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Computer Aided Material Selection Strategic Approach for Design of Ethiopian Buildings

A Thesis Submitted in Partial Fulfillment of the Requirement for the Degree of Master of Science in Civil Engineering
(Construction Technology and Management)

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Declaration

I, Undersigned here, declare that this thesis or any part thereof is my original work and has not previously been presented in any form to the University or to any other body whether for the purposes of assessment, publication or for any other purpose. Save for any express acknowledgment references and/or bibliographies cited in the work.

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Dedication

I dedicate this work to my family for their endless support throughout this thesis work. And most importantly, I would like to dedicate this work to my late childhood friend Eng. Birhane G/meskel, I know we had countless plans for the graduation but God had other plans for you, whatever happened, I know you would have been proud.

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Abstract

Building materials are one of the most financially and environmentally critical components of design, construction, and operational phases. However, these components are often overlooked as more emphasis is given to the structural integrity and aesthetics, this oversight can be detrimental to the performance of the infrastructure.

Building material selection is encountered on every project small or large, but it is not given the attention it deserves during the design process. The considerations that have to go into the building material selection process are vast and can be overwhelming, if it is not done in a simplified and strategic approach. Designers often go to most known and most obvious choices, but this might not be the best choice.

In this research it was tried to simplify and streamline the building material selection process through a strategic framework and proposal of a computer program. One of the objectives of this research was to evaluate the building material selection practice in Tigrai National Regional State (TNRS) and to identify the parameters and criteria that are considered in the selection process. Proposal of a strategic framework and development of a building material selection computer program were another objective of this research.

The parameters and criteria considered for the building material selection computer program were gathered through questionnaire, design document and literature survey. These criteria were evaluated using Multi-Criteria Analysis (MCA) techniques; specifically Multiple Attribute Utility Theory (MAUT) was used. This was done after assessing the current used building material selection practice in Tigray National Regional State (TNRS) through Questionnaire and Design Document Review.

A computer aided strategic approach was proposed using these identified criteria and MAUT as a way to evaluate the criteria. The proposed computer program was developed using python programming language. Python was chosen due to its objected oriented language and its useful application in writing graphical user interfaces (GUI).The research was confined to assessing and proposal of a computer program in the detail aspect and Tigray National Regional State in location aspect.

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

The strategic framework was developed in the form of a flowchart. The developed computer program consists of multiple windows that used the 23 criteria determined in the research. The computer program evaluated the building materials based on the weights (W_i) and utiles (U_{ij}) inputted by the user. As mentioned above the computer program uses MAUT to evaluate the building materials based on the weights and utiles inputted and gives results in a single numerical number for each building material. Then, the user has to choose the building material with the highest numerical number as it is the best material based on weights and utiles inputted for the specific project.

The developed computer program will help designers in selecting the most sustainable building material based on the project's objective and client's requirements.

Keywords*: Building material selection, Software, Python Programing language, Graphical User Interface (GUI), Computer Program, MCA, MAUT, Design process, Simplified strategic approach*

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Abbreviations

- AHP - Analytical Hierarchy Process
- AAPOR – American Association for Public Opinion Research
- BEES – Building Environmental and Economic Sustainability
- BREEAM - Building Research Establishment Environmental Assessment Method
- CA – Cluster Analysis
- DGNB - Deutsche Gesellschaft für Nachhaltiges Bauen
- EPM – Environmental Preference Method
- IDE – Integrated Development Environment
- LCA – Life Cycle Assessment
- LCC – Life Cycle Cost
- LEED – Leadership on Energy and Environmental Design
- LP - Linear Programming
- MAUT – Multi Attribute Utility Theory
- MCA – Multi Criteria Analysis
- MR – Multiple Regression
- SMAA – Scoring Multi Attribute Analysis
- WSM – Weighted Sum Method
- R – Rank
- I – Relative Importance Index
- Wt. - Weight

Chapter 1: Introduction

1.1 General

Construction as defined by the Statistics Division of the United Nations is "an economic activity aimed at creating, renovating, repairing or extending fixed assets in the form of buildings, land improvements of an engineering nature, and other engineering constructions such as roads , bridges, dams and so on" (Joro, 2015). Construction includes all construction companies, including general contractors, heavy construction companies (airports, roads and utilities) and specialist construction companies. Also included are companies involved in the preparation of new construction sites and in the subdivision of land for construction sites. Construction work can involve new construction, improvements, changes, or repairs and maintenance (Joro, 2015). The construction industry consumes by weight more raw materials than any other manufacturing field (Tafesse and Abegaz, 2019).

Ethiopia has a long tradition of excellent building ventures. The construction industry has now produced a wide range of buildings in Ethiopia, varying from homes and high-rise buildings, from schools and hospitals to factories and shopping centers, and has undertaken an equally large number of construction works, from roads to hydroelectric dams, and irrigation dams / canals. The Construction Industry has also created different incentives for jobs in Ethiopia (Joro, 2015).

The influence of construction materials is more influential than from the effect of the other sources due to the widespread use of these materials. Due to the regular behavioral shifts and human needs, the typical buildings existence is decreasing, demolition or refurbishment of buildings every year leads to further landfills or recycling. Thanks to the massive construction materials and oil use, there is a strong resource scarcity worldwide (Lomite and Kare, 2009).

As a consequence Joro (2015), indicates that materials management in building projects is a key role that contributes significantly to a project's success. Management of materials are being challenged in construction projects because of material shortages, delivery delays, volatility in costs, damage and waste, and lack of warehousing space. Management of materials is a key function of construction projects to improve efficiency.

1.2 Background

The growth of African cities is up to 5 percent annually, making them, today, the world's fastest growing cities. Extrapolations suggest that Africa's urban population actually doubles every 10 to 15 years (Hebel, 2012). As Hebel (2012) suggested, this annual rise is mainly due to migration of the masses from rural to urban areas. This migration can be attributed to two factors- exacerbated global climate situation that created difficulties for subsistence farming let alone commercial farming and regional conflicts that threaten their security and livelihood.

In the next 15 years, Ethiopia will face a population rise of 45 million, with a rise in demand for food, water, protection and housing, as well as urban settlements that are not yet accessible and already strained (Hebel, 2012). Instead than relying on obsolete first-world models, Ethiopia should develop modern urban planning and urbanization model.

Building materials are one of the most financially and environmentally critical components of design, construction and operational phases of the infrastructure element. However, this aspect of building material selection is often overlooked as more emphasis is given to the structural integrity, as should be, and aesthetics, this oversight can be detrimental to the performance of the infrastructure.

This building material selection is encountered on every infrastructure project small or large (Florez et. al.). This selection can be as simple as what kind of backfill material to use to as large as what kind façade treatment to use on the exterior of the infrastructure. This selection of building materials considers a vast array of variables. The variables can be overwhelming to consider manually, as most of the local designers do.

When we look at the environmental aspect alone, the embodied energy of a building material, which is the accumulated energy expenditure from its origin up to its usage, is an important parameter to base one's selection on. This is rarely done though, as simple internet literature survey shows, the prevailing practice remains highly randomized.

1.2.1 <u>Ethiopian Context</u>

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

1.2.2 Criteria

The criteria for building material selection is numerous and can be overwhelming. A designer, when selecting building materials, has to take into account the financial considerations, manufacturing and environmental factors that can make a substantial difference in selecting a certain material over the other.

The weight these different stated factors carry might vary in different locations and countries, for example, Environmental considerations might be the determining factor in Beijing, China than a Financial factor as the location of the project is environmentally challenged than a financial one. This works all over the world.

1.2.3 The Difficulties

The main difficulty in the building material selection process is the enormity of the available variables. Taking into account these different sometimes mutually exclusive variables listed above, the building design process might face various difficulties.

1.3 Problem Statement

As mentioned above, selection of building material is a rather complex part of a design process and is often overlooked. The process of design tends to take on the best-known, obvious options, but this may not always be the best option (Minor, 2011). Training, teaching designers how to pick building materials safely, will minimize this (Minor, 2011). As Ethiopia is going towards a green economy, it is up to us, engineers and Construction Management professionals to resource and procure green, energy efficient and economical materials. Towers in glass and steel are mistaken for the positive economic growth and the unique esthetic outcomes of a modern city (Hebel, 2012). “What works in one location will not always work in another”, that quote alone points towards a problem and a need for a solution.

In Ethiopian Context, the enormity of the variables is still prominent and with little technique to evaluate the array of variables, the designer is left with the best-known, obvious material choices as the designer doesn’t have the means to evaluate the vast array of variables that arise from material selection. The factors are interchangeable as well. For example, a material that is suitable for Debre Birhan, Amhara region with aspect to Insulation might not be suitable in Afar region. These criteria have to be taken into consideration in the design process.

1.4 Previous Research Background

Although researches have been done centered around material selection with sustainability as a driving concept, the conducted researches were focused mainly on European and Asian countries. The factors and criteria identified in these research were specific to the research location.

1.5 General Objective

The general objective of the research, if no constraints existed, would be to provide a solution to the building material selection problem in the form of a strategic selection approach and propose a computer program. The variables for the selection are vast and sometimes mutually exclusive and can be hard to intertwine. This would be done after assessing the current building material selection approach/practice.

1.6 Specific Objective

1. To evaluate the Ethiopian building material selection practice.
2. To assess the important factors for building material selection process.
3. To propose a strategic material selection approach for Ethiopian building design
4. To develop a building material selection Computer Program for Ethiopian building design

1.7 Research Questions

The main research questions this thesis research aims to address are:

1. What is the material selection practice and gap in current decision-making practice used in selecting building materials and how can it be improved?
2. What is the level of environmental awareness and sustainable practices of architects' and designers in the Ethiopia and how does it affect design decisions?
3. What are the sustainability issues, criteria, factors and their respective weights used in material selection?
4. How can they be used in modelling decision-making Computer Program in building projects?
5. What should be the appropriate model for evaluating and selecting sustainable building materials and what should it consist of?

1.8 Research Scope

The research scope will be confined to:

I. Assessment and proposal of a computer aided strategic approach in terms of depth of study and detail.

II. Questionnaire survey assessment and a computer program in terms of scale of the research.

III. Tigrai National Regional State (TNRS) in terms of location.

1.9 Thesis Organization

The thesis structure is presented as follows and the specific chapter descriptions are as follows:
Table 1: Thesis Organization

Chapter	**Description**
Chapter One	This chapter provides background information for this research. It explains why, how, objectives and significance of the research.
Chapter Two	This chapter builds a theoretical foundation for the research by reviewing literature and previous research.

Chapter Three	This chapter provides an outline of the research methodology adopted for undertaking this research.
Chapter Four	This chapter presents the data analysis of the questionnaire survey and design document review alongside the Results & Discussion of the thesis.
Chapter Five	This chapter is devoted to the development of the Computer Program while the developed working manual explains and elaborates the workings of the computer program while software testing is used to validate the computer program.
Chapter Six	This chapter provides recommendations and points towards issues for further research.

