sourced or recycled building material alternatives, material selection and evaluation factors or variables will be defined in this stage.

Stage 4: Assessing impact of the material/product

Using the Analytical Hierarchy Process (AHP) or technique, this stage will involve detailed analysis of each selected factor or variable in order to determine and assign the performance preference or rating score/scale of each criterion in relation to the material/product impact(s). Material alternatives will be compared in this section based on a set of criteria or factors. It will involve expressing the impacts in a spreadsheet against criteria (Chen, et al., 1992).

Stage 5: Estimating weights: Assigning Relative Weights

Some materials/products are likely to be more important than others in any given list. Priorities are set and weights assigned to each factor, variable, or criterion, reflecting each criterion's priority. It will assess the relative importance of each factor/variable for a particular material option. The second objective of this research will produce data to identify relative weights of material selection parameters.

Stage 6: Ranking the Materials/Products Based on Score Weights of Factors

In this stage, each material alternative is ranked based on the importance given to the material selection parameters set by the user (designer) and the overall weights assigned to each factor. It determines the relevant applicable factor/variables and alternative material options as a hierarchy of objectives.

Stage 7: Selecting the Most Suitable Alternative of Material/Product

In this stage results of the evaluation process in the form of graphs, quantitative and descriptive reports that show variance in material suitability in relation to the relevant variables/factors are obtained. After that, the preferred material/product is determined.

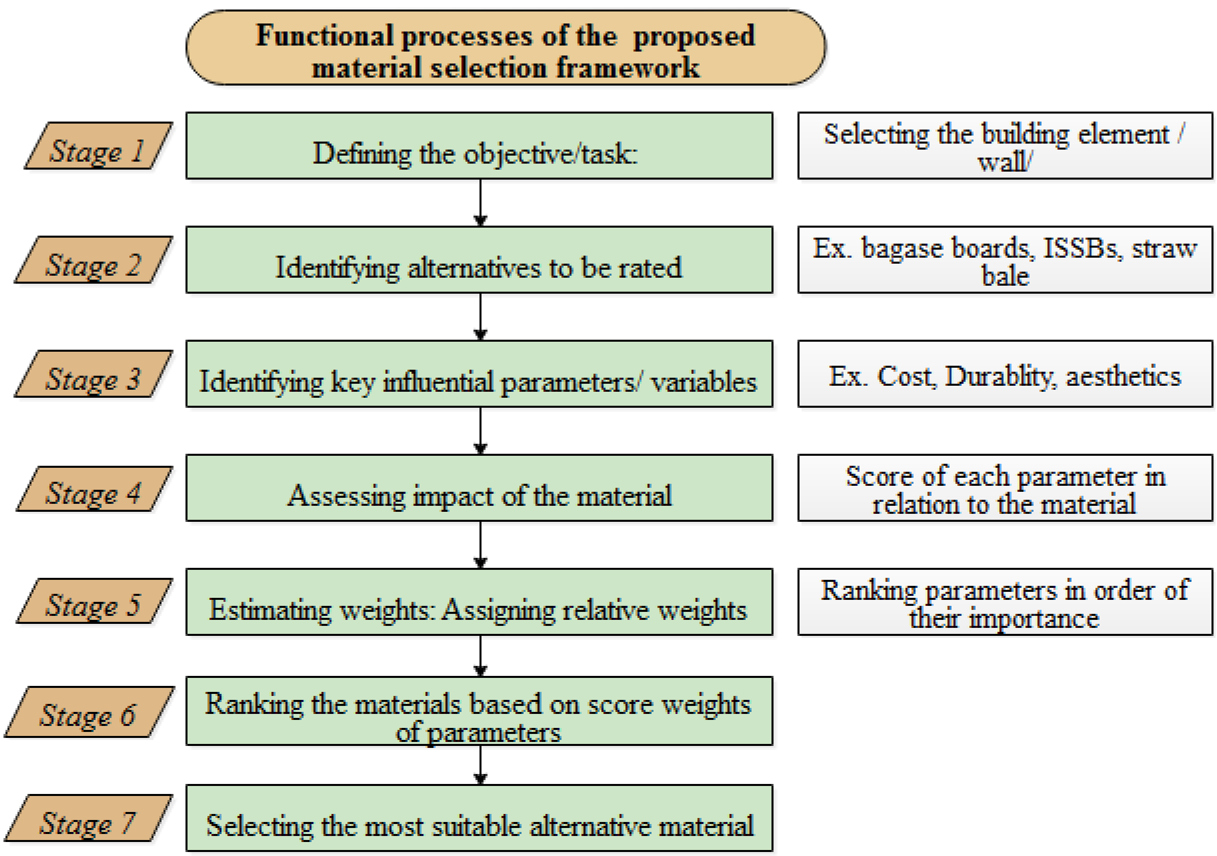

Figure 3. 2: The functional process of the material selection framework

3.5. Sample size determination

The collection of data representative of a population is a typical goal of survey research. Within the bounds of random error, the researcher applies survey data to generalize findings from a drawn sample to the entire population. "One of the real advantages of quantitative methods is their ability to use smaller groups of people to make inferences about larger groups that would be prohibitively expensive to study" (Holton & Burnett, 1997).

The question then becomes how big of a sample is needed to generalize research findings to a population. Several statistical equations are available for determining sample size. There are numerous approaches, incorporating a number of different formulas, for calculating the
sample size for continuous and categorical data. According to Cochran for continuous (or quantitative) data, survey sample size is obtained from the following equation (Bartlett, et al., 2001).

$$n = \frac{t^2 * s^2}{d^2}$$

Where

t = is the value corresponding to level of confidence required (the alpha level).

s = estimate of standard deviation in the population

d = acceptable margin of error for mean (number of points on primary scale*acceptable margin of error).

- **Alpha level (t-value):** In Cochran's formula, the alpha level is incorporated in to the formula by utilizing the t-value for the alpha level selected. E.g. t-value for alpha level of 0.1 is 1.645, for 0.05 is 1.96 and for 0.01 is 2.576. It implies the level of confidence that the results revealed by the survey findings are accurate. In general, an alpha level of 0.05 is acceptable for most research. An alpha level of 0.1 or lower may be used if the researcher is more interested in identifying marginal relationships and differences of other statistical phenomena (Holton & Burnett, 1997). Therefore, depending on the research type this research uses an alpha level of 0.1 which means 90% level of confidence.

- **Standard deviation (s):** A researcher typically needs to estimate the variance of variables. To estimate the variance of a scaled variable one must determine the inclusive range of the scale, and then divide by the number of standard deviations that would include all possible values in the range, and then square this number. In this research it is used a five-point Likert scale and have 4 standard deviations (two each side of the mean) the calculation of s would be as follows

$$s = \frac{5(\text{number of points on the scale})}{4(\text{number of standard deviations})} = 1.25$$

- **Acceptable Margin of Error:** For educational and social research a marginal error 5% is acceptable. Researchers may increase these values when a higher margin of error is acceptable or may decrease these values when a higher degree of precision is needed (Krejcie & Morgan, 1970). For these research 6% margin of error is accepted by the researcher. A 6% margin of error would result in the researcher being confident that the true mean of a five-point scale is within 0.3 (0.06 times 5 points on the scale) of the mean calculated from the research sample.

Finally inserting these results in the Cochran's formula;

$$n = \frac{t^2 * s^2}{d^2} = \frac{1.645^2 * 1.25^2}{(0.06 * 5)^2} = 47$$

Therefore, the number of sample size required for the questionnaire survey of this research is forty-seven.

3.6. Reliability of the research instrument

The quality of a research instrument is primarily concerned with determining if the test creator was correct in expecting a certain set of items to provide interpretable statements regarding individual differences. Cronbach's alpha is a method that determines the average correlation of items in a survey instrument to determine the internal consistency of a research instrument. Cronbach's alpha coefficients vary from 0 to 1, with alpha coefficients greater than 0.70 indicating acceptable reliability (Bonett, 2014).

If there is no connection between test items or if the research used a small number of test items or variables, the Cronbach alpha will produce a lower coefficient or value. Cronbach (1951) defines internal consistency as the proportion of the test variance that can be assigned to a group of items, which is used to calculate the reliability coefficient alpha;

$$\alpha = (\frac{K}{K-1})(1 - \frac{\sum s^2 y}{s^2 x})$$

Where: K is the number of test items

$\sum s^2 y$ is sum of the variance of each item

$s^2 x$ is the variance associated with the observed total scores

A high Cronbach's alpha score indicates that the construct has a higher internal consistency. The greater the linear relationship between the tested variables, the higher the coefficient, and hence the higher the internal consistency. As a result, Cronbach's alpha coefficient is the most generally used objective measure of reliability, and the internal consistency of the data scale (data gathered via questionnaire) was validated using this coefficient before the analysis in this study. If the number of variables to be examined is increased, the Cronbach alpha result will grow as well. A minimal number of things, on the other hand, results in a low alpha value.

3.7. Research Validation

The outcome of the research should be validated by different experts in the sector. This helps to make the research finding reliable. The research followed a sequential data collection system during the research period. By first performing interview data collection together with document review, information was used as an input to develop the questionnaire survey and observation study. The presence of different types of data collection systems in this study helps for the purpose of triangulation. The data from these different sources was checked and triangulated against one another during data collection process. Finally, after the objective of the research were achieved through analysis of data, the findings were commented and suggested by different experts in the sector. This includes experts in contractors, consultants, real estate developers. Generally, their idea and suggestions as well as their comment on the findings were presented jointly with the research findings.

Chapter Four

4. Data Analysis & Discussion

4.1. Introduction

This chapter presents data analysis, and discussion on the findings of the study. After data analysis, a conclusion and recommendation is given based on the findings. The general objective of the study is to develop a framework for the selection of alternative wall making materials. For this purpose, 3 types of data collection systems were used in this research which are the questionnaire survey, interview and observation study. The analysis and discussion of the results of these data collection tools are presented in this chapter as follows.

4.2. Analysis of the questionnaire survey

As described earlier in the previous chapter, the questionnaire survey in this research has two objectives. The first one is to assess existing conditions and current building material selection techniques. The second objective is, using a 5-point Likert scale, ranking the important parameters to choose among wall making alternative building construction materials. These key material selection parameters are identified and categorized by the researcher from cross referencing analysis of literatures (as it is presented in the literature review).

4.2.1. Overall survey response level rate

As presented in the previous chapter, by using the Cochran's formula the total number of sample size required for the questionnaire survey of this research is forty-seven (47). The study should include equal perspective of responses from both consultant and contractor side. Hence the total required amount of 47 questionnaires are distributed to 24 contractors and 23 consultants. Of these distributed 47 questionnaires, 6 of them were not used on the research for not being filled with adequate type professionals. Construction professionals those who can understand the meanings and types of alternative building materials, and have at least 2 years of experience in the industry are valid respondents for the survey. As a result, 41(87.2%) of the questioners were taken as valid in this study. Of 24 questionnaires distributed to contractors 22(91.6%) are valid and from 23 questionnaires distributed to consultant companies, 19(82.6%) of them are valid. Therefore, the number of valid responses that were received can be used for analysis and deduction of meaningful conclusions and recommendations.

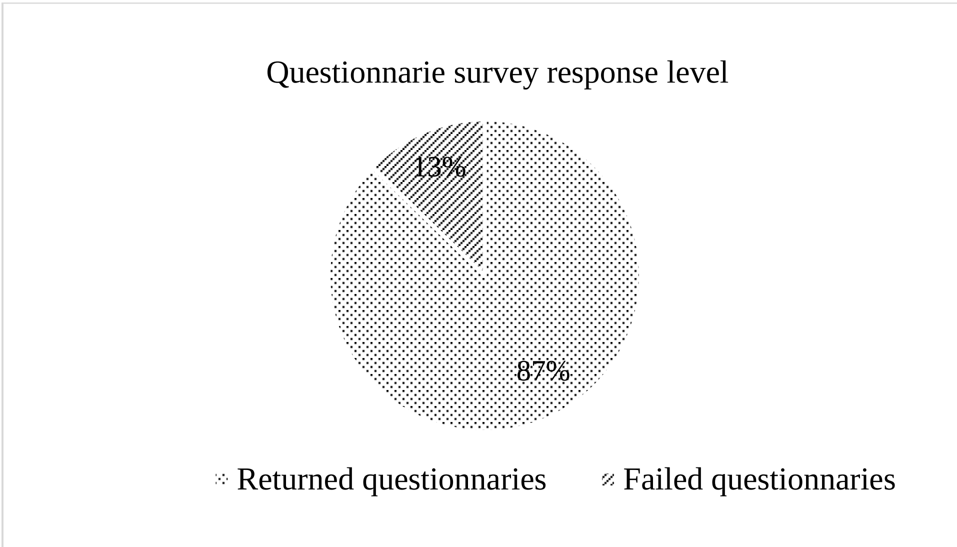

Figure 4. 1: Questionnaire survey response level

4.2.2. Questionnaire data reliability

Cronbach's alpha reliability coefficients were obtained to check internal consistency of the questionnaire data. The general rule of thumb is that a Cronbach's alpha of 0.70 and above is good, 0.80 and above is better and 0.90 and above is best.

This questionnaire data reliability is calculated using the spss software. The analysis result shows k = 42, which are the total amount of questions asked to respondents excluding their personal information. s^2y = 42.42, is the sum of the variance from each survey question. s^2x = 474.93, is the variance associated with the observed total scores. Inserting those values to the Cronbach's equation:

$$\alpha = \left(\frac{K}{K-1}\right)\left(1 - \frac{\sum s^2 y}{s^2 x}\right) = 0.933$$

According to the above calculation, α value is greater than 0.9 which is 0.933. Therefore, depending on the Cronbach alpha rule discussed above, questionnaire items are considered to be consistent and they are best to gather information from the respondents to assess existing conditions and current ABM selection techniques; and to rank important parameters for choosing among wall making ABMs.

4.2.3. Section A: Company and respondent background

This section of the questionnaire is mainly used to collect respondents' information. The response analysis is presented in pie charts as follows.

4.2.3.1. Categories of respondent companies

The types of companies chosen for valid response were 22 contractors and 19 consultants. Out of the 22 contractors, 8 are general contractors and 14 are building contractors as shown in the following figure below.

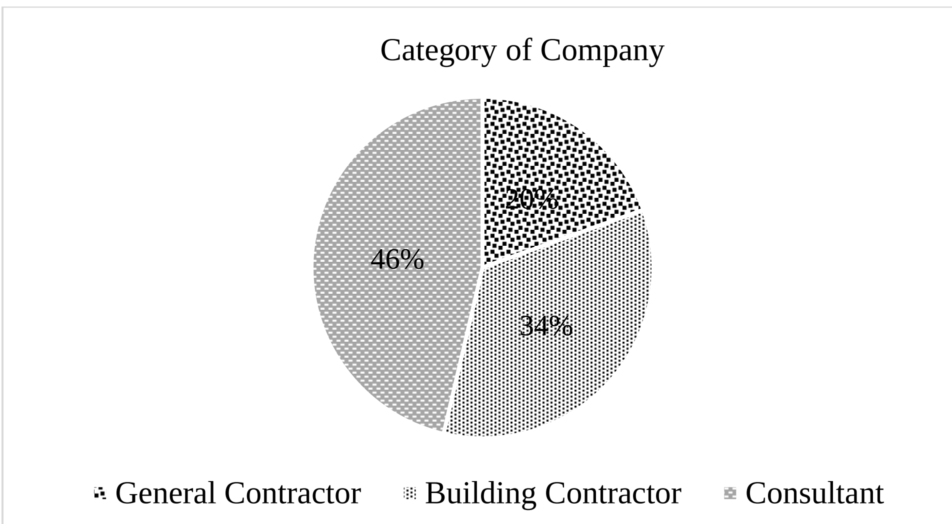

Figure 4. 2: Category of company

4.2.3.2. Grade of Respondent Contractors

In this questionnaire survey research 22 building and general contractors have given a response. The study incorporated contractors from grade 1 to grade 8 and their frequency of response is presented in the following figure.