Chapter 2: Literature Review

2.1 Introduction

The Oxford English Dictionary describes building material as "any material used for construction purposes, many naturally occurring substances have been used to create houses, such as mud, rocks , sand, and wood, and twigs and leaves, In addition to naturally occurring, many man-made materials are in use, some more and some less synthetic" (Oxford English Dictionary, 2016). In several countries, the manufacture of construction materials is an important industry and the use of such materials is typically segmented into various specialist trades, such as carpentry, insulation, plumbing and roofing work. The composition of environments and structures, including houses, is given (Oxford English Dictionary, 2016).

The increase in destructive activities by human is resulting in some serious damages including tsunami, wildfires, floods and drought due to global warming, rising in sea level, depletion of ozone layer causing growing threats of cancer and land loss due to pollution of soil. Construction industries have a greater role in contributing to environmental issues. The extensive depletion of resources is due to the use of large volumes of building materials (Lomite and Kare, 2009).

Millions of tons of waste are generated annually throughout the world (Lomite and Kare, 2009). Responsible waste management in a construction project is a vital element for optimally exploiting the limited resources available to sustain continuous development. In this context, waste management means minimizing building waste or demolition waste that leaves the jobsite for waste disposal (Mulualem, 2012 as mentioned in Joro 2015).

Construction industry uses more raw materials by weight than any other industry. About 50% of all Earth crust materials have been converted into construction materials (Torgal 2011, cited in Tafesse and Abegaz, 2019). A number of materials are used for construction, with energy consumed and CO2 generated in the manufacture of each material.

Ethiopia is one of the developing countries in Sub-Saharan Africa where building energy codes are unavailable. Recently, the country has been experiencing a rapid economic growth which has been attributed mainly to the building construction boom. The building construction is expected to continue to flourish, because the rapid urbanization and capital growth is the foremost priority for the Ethiopian government to achieve the status of a middle-income country by 2025. (MoUDC, 2012 as cited in Tafesse and Abegaz, 2012).

2.2 Existing Material Selection Assessment Models

For many years, a variety of building material performance evaluation methods has been developed internationally and domestically in UK (Akadiri, 2011). A variety of assessment approaches are currently in use worldwide, primarily voluntary. Methods of evaluation can differ depending on local situations and the interest of stakeholders (Riascos et al., 2015). Khoshanava et al, (2010) also reiterate that the overall energy and carbon usage of the construction industry and its emissions are also raising increasing concerns among experts and stakeholders with regard to this industry.

Most assessment institutions are found in European countries, other countries such as USA, Canada, Australia, Japan, and Hong Kong, have their own evaluation and classification methods for the building environmental performance (Riascos et al., 2015). In this section, some of the popular assessment methods were reviewed. The following assessment methods evaluate building material in particular. These methods can be used pre construction or post construction when the building is operational.

A. ENVEST

ENVEST is the first UK software for estimating the life-cycle environmental impacts of a building from the early design stage (Erlandsson and Borg, 2003). Currently, ENVEST is designed for offices and commercial buildings and enables architects and designers to evaluate the environmental impacts of different design option for a chosen building. It considers the environmental impacts of materials used during construction and maintenance, and energy and resources consumed over the buildings life (Akadiri, 2011).

ENVEST has been created principally for designers, to help them compare different options in terms of environmental performance. It is intended for use from the early design stages. Clients may also be used ENVEST to establish an environmental performance requirement for their design team (Akadiri, 2011). ENVEST is therefore an attempt to simplify LCA studies by expressing the results in terms of a single point score.

B. BEES – Building for Environmental and Economic Sustainability

BEES is a computerized tool for choosing environmentally preferable building materials. (Lippiatt and Ahmad, 2004 as cited in Akadiri, 2011). The user must allocate relative values to various categories of impacts, such as acidification, global warming etc. Although the designers are unable to determine the environmental implications because they are not specialists in environmental assessment (Lomite & Kare, 2009), BEES needs weighting.

The purpose of the BEES has been to “develop and implement a systematic methodology for selecting building products that achieve the most appropriate balance between environmental and economic performance based on the decision makers values” (Lippiatt and Ahmad, 2004 as cited in Akadiri, 2011, P.137).

In his extensive review of the assessment method, Akadiri, (2011), P.137 described the method as follows; “The BEES environmental performance assessment is based on the LCA standards, including categorising in impact categories, normalising by dividing by the U.S. emission per year per capita, and weighing by relative importance. The economic performance is based on LCC calculation, and normalised by dividing by the highest life cycle cost, thereby ranking the materials from 0 to 100. Finally, an overall evaluation involves the environmental score and the economic score being weighted together using relative importance decided by the user.”

C. EPM – Environmental Preference Method

The principle of this method is to take simultaneously into account different factors, such as various damages of eco system, consumption/exhaustion of resources, energy consumption (in all phases of production, including transport), environmental pollution with different waste and hazardous materials, waste disposal problems, hazardous emissions int0o the atmosphere, global warming, impact on human beings, re-use and recycling possibilities, etc (Akadiri, 2011).

Adadiri (2011) continues to state that this approach also takes account of whether the building is being constructed or renovated. Material preferences for certain positions are made through a four-level system which places or excludes materiel and products from the final choice into three priorities-I, II, III.

2.3 Multi criteria Analysis (MCA) Techniques

Generally, the spotlight in construction is on limiting the underlying building cost. It has, nonetheless, since the 1930s become evident that it is troublesome to base the decision between material options exclusively on the underlying cost alone (Kishk *et al.,* 2003 as cited by Akadiri, 2011). An inefficient building imposes a cost penalty on the client throughout its lifetime. While the client has an incentive to minimize whole life costs, the contractors and consultants do not, as they have no long-term interest in the building and are not accountable for performance in use (Sorrell, 2003 as cited by Akadiri, 2011).

Statistical processes provide a range of resources that allow researchers to summarize their empirical findings in ways that are easily interpreted and understood by the intended audience. The only focus on univariate and bivariate analysis has been found to be insufficient and opted for multivariate analyses (Singh et al., 2007; 2009 as cited by Akadiri 2011).

There is no standard accepted MCA framework for aggregating composite sustainability evaluation requirements (Singh et al., 2007; Zhou et al . , 2010, as cited in Akadiri, 2011). Weights a composite set of parameters strongly affects the considerations considered when choosing an MCA approach include internal continuity, methodological versatility and ease of use. A trade-off between its objectivity and its comprehensiveness will direct the selection of the correct MCA methodology (Janssen, 1991 as cited by Akadiri, 2011).

Most of the differences between the various multi-criteria evaluation methods arise from the arithmetic procedures used as a means to aggregate information into a single indicator of relative performance (Akadiri, 2011).

Generally solution of Multi Criteria Decision Making (MCDM), which is another word for Multi-criteria Analysis (MCA), problems involves five key steps (Hung et.al, 2011):

1) Problem / issue identification: Decision-makers (agents) need to define the nature of the question being investigated. Determination of the parameters to be followed and the methods to be implemented for making decisions.

2) Problems structuring: practitioners / decision-makers need to define this enterprise's goals, priorities, constraints, external climate, core problems, uncertainties and stakeholders. In this stage, the required data or information is obtained, so that decision-makers' interests can be correctly defined and considered.

3) Model construction: the decision-makers then determine the alternatives, identify all parameters, and generate values for model construction. This method helps them to compile variety of potential solutions or methods to ensure the target is accomplished.

4) Using the model as a new assessment method particularly for decision-makers; collecting and synthesizing knowledge, proposing new alternatives and evaluating the model's robustness and responsiveness, taking into consideration the intuition of people.

5) Creation of an action plan: an action plan shall be developed as a solution in the final phase. In other words, choosing an acceptable tool to enable decision-maker to analyze and rank the potential alternatives or approaches (i.e. decide the best alternative).

According to Akadiri, (2011) two strategies are currently being debated; on the one hand, all impacts should be converted into financial terms, which decision-makers mostly understand. On the other hand, putting an economic value on all the environmental and social effects is challenging, if not impossible, and a qualitative route with techniques for decision analysis should be used. Combinations of those two methods have been suggested in some cases.

Nevertheless, the problem remains as to which of these MCA approaches are sufficient as a theoretical basis for constructing a composite criterion. The method chosen for the formulation of composite criteria must allow the weighted aggregation of quantitative individual indicators, which requires the method to be utility or value-based, quantitative in format and provide a cardinal assessment of the weighted differences between indicators and not just ordinal differences (Nijkamp et al., 1990).

“Numerous techniques for multi-criteria or multi attribute decision-making have emerged. Some of the simpler and more useful techniques include Scoring Multi-Attribute Analysis

(SMAA), Multi-attribute utility theory (MAUT), Multiple Regression (MR), Linear programming (LP), Cluster analysis (CA), Multivariate discriminant analysis (MDA), Weighted sum method (WSM) and the Analytical hierarchy process (AHP)" (Akadiri, 2011, P.275).

Akadiri, (2011) reviewed numerous Multi Criteria Assessment (MCA) techniques and are summarized as follows:

i. ***Scoring Multi-Attribute Analysis (SMAA)*****:** The technique uses linear evaluation method by aggregating the weight (W_i) of the criteria (C_i) and the rating (r_{ij}) of the criteria (C_i) with respect to the decision alternative (A_j).

Equation 1 [Eq.1]: SMAA Model

$$Sj = \sum_{j=1}^{N} w_i r_{ij}$$

Where:

S_j = Score of the decision alternative A_j

Anderson et al., (2005) spelt out the working steps for SMAA evaluation:

a) Step 1: Identify the list of criteria the decision maker considers relevant for evaluating each decision alternative.
b) Step 2: Assign weight (W_i) to each the criteria (C_i) according to that criteria's relative of importance.
c) Step 3: Assign a rating (r_{ij}) according to how each decision alternative satisfies each criterion.
d) Step 4: Evaluate the score for each decision alternative using Equation 4.
e) Step 5: The decision alternative with the highest score is the recommended decision alternative. .

ii. ***Multi-attribute utility theory (MAUT):*** This method is similar to SMAA however though it uses "Utility" instead of the "Rating.". "Utility" shall give an abstract equivalent of the attribute considered from natural units such as years, or, £to a sequence of commensurable units (useful) at an interval of zero to. (Holt, 1998).

Equation 2 [Eq. 2]; MAUT Model

$$S_j = \sum_{j=1}^{N} w_i \, u_{ij}$$

Where:

S_j = Score of the decision alternative A_j

U_{ij} = Abstract utiles of criteria (C_i) with respect to Alternative (A_j)

a) Step 1: Identify the list of criteria the decision maker considers relevant for evaluating each decision alternative.
b) Step 2: Assign weight (W_i) to each the criteria (C_i) according to that criteria's relative of importance.
c) Step 3: Assign a utility (U_{ij}) according to how each decision alternative satisfies each criterion.
d) Step 4: Evaluate the score for each decision alternative using Equation 2.
e) Step 5: The decision alternative with the highest score is the recommended decision alternative.

iii. ***Multiple Regression (MR):*** A statistical method that can be used to analyze the influence of multiple independent variables on a variable dependent on it. A simple MR model is given to observe the effect of an independent variables function (X1 , X2, X3 ... Xn) on a Y outcome as (Akadiri, 2011):

Equation 3 [Eq. 3]: Multiple Regression (MR) Model

$$Y = a + b_1(X_1) \pm b_2(X_2) + \cdots + b_n(X_n)$$

Where:

a = a constant representing y-axis intercept of the regression line

$b_1, b_2, \ldots, b_n$ = partial coefficient for the independent variables

When using Multiple Regression (MR) as a Multi Attribute Analysis (MCA) technique, the various parameters will be expressed by the independent variables (X1 , X2, ... , Xn), and the dependent variable will represent the score obtained by each alternative (Akadiri, 2011).

iv. ***Linear Programming (LP):*** LP is an optimized method to define the maximum or minimum value of a linear function, called $f(x_1, x_2 \ldots x_n)$ an objective measure, subject to a number of linear type $A_x + B_y + C_z + \ldots \leq N$ or $A_x + B_y + C_z + \ldots \geq N$. The optimal value is the largest or smallest value of the objective function, and a set of values of x

, y, z,. Which gives the optimum value is the ideal solution. The x, y, z. Variables Are named variables of the decision (Akadiri, 2011).

v. ***Analytical Hierarchy Process (AHP):*** Probably the most widely used Analytical Hierarchy Method (AHP) for prioritizing alternative decisions. The essence of the method, introduced by Saaty (1980), is the decomposition of a complex problem into a hierarchy with target (objective) at the top of the hierarchy, criteria and sub-criteria at the levels and sub-levels of the hierarchy, and alternatives of decision at the bottom of the hierarchy. Elements at a given hierarchy level are compared in pairs to determine the irrelative choice at the next higher level with respect to each of the elements.

Table 2: Characteristics of MCA tools (Akadiri, 2011, P.281)

Technique	Nature of input data	Nature of output
Scoring multi attribute analysis (SMAA)	Interval and ordinal but Subjective	Numeric score and ranks and hence rank amongst alternatives
Multi-attribute utility theory (MAUT)	Raw data is often qualitative, utility achieves interval data	Numeric score and ranks and hence rank amongst alternatives
Multiple regression	Interval predictive	Numeric; further value
Linear programming	Value judgment on the importance of an over-all objective	Maximization of objective function
Cluster analysis	Multivariate	Group membership/group characteristics
Weighted sum method	Interval and ordinal but Subjective	Numeric score and ranks and hence rank amongst alternatives
Analytical hierarchy process	Raw data is often qualitative, utility achieves interval data	Numeric score and ranks and hence rank amongst alternatives

2.4 Material Selection Criteria

Akadiri (2011) describes the idea of building sustainability as a means of developing and sustaining a safe built environment while at the same time concentrating on minimizing resource and energy use, thereby reducing environmental harm, promoting reuse and recycling and enhancing the protection of the natural environment. These goals can be accomplished by considering at an early stage, through the method of material assessment, the most productive choice among competing alternatives. Medineckiene et al., (2014) argue, therefore, that it is important to include the construction sector in the 'urban,' 'eco,' 'sustainable' or other similar trend, which will enhance the quality of the building according to the criteria set.

To address this, Akadiri et al., (2012) noted that practitioners in the construction industry have started to pay attention to monitoring and mitigating environmental harm as a result of their activities. Architects, designers, engineers and those involved in the construction process have a rare opportunity to reduce the environmental impact by incorporating sustainability targets during a building project's design development period.

2.4.1 Parameters and Factors

Numerous researchers have devoted their expertise into material selection criteria and parameters, notably; Adadiri, (2011), Akadiri et al., (2012), Bahtt R., (2010), Medneckiene M. et al., (2014), Florez L. (2010), and Watiels and Wouters (2008). Akadiri, (2011) noted that a wide scope review of literature revealed that there was no comprehensive list of assessment criteria developed specifically for material selection in building projects.

Watiels and Wouters (2008) conducted a focus group study of five Belgian architects to understand the method of selecting materials and the factors that are considered when selecting materials. The participants came up with seven different aspects groups.

i. **Physical Aspects:** Relate to the technical features found on, or directly related to, a technical material data sheet (strength, porosity, acoustics and weight). The respondents refer to it as straight aspects of engineering.

ii. **Appearance:** covers the material's visual or tactual aspects (color, texture, gloss, softness).

iii. **Subjective:** In this aspect category the material choice is related to intuition and is personally influenced (memory, aesthetically pleasing, character, and atmosphere).

iv. **Cultural Context:** Aspects such as quality, style, and expression, are grouped together under the name

v. **Physical context:** classes considerations such as location, use, application, and orientation of the building.

vi. **Time;** Adaptability, Flexibility and Temporality

vii. **Money:** Cost, Time, and Delivery

Even though the manufacturing process and its implications were not mentioned by Watiels and Wouters, (2008)'s focus group during their grouping task, during the discussion of the framework they acknowledged that these aspects can be of major importance while selecting a material. The focus group reiterates that the manufacturing process will certainly affect the selection of material in a project where a large number of identical elements are needed.

Material properties are defined as "the tangible aspects, or actual measurable properties, of the chosen material. These aspects are directly related to the (physical) behavior of the material and the production technique." (Watiels and Wouters, 2008, P.379/9).

A distinction can be made between aspects relating to the technical performance (the physical aspects) and those relating to our senses (the sensorial aspects). *Physical aspects* refer to the different aspects that concern the engineering, like stiffness, strength, porosity, density, thermal absorption coefficient etc. (Watiels and Wouters, 2008).

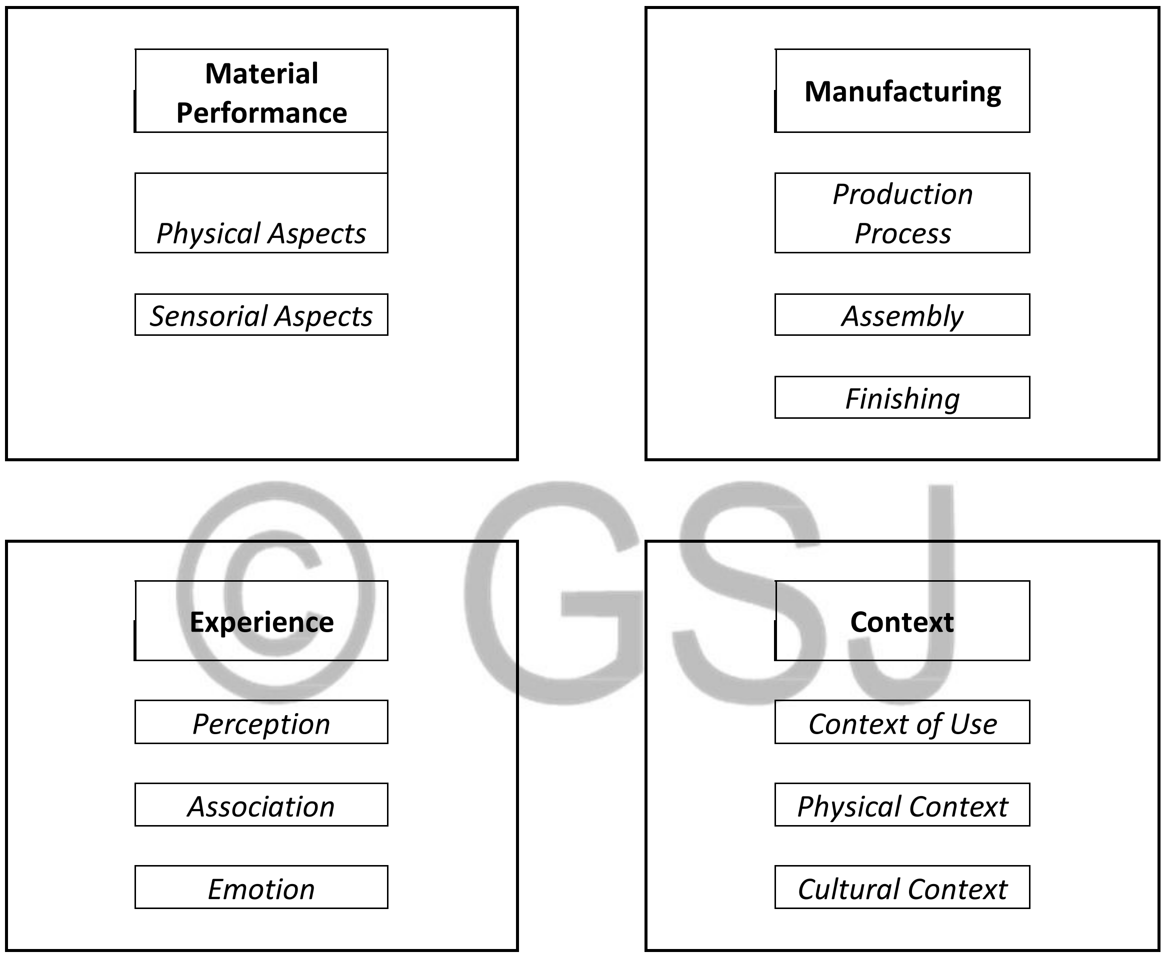
Akadiri (2011) also developed the following set of guidelines to aid the choice of criteria to assess the options under consideration for material selection

i. ***Comprehensiveness:*** The criterion chosen should cover the four categories of economic, environmental, social and technological, in order to ensure that account is being taken of progress towards sustainability objectives (Akadiri, 2011).

ii. ***Applicability:*** The criteria chosen should be applicable across the range of options under consideration. This is needed to ensure the comparability of the options (Akadiri, 2011).

iii. ***Transparency:*** The criteria should be chosen in a transparent way, so as to help stakeholders to identify which criteria are being considered, to understand the criteria used and to propose any other criteria for consideration (Akadiri, 2011).

Table 3: Refined framework of material selection considerations (Watiels and Wouters, 2008, P.379/10)



iv. ***Practicability:*** The set of parameters selected must form a realistic framework for the purposes of the decision to be made, the methods to be used and the time and resources available for review and evaluation (Akadiri, 2011).

In his PhD dissertation, Akadiri (2011) conducted a survey as a result of which he identified the 24 criteria as being important components of material selection. These criteria are listed as follows on Table 4:

Table 4: Material Selection Criteria (Akadiri, 2011, P.241)

Environmental Criteria	**Socio-economic Criteria**	**Technical Criteria**
E1: Potential for receiving and reuse	S1: disposal cost	T1: Maintainability
E2: Availability of environmentally sound disposal options	S2: Health and safety	T2: Ease of construction (buildability)
E3: Impact of material on air quality	S3: Maintenance Cost	T3: Resistance to decay
E4: Ozone depletion Potential	S4: Aesthetics	T4: Fire resistance
E5: Environmental impact during material harvest	S5; Use of local material	T5: Life expectancy of material
E6: Zero or low toxicity	S6: Initial (acquisition cost)	T6: Energy saving and thermal insulation
E7: Environmental statutory compliance	S7: Labor availability	
E8: Minimize pollution (e.g. air, land)		
E9: Amount of likely wastage in use of material		
E10: Method of raw material extraction		
E11: Embodied energy within material		

These The 24 criteria were further compressed into six of assessment criteria factors –

i. Environmental Impact
ii. Resource Efficiency
iii. Waste Minimization
iv. Life Cycle Cost

v. Performance Capability
vi. Social Benefit

Akadiri et al., (2012) indicates that there are several ways to monitor and enhance the current nature of construction operation to make it less environmentally harmful, without reducing the productive performance of building activities. Similarily, Bhatt et al., (2010) agrees with this statement that it is high time that countries develop their building assessment tools to cover all areas such as environmental, social, economic and cultural security.