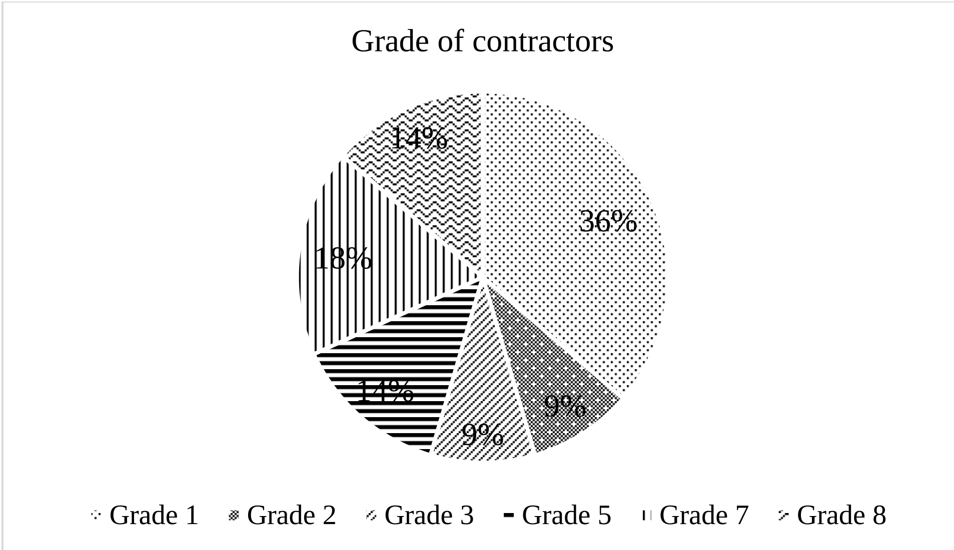

Figure 4. 3: Grade of contractors

4.2.3.3. Grade of Respondent Consultants

In this questionnaire survey 19 consultants have given a valid response. The study incorporated building consultants from grade 1 to grade 5 and their frequency of response is presented in the following figure.

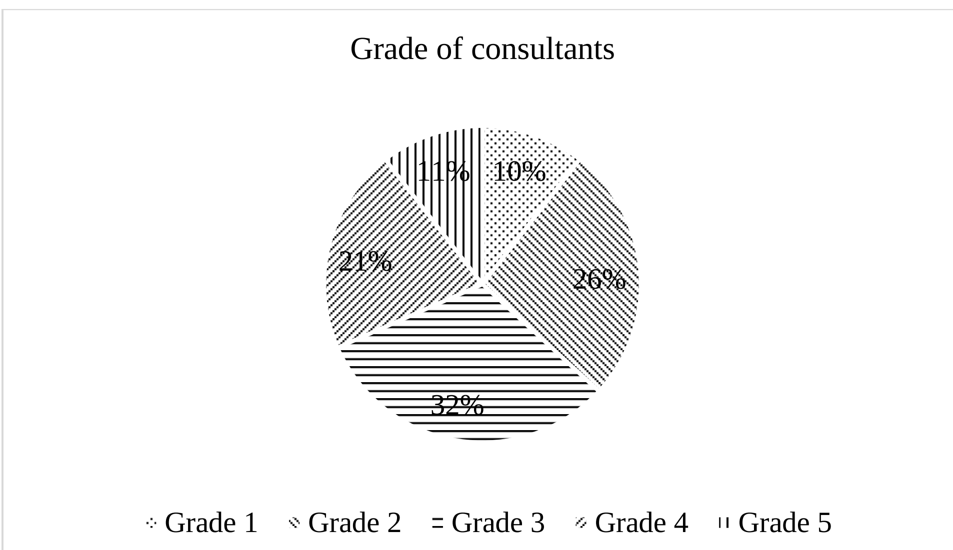

Figure 4. 4: Grade of consultants

4.2.3.4. Position of respondents in their organization/company

Construction professionals included in this study are architects, structural engineer and site/office engineer from consultant companies and project managers & site engineers from contractor companies. In addition, in the 'other' profession section, two positions of 'project engineer' are obtained in the response.

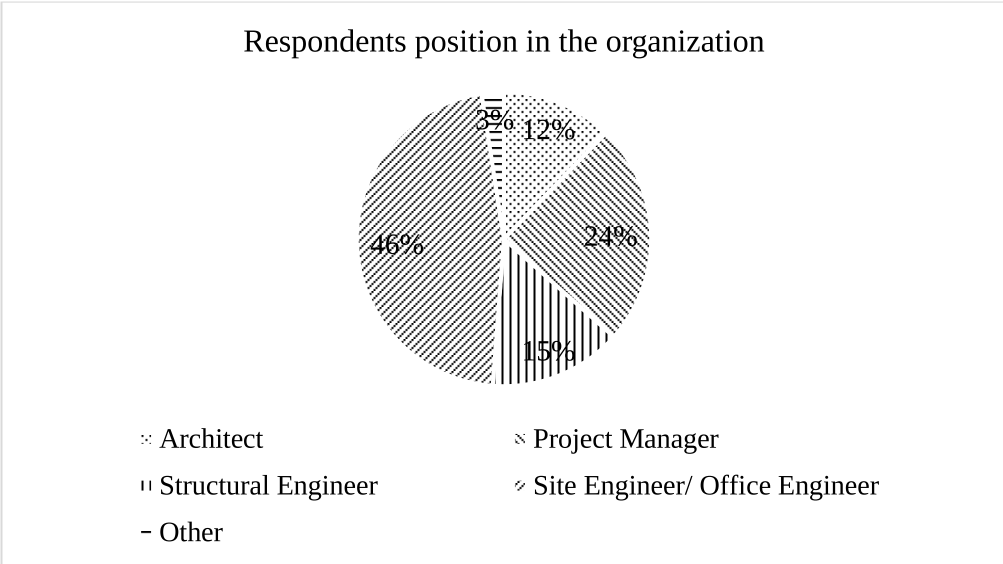

Figure 4. 5: Respondents position in the organization

4.2.3.5. Respondents' education level

The research has limited its respondents as construction professionals those who can understand the use and purpose of alternative construction materials; as presented in the previous chapter. Thus all of the respondent's education level is 1st degree and above.

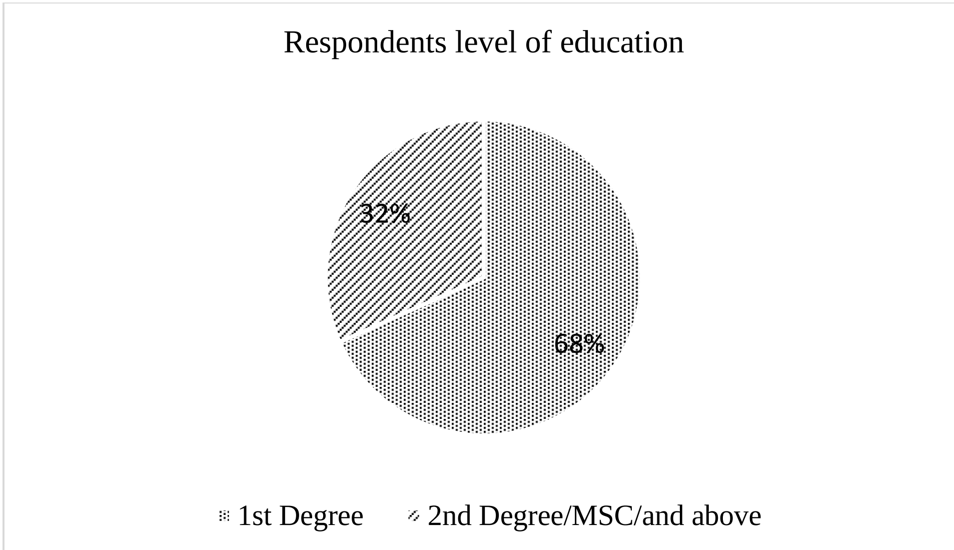

Figure 4. 6: Respondents level of education

4.2.3.6. Respondents total experience in the construction industry

The questionnaire survey requires construction professionals who have been working in the Ethiopian construction industry for at least two years. As a result, respondents experience is presented in the following figure.

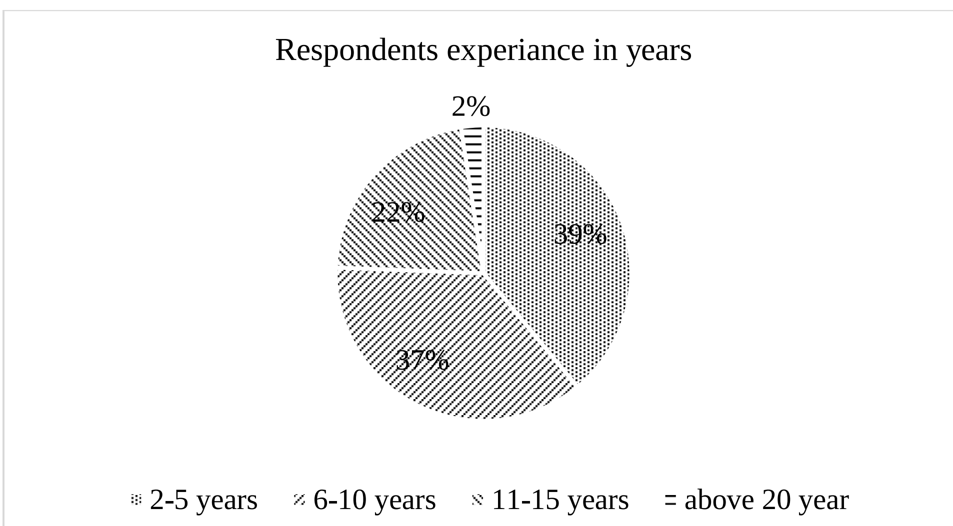

Figure 4. 7: Respondents experience in years

4.2.4. Section B: Assessing existing conditions and current building material selection techniques

This section of the questionnaire gathered information on the current ABMs application practice in the local construction industry. The analysis result is presented as follows.

4.2.4.1. Rating the importance of adoption of alternative wall making materials in the Ethiopian construction industry

This questionnaire analysis presents respondents perception in the importance of adoption of alternative wall making materials in the Ethiopian construction industry. The response analysis shows, most of the Ethiopian construction industry professionals agree in the importance of adoption of ABM for walling. The analysis result generally indicates the adoption of different alternative wall making materials is important in the Ethiopian construction sector.

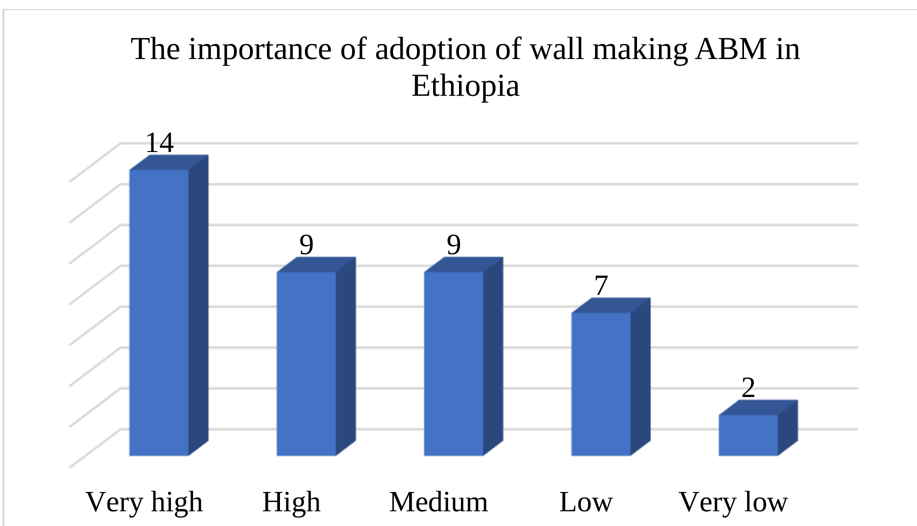

Figure 4. 8: The importance of adoption of wall making ABM in Ethiopia

4.2.4.2. Usage of an existing material selection support system to choose among alternative building material options

Material selection is one of the most important yet challenging task that is faced by construction engineers, because it is directly related to overall project performance. Construction engineers must select the best performing material based on its various properties. Construction material selection should be done in a systematic manner, to evaluate each criterion's impact for deciding the best alternative material under existing conditions.

Respondents were asked to their knowledge about existing material selection support systems. The survey result generally does not show the agreement between professionals regarding to the usage of existing material selection systems. But most of the respondents tend to agree the Ethiopian construction industry rarely uses a material selection support system to choose among alternative construction materials.

Limitations: Half of respondents are contractors who doesn't participate in design directly

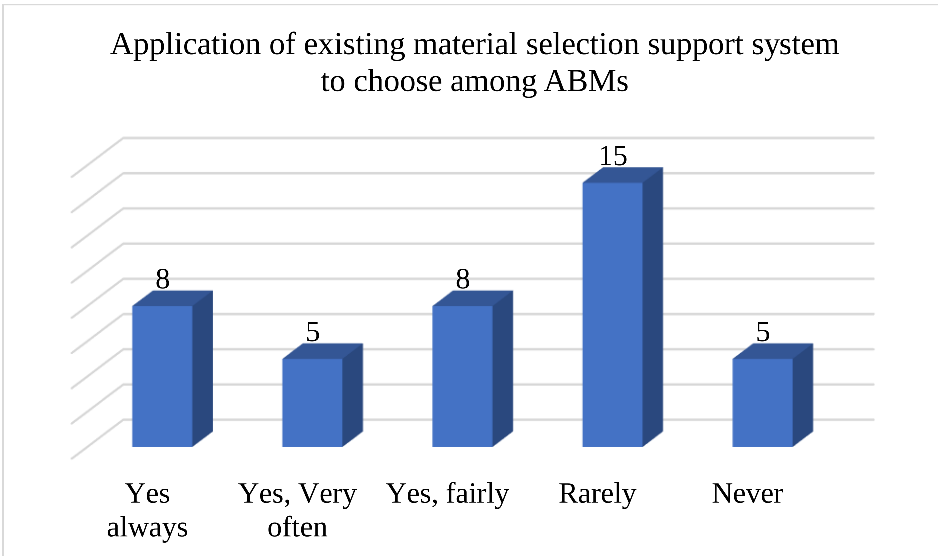

Figure 4. 9: Application of existing material selection support system to choose among ABMs

4.2.4.3. Effectiveness of the current construction material selection system in Ethiopia

For the effectiveness of the existing construction material selection system, most of respondents expressed the current material selection system is to be 'effective'. In the previous survey question analysis result, it tells the usage of material selection support system is low in Ethiopia. But the selection system is said to be effective, this indicates that there are few common types of materials that are available to be used in the construction industry.