Akadiri et al.,(2012) reviewed of numerous literatures and had identified three general objectives which should shape the framework for implementing sustainable building design and construction, while keeping in mind the principles of sustainability issues (social, environmental and economic) identified previously. These objectives are:

i. Resource Conservation
  a) Energy Conservation
  b) Material Conservation
  c) Water Conservation
  d) Land Conservation

ii. Cost efficiency
  a) Initial cost
  b) Cost in use
  c) Recovery Cost

iii. Design for Human Adaption
  a) Protecting Human health and comfort
  b) Protecting physical resources

Bhatt R. et al. (2010) reiterates the idea of sustainability by saying that while the idea of 'green' is rising in the Asian subcontinent, it needs to be made 'sustainable' in order to address a wide spectrum of sustainability issues. Accordingly,

Assessment framework for sustainable building- Indian Context:

i. Sustainable site

ii. *Water Efficiency*

iii. *Energy Efficiency*

iv. *Materials and Resources*

v. *Indoor Environmental Quality*

vi. *Environmental Loadings*

vii. *Social and Economic Aspects*

viii. *Cultural Aspects*

ix. *Service Quality*

In their analysis, Bhatt R. et al., (2010) used the Analytical Hierarchy Method (AHP) as a. Multi-Criteria Analysis (MCA) for evaluating and analyzing the criteria and factors that stakeholders consider in their Indian construction industry material selection process.

After devising the possible factors into hierarchical structure with the above list as issue, the study found the following 20 parameters as paramount in material selection process – Indian Context:

Table 5: Crucial Parameters for Sustainable Building (Bhatt R. et al., 2010, P. 887)

Parameters	Rank
C.2 Renewable Energy use for building operations	1
C.1 Optimum Energy Performance from non-renewable energy source	2
C.4 Energy Accountability	3
B.4 Water Use Reduction	4
B.3 Reduced Waste Water Generation	5
C.3 Off-Site Renewable energy use for building operations	6
B.1 Eliminate Water use for Landscaping in Garden	7
F.4 Retention- Rain Water	8
F.1.2 Annual Green House Gas emissions from Facility operations	9
B.5 Efficient Water Use during Construction	10
B.2 Water Efficiency in Air-Conditioning system	11
H.3 Maintain Heritage Value	12

G.2.1 Minimize Life-Cycle Cost of the building	13
H.2 Urban Design to suit Local Cultural Values	14
D.1 Reuse of Existing Structure	15
E.2.1 Natural Ventilation in Occupancy areas	16
G.2.3 Minimum Operation & Maintenance Cost	17
H.1 Design Relate to Existing Streetscape – Cultural value	18
I.1 Safety- Security of building	19
D.3 Recycled Material use	20

Akadiri et al., (2012) argue that there is general agreement that the nature of the concept of sustainable construction reflects that of sustainable development, which is about synergistic relationships between economic, social and environmental sustainability aspects.

2.5 Research Gap

Although researches have been done centered around material selection with sustainability as a driving concept, the conducted researches were focused mainly on European and Asian countries. The methodology of the conducted researches were mainly concerned with identifying criteria for material selection for instance Shirazi et. al., (2013), Marques et. al., (2019) etc… while few such as Akadiri, (2011), Bhatt R. et.al,, (2010) etc… went even further by using various techniques (MCA, MCDM etc…) to evaluate these identified criteria. And, no evidence was found in the extensive literature survey (100 literatures) and ERA research database that similar research to this thesis work was conducted in Ethiopia.

Since building material selection is site sensitive as in the criteria and weightage for building material selection vary significantly with changing geographical location, local designers and consultants can't logically use these foreign identified criteria in Ethiopia. In addition to the geographical location gap, this thesis work goes further in that after identifying and evaluating the criteria, a computer program is proposed to facilitate and streamline the selection process. Past research works developed sustainability index such as Akadiri (2011) while others like Watiels and Wouters (2008) only developed a framework.

Therefore, on the back of these aforementioned research gaps, conducting this research was deemed appropriate.

Chapter 3: Materials and Methods

This chapter includes the methodology used in this thesis work and provides information about the research strategy, research design, research location, case study, questionnaire design, questionnaire content, the process and methods of data analysis, and software coding process and methods used.

3.1 Research Design

Research design is the overall plan for obtaining answers to the questions being studied and for handling some of the difficulties encountered during the research process (Seyoum A., 2015). Research design is an action plan for getting from here to there where here may be defined as the initial set of questions to be answered, and there is some set of conclusion (answers) about these questions.

Two types of research strategies are used at studies, quantitative and qualitative research. Quantitative approach is used to gather factual data and to study relationships between facts and how such facts and relationships accord with theories and the findings of any research executed previously, but the qualitative approach seek to gain insights and to understand people's perception of "the world" whether as individuals or groups (Royal geographical society, 2012). The research strategies adapted for this research were both qualitative and quantitative research.

The research design and strategy is best illustrated in a flowchart on Chart 1.

The following clear steps will be used in the research process:

I. The first step in this research design would be “Assessment of current practice”, this will be done through Intensive literature survey review, design document survey review, discussion, and questionnaire survey. This assessment will focus on the current Financial, Manufacturing, Technical and Environmental considerations of the current building material selection process, if any.

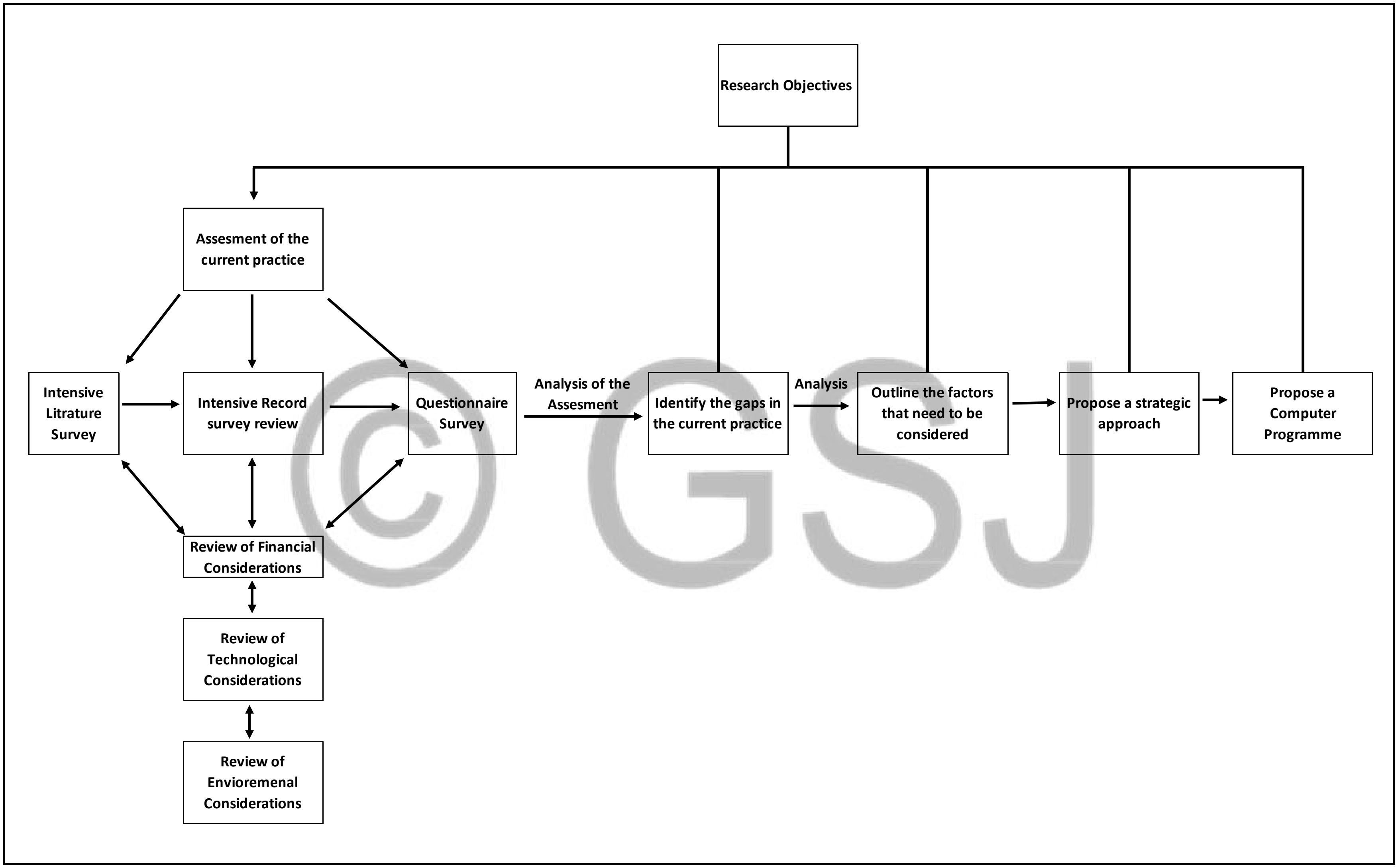


Chart 1: Research Methodology

II. The second step in this research design would be “Identify the gaps in the current practice”, this will be accomplished after a thorough analysis of the assessment of the current practice. The Assessment will lead us to the gaps.

III. The third step in this research design would be “Outline the factors that ought to be considered”: After identifying the gaps in the current practice, factors will be recommended to be considered in the selection process.

IV. The fourth step in this research design would be “to propose a strategic approach and flowchart”: a strategic approach will be recommended based on the gaps identified.

V. The fifth step in this research design would be “to propose a Computer Program”: a computer and coding will be used for this objective.

3.2 Data collection

Both primary and secondary data were included in this research. Primary data were gathered from observation, checklist and questionnaire with study participants such as consultants, contractors and academics. Secondary data used include literatures, Design Document drawings, reference books, journals, previous studies etc. written on similar topic.

Questionnaire was developed and distributed to consultants, contractors, and academics. The questionnaire was close ended and general and were helpful as an additional guidance in the data collection process.

3.3 Questionnaire Design

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

3.4 Sample Size Determination

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

The population of this research included Consultancy Firms, Construction Contracting Firms and Academicians. Therefore, the populations this research, includes Consultancy firms classified as G1- G6 and Contractors classified as G1 - G3.

In this research, the population includes consultancy companies of G1 up to G6 Consultants, G1 Contracting companies and Academicians/Professionals that have a valid registration by Tigrai Bureau of Construction, Road & Transport in National Regional State of Tigrai. Because those selected population, have a sufficient experience in construction, managerial capability and has more than one hundred seventy five million Birr contracting amount capacity.

There are 135 total numbers of G1-G6 consultants and there are 24 G1-G3 contractors companies registered in National Regional State of Tigrai. The sample population was distributed between Consultancy Firms: 7 of G3, 13 G5, 115 G6 consultants and 2 G1 contractor, 8 G2 contractor and 14 G3 contracting companies.

To Sample Academicians/Professionals with building design and construction experience in Mekelle University, reconnaissance survey was made and 5 suitable Academicians were identified. Therefore, this research paper considers these Academicians as sample representatives.

Therefore, the following equation is used to determine the sample size (Czaja and Blair, 1996).

Equation 5 [Eq.5]: Sample Size Determination (Czaja and Blair, 1996)

$$Ss = \frac{Z^2 \times P(1-P)}{C^2}$$

Where:

Ss =sample size

z = standardized variable

p = percentage picking a choice, expressed as a decimal

c = confidence interval, expressed as a decimal

As with most other research, a confidence level of 95% was assumed (Munn and Drever, 1990; Creative Research Systems, 2003 as cited by Akadiri, 2011). For 95% confidence level (i.e. significance level of $\alpha = 0.05$), $z = 1.96$. Based on the need to find a balance between the level of precision, resources available and usefulness of the findings (Maisel and Persell, 1996 as cited by Akadiri, 2011), a confidence interval (c) of ±10% was also assumed for this research. According to Czaja and Blair (1996), when determining the sample size for a given level of accuracy, the worst case percentage picking a choice (p) should be assumed. This is given as 50% or 0.5. Based on these assumptions, the sample size was computed using [Eq.6] as follows:

$$Ss = \frac{1.96^2 \times 0.5(1-0.5)}{0.1^2}$$

$$\underline{Ss = \mathbf{96.04}}$$

Equation 6 [Eq.6]: Correction for Finite Sample (Czaja and Blair, 1996)

$$new\ Ss = \frac{Ss}{1 + \frac{Ss-1}{Pop}}$$

$$new\ Ss = \frac{96.04}{1 + \frac{96.04-1}{164}}$$

$$\underline{Ss = \mathbf{60.8 = 61}}$$

In this research a margin of error of 10% was used which is slightly higher than the recommended 5% margin of error for academic research. This was done to find a balance between the usefulness of the findings, the resources available and level of precision required. Margin of error is a figure that indicates how much your sample size represents your population. The higher the margin of error indicates a less representation of your population by your sample size. In this case, 10% margin of error is less representative than if 5% were to be used.

To ensure good representation of each stratum, the following was done:

Table 6: Classification of Target Population based on Competency Grade

Sr. No	Category	Grade	Original Population (Ss old)	New Population (Ss new)
1	Consultant	G1	0	0
2		G2	0	0
3		G3	7	(61*7)/(164)= 2.6=**3**
4		G4	0	0
5		G5	13	(61*13)/(164)=4.83=**5**
6		G6	115	(61*115)/(164)= 42.77= **39**
7	Contractor	G1	2	(61*2)/(164)=0.65=**1**
8		G2	8	(61*8)/(164)=2.94=**3**
9		G3	14	(61*14)/(164)=4.86= **5**
10	Academics	-	5	**5**
		Total	**164**	**61**

Table 7: Classification of Target Population based on Operating Address

Sr. No.	Category	City	Population (S_s)	New Population (Ss new)
1	Consultant	Mekelle	106	(61*106)/(164)= 37.2=**38**
2		Axum	7	(61*7)/(164)= 2.6=**3**
3		Adwa	3	(61*3)/(164)= 1.11=**1**
4		Adi Grate	4	(61*4)/(164)= 1.48=**1**
5		Shire	15	(61*15)/(164)= 6.12=**5**
6	Contractor	Mekelle	23	(61*23)/(164)= 8.55=**8**
7		Adi Grate	1	(61*1)/(164)= 0.37=**0**
8	Academics	Mekelle	5	**5**
		Total	**164**	**61**

3.5 Sampling Technique

The guiding principle behind simple random sampling technique is that each element must have an equal and nonzero chance of being selected. This can be achieved by applying a table of random numbers or a computer generated random numbers to a numbered sampling frame (Abiy et al. 2009).

Random Sampling was used for this research using Microsoft Excel's built-in "RAND ()" function. The Sample Population were inserted in to Excel and the population turned out after implementing the function were used for this research.

3.6 Analysis and Findings

Analysis of data collected using check list, questionnaire and reports was done. Based on the analysis there were in depth discussions on the analysis and then finally conclusions were made from the discussion made in the research and recommendations were made. In addition some areas of further research were suggested.

3.6.1 Relative Importance Index (RII)

The sample for this study is relatively small. As a result, the analysis had combined all groups of respondents in order to obtain significant results. Data was analyzed by calculating frequencies and Relative Importance Index (RII). The Relative Importance Index (RII) is calculated as follows (Aibinu and Jagboro, 2002 as cited by Joro, 2015) using IBM SPPS Statistics Software 20 and Microsoft Excel 2016 as a tool.

Equation 7 [Eq.7]: Relative Importance Index (RII)

$$RII = \frac{5n_5 + 4n_4 + 3n_3 + 2n_2 + 1n_1}{5 \times N}$$

Where:

N = Total number of respondents

n_5= Number of frequency 'Highest/Strongly Agree' response,

n_4= Number of frequency '4' response.

n_3 = Number of frequency '3' response.

n_2= Number of frequency '2' response.

n_1= Number of frequency 'Lowest/Strongly Disagree' response. .

The levels of response are:

"5" = Strongly Agree/Highest [100%] "4" = Agree/High [75%]

"3" = Neutral [50%] "2" = Disagree/ Low [25%]

"1" = Strongly Disagree/Lowest [0%].

3.6.2 Spearman's Rank Correlation Coefficient

"In statistics, Spearman's rank correlation coefficient or Spearman's ρ, named after Charles Spearman, is a nonparametric measure of rank correlation (statistical dependence between the rankings of two variables). It assesses how well the relationship between two variables can be described using a monotonic function." ("Spearman's Rank Correlation Coefficient", n.d., para. 1).

Equation 8 [Eq. 8]: Spearman's rank correlation coefficient

$$T_s = 1 - \frac{6 \sum D^2}{n(n^2 - 1)}$$

Where:

D = the numerical difference between the rankings of two stakeholders

n = Number of items in the List

If there are no repeated data values, a perfect Spearman correlation of +1 or −1 occurs when each of the variables is a perfect monotone function of the other. ("Spearman's Rank Correlation Coefficient", 2020)

3.7 Programming Language

Programming language is a text like readable code that can be used to communicate with a computer of any kind. Python programming language was used for the development of the computer program. Python was chosen for its readable code, and also has a compressive library which made it the fastest growing programming language of 2019 globally according to 2019 IEEE ranking (Cass, 2019).

Chapter 4: Results and Discussion

This thesis research employed literature survey review, Discussion, Questionnaire survey and design document review to gage and to collect data about sustainability awareness and material selection practices in Ethiopian architects and designers that are heavily involved in building design and construction industry.

After the questionnaire survey was carried out, statistical analyses were undertaken on the responses using various methods described in the research methodology. Literature survey was conducted on numerous literatures of which the outcome played the primary role in shaping the questionnaire design and questions.

The discussion was conducted by discussing sustainability awareness and material selection practices with fellow professionals and various stakeholders that might be involved in the designing and planning phases of a project. The results of the discussions have directed the theme and talking points of the thesis. And at last, a design document review was done on 40 completed and ongoing design drawings to assess the current practice of building material usage and material selection trends.

4.1 Analysis of the Questionnaire Survey

In this section of the thesis, the survey done through questionnaire will be investigated to ascertain the objectives and questions for the research.

4.1.1 General Questionnaire Information

In This section, general questionnaire information such as classification of the sample population, response rate, and questionnaire distribution will be discussed.

4.1.1.1 Classification of the Sample Population

To get a better assessment of Material Selection practice results and analysis have been obtained from processing of Sixty-One (61) questionnaires using Excel and statistical package for social sciences (SPSS) version 20 . The results are prepared to present the information about the sample size, response rate and Awareness of Material Selection in Ethiopia, Tigrai. It also includes the ranking of factors affecting Material Selection.

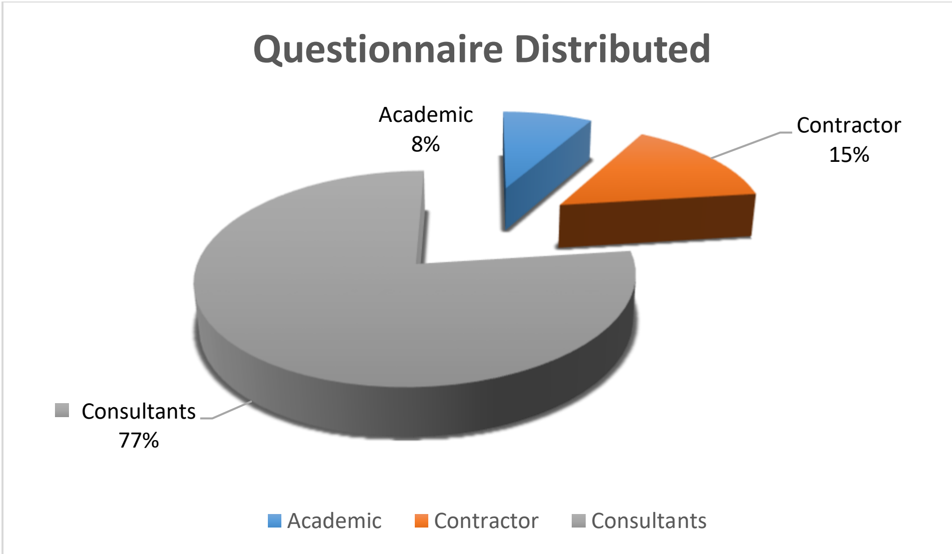


Chart 2: Questionnaires Distributed

4.1.1.2 Response Rate

As the population size is a small one, it was tried to include respondents from different aspects of the profession. Table 8 illustrates the response rate of the questionnaire survey which is 61%. Four (4) of the responses were Illogical or Uncompleted whereas twenty (20) were not returned at all and thirty seven (37) were returned. This is illustrated in Chart 3.

The response rate for this research is 61%. The response rate is calculated by dividing valid response questionnaires by distributed questionnaires (sample size). Even though there is no agreed-upon requirement for research response rate; American Association for Public Opinion Research (AAPOR) recommends 60% (Marske, 2019) while Lindermann (2019) found that 33% is the average response rate using most recent data (as of 2019) from commonly used survey method (in-person, e-mail etc…) with in-person questionnaire survey averaging 57%. Schutt (1999) was more definite by saying that response rate below 60% is unacceptable while Babbie (1990) indicated a 50% response rate is adequate.