Limitations: Half of respondents are contractors who doesn't participate in design directly

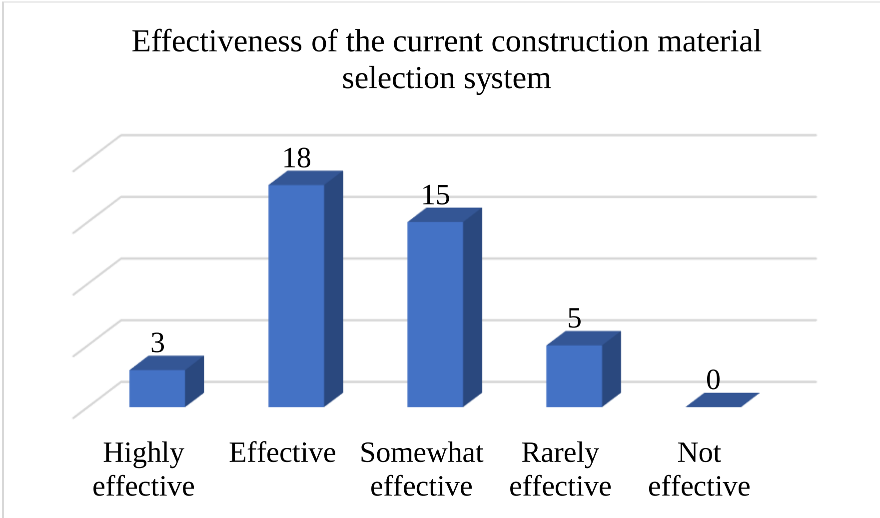

Figure 4. 10: Effectiveness of the current construction material selection system

4.2.4.4. How does the construction firm prefer to select from different material selection procedures?

Regarding to the preference of the construction firm to select from material selection procedures, respondents are given with three guiding choices. 19 of the respondents said material procedures are selected based on from previous experiences, and similarly 19 of the respondents said material selection procedures are chosen based on considering essential factors. The remaining 3 respondents in the other section mentioned materials are approved by the consultant, are chosen by considering material properties and 1 respondent mentioned a combination of these procedures. Limitations: Half of respondents are contractors who doesn't participate in design directly

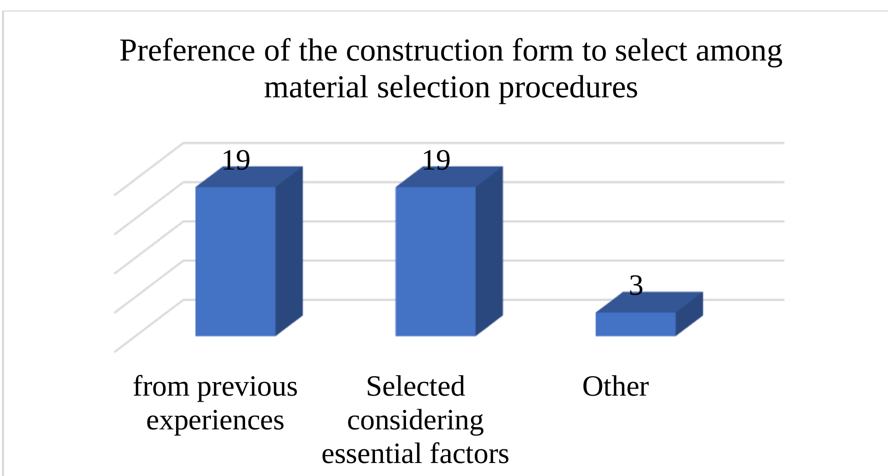

Figure 4. 11: Preference of the construction form to select among material selection procedures

4.2.4.5. Current interest of the industry to likely use local and recycled wall making ABMs in design.

As it is investigated in the literature review, the use of a wide range of local and recycled wall making material in the Ethiopian construction industry is low. But needs will change with time, and usage of local alternative martials is generally appreciated from the concept of sustainability and other essential benefits. The questionnaire survey result shows the likelihood of the current interest of the construction industry to use local and recycled wall making ABMs is said to be 'remotely likely'. This indicates the construction industry has low tendency to use local and recycled materials in the design.

Limitations: Half of respondents are contractors who doesn't participate in design directly

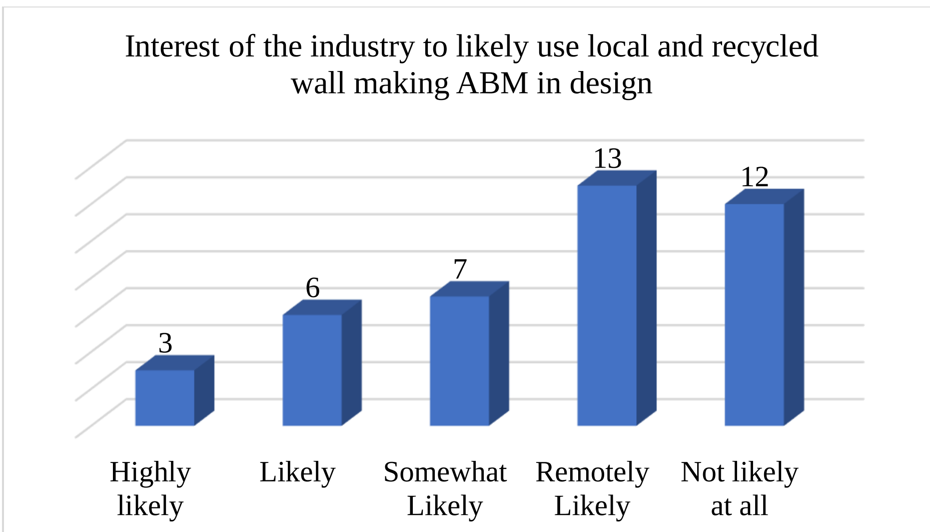

Figure 4. 12: Interest of the industry to likely use local and recycled wall making ABM in design

4.2.4.6. Respondent level of interest to use a framework (tool) that helps choosing among ABMs.

Material selection is a complex task when choosing among large number of available option of materials. As expressed in previous question results, the Ethiopian construction industry chooses among limited number of conventional materials which often makes the selection process easy. When different alternative materials are available, the level of interest of professionals to use a framework (a tool) that helps for choosing among local and recycled alternative wall making materials, according to the questionnaire result is high to medium level.

Limitations: Half of respondents are contractors who doesn't participate in design directly

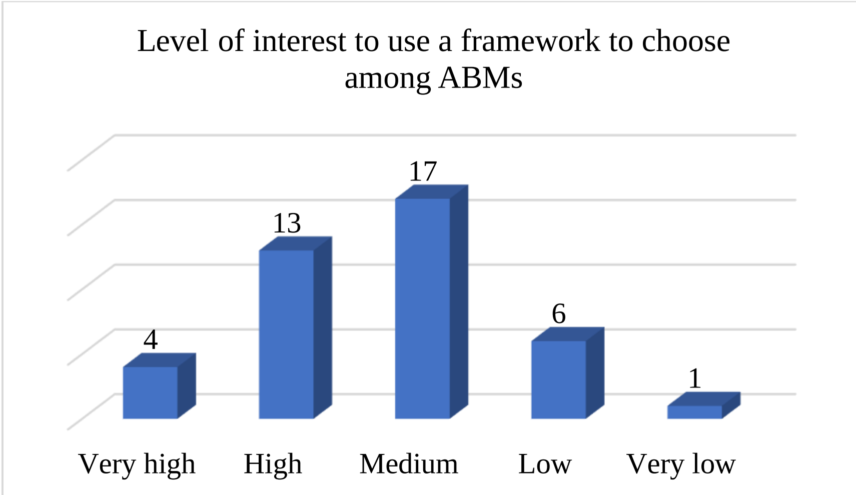

Figure 4. 13: Level of interest to use a framework to choose among ABMs

4.2.5. Section C: Ranking the important parameters to choose among wall making alternative building materials.

The following results are obtained from respondents in ranking of the important parameters that need to be considered in the process of selection among wall making alternative building construction materials. Respondents are asked based on their experience, to rank these key parameters using a 5-point Likert scale score to their importance level, where 1= not important, 2= slightly important, 3= moderately important, 4= important and 5= very important. These selection parameters are presented in to eight categories in the questionnaire survey and the analysis results are presented as follows.

4.2.5.1. General statistical data of section C: ranking important parameters to choose among wall making ABMs

Table 4. 1: Questionnaire descriptive Statistics

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Economic Factors							
Initial investment/Capital cost	41	3	2	5	4.20	0.928	0.861
Saving on construction cost	41	2	3	5	4.34	0.656	0.430
Maintenance costs	41	4	1	5	3.85	1.195	1.428

Transportation costs	41	3	2	5	3.59	0.948	0.899
General/ Site factors							
Location of the site	41	3	2	5	3.73	1.049	1.101
Market availability of materials	41	2	3	5	4.49	0.746	0.556
Experience with the material	41	3	2	5	4.22	0.791	0.626
Building space usage	41	3	2	5	3.66	0.965	0.930
Need for creativity	41	4	1	5	3.78	1.129	1.276
Aesthetics	41	2	3	5	4.46	0.745	0.555
Climatic conditions	41	4	1	5	3.80	1.167	1.361
Social & Cultural Issues							
Compatibility with cultural traditions	41	4	1	5	3.27	1.141	1.301
Cultural implication of materials	41	4	1	5	3.22	1.194	1.426
Owners/Users perspective	41	2	3	5	4.12	0.748	0.560
Job creation	41	3	2	5	3.80	1.077	1.161
Technical Know-how							
Ease of production and installation technology	41	3	2	5	4.37	0.829	.688
Training needs	41	4	1	5	3.51	1.287	1.656
Availability of labor	41	3	2	5	3.61	1.115	1.244
Availability of raw materials	41	2	3	5	4.37	0.733	0.538
Environmental/ Health factors							
Reduction of depletion of natural resources	41	4	1	5	3.78	1.215	1.476
Waste prevention	41	3	2	5	3.66	0.938	0.880
Reduction of pollution	41	4	1	5	3.51	1.381	1.906
Safety and health of user	41	3	2	5	4.22	0.909	0.826
Use of recycled materials	41	4	1	5	3.54	1.142	1.305
Quality Issues							
Durability	41	2	3	5	4.59	0.741	0.549
Structural strength	41	2	3	5	4.22	0.822	0.676
Fire resistance	41	3	2	5	4.12	1.005	1.010
Sound insulation	41	3	2	5	4.07	0.905	0.820
Technical Factors							
Reusability	41	4	1	5	3.29	1.209	1.462
Demolish ability	41	4	1	5	3.17	1.263	1.595
Maintenance level	41	3	2	5	3.85	1.062	1.128
Installation Speed	41	3	2	5	4.24	0.943	0.889
Logistics							
Material handling	41	4	1	5	3.95	1.048	1.098
Transportation mode	41	3	2	5	3.68	0.960	0.922

Hoisting/lifting up on installation requirement	41	3	2	5	4.02	0.790	0.624
Material storage	41	3	2	5	3.66	0.911	0.830

4.2.5.2. Ranking of wall making ABM selection parameters according to questionnaire survey analysis

Table 4. 2:Ranking of ABM selection parameters with respect to their mean score

		N	Minimum	Maximum	Std. Deviation	Mean
1	Durability	41	3	5	0.741	4.59
2	Market availability of materials	41	3	5	0.746	4.49
3	Aesthetics	41	3	5	0.745	4.46
4	Availability of raw materials	41	3	5	0.733	4.37
5	Ease of production and installation technology	41	2	5	0.829	4.37
6	Saving on construction cost	41	3	5	0.656	4.34
7	Installation Speed	41	2	5	0.943	4.24
8	Structural strength	41	3	5	0.822	4.22
9	Experience with the material	41	2	5	0.791	4.22
10	Safety and health of user	41	2	5	0.909	4.22
11	Initial investment/Capital cost	41	2	5	0.928	4.20
12	Fire resistance	41	2	5	1.005	4.12
13	Owners/Users perspective	41	3	5	0.748	4.12
14	Sound insulation	41	2	5	0.905	4.07
15	Hoisting/lifting up on installation requirement	41	2	5	0.790	4.02
16	Material handling	41	1	5	1.048	3.95
17	Maintenance level	41	2	5	1.062	3.85
18	Maintenance costs	41	1	5	1.195	3.85
19	Climatic conditions	41	1	5	1.167	3.80
20	Job creation	41	2	5	1.077	3.80
21	Need for creativity	41	1	5	1.129	3.78
22	Reduction of depletion of natural resources	41	1	5	1.215	3.78
23	Location of the site	41	2	5	1.049	3.73
24	Transportation mode	41	2	5	0.960	3.68
25	Waste prevention	41	2	5	0.938	3.66
26	Material storage	41	2	5	0.911	3.66
27	Building space usage	41	2	5	0.965	3.66

28	Availability of labor	41	2	5	1.115	3.61
29	Transportation costs	41	2	5	0.948	3.59
30	Use of recycled materials	41	1	5	1.142	3.54
31	Reduction of pollution	41	1	5	1.381	3.51
32	Training needs	41	1	5	1.287	3.51
33	Reusability	41	1	5	1.209	3.29
34	Compatibility with cultural traditions	41	1	5	1.141	3.27
35	Cultural implication of materials	41	1	5	1.194	3.22
36	Demolish ability	41	1	5	1.263	3.17
	Valid N (listwise)	41				

4.3. Interview result and analysis

4.3.1. Respondents experience related to usage of wall making ABMs

The first interview question is designed to examine the respondent's experience with regard to the usage of alternative wall making material in the local construction industry. It is found that respondents experience to be not satisfactory associated with alternative wall making materials. And ABMs usage is described as occasional. The result mostly shows, usage of wall making ABMs is limited to internal partitions of a building. Among the materials used by the professionals as an ABM include: agrostone, gypsum block, gypsum board, magnesium board, hydraform, bamboo, adobe, straw bales and rammed earth. The analysis result indicates, of these materials, gypsum block is currently the most selected ABM to divide floors for building partitions and used in real estate internal partitions.

4.3.2. Current usage of wall making ABMs in the Ethiopian construction industry

For the analysis of which materials are being used as an ABM in the Ethiopian industry, it's found low application as in general. Hydraform is used as an ABM being used for fences, usage in some hotels, and storage kind of buildings. Agrostone is widely used alternative material especially in the housing sector, but currently its popularity is decreasing through time. The cause for its less popularity over time needs further investigation with the material, but some respondents raise its because quality issues. Gypsum block is being used as an ABM for internal partitions, and it is more effective where it is not placed in contact with water.

4.3.3. The benefits of adoption and use of several alternative wall making ABMs

The benefits if we adopt the use of several wall making ABMs in the construction industry is investigated. Among the responses cost minimization and benefits on speed of construction are found to be most influential. Locally fabricated, creating jobs, quality, sustainability, lower ways to maintenance, economic advantages, saves energy, easy installation, architectural aesthetics are also the benefits associated with usage of ABMs. Appreciating local materials helps for job creation, and it will become more economical. The usage of ABMs resulting less area than usual block is also a needed advantage. Additionally, among the important points that should be raised are, minimization of shortage of raw materials, when more ABMs are introduced to the construction; abundance of construction materials, use of lightweight materials; total weight of building will decrease since HCB is heavy, and minimizing negative effects from the environment which reduces global warming.

4.3.4. The extent of usage of ABMs

In describing the extent of usage of ABMs in the local construction industry, generally the existing conditions are expressed as very low. Among the common expressions that can describe the existing conditions regarding the usage of ABMs in the local construction, very low, not that much seen enough, not applied to almost all projects, can't find other options to replace current materials, it is so rare, not that great almost zero, in our country it is not adopted and rarely used are the common ways. This shows the extent of the usage of ABMs from the professionals' perspective in the Ethiopian construction.

4.3.5. Factors that are barriers to use alternative materials

For the barriers to use ABMs in the Ethiopian construction industry, the analysis result found key points of knowledge issues and availability of the materials. Among the general reasons of barriers to use ABMs, shortage of production of ABM materials in the local condition, lack of awareness, not easily available to get these materials everywhere, availability of technology, building owner or end user negative perspective, lack of skilled labor and proper training, and negative perceptions in the industry are the common. The need of promotion by stakeholders to act towards usage of ABMs is generally found to be important.