The response rate for this research is acceptable according to Fincham (2008) by suggesting that researchers should aim for response rates approximating 60% as it is the expectation of the editors of the *Journal* (American Journal of Pharmaceutical Education). Although literature does not reflect requirement on a minimum acceptable response rate, there is a general consensus that at least half of the sample should complete the survey instrument (Draugalis et al., 2008).

Table 8: Questionnaire Response Rate

Questionnaire Response Rate					
No	**Respondents**	**Distributed**	**Returned**	**Valid Response**	**Percentage**
1	**Consultants**	47	28	25	53.19%
2	**Contractors**	9	9	8	88.88%
3	**Academics**	5	4	4	80%
	Total	61	41	37	60.66%

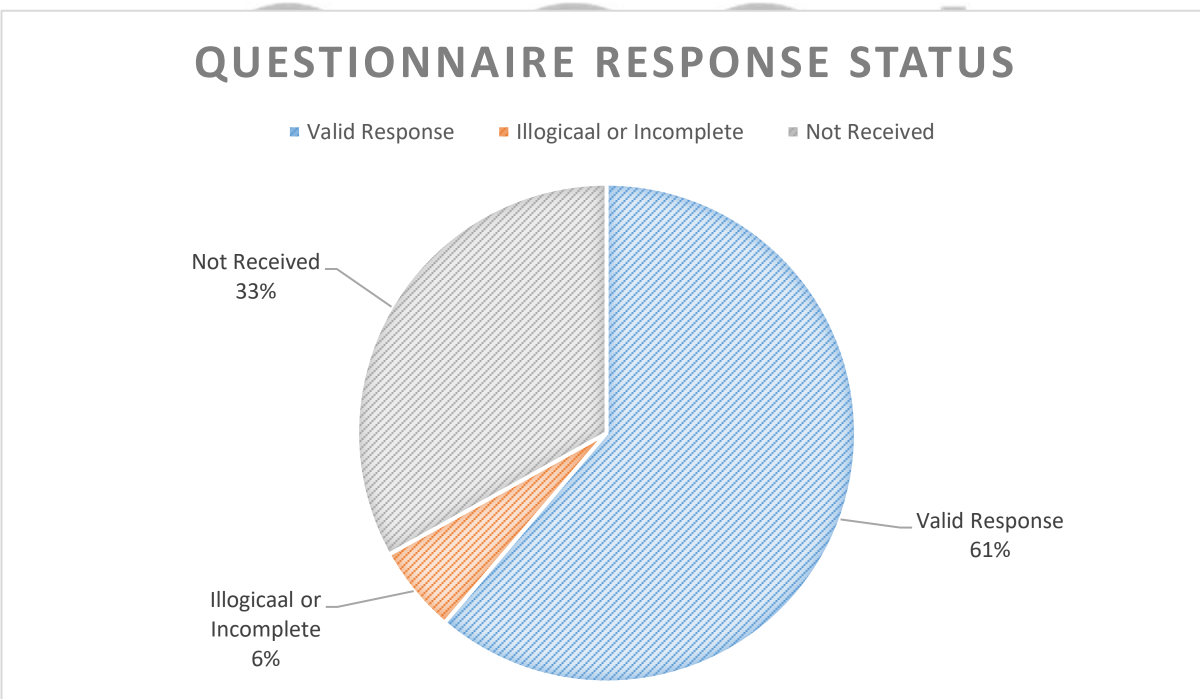


Chart 3: Questionnaire Response Status

4.1.2 Background of the Respondents

The sample population consisted of Consultancy Companies, Contracting Companies and Academics. In this section, the experience of the respondents, type of organization they work for and area of the specialization is presented.

4.1.2.1 Experience of the Respondents

As Table 9 shows, the experience of the respondents' ranges from 0 – 20 years which is quite respectable, with a mean of 5.36 years and Standard deviation of 1.873. The minimum experience of a respondent is 1 year and the maximum is 11 years. We can safely presume that opinions and views obtained through the survey can be regarded as important and reliable. Majority of the Respondents (62.16%) work in Design which is the primary concerned body in Material selection and Sustainability aspects which further shows that respondents are sufficiently experienced enough to provide data which are credible.

Table 9: Amount and Nature of Experience of the Respondents

Work Experience of the Respondents					
No	**Year Range**	**Respondents**	**Percentage**	**Mean**	**Std. deviation**
1	0-5 Years	23	62.16%		
2	5-10 Years	13	35.14%	5.36	1.873
3	>10 Years	1	2.7%		
	Total	37	100%		
Nature of Experience					
No	**Category**	**Respondents**	**Percentage**	**Mean**	**Std. deviation**
1	Design	23	62.16%		
2	Construction	8	21.62%	1.65	1
3	Construction Management	2	5.41%		
4	Academic	4	10.81%		
	Total	37	100%		

4.1.2.2 Type and Size of the Respondent Organization

As Table 10 shows, the type of Organization the respondent works for ranges from Architectural & Design office to Contractor opinions whereas Size of their organization ranges from few people to 7000 people in a construction firm. This shows the large variance the industry has in the professionals and the organization structure they follow.

Table 10: Type and Size of the Respondent Organization

Type of Organization					
No	**Organization Type**	**Respondents**	**Percentage**	**Mean**	**Std. deviation**
1	Architecture & Design Office	23	62.16%	2.89	2.81
2	Engineering	1	2.7%		
3	Quantity Surveying	2	5.4%		
4	Education	4	10.81%		
5	Contractor	7	12.93%		
	Total	37	100%		
Size of Organization					
No	**Number of Employee**	**Respondents**	**Percentage**	**Mean**	**Std. deviation**
1	0 – 10 Employees	23	62.16%	846.37	2014.69
2	10 – 100 Employees	4	10.81%		
3	100 – 7000 Employees	8	21.63%		
4	Missing Data	2	5.4%		
	Total	37	100%		

4.1.2.3 Regular Client Type and Area of Specialization of the Respondents

As Table 11 shows, the regular client type of the respondent is mostly private sector (78.38%), this shows that the respondent are heavily involved in private construction. And there are of Specialization also caries from Commercial (13.5%) to Institutional (27.5%).

Table 11: Regular Client Type and Area of Specialization of the Respondents

Regular Client Type					
No	**Regular Client Type**	**Respondents**	**Percentage**	**Mean**	**Std. deviation**
1	Public Sector	8	21.62%	1.78	0.417
2	Private Sector	29	78.38%		
3	Quasi-Public	0	0%		
4	Industrial	0	0%		
	Total	37	100%		
Area of Specialization					
No	**Specialization**	**Respondents**	**Percentage**	**Mean**	**Std. deviation**
1	Commercial	5	13.5%	2.14	0.63
2	Residential	22	59.5%		
3	Institutional	10	27.5%		
4	Industrial	0	0%		
5	Leisure	0	0%		
6	Other	0	0%		
	Total	37	100%		

4.1.3 Sustainability Awareness and Material Selection Practice

The main purpose of this research paper is to know the sustainability level of awareness and the Material Selection practice of the architects and designers.

4.1.3.1 Sustainability and Environmental Awareness

Respondents were asked to rate their level awareness of sustainability and environmental issues, with most respondents answering "Somewhat Aware". The analysis of the data shows the peak to be concentrated on "Somewhat Aware" with the mean 2.95 which is also close to "Somewhat Aware".

Another Interesting Finding is that the Std. deviation is 0.911. Having this value if we calculate the coefficient of Variation as follows:

Equation 9 {Eq. 9]: Coefficient of Variation (CV)

$$\text{Coefficient of Variation (CV): } \frac{Standard\ Deviation}{Mean}$$

With CV >=1 = High Variation

CV < 1 = Low Variation

Table 12: Level of Awareness

Level of Awareness							
No		**Respondents**	**Percentage**	**Mean**	**Sd (σ)**	**Mode**	**CV**
1	Extremely Aware	2	5.4%	2.95	0.911	3.00	0.31
2	Moderately Aware	9	24.3%				
3	Somewhat Aware	16	43.2%				
4	Slightly Aware	9	24.3%				
5	No Idea	1	2.7%				
	Total	**37**	**100%**				

As it is sown in Table 12, the Coefficient of Variation is 0.31 which shows low Variation in the level of awareness of the respondents. In other words, we can say that the respondents have similar level of awareness about sustainability and environmental issues in construction which is 'Somewhat Aware".

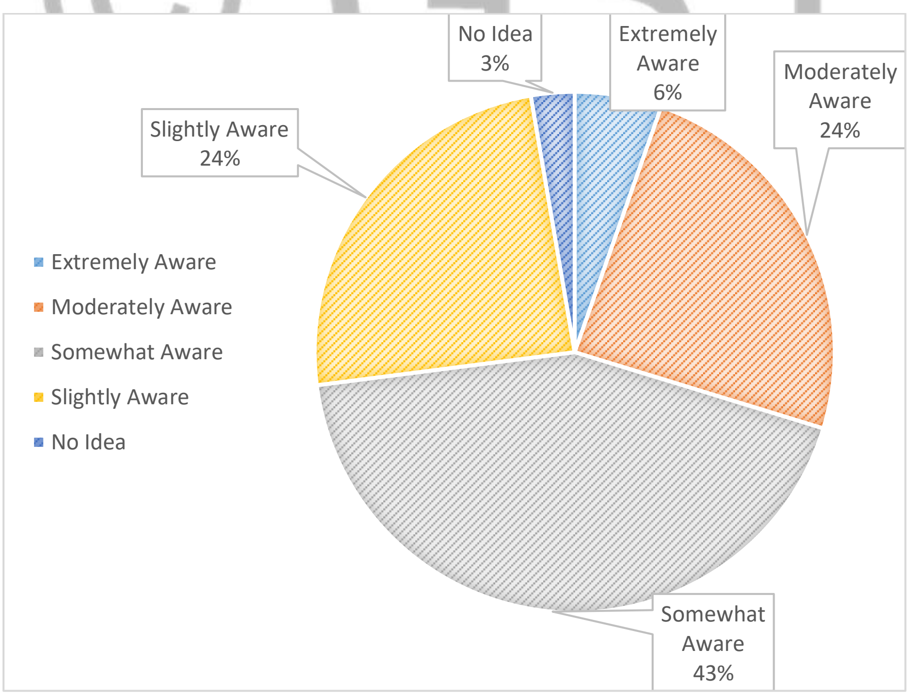


Chart 4: Level of Awareness

4.1.3.2 Sustainability Issues in the Planning stage of a Building Project

The respondent were asked to evaluate the notion that Sustainability Issues should be included in the planning stage of a building project. As it can be shown in Table 13, the respondents almost exclusively agreed or strongly agreed with the statement.

Table 13: Sustainability Issues in Planning Stage

Sustainability Issues at Conceptual/Planning Stage							
No		**Respondents**	**Percentage**	**Mean**	**Sd (σ)**	**Mode**	**CV**
0	Strongly Disagree	0	0%	3.38	0.639	3.00	0.19
2	Disagree	0	0%				
3	Neutral	3	8.2%				
4	Agree	17	45.9%				
5	Strongly Agree	17	45.9%				
	Total	**37**	**100%**				

The mean answer of the respondents is 3.38 which is almost in the midpoint of “Agree” and “Strongly Agree”, slightly notched to the “Agree” option. The CV value of 0.19 also shows the level agreement of the respondents such that their answers doesn’t vary much.

Sustainability Awareness nowadays is not a luxury action to take, it has become a vital part of the designing and planning stage. Respondents were asked to rate their level of awareness and the result indicated that majority of the respondents were “Somewhat Aware”. This result shows a much needed work should be done to implement the issue in a broader and accommodating manner such that the designers and other stakeholders become more aware and apply it in our construction industry.

Awareness of Sustainability and environmental issues are directly related to the application of the practice. Low awareness implies low application and vise-versa.

Another issue the research tried to find out is the application of sustainability in planning and design stage of a building projects. Even though almost all respondents (91.8%) exclusively agreed or strongly agreed that sustainability issues should be included in the planning/design stage, its actual application is doubtful as discussions and interviews with various designers and architects yielded not so definite answer. The perception that the idea of sustainability incurs additional cost and some other obstacles have played their part in its low application in Tigrai. The obstacles and perception of sustainability will be discussed more in detail later.

It is also important to acknowledge that any decisions and choices the designer makes when embarking on a building project will impact and affect the environment. This very question was presented to the respondents to which they almost exclusively (91.8%) agreed or strongly agreed with the idea. This also takes us back to low application of material selection practice which was observed in the design document review conducted alongside the questionnaire survey. Another related question was presented to the respondents in the form of sustainability considerations in material selection decision making. For this question majority of respondent agreed or strongly agreed with the statement. However though, its application is doubtful as can be observed in the design document review with 75% of the floor area covered by only two floor finish materials even though the assessed building were located in various locations, designed by various consultancy companies and most importantly, the materials covered floor areas for various room functions, which can imply the low application of material selection and use of generic, overused materials with little attention and focus to material selection.

4.1.4 Building Project Objectives in Building Construction

The respondents were asked what project objectives they aimed for when embarking on a building project, the Relative Importance Index (RII) of their response and their respective rank is presented on Table 14.

The most important objectives for Consultants when embarking on building project is meeting building regulations and minimizing project cost whereas the most important objective for Contractors is meeting project deadline and minimizing project cost.

Table 14: RII of Building Project Objectives in Building Construction

Project Objectives	Consultants		Contractor		Academics		Overall Rank	
	RII	Rank	RII	Rank	RII	Rank	RII	Rank
1. Meet project deadline	0.84	3	1	1	0.94	1	0.93	1

2. Meet building regulations	0.86	1	0.875	3	0.94	1	0.89	2
3. Minimize Project Cost	0.85	2	0.91	2	0.875	2	0.88	3
4.Satisify client specification	0.81	4	0.875	4	0.94	1	0.88	3
5.Minimize project impact on environment	0.73	5	0.719	5	0.94	1	0.8	5

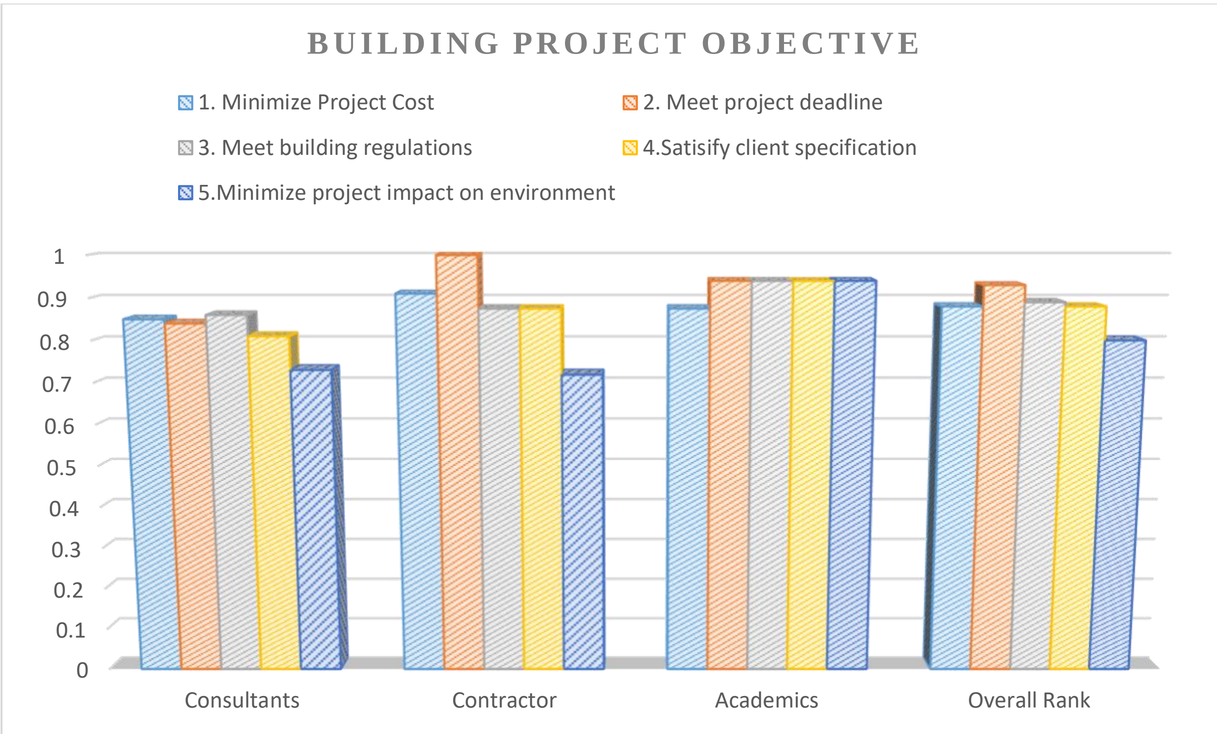


Chart 5: Building Project Objectives in Building Construction

Project objectives when embarking on a building project will be huge determinant of how the designer and planner will handle the project. This is an easy indicator of material selection and whether the sustainability considerations will be applied in project design and planning. The question was presented to the respondents, and their responses were presented and ranked on Table 14. The findings showed that Consultants' objective is to meet building objectives. This can be because the stricter building requirements enacted past few years. This can be a good thing as building regulations contain requirement for environmental and material selection. However though, a rough review of Ethiopian building regulations shows that only minor environmental issues such as green space area requirements but not much is required on the building itself in terms of sustainability.

Meanwhile Contractors' objective is to meet project deadline. This can be the obvious reason as most contractors are contractually obligated to meet the deadline. However though, this insistence of meeting the project deadline may lead to shortcuts that negatively impact sustainability and material selection decisions made in the planning and design phase. As some sustainable actions and materials might take more deliberation and more time to apply and construct.

Academics can play a starring role in pushing sustainability and material selection concepts to the forefront of the construction industry. As a result, Academics were part of the focus for this research. The same question was presented to Academics to find out which objectives should be aimed for when embarking on a building project. Of the provided project objective alternatives, Academics ranked "Meet project deadline, Meet building regulations, satisfy client specification, minimize project impact on environment" as their first choice objectives. This may show that Academics value these objectives equally and try to aim for them when embarking on a project.

4.1.5 Application of Sustainability in Design and Material Selection Practice

In this section, application of sustainability in design and material selection practice will be analyzed and interpreted.

4.1.5.1 Knowledge of Material Selection

The respondents were asked to evaluate the extent of their knowledge of material selection. As it can be shown in Table 15, the majority of the respondents from consultant side (40%) had Sufficient or Good knowledge of material selection with a mean 2.68 which is almost at the midpoint of "Good" and "Sufficient" with 4 of the respondents answering "Insufficient". The CV of the analysis is 0.299 which shows that the majority of consultants have acceptable knowledge of material selection with little variation.

The majority of the respondents from contractor side (60%) had sufficient knowledge of material selection with a mean 2.88 which is almost at the midpoint of "Good" and "Sufficient" with 1 of the respondents answering "Insufficient". The CV of the analysis is 0.29 which shows that the majority of contractors have acceptable knowledge of material selection with little variation.

Table 15: Knowledge of Material Selection

Knowledge of Material Selection							
Consultants							
No		**Respondents**	**Percentage**	**Mean**	**Sd (σ)**	**Mode**	**CV**
1	Excellent	1	4%	2.68	0.802	2.00	0.299
2	Good	10	40%				
3	Sufficient	10	40%				
4	Insufficient	4	16%				
5	Don't Know	0	0%				
6	Not Applicable	0	0%				
	Total	**25**	**100%**				
Contractors							
1	Excellent	1	12.5%	2.875	0.834	3.00	0.29
2	Good	0	0%				
3	Sufficient	6	75%				
4	Insufficient	1	12.5%				
5	Don't Know	0	0%				
6	Not Applicable	0	0%				
	Total	**8**	**100%**				
Academics							
1	Excellent	0	0%	3.00	0.82	3.00	0.27
2	Good	1	25%				
3	Sufficient	2	50%				
4	Insufficient	1	25%				
5	Don't Know	0	0%				
6	Not Applicable	0	0%				
	Total	**4**	**100%**				

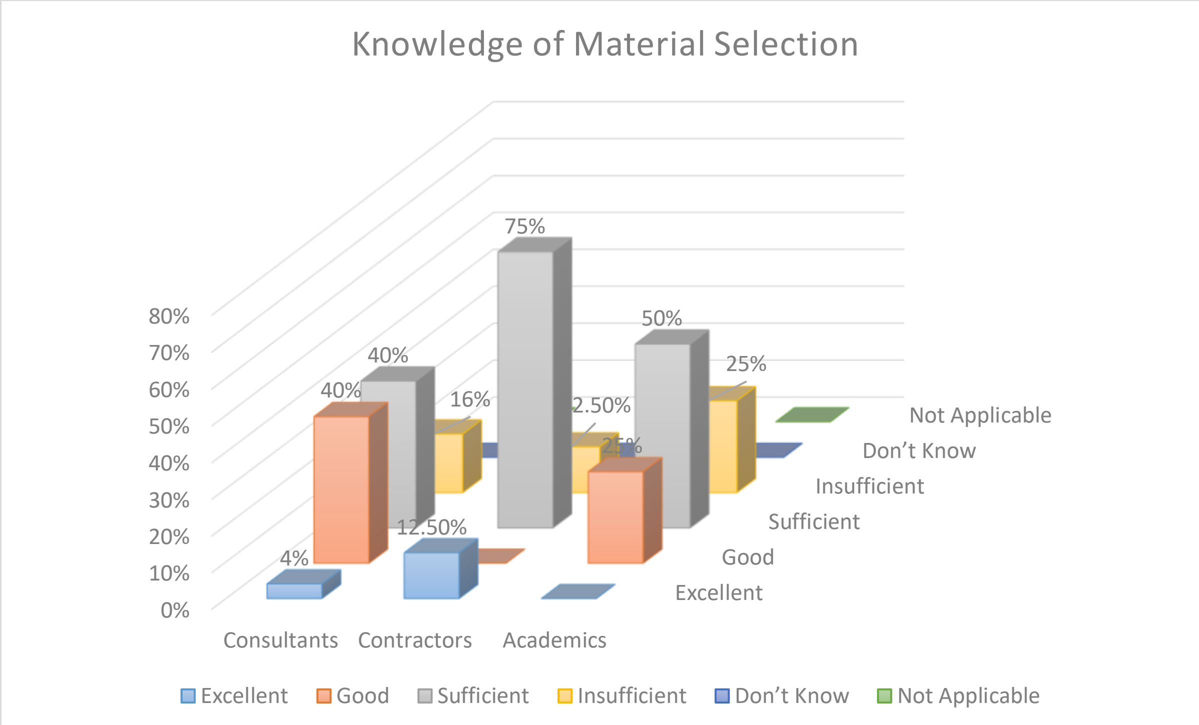


Chart 6: Knowledge of Material Selection

4.1.5.2 Material Selection Practice

A. Factors that Affect Material Selection practice

The respondents were asked to rate the following factors that affect their material selection practice, the Relative Importance Index (RII) of their response and their respective rank is presented on Table 16.