4.3.6. What to improve in policies and methods to motivate the use of ABMs

To mitigate and overcome the above stated barriers, the analysis result found the following points related to improving the usage of ABMs. The most important points are presented as follows.

- Related to work of the government leaders: The need to be taken seriously by gov't is found to be important. As an example, agrostone has become popular in the housing sector with government related supports. Making policies that appreciate micro and small construction material manufacturing enterprises, helps in both job creation and to appreciate usage of ABMs.
- To motivate and encourage investors to build ABM producing industries locally,
- Introducing cost effective materials to the construction firm is important. With research and study, introducing ABMs that can replace the existing materials which can be produced locally;
- Increase availability of ABMs in the industry, producing local materials in huge amount;
- Produce professionals on this area in both design and production,
- Giving knowledge to construction firms: contractors, consultants etc.
- Train labors skilled and unskilled on these areas
- Use technologies
- Machineries for producing ABMs to be let imported to the country duty free

4.3.7. Influential parameters that should be considered in choosing wall making ABMs

The local influential parameters that should be considered in choosing among ABMs are analyzed. The most influential parameters to select among ABMs are found to be cost, durability, availability and quality. Additional parameters which are important include: aesthetics, sound insulation, cost matching with people income, strength, availability of skilled labor, energy saving and time saving.

It is found that these parameters will be more effective if there are plenty of alternatives available in the market.

4.3.8. Materials which have good potential to be an alternative wall making ABMs

From the interview data collection system, it is investigated that which materials have good potential to be an alternative wall making material. Results generally indicates the need of research in the construction firm to suggest potential materials that meets current needs, locally produced, may be recyclable and reusable and at the same time helping creating job opportunities in the process of production. Although it's agreed there could be different materials to have potential for being alternative, the general conclusion of the analysis suggests the need of research in the area.

4.4. Observation study

Based on information obtained from the interview, the research has performed observation study on the current status of usage of wall making ABMs. The observation study has included both places of manufacture and installation of these materials. These materials are presented as follows.

4.4.1. Gypsum block

Gypsum block is a building material composed of solid gypsum, for building and erecting lightweight fire resistant, non-load bearing internal walls and partition walls. Gypsum block observation was made at its manufacturing place around Lamberet area in Addis Ababa. It is mostly used for internal partitions for hotels, office and real estate. Its price is 250 birr per m^2. This material has become more popular in Addis Ababa since the last 4 years. This material is said to replace agrostone whose usage is decreasing over time because of mentioned low strength and durability. Gypsum blocks are sound proof and fire-resistant internal walls. One of its draw backs is its less ability to resist water.

Figure 4. 14: Gypsum block at manufacturing

During construction it is joined together by itself gypsum. The final surface finish is also a thin gypsum chack. Its produced with length 67cm and height of 50cm. The manufacturing width is in two types, 10cm and 6cm. Its construction is fast, easy to electric conduit installation, and it is durable internal partition material.

Figure 4. 15: Gypsum block construction for office partitions

According to the observation, no machineries are needed for installation and handling the material on the site, it is easy for storage, no special skills are needed for the installation, there are enough available professionals for the installation, the building material fits to the purpose well, it is only used for internal walling, have excellent aesthetic appearance, it needs additional surface finishing including paint, and it contributes to saving construction time when compared to conventional materials.

4.4.2. Hydraform (Interlocking stabilized soil blocks, ISSBs)

An observation study was conducted in the production and construction of hydraform. Selam children's village which is found around Kotebe Hanna Mariyam church is known to manufacture hydraform. Most of the compound's store, office and manufacturing factories are constructed from hydraform.

Figure 4. 16: hydraform buildings

The process of making hydraform is importing proper type of soil from other places, crushing, sieving, mixing with water and cement. The semi wet soil combined with cement is compressed in a compressing mould machine. Then the final product of hydraform block is formed. For seven days it is protected from direct sunlight, and cured for these 7 days. After that it will be ready for the market.

Figure 4. 17: The process of sieving, mixing and machine compression of hydraform

The front size of the product is 25cm*12cm. The width of the hydraform is produced in two different sized molds. The block which is used to construct external wall, has wider with which is 22cm and the 14cm hydraform block is used for internal walling. The 14cm internal walling has internal spacing which allows the entry of cement paste for holding the blocks together. The wider external 22cm block does not use any kind of cement or binder, it connects with each other by interlocking and it maintains its stability by its own heavy weight. The drawbacks of these blocks are its heavy weight. The 22cm width block is said to weigh from 6 to 7kg. When comparing the cost with common HCB, HCB needs 13 blocks to construct $1m^2$, but the hydraforms need 42 blocks. Their price is 11 birr for the internal 14cm width block and 13birr for 22cm width external block. The comparison indicates hydraform has higher cost per m^2, but does not need additional surface finishing's like that of HCB.

Figure 4. 18: Method of construction and storage of hydraform

The analysis result indicates the market need as high, customers buy the product with que at Selam children's village manufacturing site. Among the two hydraform factories in and around Addis Ababa, this factory is the first one and the second is FKT hydraform which is found around Debrezeyt. If the product of this material is high, its usage would be high. It is mostly used in Addis Ababa for external fences, hotels, manufacturing and stores, etc.

According to the observation study of the hydraform construction, no machineries are used for installation and handling in the site, it's easy for storage but has relatively high weight, needs no special skills for the installation and there are enough professionals for the construction, it is used as both internal and external walling, have good aesthetic appearance, needs no additional surface finishing and it saves construction time.

4.4.3. Gypsum board

Gypsum board is wall building material for partition systems in residential, institutional, office and commercial structures. The construction of gypsum board was observed in Addis around stadium in the maintenance of policy studies institute building. The gypsum board was used for partition of offices. As it is shown in the photos, its constructed on 20 cm high concrete above the ground to increase its strength. A Chinese company at the Dukem industrial park called Youlong is well known for the manufacturing of these gypsum bord which are used in Addis.

Its manufacturing size is 1.2m*2.4m and its price is 600br per piece. Their manufacturing thickness varies from 6.5mm to 12mm. Gypsum boards advantage include lightweight, good strength, fire proofing and sound insulation. It is constructed by nailing or drilling to a wooden frame in both sides.

Figure 4. 19: Gypsum board construction

According to the observation study of the gypsum board construction, no machineries are used for installation and handling in the site, its easy for storage, needs no special skills for the installation and there are enough professionals for the construction, it is used for internal walling, have good aesthetic appearance, needs additional surface finishing and it saves construction time.

4.5. Choosing alternative building materials using the AHP method

As it is proposed on the methodology part of this study, this paper proposes a building material selection model based on analytical hierarchy process (AHP) techniques. Assessment criteria should be identified based on the need of stakeholders of the building. This study has conducted an assessment on the relative importance of the selection parameters. The AHP is used to prioritize materials based on important weightings for the identified selection criteria. The developed material selection method provides guidance to building designers in selecting suitable wall making materials according to the selection parameters they have chosen to compare among the materials.

The proposed material selection framework needs three decisive data to recommend decisions.

1. Decision criteria/ parameters
2. Decision alternatives
3. Properties of the chosen materials in relation to the decision criteria

4.5.1. Development of template to choose among ABMs using the AHP method.

The following series of steps should be followed to choose among given alternative building materials and given material selection criterions.

1. Choose influential material selection criterions for the project (Suppose we have 4 selection criterions S1, S2, S3 and S4).
2. Choose suitable candidate of ABMs that can be used in the project (Suppose if we are choosing among 3 materials A, B and C).
3. Make pairwise comparisons using a ratio scale

A ratio scale is used to compare among ABMs with respect to the chosen material selection criterions. In this stage relative properties of chosen materials should be studied with respect to the selected material selection criterions.

Table 4. 3: ratio scale

Preference level of factors or criteria
9 = extremely preferred, 8 = very strongly to extremely preferred, 7 = very strongly preferred, 6 = strongly to very strongly preferred, 5 = strongly preferred, 4 = moderately preferred, 3 = moderately preferred, 2 = equally to moderately preferred, 1 = equally preferred

A. Pair wise comparisons using selection criteria S1
    - Comparison of material A with respect to Material B (ABS1) & (BAS1)
    - Comparison of material A with respect to Material C (ACS1) & (CAS1)
    - Comparison of material B with respect to Material C (BCS1) & (CBS1)
B. Pair wise comparisons using selection criteria S2
    - Comparison of material A with respect to Material B (ABS2) & (BAS2)
    - Comparison of material A with respect to Material C (ACS2) & (CAS2)
    - Comparison of material B with respect to Material C (BCS2) & (CBS2)
C. Pair wise comparisons using selection criteria S3
    - Comparison of material A with respect to Material B (ABS3) & (BAS3)
    - Comparison of material A with respect to Material C (ACS3) & (CAS3)
    - Comparison of material B with respect to Material C (BCS3) & (CBS3)
D. Pair wise comparisons using selection criteria S4
    - Comparison of material A with respect to Material B (ABS4) & (BAS4)
    - Comparison of material A with respect to Material C (ACS4) & (CAS4)
    - Comparison of material B with respect to Material C (BCS4) & (CBS4)

Build weighted matrix using pairwise comparisons.

Table 4. 4: weighted matrix

Material Alternatives	Criterions											
	S1			S2			S3			S4		
	A	B	C	A	B	C	A	B	C	A	B	C
A	1	ABS1	ACS1	1	ABS2	ACS2	1	ABS3	ACS3	1	ABS4	ACS4
B	BAS1	1	BCS1	BAS2	1	BCS2	BAS3	1	BCS3	BAS4	1	BCS4
C	CAS1	CBS1	1	CAS2	CBS2	1	CAS3	CBS3	1	CAS4	CBS4	1

4. Add up all the values in each column

Table 4. 5: summing up the matrices given criteria and performances

Material Alternatives	Criterions											
	S1			S2			S3			S4		
	A	B	C	A	B	C	A	B	C	A	B	C
A	1	ABS1	ACS1	1	ABS2	ACS2	1	ABS3	ACS3	1	ABS4	ACS4
B	BAS1	1	BCS1	BAS2	1	BCS2	BAS3	1	BCS3	BAS4	1	BCS4
C	CAS1	CBS1	1	CAS2	CBS2	1	CAS3	CBS3	1	CAS4	CBS4	1
Total	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12

T1 = 1 + BAS1 + CAS1

T2 = ABS1 + 1 + CBS1 and it's the same procedure until T12

5. The values in each column are divided by the corresponding column sums. Note that value in each column sums up to 1.

Table 4. 6: dividing to the total sum

Material Alternatives	Criterions											
	S1			S2			S3			S4		
	A	B	C	A	B	C	A	B	C	A	B	C
A	AA1	AB1	AC1	AA2	AB2	AC2	AA3	AB3	AC3	AA4	AB4	AC4
B	BA1	BB1	BC1	BA2	BB2	BC2	BA3	BB3	BC3	BA4	BB4	BC4
C	CA1	CB1	CC1	CA2	CB2	CC2	CA3	CB3	CC3	CA4	CB4	CC4
Total	1	1	1	1	1	1	1	1	1	1	1	1

AA1 = 1/T1

BA1 = BAS1/T1

CA1 = CAS1/T1

AB1 = ABS1/T2 and the same procedure continues to fill the table.

6. Next step is to find the average of each criterion, which is the average of each row

Table 4. 7: results of the average of all the criterions

Material Alternatives	Criteria			
	Cost	Availability	Durability	Aesthetics
A	Avg AS1	Avg AS2	Avg AS3	Avg AS4
B	Avg BS1	Avg BS2	Avg BS3	Avg BS4
C	Avg CS1	Avg CS2	Avg CS3	Avg CS4

Avg AS1 = (AA1 + AB1 + AC1)/3

Avg AS2 = (AA2 + AB2 + AC2)/3, using the same step fill the average rows.

7. Rank the factors or criteria in order of their importance

In this step the preference of each material selection criteria over the other is studied. Using same method used before, their pairwise comparisons should be done.

- Compare preference of S1 with respect to S2 (S12 & S21)
- Compare preference of S1 with respect to S3 (S13 & S31)
- Compare preference of S1 with respect to S4 (S14 & S41)
- Compare preference of S2 with respect to S3 (S23& S32)
- Compare preference of S2 with respect to S4 (S24 & S42)
- Compare preference of S3 with respect to S4 (S34 & S43)

Table 4. 8: ranking criterions in order of their importance

Criteria	S1	S2	S3	S4
S1	1	S12	S13	S14
S2	S21	1	S23	S24
S3	S31	S32	1	S34
S4	S41	S42	S43	1

8. As it is shown in the above procedures, summing up each values in each column and dividing each column by the corresponding column sums, the following table is created.

Table 4. 9: results of new matrices

Criteria	S1	S2	S3	S4	Row Avg
S1	SS11	SS12	SS12	SS14	Avg S1
S2	SS21	SS22	SS23	SS24	Avg S2
S3	SS31	SS32	SS33	SS34	Avg S3
S4	SS41	SS42	SS43	SS44	Avg S4
Total	1.00	1.00	1.00	1.00	1.00

9. The row averages in the above table are the priority or performance vector for the criteria. The ranking of the material selection criterions is done by their average score which will be obtained in the following table.

Table 4. 10: priority or preference vector for the factors or criteria

Criteria	Priority or performance vector
S1	Avg S1
S2	Avg S2
S3	Avg S3
S4	Avg S4

10. The final step is to take the material score matrix and multiply each by their respective priority or preference vectors.

Table 4. 11: final calculations multiplying the criteria matrix by the preference vector

Material Options	S1	S2	S3	S4	Priority Factor
A	Avg AS1	Avg AS2	Avg AS3	Avg AS4	Avg S1
B	Avg BS1	Avg BS2	Avg BS3	Avg BS4	Avg S2
C	Avg CS1	Avg CS2	Avg CS3	Avg CS4	Avg S3
					Avg S4

Material option A score = Avg S1(Avg AS1) + Avg S2(Avg AS2) + Avg S3 (Avg AS3) + Avg S4(Avg AS4)

Material option B score = Avg S1(Avg BS1) + Avg S2(Avg BS2) + Avg S3 (Avg BS3) + Avg S4(Avg BS4)

Material option C score = Avg S1(Avg CS1) + Avg S2(Avg CS2) + Avg S3 (Avg CS3) + Avg S4(Avg CS4)

From the above material score results, the material with the highest score should be chosen.

4.5.2. An illustrative example of analytical hierarchy process (AHP) technique

The following example is used to illustrate the practical application of the material selection framework using AHP. A building designer is selecting a set of locally produced wall making ABMs for internal partition of an office building. There are four criteria chosen to be considered in the decision making, which are:

1. Initial cost
2. Market availability
3. Durability
4. Aesthetics

According to the interview and observation study of this research, three market available wall making materials in Addis Ababa were chosen for this illustrative example. As a result there are three material options to decide from:

1. Gypsum block
2. Magnesium board
3. Agrostone

The designer is provided with relative importance of the parameters from this study and is expected to rank and decide the best option using these criterions. Table 4.39 shows the ratio scale where importance of factors or criteria is selected from 1 to 9.

Table 4. 12: ratio scale

Preference level of factors or criteria
9 = extremely preferred, 8 = very strongly to extremely preferred, 7 = very strongly preferred, 6 = strongly to very strongly preferred, 5 = strongly preferred, 4 = moderately preferred, 3 = moderately preferred, 2 = equally to moderately preferred, 1 = equally preferred

Step 1: Build weighted matrix

The Properties of the chosen materials in relation to the decision criteria is required to make pair wise comparisons between the materials.

A. **Cost pairwise comparisons**

From the market study, agrostone is relatively the cheaper product, next is gypsum block and magnesium board is the costly one. Their preference level in the cost pairwise comparisons is presented as follows.

- Gypsum block is equally to moderately preferred over magnesium board (factor of 2).
- Agrostone is moderately preferred over gypsum block (factor of 3)
- Agrostone is strongly preferred over magnesium board (factor of 5)

B. **Market availability pairwise comparisons**

Market availability study is conducted before deciding the availability level of materials. In the current existing market, gypsum block is more available, next is agrostone and magnesium board is the least available. Their preference level in the market availability pairwise comparisons is presented as follows.

- Gypsum block is strongly preferred over magnesium board (factor of 5)
- Gypsum block is moderately preferred over agrostone (factor of 3)
- Agrostone is moderately preferred over magnesium board (factor of 3)

C. **Durability pairwise comparisons**

The relative durability of the materials is known and obtained from properties of the materials from research and studies. Gypsum block is more durable, next is magnesium block and agrostone is the least durable in comparison.

- Gypsum block is moderately preferred over magnesium board (factor of 3)
- Gypsum block is strongly preferred over agrostione (factor of 5)
- Magnesium board is moderately preferred over agrostone (factor of 3)

D. **Aesthetics pairwise comparisons**

The relative aesthetic appearance of the materials is presented as, gypsum block is more aesthetically appealing, next is magnesium board and agrostone is placed in the third position. Their pairwise comparisons is presented as follows.

- Gypsum block is equally to moderately preferred over magnesium board (factor of 2)
- Gypsum block is moderately preferred over agrostone (factor of 3)

- Magnesium board is equally to moderately preferred over agrostone (factor of 2)

In the next analysis, material A = gypsum block, material B = magnesium board and material C = agrostone.

Table 4. 13: weighted matrix

Material Alternatives	Criteria											
	Cost			Market Availability			Durability			Aesthetics		
	A	B	C	A	B	C	A	B	C	A	B	C
A	1	2	1/3	1	5	3	1	3	5	1	2	3
B	1/2	1	1/5	1/5	1	1/3	1/3	1	3	1/2	1	2
C	3	5	1	1/3	3	1	1/5	1/3	1	1/3	1/2	1

Step 2: sum (add up) all the values in each column as shown in table 4.14

Table 4. 14: summing up the matrices given criteria and performances

Material Alternatives	Criteria											
	Cost			Market Availability			Durability			Aesthetics		
	A	B	C	A	B	C	A	B	C	A	B	C
A	1	2	1/3	1	5	3	1	3	5	1	2	3
B	1/2	1	1/5	1/5	1	1/3	1/3	1	3	1/2	1	2
C	3	5	1	1/3	3	1	1/5	1/3	1	1/3	1/2	1
Total	4.50	8.00	1.53	1.53	9.00	4.33	1.53	4.33	9.00	1.83	3.50	6.00

Step 3: The values in each column are divided by the corresponding column sums as shown in table 4.15. Notice the value in each column sum up to 1.

Table 4. 15: dividing to the column sums

Material Alternatives	Criteria											
	Cost			Market Availability			Durability			Aesthetics		
	A	B	C	A	B	C	A	B	C	A	B	C
A	0.22	0.25	0.22	0.65	0.56	0.69	0.65	0.69	0.56	0.55	0.57	0.50
B	0.11	0.13	0.13	0.13	0.11	0.08	0.22	0.23	0.33	0.27	0.29	0.33
C	0.67	0.63	0.65	0.22	0.33	0.23	0.13	0.08	0.11	0.18	0.14	0.17
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Step 4: Next find the average of each criterion (average of each row)

Table 4. 16: results of finding the average of all the criteria

Material Alternatives	Criteria			
	Cost	Availability	Durability	Aesthetics
A	0.2299	0.6333	0.6333	0.5390
B	0.1222	0.1062	0.2605	0.2973
C	0.6479	0.2605	0.1062	0.1638

Step 5: rank the factors or criteria in order of importance using same method used in table 4.13 (ratio scale)

According to the results on the questionnaire survey of this study, the influential parameters are ranked according to their importance in the process of selection of wall making ABMs. Of these parameters, durability with mean score (4.59) ranked first of the four parameters selected to compare these materials, market availability (4.49) is ranked second, aesthetics with mean (4.46) is ranked third and initial cost of the material with mean score of (4.2) is ranked fourth. This result shows their relative importance in selection of a material. Thus their pairwise comparisons is presented according to their relative rank, and it's presented as follows.

- Durability is moderately to strongly preferred over initial cost (factor of 4)
- Durability is equally to moderately preferred over availability (factor of 2)
- Durability is moderately preferred over aesthetics (factor of 3)
- Availability is moderately preferred over initial cost (factor of 3)
- Availability is equally to moderately preferred over aesthetics (factor of 2)
- Aesthetics is equally to moderately preferred over initial cost (factor of 2)

Table 4. 17: ranking criteria in order of importance

Criteria	Cost	Available	Durability	Aesthetics
Cost	1	1/3	1/4	1/2
Availability	3	1	1/2	2
Durability	4	2	1	3
Aesthetics	2	1/2	1/3	1

Step 6 – 9: repeat steps 2 to 4 with the new matrices to arrive at the following results as shown in table 4.18.

Table 4. 18: results of new matrices

Criteria	Cost	Available	Durability	Aesthetics	Row Avg
Cost	0.1000	0.0870	0.1200	0.0769	0.0960
Availability	0.3000	0.2609	0.2400	0.3077	0.2771
Durability	0.4000	0.5217	0.4800	0.4615	0.4658
Aesthetics	0.2000	0.1304	0.1600	0.1538	0.1611
Total	1.00	1.00	1.00	1.00	1.00

Step 10: Row average = priority or performance vector for the criteria. The proposed method ranks candidate materials using multiple criteria, allowing decision makers to easily include their preferences.

Table 4. 19: priority or preference vector for the factors or criteria

Criteria	Priority or performance vector
Cost	0.0960
Availability	0.2771
Durability	0.4658
Aesthetics	0.1611

From the above table it shows that the durability ranks topmost, followed by availability, then aesthetics and initial cost.

Final step: Take the material score matrix and multiply each by their respective priority or preference vectors.

Table 4. 20: final calculations multiplying the criteria matrix by the preference vector

Material Options	Cost	Location	Durability	Aesthetics	Priority Factor
A	0.2299	0.6333	0.6333	0.5390	**x0.0960**
B	0.1222	0.1062	0.2605	0.2973	**x0.2771**
C	0.6479	0.2605	0.1062	0.1638	**x0.4658**
					x0.1611

Material option A score = 0.0960(0.2299) + 0.2771(0.6333) + 0.4658(0.6333) + 0.1611(0.5390) = **0.5794**

Material option B score = 0.0960(0.1222) + 0.2771(0.1062) + 0.4658(0.2605) + 0.1611(0.2973) = **0.2104**

Material option C score = 0.0960(0.6479) + 0.2771(0.2605) + 0.4658(0.1062) + 0.1611(0.1638) = **0.2102**

Considering the scores of the material options in table 4.60, material A = gypsum block with a score of 0.5794 should be chosen as the best wall material for the building project given the various factors or criteria.

Chapter Five

Conclusion and Recommendation

5.1. Conclusion

The main objective of this research was to study the most influential parameters related to the selection of wall making alternative building materials. Using these material selection parameters, a wall making ABM selection frame work is developed. Additionally, the study has also investigated the current existing conditions regarding to the use and application of wall making ABMs in design and construction of projects. Therefore, the following major conclusions have been drawn from each research objective.

Through the assessment of the current practice of using alternative wall making construction materials in Ethiopia, the following conclusions are drawn.

- The application of different alternative wall making materials is important in the current Ethiopian construction sector.
- The construction industry rarely uses a material selection support system to choose among alternative construction materials.
- The existing material selection system in the construction sector is said to be 'effective' because there are few common types of materials that are available and being used in design and construction.
- Currently the construction industry has low tendency to use local and recycled building materials in the design because of low availability of these materials.
- When large number of different alternative materials are available, the need to use a material selection framework to choose among ABMs is high.
- The current usage of wall making ABMs is found to be mostly limited to internal partitions of a building. Gypsum block, gypsum board, magnesium board and hydra form are currently being used as an alternative wall making ABMs.
- The benefits of adoption and use of several alternative wall making ABMs in the construction industry are: creating jobs, sustainability, economic advantages, abundance of construction materials, cost competency and use of lightweight materials.

- The extent of usage and acceptance of alternative building materials is low in the construction sector.
- Factors that are barriers to use ABMs in the construction sector are: lack of awareness of stakeholders, lack of availability, availability of technology, building owner or end user negative perspective, lack of skilled labor and proper training.
- The construction sector needs to improve in policies and methods to motivate the use of ABMs. The awareness on the importance and usage of ABMs should be well addressed to the stakeholders for those who play important role on the construction sector.
- Availability of cost effective and durable wall making ABMs which can be supported with research and study, and with governmental support, can change the current low usage status of alternative materials in the construction sector.

The identification of parameters that need to be considered in selecting alternative wall making materials in the Ethiopian construction industry, has drawn the following conclusion.

- Among the influential factors/ parameters that need to be considered during selection of wall making ABMs, the study has investigated the most influential parameters. Durability, market availability of materials, aesthetics, availability of raw materials, ease of production and installation technology, savings on construction cost, installation speed, structural strength, experience with the material, safety and health of user, initial investment/ capital cost and fire resistance are found to be the more influential parameters in the selection of wall making ABMs.

5.2. Recommendations

Based on the research results and findings it is recommended that if the following measures are taken, it will improve the application of alternative wall making materials on the Ethiopian construction sector.

- For creating awareness among stakeholders the following points are recommended:
    - It is recommended that in their study and research, universities and technical schools focus more on creating and studying alternative wall making material & technologies that are applicable for the Ethiopian construction industry.
    - It is recommended that introducing alternative building materials in the curriculum of universities and technical schools. It will encourage students to come up with research and ideas that can result in creating competent and well-studied materials that can be feasible for the Ethiopian construction sector.
    - It is recommended to give technical and knowledge support for major stakeholders and suppliers on the construction sector. This is achieved through governmental support through policies and methods.
- Researches should be carried out based on the most influential parameters to produce well competent alternative wall making material to fully or partially replace conventional materials.
- It is recommended that government policies should be developed to support the application of wall making ABMs and direction should be given to ensure quality and application of ABMs. The developed policy should also include financial support for parties willing to introduce and produce wall making ABMs.
- It is recommended a governmental support in technology introduction, knowledge and promotion in introducing new cost efficient wall making materials.
- The potential of raw material availability in Ethiopia to produce wall making ABMs should be studied to promote local and recycled materials.
- It is recommended to encourage the existing wall making ABMs. Government policies to encourage the usage of currently market available ABMs improves stakeholders' awareness.

Recommendation for future studies

The research results have identified areas that require further research efforts. The following points discuss suggestions.

1. A study of materials that have a potential to be alternative wall making materials in Ethiopia.
2. The effectiveness of agrostone application on the Addis Ababa housing sector.
3. A study of raw materials availability for production of alternative wall making materials in Ethiopia.

References

Abeysundara, Babel, S. & Gheewala, S., 2009. A matrix in life-cycle perspective for selecting sustainable materials for buildings in Sri Lanka. 44(Build. Environ), pp. 997-1004.

Adedeji, A., 2002. Thermal effects on the bearing capacity of earth wall in optimal design. *Association for the advancement of modeling and simulation techniques in enterprises(AMSE),* Volume 71, pp. 17-28.

Adedeji, A. A., Jimoh, A. & Jimoh, B., 2011. Construction procedure of a straw bale walled building - A rewew. *International journal of Engineering,* pp. 255-261.

Aghazadeh, E. & Hassan, Y., 2019. Materials selection in the construction projects: challengs, criteria and patterns. *International journal of advances in mechanical and civil engineering,* 6(1), pp. 42-48.

Aineias, O., Flora, B. & Panagiotis, G., 2017. The course of building materials in historic buildings creation to reuse. Issue Conference paper.

Akadiri, P. O., Olomolaiye, P. O. & Chinyio, E. A., 2013. Multi-criteria evaluation model for the selection of sustainable materials for building projects. *Automation in Construction.*

Ariani Mandala, 2019. The improvements of building materials innovation: A review of the future architecture concept.

Bartlett, Kotrlik, J. W. & Hoggins, C. C., 2001. Organizational Research: Determining Appropriate Sample Size in Survey Research. *Learning and performance journal,* Volume 19, pp. 43-50.

Bihon, A. K., 2012. Housing for the poor in Addis Ababa.

Bonett, D. G., 2014. Cronbach's alpha reliability: Interval estimation, hypothesis testing, and size planning. *Journal of organizational behaviour.*

Cagan, J. & Vogel, C., 2002. Creating Breakthrough Products. *Prentice hall PTR: Upper saddle river, NJ, USA.*

Calkins, M., 2009. Materials for sustainable sites. *A complete guide to the evaluation, selection and use of sustaibable construction materials.*

Chen, S.-J., Hwang, C.-L. & Making, M. A. D., 1992. Multiple Attribute Decision Making.

Chueh, T. & Kao, D., 2004. The moderating effects of consumer perception to the impacts of country-of-design on perceived quality. pp. 70-74.

Dongmin Lee, et al., 2020. Analytic hierarchy process-based construction material selection for performance improvement of building construction: The case of a concrete system form.

Dr. Jayeshkumar, P., Krunalkumar, B. & Hardik, B., 2016. A critical review on non-load bearing wall based on different materials. *International journal of constructive research in civil Engineering*, II(4), pp. 33-40.

Edna, W. O., 2017. Acceptance criteria of alternative building materials and technologies for walling.

Farahzadi, L., 2014. Designing a condominium in Tehran which ecological perispective by using eco-friendly materials. *Science and research of Islamic Azad University,* Issue MA Thesis.

Fernandez, J., 2006. Material Architecture: Emergent Materials for Innovative Buildings and Ecological Construction. *Architectural Press,* Issue Material Architecture.

Flórez, L., Castro-Lacouture, D., Sefair, J. & Medaglia, A., 2009. Optimization model for the selection of materials using the LEED green building rating system. pp. 44, 1162-1170.

Gbadebo, M. A., 2014. Promoting the use of alternative building technologies in Nigerian construction industry: the problems and recommendations.

Hema, C., 2012. Green techniques in building construction. *International journal of biotech trends and technology,* Issue 2, pp. 26-36.

Hjort, B. & Widen, K., 2015. Introduction of sustainable low-cost housing in Ethiopia - an innovation diffusion perspective.

Holton, E. & Burnett, M., 1997. Qualitative research methods. *Human resource development research,* p. 71.

Jadid, M. N. & and Badrah, M. K., 2012. Decision support system approach for construction materials selection. *Proceedings of the 2012 Symposium on Simulation for Architecture and Urban Design, Society for Computer Simulation International.*

Jato-Espino, Diaz-Sarachaga & Castro-Fresno, 2017. Methodology for the development of a new Sustainable Infrastructure Rating System for Developing Countries.

Joseph, P. & Tretsiakova, M. S., 2010. *Sustainable Non-Metallic Building Materials.* s.l.:s.n.

Joseph, P. & Tretsiakova, S., 2010. Sustainable Non-Metallic Building materials. *Sustainablity,* Issue Sustainablity, pp. 401-423.

Kebede, S., 2013. The impact of alternative construction technology on condominium housing project: The case of Addis Ababa.

Kesteren, V., P.J, S. & P.V, K., 2005. Representing product personality in relation to materials in a product design problem. *In proeedings of the 1st Nordic Design Research Conference,* pp. 29-31.

Kibert, C., 2008. Sustainable Construction: Green Building Design and Delivery.

Kohler, N. & Chini, A., 2005. Resource-productive material use. *The 2005 world sustainable building conference, Japan,* Issue sustainable building conference.

Krejcie, R. & Morgan, D., 1970. Determining sample size for research activities. *Educational and psychological measurement,* Volume 30, pp. 607-610.

Larissa, L. et al., 2019. The impact of rapid urbanization and public housing development on urban form and density in Addis Ababa Ethiopia.

Ljungberg, L., 2007. Materials selection and design for development of sustainable products. Volume 28, pp. 466-479.

Luis, M. & Tormenta, P., 1999. High performance building guidelines. *City of New York Department of Design and Construction.*

Madhusudanan, S. & Amirtham, L. R., 2015. Alternative building material using industrial and agricultural wastes. *Key Engineering Materials.*

Martin Nwodo, Chimay J. Anumba & Somayeh Asadi, 2018. Decision support system for building materials selection: current trends and opportunities.

Marut, J. J., Anigbogu, N. A. & Daniel, M. M., 2020. Alternative building materials (ABM): Towards adoption of common terminology and definitions,. *Civil and Envirnmental research,* Volume 12, pp. 16-20.

Meyer, C., 2009. cem, conc, compos.. In: *The greening of the concrete industry.* s.l.:s.n., pp. 601-605.

Micheal, F. A., 1999. *Materials selection in mechanical design second edition.* England: A division of Reed Educational and Professional Publishing Ltd.

Mishra, A. K. & Rai, A. S., 2017. Comparative performance assessment of convntional buildings of Kathmandu. *Comparative performance assessment of eco-friendly buildings and conventional buildings of Kathmandu valley,* Issue international journal of current research, pp. 62959-62965.

Mohammad, S. A., Abdu, l. A. & Mahaboob, P., 2020. Alternativ Buildng Material for Sustainable development in Ethiopian construction,.

Moreal, J., Mesbah, A., Oggero, M. & Walker, P., 2001. Building houses with local materials means to drastically reduce the environmental impact of construction. *Building and Environment,* Issue 36, pp. 1119-1126.

Mustafa Yilmaz & Adem Bkis, 2015. Sustinability in Construction Sector. *World Conference on Technology, Innovation and Entrepreneurship,* Issue Innovation and Entrepreneurship, pp. 2253-2262.

Naoshad, J. & Mustafa, B., 2012. Decision support system approach for construction materials selection. *Proceedings of the 2012 Symposium on simation for architecture and urban design,* Issue conference.

Naoum, 2007. Dissertation research and writing for construction students. Volume 2nd edition.

Ngugi, H. & kalull, J. W., 2017. Use of expanded polystyrene technology and materials recycling for building construction in Kenya. *International journal of technology management.*

O. Canarslan & Elias-Ozkan, S., 2010. A discussion on the selection of sustaibable building materials. pp. 327-333.

Ogunkah, I. & Yang, J., 2012. Investigating Factors Affecting Material Selection: The Impacts on Green Vernacular Building Materials in the Design-Decision Making Process.

Okonomou Aineias, Bougiatioti Flora & Panagiotis, G., September 2017,. The course of building materials in historic buildings creation to reuse.

Opoko, A., 2006. Prospects and challenges of local building materials development and use in Nigeria. *Journal of the Nigerian Institute of Building,* pp. 13-17.

Osso, A., Walsh, T. & Gottfrled, D., 1996. Sustainable building technical manual.

Otiki, O., 2004. Fire resistance of finishes in straw bale wall using cement plaster as case study. *Project report,* pp. 30-33.

Patel, K. V. & Vyas, C. M., 2011. Construction materials management on project sites. *National Conference on Recent Trends in Engineering & Technology.*

Pearce, R., 1998. Sustaibanle Building Materials. *A Primer.*

Peter, O. A., Ezekiel, A. C. & Paul, O. O., 2012. Design of A Sustainable Building: A conceptual framework for implementing sustainability in the building sector.

Platts, B., 1997. Pilot study of moisture control in stuccoed straw bale walls. *Report to Canada mortgage and housing cooperation.*

Pulselli, R., Simonchini, E., Ridolfi, R. & Bastianoni, S., 2008. An energy based appraisal of building materials and their transport. In: *Specific emergy of cement and concrete.* s.l.:Ecol. Indic, pp. 647-656.

Qian, W. & Cong, Z., 2018. Fire saftey analysis of building partition wall engineering. *8th international conference on fire science and fire protection engineering,* pp. 747-754.

Rahman, S., Perera, S. & Odeyinka, H., 2008. A Conceptual Knowledge-based Cost Model for Optimizing the Selection of Materials and Technology for Building Design. *In Proceedings of the 24th Annual ARCOM Conference,* pp. 217-225.

Saaty T.L, 1980. The Analytic Hierarchy Process. *McGraw-Hill:*.

Saaty T.L, 1994. Decision Making in Economic, Political, Social, and Technological Environments with the Analytic Hierarchy Process.

Sazzadur, R., Srinath, P. & Henry Odeyinka, 2018. A conceptual knowledge – based cost model for optimizing materials and technology for building design.

Scheubreina R & Ziontsb S, 2006. problem structuring front end for a multiple criteria decision support system. *Computers and Operations Research.*

Somaieh, H., Redzuan, A. & Abdul Marsono, 2015. Parametric study of concrete load bearing wall with opening based on stress criterion. pp. 119-124.

Stefano Cascone, Renata Rapisarda & Dario Cascone, 2019. Physical Properties of Straw Bals as a Construction Material.

Stulz, R. & Mukerji, K., 1993. Appropriate Building Materials,. In: *A catlogue potential solutions.* 3rd ed. s.l.:Practical action publishing.

Taffese, W. Z. & Abegaz, K. A., 2019. Embodied Energy and CO2 Emissions of Widely Used Building Materials: The Ethiopian Context.

Trusty W.B, 2010. Understanding the Green Building Toolkit: Picking the Right Tool for the Job.. *In Proceedings of the USGBC Greenbuild Conference & Expo.*

Van Kesteren, Stappers, P. & Kandachar, P., 2005. Product Personality in Relation to Materials in a Product Design Problem. *In Proceedings of the 1st Nordic Design research conference.*

Venkta, s. k., 2014. Shear walls a review. *International journal of innovative research in science, engineerin and technology,* 3(II), pp. 9691-9693.

Wastiels, L. & Wouters, I., 2008. Material Considerations in Architectural Design: A Study of the Aspects Identified by Architects for Selecting Materials.. *In Proceedings of the Undisciplined! Design Research Society Conference.*

APPENDICES

Appendices A: Questionnaire Survey

A Questionnaire Survey on: Alternative wall construction materials
Part – I: General Information

A: Objective of this survey
➢ To identify the existing wall construction material selection systems in Ethiopia
➢ To identify and rate the important wall construction material selection factors/ parameters

B: Purpose of this survey
➢ ***Research title:***
➢ The purpose of this survey is to obtain data for the specified research conducted as a partial fulfilment of MSc. Degree in Construction Management at Addis Ababa University, Ethiopian Institute of Architecture, Building Construction and City Development (EiABC).
➢ ***Confidentiality***: All information provided in this survey will be treated with strict confidentiality, and allowed to serve only for the purpose of the research under consideration.

C. Feedback and Results
➢ Interested participants of this study will be given feedback on the overall research results after the completion of the research work.
➢ Your cooperation and prompt response is highly essential to address the research objectives
➢ For any further information, you are kindly requested to contact the researcher on Tel. +251-9-20-73-03-32 (Behailu Workneh) & email address: behailu15@gmail.com
With best regards!

Part – II: Questionnaires

Response Information	
Name of Respondent (Optional):	
Date:	
Name of company/organization:	

Important Definitions

- *General definition of Alternative building materials (ABMs) is building materials that are an alternative to conventional building materials in the form of total or partial substitution of the materials for the purpose of reducing the cost, addressing environmental issues or dealing with lack of conventional materials.*
- *Alternative construction material selection framework is a tool that guides designers to select among available material options*

Section A: Company and respondent background

- *Please thick ✓ on the box which contains your answer*

1 Category of your company

a) General contractor ☐ b) Building contractor ☐ C) Consultant ☐

2 For construction companies, grade level of your company

a) Grade 1 ☐ b) Grade 2 ☐ c) Grade 3 ☐ d) Grade 4 ☐

e) Grade 5 ☐ f) Grade 6 ☐ g) Grade 7 ☐ h) Grade 8 ☐

3 For consultants, specify your grade/category of your company

____

4 Mark your position in the organization /company

a) Architect ☐ c) Structural engineer ☐

b) Project Manager ☐ d) Site Engineer/office Engineer ☐

e) other (specify) ______________________________

5 What is your level of education?

a) Basic ☐ b) TVET/ Diploma ☐

c) 1st Degree ☐ d) 2nd Degree/MSC/and above ☐

6 Total experience you have been working in construction industry

a) 2-5 years ☐ b) 6-10 years ☐ c) 11-15years ☐

d) 16-20years ☐ e) above 20 year ☐

Section B: Assessing existing conditions and current building material selection techniques

- *Please thick ✓ on the box which contains your answer*

1 How do you rate the importance of adoption of alternative wall making materials in the Ethiopian construction industry?

A. Very High ☐ B. High ☐ C. Medium ☐ D. Low ☐ E. Very Low ☐

2 Does the construction industry use an existing material selection support system to choose among alternative building material options?

A. Yes always ☐ B. Yes, very often ☐ C. Yes, fairly ☐ D. Rarely ☐ E. Never ☐

3 Is the current construction material selection system effective?

A. Highly effective ☐ B. Effective ☐ C. Somewhat effective ☐

D. Rarely effective ☐ E. Not effective at all ☐

Other ____

4 How do the construction firm prefer to select from different material selection procedures?

A. Materials are selected based on individual preferences ☐

B. Very often from previous experiences ☐

C. Materials are selected considering essential factors ☐

Other ____

5 What is the current interest of the industry to likely use local and recycled wall making alternative materials in the design?

A. Highly likely ☐ B. Likely ☐ C. Somewhat likely ☐

D. Remotely likely ☐ E. Not likely at all ☐

6 What is your level of interest to use a framework (a tool) that helps for choosing among local and recycled alternative wall making materials?

A. Very High ☐ B. High ☐ C. Medium ☐ D. Low ☐ E. Very Low ☐

Section C: Ranking the important parameters to choose among wall making ABMs
➢ Based on your experience, rank these key parameters that need to be considered in selection of alternative building materials for walling. Give your opinion using a 5 – point Likert scale score to their importance level, where: ***1= Not important, 2= Slightly important, 3= Moderately important, 4= Important, 5= Very important.***

	Important factors/ Parameters	Please thick ✓ on the box				
		1	**2**	**3**	**4**	**5**
1	**Economic factors**					
1.1	Initial investment/Capital cost					
1.2	Savings on construction cost					
1.3	Maintenance costs					
1.4	Transportation costs					
2	**General/ Site factors**					
2.1	Location of the site					
2.2	Availability of materials					
2.3	Experience with the material					
2.4	Building space usage					
2.5	Need for creativity					
2.6	Aesthetics					
2.7	Climatic conditions					
3	**Social & Cultural Issues**					
3.1	Compatibility with cultural traditions					
3.2	Cultural implication of materials					
3.3	Owners/users perspective					
3.4	Job creation					
4	**Technical know-how**					
4.1	Ease of production and installation technology					
4.2	Training needs					
4.3	Availability of labor					
4.4	Availability of raw materials					
5	**Environmental/ Health factors**					
5.1	Reduction of depletion of natural resources					
5.2	Waste prevention					
5.3	Reduction of pollution					
5.4	Safety and health of user					
5.5	Use of recycled materials					

6	**Quality Issues**					
6.1	Durability					
6.2	Structural strength					
6.3	Fire resistance					
6.4	Sound insulation					
7	**Technical Factors**					
7.1	Reusability					
7.2	Demolish ability					
7.3	Maintenance level					
7.4	Installation speed					
8	**Logistics**					
8.1	Material handling					
8.2	Transportation mode					
8.3	Hoisting/lifting up on installation requirement					
8.4	Material storage					

Appendices B: Interview Questions

Interview Questions

Respondent Information	
Respondent company type:	
Position in the company:	
Name of company/organization:	
Date:	

1 Express your experience in the usage of alternative wall making material in the local construction industry, which materials you have used before?

2 From your experience which materials are being used as an alternative wall making materials in the Ethiopian construction industry?

3 What are the benefits if we adopt the use of several alternative wall making materials in the construction?

4 How do you describe the extent of usage of ABM in local construction industry?

5 Which factors are the barriers to use alternative materials in the Ethiopian construction industry?

6 What could the industry improve in policies and methods to motivate the use of alternative building materials?

7 What are the local influential parameters that should be considered in choosing among alternative building materials in Ethiopia?

8 From your experience which materials have good potential to be an alternative wall making material in Ethiopian construction?

Appendices C: Observation Checklist

Observation Checklist

Contractor Details

Company/ Business Name:	
Project site location:	
Project Name:	
Date of audit:	
ABM for walling used:	
Place of manufacturing:	

Criteria: Evidence of using alternative wall making material

	Observation Contents	Observed?	Comments
1	Evidence of using wall making ABM	Yes No	
2	Machineries used for installation	Yes No	
3	Machineries used for handling in the site?	Yes No	
4	Easy for storage	Yes No	
5	Need special skills for the installation	Yes No	
6	Availability of enough professionals for the installation	Yes No	
7	Does ABM fit to the purpose well	Yes No	
8	Does the ABM used for external walling	Yes No	
9	Does the ABM is used for internal walling	Yes No	
10	Have good aesthetic appearance	Yes No	
11	Needs additional surface finishing	Yes No	
12	Saves construction time compared to conventional materials	Yes No	

Appendix D: Publishable manuscript

A Study of Alternative Wall Making Materials Selection Using AHP Method

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ABSTRACT

Material selection is a complex and delicate task determined by the vast number of building material options. Likewise, multiple factors are often considered by the architect or building designer when evaluating the various categories of building materials. As a result, these sets of factors or variables often present trade-offs that further complicate the decision-making process. To ease the material-selection process, this study examines the relevant factors or variables needed to develop a systematic and efficient material-selection system. Through the analysis of frequency data and results of the study, it has identified the potential factors that will impact designers' decisions in their choice of wall making alternative building materials, during the design-decision making process. The application of the criteria for the quantitative evaluation and selection of the best alternative building material, using the Analytic Hierarchy Process model, are discussed. Outcome of the study is to develop a decision support framework to assist designers assess their consequences in terms of whether or not a material option is likely to be best chosen over the existing conditions. The study also assesses the current materials which are being used as a wall making ABMs, the extent of usage and barriers to use ABMs.

Keywords: decision making process; factors or variables; selection criteria; alternative building materials; selection framework; analytical hierarchy process (AHP)

1. Introduction

Material selection is one of the most important and puzzling tasks encountered by construction experts. In the construction materials market, there are different commercially available materials to choose from. The availability of materials in a specific place may differ according to the country, market, and time, so the designer, architect or the material engineer etc should consider the available material candidates first before making a choice. The process is conducted in the order of translating, screening, and rating (Dongmin Lee, et al., 2020).

The most common building materials used in construction are wood, metal, brick, glass, plastic, precast concrete components and concrete. Selecting the right materials for a building is no easy task under any conditions. Just meeting the common criteria, such as cost, performance, and aesthetics, can be a challenge (Micheal, 1999). The most common influential factors that should be considered when choosing among construction materials are: local availability, cost, structural capability, durability and maintenance, handling and storage, climate, skills required for installation, nature of project and its aesthetic appeal (Peter, et al., 2012).

Conventional building materials are those materials that have been traditionally used to make buildings and structures. The term "conventional" is used to describe them because these are the materials that most people use, and have done so for a long time (Joseph & Tretsiakova, 2010). Alternative Building Materials (ABM) have different definitions by different researchers in the construction industry. There are also differences on the definitions of terminologies that are used in describing ABM. An operational definition of Alternative Building Materials could be described as building materials that are an alternative to conventional building materials in the form of total or partial substitution of the materials or its constituents for the purpose of reducing the cost, addressing environmental issues or dealing with lack of conventional materials (Marut, et al., 2020).

The existence and availability of an alternative construction material have several advantages for the construction industry. The cost of building materials and components is known to constitute about 60-70% of the cost of the buildings. This inevitably implies that high cost of building materials will make construction cost equally high (Gbadebo, 2014). With the lack of competitive construction material, when cement production goes down or price suddenly escalates, there could be no alternative solution to execute a project.

Buildings have same common components such as foundation, walls, floors, and roof. Different building components can be made of same or different materials. Wall in a building construction as one of the common building component can be made of wide range of materials. Although the relationship between the volume of a building and its wall area differs as of design, it is an important component of a building that should be researched for greater improvements, which can lead to increased total building construction efficiency.

New materials helped to advance engineering design over time. Today, there are more materials than ever before and the opportunities for innovation are vast. But improvement or progress is possible only if a method exists for making an informed selection. Thus, there should be a systematic method for selecting materials which leads to best matches of existing conditions and the requirements of a design (Micheal, 1999). Making decision which is based on information is a key success factor in any discipline. This is particularly important in an industry such as construction that involves immense information and knowledge management (Jato-Espino, et al., 2017).

The selection of building materials is regarded as a multi-criteria decision-making problem (MCDM). MCDM is also referred to as multiple criteria decision analysis (MCDA) or multi- attribute decision analysis (MADA).

MCDM is the study of methods and procedures concerning about multiple conflicting criteria that can be formally incorporated into the management planning process. It could be categorized into single decision and group decision making problems. In MCDM problems, defining the criteria is an important element of the structuring process (Scheubreina R & Ziontsb S, 2006).

The analytic hierarchy process (AHP) method, conceptualized by (Saaty T.L, 1994), is one of the most popular MCDM methods. The purpose of MCDM is to select the best alternative from a set of competitive alternatives and evaluate it with a set of criteria. The AHP method can be successfully applied to analyze qualitative data quantitatively. It transforms a complex and multi-criteria problem into a structured hierarchy. The AHP requires minimal mathematical calculations and is the only methodology that can consider consistency in decision-making. In addition, it has been applied in construction industry to select suppliers & construction method (Dongmin Lee, et al., 2020).

2. Literature Review

2.1. The need for adoption of ABMs for walling

Worldwide need of ABMs

Currently the need for usage of ABM throughout the world is highly related to sustainability requirements. Buildings are the largest consumers of energy and emitters of greenhouse gases in both developed and developing countries. Buildings alone account for up to 50% of carbon dioxide emissions in continental Europe. As a result, immediate changes are required in the areas of energy saving, emissions control, material production and application, renewable resource use, and building material recycling and reuse. Furthermore, due to growing environmental concerns, the development of new eco-friendly building materials and practices is critical. (Joseph & Tretsiakova, 2010).

The need and extent of ABMs adoption in the Ethiopian construction industry

In Ethiopia, housing inadequacy is largely felt at the level of low and middle income and more so with continuous rise in cost of construction at all levels. This necessitates the use of appropriate and cost effective materials & technologies in house construction. Because the leading type of housing construction system in Ethiopia which is conventional system couldn't be compatible with increasing rate of housing provide and this created a negative impact on housing construction such as long time construction, rising cost material wastage, high embedded energy and so on (Kebede, 2013).

As the study of Shimeles Kebede indicates, introduction and application of alternative construction materials & technology such as agro stone, stabilized soil blocks (Chemically stabilized soil block and cement stabilized soil block), hydra foam, fly ash brick/blocks, stone colored roofing, pre cast panels are not new in Ethiopia. These materials have the potential for increasing the housing stock, and also it is the most important that can reduce the housing cost to a reasonable rate in the case of Ethiopia.

3. Research Methodology

In this research, both primary and secondary data were used in an attempt to solve the problems and address its objectives. The primary data were sourced from various individuals, professionals and organizations. Observations, semi-structured interviews and questionnaire surveys are sources of primary data and exploratory document review is used as a secondary data. Data collecting and gathering adequate information related to the essential factors or variables that will influence decisions of material selection process is performed. This is achieved by conducting both quantitative and qualitative methods of survey with qualified construction experts using semi-structured questionnaire and interviews.

3.1. Interview

In developing the conceptual framework, the knowledge of domain experts is captured through semi-structured interviews. Interview method is adopted for the research in order to get professionals and individuals perception and lived experience towards the usage of different construction materials in the construction industry. This includes representatives form contractors, consultants and real estate developers. Generally, the interview data collection system is used to the current trends in the Ethiopian construction industry in using ABMs; and helps to identify and prioritize the key local parameters that helps in selecting among alternative wall making materials.

3.2. Questionnaire survey

The research used a questionnaire survey mainly to prioritize the parameters that influence the decision-making process to choose ABMs. The survey tool is designed comprising questions based on the background analysis and literature review. Questions are prepared in the questionnaire with different options to be answered which helps in the quantitative analysis. To collect qualitative information and gain in depth and better understanding of knowledge on the subject, participants are provided a blank space to give additional information in the subject matters.

3.3. Research Technique

This paper proposes a building material selection framework based on the analytical hierarchy process (AHP) techniques. Assessment criteria are identified based on the need of building stakeholders. A questionnaire survey of building experts is conducted to assess the relative importance of the criteria to aggregate or categorize them into independent assessment factors. The AHP is used to prioritize and assign important weightings for the identified criteria. The proposed framework provides guidance to building designers in selecting sustainable wall building materials.

This material selection model framework needs three decisive data to recommend decisions. It creates a hierarchy using the **goal, decision criteria** and **decision alternatives**, and sorts the various alternatives according to their relative importance. The aim in AHP is to choose the most suitable and important alternative, by making an arrangement from the most important to the least.

3.3.1. The functional process of the various stages of the proposed framework using AHP technique

Stage 1: Defining the objective/task: Selecting the Building Element: The process of evaluating and selecting materials usually begins with the definition of the overall goal or task. This stage of the process will begin with the definition of decision objectives, followed by the selection of a preferred building element, which is wall in this study.

Stage 2: Identifying alternatives to be rated: Based on the structure of the decision objectives, the next step is to identify a set of locally sourced or recycled building material alternatives for the selected building element.

Stage 3: Identifying key influential factors/variables: Following the identification of a set of locally sourced or recycled building material alternatives, material selection and evaluation factors or variables will be defined in this stage.

Stage 4: Assessing impact of the material/product: Using the Analytical Hierarchy Process (AHP) or technique, this stage will involve detailed analysis of each selected factor or variable in order to determine and assign the performance preference or rating score/scale of each criterion in relation to the material/product impact(s). Material alternatives will be compared in this section based on a set of criteria or factors. It will involve expressing the impacts in a spreadsheet against criteria (Chen, et al., 1992).

Stage 5: Estimating weights: Assigning Relative Weights: Some materials/products are likely to be more important than others in any given list. Priorities are set and weights assigned to each factor, variable, or criterion, reflecting each criterion's priority. It will assess the relative importance of each factor/variable for a particular material option. The second objective of this research will produce data to identify relative weights of material selection parameters.

Stage 6: Ranking the Materials/Products Based on Score Weights of Factors: In this stage, each material alternative is ranked based on the importance given to the material selection parameters set by the user (designer) and the overall weights assigned to each factor. It determines the relevant applicable factor/variables and alternative material options as a hierarchy of objectives.

Stage 7: Selecting the Most Suitable Alternative of Material/Product: In this stage results of the evaluation process in the form of graphs, quantitative and descriptive reports that show variance in material suitability in relation to the relevant variables/factors are obtained. After that, the preferred material/product is determined.

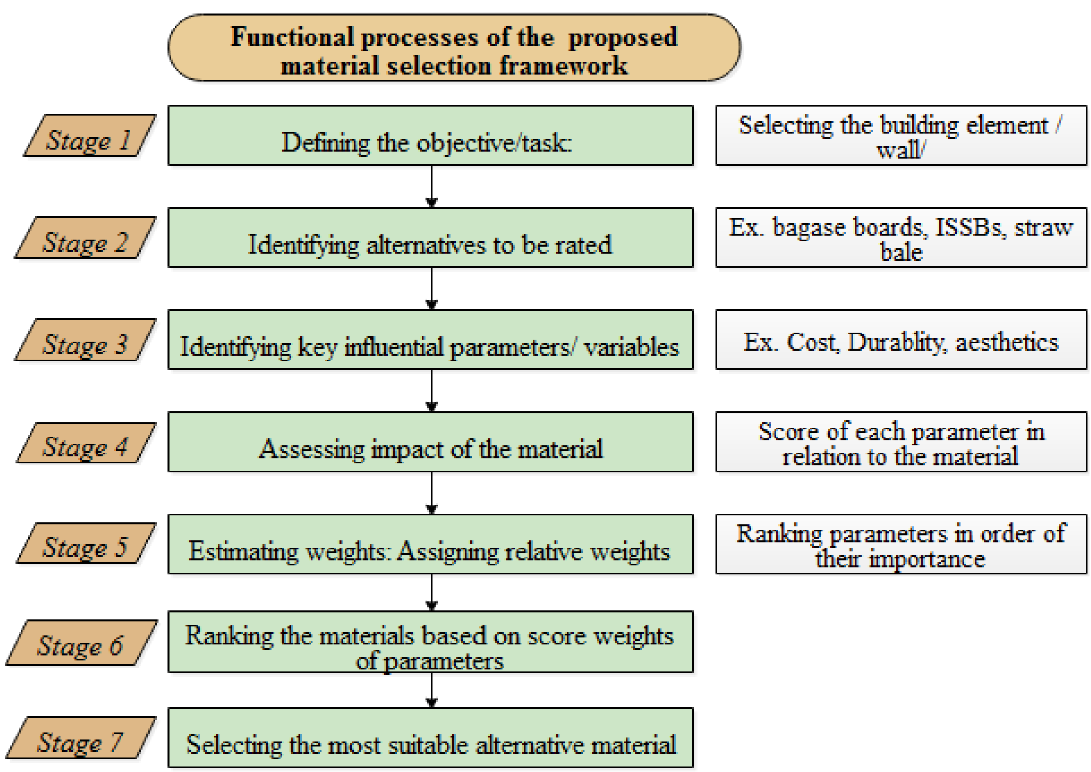

Figure 1: The functional process of the materials selection framework

4. Results and Discussion

This section presents data analysis, and discussion on the findings of the study. The general objective of the study is to develop a framework for the selection of alternative wall making materials. For this purpose, 3 types of data collection systems were used in this research which are the questionnaire survey, interview and observation study. The analysis and discussion of the results of these data collection tools are presented as follows.

4.1. Analysis of the questionnaire survey

The questionnaire survey in this research has two objectives. The first one is to assess existing conditions and current building material selection techniques. The second objective is, using a 5-point Likert scale, ranking the important parameters to choose among wall making alternative building construction materials. Out of the 47 distributed questionnaires, 41 were returned as valid for this study.

4.1.1. Assessing existing conditions and current building material selection techniques

The questionnaire survey gathered information on the current ABMs application practice in the local construction industry. The analysis result is presented as follows.

- Rating the importance of adoption of alternative wall making materials in Ethiopian construction industry: The response of questionnaire analysis shows, most of the Ethiopian construction industry professionals agree in the importance of adoption of ABM for walling. The analysis result generally indicates the adoption of different alternative wall making materials is important in the Ethiopian construction sector.
- Usage of an existing material selection support system to choose among alternative building material options: The survey result generally does not show the agreement between professionals regarding to the usage of existing material selection systems. But most of the respondents tend to agree the Ethiopian construction industry rarely uses a material selection support system to choose among alternative construction materials.
- Effectiveness of the current construction material selection system in Ethiopia: Most of respondents expressed the current material selection system is to be 'effective'. In the previous survey question analysis result, it tells the usage of material selection support system is low in Ethiopia. But the selection system is said to be effective, this indicates that there are few common types of materials that are available to be used in the construction industry.
- Current interest of the industry to likely use local and recycled wall making ABMs in design: The use of a wide range of local and recycled wall making materials in the Ethiopian construction industry is low. But needs will change with time, and usage of local alternative martials is generally appreciated from the concept of sustainability and other essential benefits. The questionnaire survey result shows the likelihood of the current interest of the construction industry to use local and recycled wall making ABMs is said to be 'remotely likely'. This indicates the construction industry has low tendency to use local and recycled materials in the design.
- Respondents level of interest to use a framework (tool) that helps choosing among ABMs: Material selection is a complex task when choosing among large number of available option of materials. As expressed in previous question results, the Ethiopian construction industry chooses among limited number of conventional materials which often makes the selection process easy. When different alternative materials are available, the level of interest of professionals to use a framework (a tool) that helps for choosing among local and recycled alternative wall making materials, according to the questionnaire result is high to medium level.

4.1.2. Ranking the important parameters to choose among wall making alternative materials.

The following results are obtained from respondents in ranking of the important parameters that need to be considered in the process of selection among wall making alternative building construction materials. Respondents are asked based on their experience, to rank these key parameters using a 5-point Likert scale score to their importance level, where 1= not important, 2= slightly important, 3= moderately important, 4= important and 5= very important. These selection parameters were presented in to eight categories in the questionnaire survey and the analysis results are presented as follows.

Table 1: Ranking of ABM selection parameters with respect to their mean score

		N	Minimum	Maximum	Mean
1	Durability	41	3	5	4.59
2	Market availability of materials	41	3	5	4.49
3	Aesthetics	41	3	5	4.46
4	Availability of raw materials	41	3	5	4.37
5	Ease of production and installation technology	41	2	5	4.37
6	Saving on construction cost	41	3	5	4.34
7	Installation Speed	41	2	5	4.24
8	Structural strength	41	3	5	4.22
9	Experience with the material	41	2	5	4.22
10	Safety and health of user	41	2	5	4.22
11	Initial investment/Capital cost	41	2	5	4.20
12	Fire resistance	41	2	5	4.12
13	Owners/Users perspective	41	3	5	4.12
14	Sound insulation	41	2	5	4.07
15	Hoisting/lifting up on installation requirement	41	2	5	4.02
16	Material handling	41	1	5	3.95
17	Maintenance level	41	2	5	3.85
18	Maintenance costs	41	1	5	3.85
19	Climatic conditions	41	1	5	3.80
20	Job creation	41	2	5	3.80
21	Need for creativity	41	1	5	3.78
22	Reduction of depletion of natural resources	41	1	5	3.78
23	Location of the site	41	2	5	3.73
24	Transportation mode	41	2	5	3.68
25	Waste prevention	41	2	5	3.66
26	Material storage	41	2	5	3.66
27	Building space usage	41	2	5	3.66
28	Availability of labor	41	2	5	3.61
29	Transportation costs	41	2	5	3.59

30	Use of recycled materials	41	1	5	3.54
31	Reduction of pollution	41	1	5	3.51
32	Training needs	41	1	5	3.51
33	Reusability	41	1	5	3.29
34	Compatibility with cultural traditions	41	1	5	3.27
35	Cultural implication of materials	41	1	5	3.22
36	Demolish ability	41	1	5	3.17
	Valid N (listwise)	41			

4.2. Interview result and analysis

- Existing experience related to usage of wall making ABMs: It is found that respondents experience to be not satisfactory associated with alternative wall making materials. And ABMs usage is described as occasional. The result mostly shows, usage of wall making ABMs is limited to internal partitions of a building. Among the materials used by the professionals as an ABM include: agrostone, gypsum block, gypsum board, magnesium board, hydraform, bamboo, adobe, straw bales and rammed earth. The analysis result indicates, of these materials, gypsum block is currently the most selected ABM to divide floors for building partitions and used in real estate internal partitions.
- The benefits of adoption and use of several alternative wall making ABMs: The benefits if we adopt the use of several wall making ABMs in the construction industry is investigated. Among the responses cost minimization and benefits on speed of construction are found to be most influential. Locally fabricated, creating jobs, quality, sustainability, lower ways to maintenance, economic advantages, saves energy, easy installation, architectural aesthetics are also the benefits associated with usage of ABMs. Appreciating local materials helps for job creation, and it will become more economical. The usage of ABMs resulting less area than usual block is also a needed advantage. Additionally, among the important points that should be raised are, minimization of shortage of raw materials, when more ABMs are introduced to the construction; abundance of construction materials, use of lightweight materials; total weight of building will decrease since HCB is heavy, and minimizing negative effects from the environment which reduces global warming.
- The extent of usage of ABMs: In describing the extent of usage of ABMs in the local construction industry, generally the existing conditions are expressed as very low. Among the common expressions that can describe the existing conditions regarding the usage of ABMs in the local construction, very low, not that much seen enough, not applied to almost all projects, can’t find other options to replace current materials, it is so rare, not that great almost zero, in our country it is not adopted and rarely used are the common ways. This shows the extent of the usage of ABMs from the professionals’ perspective in the Ethiopian construction.
- Factors that are barriers to use alternative materials: For the barriers to use ABMs in the Ethiopian construction industry, the analysis result found key points of knowledge issues and availability of the materials. Among the general reasons of barriers to use ABMs, shortage of production of ABM materials in the local condition, lack of awareness, not easily available to get these materials everywhere, availability of technology, building owner or end user negative perspective, lack of skilled labor and proper training, and negative perceptions in the industry are the common. The need of promotion by stakeholders to act towards usage of ABMs is generally found to be important.

- What to improve in policies and methods to motivate the use of ABMs: To mitigate and overcome the above stated barriers, the analysis result found the following points related to improving the usage of ABMs. The most important points are presented as follows.

    - The need to be taken seriously by gov't is found to be important. Making policies that appreciate micro and small construction material manufacturing enterprises, helps in both job creation and to appreciate usage of ABMs.
    - To motivate and encourage investors to build ABM producing industries locally,
    - Introducing cost effective materials to the construction firm is important. With research and study, introducing ABMs that can replace the existing materials which can be produced locally;
    - Increase availability of ABMs in the industry, producing local materials in huge amount;
    - Produce professionals on this area in both design and production,
    - Giving knowledge to construction firms: contractors, consultants etc.
    - Train labors skilled and unskilled on these areas & use technlolgies

4.3. Development of template to choose among ABMs using the AHP method.

The following series of steps should be followed to choose among given alternative building materials and given material selection criterions.

1. Choose influential material selection criterions for the project (Suppose we have 4 selection criterions S1, S2, S3 and S4).
2. Choose suitable candidate of ABMs that can be used in the project (Suppose if we are choosing among 3 materials A, B and C).
3. Make pairwise comparisons using a ratio scale

A ratio scale is used to compare among ABMs with respect to the chosen material selection criterions. In this stage relative properties of chosen materials should be studied with respect to the selected material selection criterions.

Table 2: ratio scale

Preference level of factors or criteria
9 = extremely preferred, 8 = very strongly to extremely preferred, 7 = very strongly preferred, 6 = strongly to very strongly preferred, 5 = strongly preferred, 4 = moderately preferred, 3 = moderately preferred, 2 = equally to moderately preferred, 1 = equally preferred

A. Pair wise comparisons using selection criteria S1
    - Comparison of material A with respect to Material B (ABS1) & (BAS1)
    - Comparison of material A with respect to Material C (ACS1) & (CAS1)
    - Comparison of material B with respect to Material C (BCS1) & (CBS1)

B. Pair wise comparisons using selection criteria S2
    - Comparison of material A with respect to Material B (ABS2) & (BAS2)
    - Comparison of material A with respect to Material C (ACS2) & (CAS2)
    - Comparison of material B with respect to Material C (BCS2) & (CBS2)

C. Pair wise comparisons using selection criteria S3
    - Comparison of material A with respect to Material B (ABS3) & (BAS3)
    - Comparison of material A with respect to Material C (ACS3) & (CAS3)

- Comparison of material B with respect to Material C (BCS3) & (CBS3)

D. Pair wise comparisons using selection criteria S4
   - Comparison of material A with respect to Material B (ABS4) & (BAS4)
   - Comparison of material A with respect to Material C (ACS4) & (CAS4)
   - Comparison of material B with respect to Material C (BCS4) & (CBS4)

Build weighted matrix using pairwise comparisons.

Table 3: weighted matrix

Material Alternatives	Criterions											
	S1			S2			S3			S4		
	A	B	C	A	B	C	A	B	C	A	B	C
A	1	ABS1	ACS1	1	ABS2	ACS2	1	ABS3	ACS3	1	ABS4	ACS4
B	BAS1	1	BCS1	BAS2	1	BCS2	BAS3	1	BCS3	BAS4	1	BCS4
C	CAS1	CBS1	1	CAS2	CBS2	1	CAS3	CBS3	1	CAS4	CBS4	1

4. Add up all the values in each column

Table 4: summing up the matrices given criteria and performances

Material Alternatives	Criterions											
	S1			S2			S3			S4		
	A	B	C	A	B	C	A	B	C	A	B	C
A	1	ABS1	ACS1	1	ABS2	ACS2	1	ABS3	ACS3	1	ABS4	ACS4
B	BAS1	1	BCS1	BAS2	1	BCS2	BAS3	1	BCS3	BAS4	1	BCS4
C	CAS1	CBS1	1	CAS2	CBS2	1	CAS3	CBS3	1	CAS4	CBS4	1
Total	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12

T1 = 1 + BAS1 + CAS1

T2 = ABS1 + 1 + CBS1 and it's the same procedure until T12

5. The values in each column are divided by the corresponding column sums. Note that value in each column sums up to 1.

Table 5: dividing to the total sum

Material Alternatives	Criterions											
	S1			S2			S3			S4		
	A	B	C	A	B	C	A	B	C	A	B	C
A	AA1	AB1	AC1	AA2	AB2	AC2	AA3	AB3	AC3	AA4	AB4	AC4
B	BA1	BB1	BC1	BA2	BB2	BC2	BA3	BB3	BC3	BA4	BB4	BC4
C	CA1	CB1	CC1	CA2	CB2	CC2	CA3	CB3	CC3	CA4	CB4	CC4
Total	1	1	1	1	1	1	1	1	1	1	1	1

AA1 = 1/T1
BA1 = BAS1/T1
CA1 = CAS1/T1
AB1 = ABS1/T2 and the same procedure continues to fill the table.

6. Next step is to find the average of each criterion, which is the average of each row

Table 6: results of the average of all the criterions

Material Alternatives	Criteria			
	Cost	Availability	Durability	Aesthetics
A	Avg AS1	Avg AS2	Avg AS3	Avg AS4
B	Avg BS1	Avg BS2	Avg BS3	Avg BS4
C	Avg CS1	Avg CS2	Avg CS3	Avg CS4

Avg AS1 = (AA1 + AB1 + AC1)/3
Avg AS2 = (AA2 + AB2 + AC2)/3, using the same step fill the average rows.

7. Rank the factors or criteria in order of their importance

In this step the preference of each material selection criteria over the other is studied. Using same method used before, their pairwise comparisons should be done.

- Compare preference of S1 with respect to S2 (S12 & S21)
- Compare preference of S1 with respect to S3 (S13 & S31)
- Compare preference of S1 with respect to S4 (S14 & S41)
- Compare preference of S2 with respect to S3 (S23& S32)
- Compare preference of S2 with respect to S4 (S24 & S42)
- Compare preference of S3 with respect to S4 (S34 & S43)

Table 7: ranking criterions in order of their importance

Criteria	S1	S2	S3	S4
S1	1	S12	S13	S14
S2	S21	1	S23	S24
S3	S31	S32	1	S34
S4	S41	S42	S43	1

8. As it is shown in the above procedures, summing up each values in each column and dividing each column by the corresponding column sums, the following table is created.

Table 8: results of new matrices

Criteria	S1	S2	S3	S4	Row Avg
S1	SS11	SS12	SS12	SS14	Avg S1
S2	SS21	SS22	SS23	SS24	Avg S2
S3	SS31	SS32	SS33	SS34	Avg S3
S4	SS41	SS42	SS43	SS44	Avg S4
Total	1.00	1.00	1.00	1.00	1.00

9. The row averages in the above table are the priority or performance vector for the criteria. The ranking of the material selection criterions is done by their average score which will be obtained in the following table.

Table 9: priority or preference vector for the factors or criteria

Criteria	Priority or performance vector
S1	Avg S1
S2	Avg S2
S3	Avg S3
S4	Avg S4

10. The final step is to take the material score matrix and multiply each by their respective priority or preference vectors.

Table 10: final calculations multiplying the criteria matrix by the preference vector

Material Options	S1	S2	S3	S4	Priority Factor
A	Avg AS1	Avg AS2	Avg AS3	Avg AS4	Avg S1
B	Avg BS1	Avg BS2	Avg BS3	Avg BS4	Avg S2
C	Avg CS1	Avg CS2	Avg CS3	Avg CS4	Avg S3
					Avg S4

Material option A score = Avg S1(Avg AS1)+Avg S2(Avg AS2) + Avg S3 (Avg AS3) + Avg S4(Avg AS4)
Material option B score = Avg S1(Avg BS1) +Avg S2(Avg BS2) + Avg S3 (Avg BS3) + Avg S4(Avg BS4)
Material option C score = Avg S1(Avg CS1) + Avg S2(Avg CS2)+Avg S3 (Avg CS3) + Avg S4(Avg CS4)
From the above material score results, the material with the highest score should be chosen.

5. Conclusion and Recommendations

The study has investigated the current existing conditions regarding to the use and application of wall making ABMs in design and construction of projects. Through the assessment of the current practice of using alternative wall making construction materials in Ethiopia, the following conclusions are drawn.

- The application of different alternative wall making materials is important in the current Ethiopian construction sector.
- The construction industry rarely uses a material selection support system to choose among alternative construction materials.
- The existing material selection system in the construction sector is said to be ‘effective’ because there are few common types of materials that are available and being used in design and construction.
- Currently the construction industry has low tendency to use local and recycled building materials in the design because of low availability of these materials.
- When large number of different alternative materials are available, the need to use a material selection framework to choose among ABMs is high.
- The current usage of wall making ABMs is found to be mostly limited to internal partitions of a building. Gypsum block, gypsum board, magnesium board and hydra form are currently being used as an alternative wall making ABMs.

- The benefits of adoption and use of several alternative wall making ABMs in the construction industry are: creating jobs, sustainability, economic advantages, abundance of construction materials, cost competency and use of lightweight materials.
- The extent of usage and acceptance of alternative building materials is low in the construction sector.
- Factors that are barriers to use ABMs in the construction sector are: lack of awareness of stakeholders, lack of availability, availability of technology, building owner or end user negative perspective, lack of skilled labor and proper training.
- The construction sector needs to improve in policies and methods to motivate the use of ABMs. The awareness on the importance and usage of ABMs should be well addressed to the stakeholders for those who play important role on the construction sector.
- Availability of cost effective and durable wall making ABMs which can be supported with research and study, and with governmental support, can change the current low usage status of alternative materials in the construction sector.

Recommendations

Based on the research results and findings it is recommended that if the following measures are taken, it will improve the application of alternative wall making materials on the Ethiopian construction sector.

- For creating awareness among stakeholders the following points are recommended:
  - It is recommended that in their study and research, universities and technical schools focus more on creating and studying alternative wall making material & technologies that are applicable for the Ethiopian construction industry.
  - It is recommended that introducing alternative building materials in the curriculum of universities and technical schools. It will encourage students to come up with research and ideas that can result in creating competent and well-studied materials that can be feasible for the Ethiopian construction sector.
  - It is recommended to give technical and knowledge support for major stakeholders and suppliers on the construction sector. This is achieved through governmental support through policies and methods.
- Researches should be carried out based on the most influential parameters to produce well competent alternative wall making material to fully or partially replace conventional materials.
- It is recommended that government policies should be developed to support the application of wall making ABMs and direction should be given to ensure quality and application of ABMs. The developed policy should also include financial support for parties willing to introduce and produce wall making ABMs.
- It is recommended a governmental support in technology introduction, knowledge and promotion in introducing new cost efficient wall making materials.
- The potential of raw material availability in Ethiopia to produce wall making ABMs should be studied to promote local and recycled materials.
- It is recommended to encourage the existing wall making ABMs. Government policies to encourage the usage of currently market available ABMs improves stakeholders' awareness.

References

1. Calkins, M., 2009. Materials for sustainable sites. *A complete guide to the evaluation, selection and use of sustaibable construction materials.*
2. Chen, S.-J., Hwang, C.-L. & Making, M. A. D., 1992. Multiple Attribute Decision Making.
3. Dongmin Lee, et al., 2020. Analytic hierarchy process-based construction material selection for performance improvement of building construction: The case of a concrete system form.
4. Gbadebo, M. A., 2014. Promoting the use of alternative building technologies in Nigerian construction industry: the problems and recommendations.
5. Jato-Espino, Diaz-Sarachaga & Castro-Fresno, 2017. Methodology for the development of a new Sustainable Infrastructure Rating System for Developing Countries.
6. Joseph, P. & Tretsiakova, S., 2010. Sustainable Non-Metallic Building materials. *Sustainablity,* Issue Sustainablity, pp. 401-423.
7. Kebede, S., 2013. The impact of alternative construction technology on condominium housing project: The case of Addis Ababa.
8. Marut, J. J., Anigbogu, N. A. & Daniel, M. M., 2020. Alternative building materials (ABM): Towards adoption of common terminology and definitions,. *Civil and Envirnmental research,* Volume 12, pp. 16-20.
9. Micheal, F. A., 1999. *Materials selection in mechanical design second edition.* England: A division of Reed Educational and Professional Publishing Ltd.
10. Ogunkah, I. & Yang, J., 2012. Investigating Factors Affecting Material Selection: The Impacts on Green Vernacular Building Materials in the Design-Decision Making Process.
11. Peter, O. A., Ezekiel, A. C. & Paul, O. O., 2012. Design of A Sustainable Building: A conceptual framework for implementing sustainability in the building sector.
12. Saaty T.L, 1994. Decision Making in Economic, Political, Social, and Technological Environments with the Analytic Hierarchy Process.
13. Sazzadur, R., Srinath, P. & Henry Odeyinka, 2018. A conceptual knowledge – based cost model for optimizing materials and technology for building design.
14. Scheubreina R & Ziontsb S, 2006. problem structuring front end for a multiple criteria decision support system. *Computers and Operations Research.*