Table 16: Factors that Affect Material Selection

Factors	Consultants		Contractor		Academics		Overall Rank	
	I	R	I	R	I	R	I	R
Inadequate current construction techniques	0.79	6	0.84	2	0.94	1	0.86	1
Budget Constraints	0.81	5	0.91	1	0.81	2	0.84	2
Lack of access to current and relevant information	0.89	1	0.81	3	0.75	4	0.82	3

Building regulation(codes & ordinances	0.84	3	0.66	8	0.81	2	0.77	4
Consideration of sustainable materials	0.87	2	0.69	7	0.75	4	0.77	4
Lots of manpower and time in analyzing & selecting proper material	0.79	6	0.78	4	0.69	6	0.75	6
Problem in determining priorities	0.82	4	0.75	5	0.69	6	0.75	6
Inadequate instructions about materials	0.79	6	0.75	5	0.56	8	0.7	8

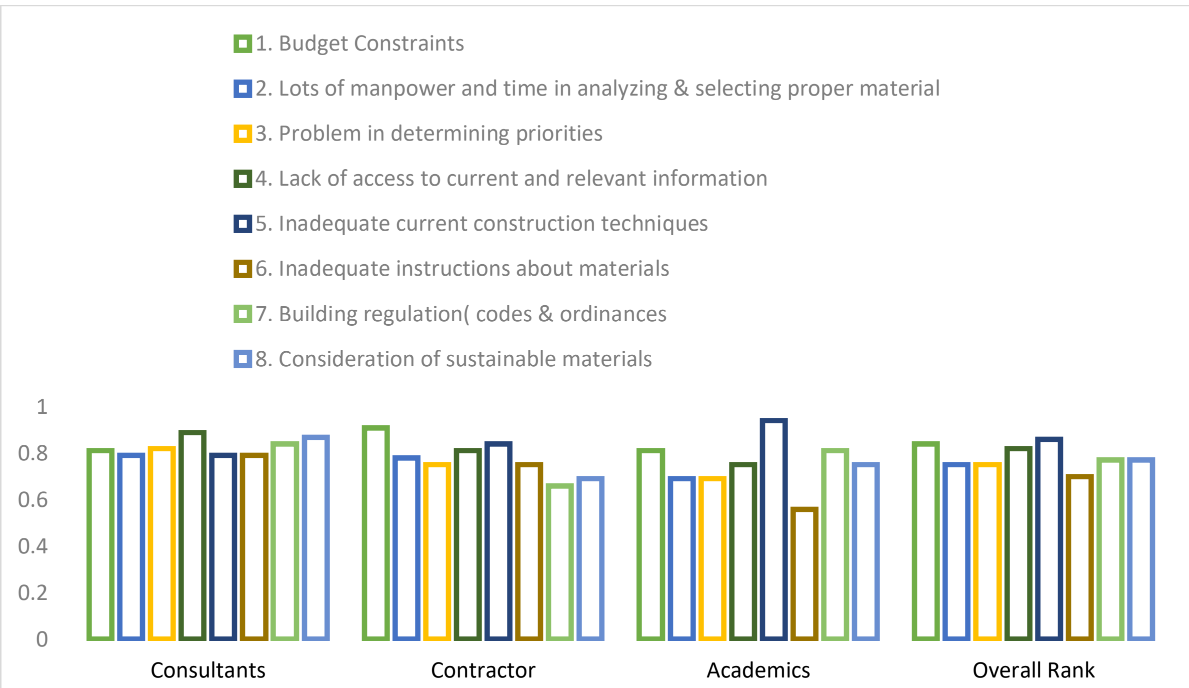


Chart 7: Factors that Affect Material Selection practice

Knowledge of Material Selection can be measured by its application in the construction industry. And to assess the current level of understanding among our local designers, consultants and contractor, that very question was presented to the respondents.

Among Local Consultants, which includes designers and architects, about 80% of them had "Good" or "Sufficient" knowledge of material selection. It can be inferred from this result that, the majority of local consultants have at least theoretical understanding of material selection. However though, its practical application is another matter To understand the practical application of material selection, the researcher reviewed 40 public and private building design documents to understand how the trend of material selection and usage. In the design document review, 149,979.63 m2 total floor area was assessed of which 75% of the floor area was covered by only two floor finish materials, as can be seen in chart 17, even though the assessed building were located in various locations, designed by various consultancy companies and most importantly, the materials covered floor areas for various room functions, which can imply the low application of material selection and use of generic, overused materials with little attention and focus to material selection.

This inference of good theoretical understanding of material selection can be backed up by the next finding. A question that asks whether sustainability assessment is an important issue was presented to the respondent and majority of the respondents agreed with the statement.

Is awareness of sustainability in building projects among various construction stakeholders the same or is one group more attuned than the other? That's one of the question this research tried to answer. And that very question was presented to the respondents, respondents from the consultants group were divided while 36% of them believed that private clients were more attuned to sustainability issues, another 36% believed that there was no difference between public or private clients. This division in their response can imply a lack of attention and focus given to the matter, the response from all the groups was divided, it can back up the assumption that due attention and focus is not given to the matter.

4.1.6 Influence of Construction Stakeholders on Material Selection

The respondents were asked which construction stakeholder influenced material selection process, the Relative Importance Index (RII) of their response and their respective rank is presented on Table 17.

As can be shown from Table 17, almost all the respondents from all the respondent groups identified client/client representative as the most influential stakeholder in the material selection process.

The Relative Importance Index (RII) of most of the stakeholders is very low, show that they don't have much significance in material selection process.

The most prominent influential stakeholders are Client/Client Representative, Supplier and Manufacturer of products and Architects & Designers.

Table 17: Influence of Construction Stakeholders on Material Selection

Construction Stakeholders	**Consultants**		**Contractor**		**Academics**		**Overall Rank**	
	RII	**Rank**	**RII**	**Rank**	**RII**	**Rank**	**RII**	**Rank**
a. The client / client representative	0.88	1	0.94	1	1	1	0.94	1
b. Architects & designers	0.82	3	0.81	4	0.94	2	0.86	2
h. Suppliers of products	0.83	2	0.84	3	0.75	3	0.81	3
i. Product manufacturers	0.8	4	0.88	2	0.69	6	0.79	4
c. Quantity surveyors	0.69	7	0.44	9	0.75	3	0.63	7
d. Project Managers	0.68	8	0.47	8	0.69	6	0.61	8
e. Site Managers	0.68	8	0.5	7	0.63	9	0.60	9
f. Contractors	0.76	5	0.59	6	0.69	6	0.68	6
g. Technical consultants	0.74	6	0.63	5	0.75	3	0.71	5

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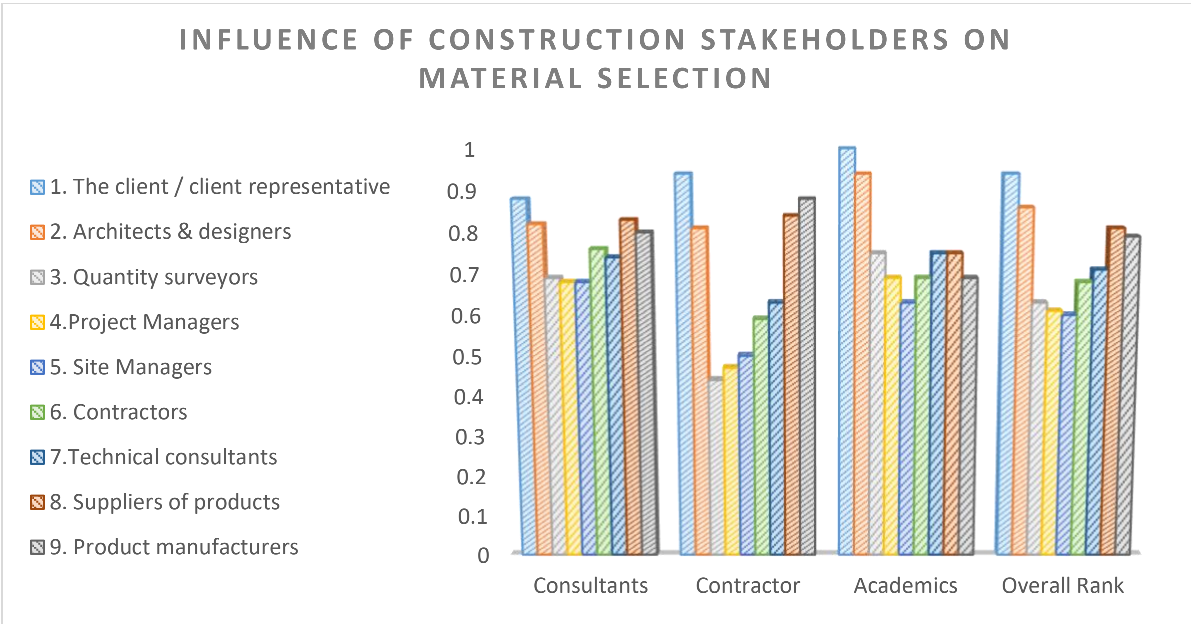

Chart 8: Influence of Construction Stakeholders on Material Selection

Construction is an activity that has various stakeholders and involved parties. From the client to the contractor to the government regulator, it has numerous stakeholders that can influence its outcome. Starting from the design up to the completion of the actual construction. Design decisions are not exclusively made by the designer, the designer has to take into account matters such as the needs of the client, the regulations, and the constructability of the design.

It will be interesting to find which of these stakeholders influence material selection as it an important design decision is. The material selection procedure is a part of the building process, but also includes stakeholders that are not traditionally regarded as a part of the process (Akadiri, 2011).

A question that inquired about this aspect was presented to the respondents with client/client's representative ranked first as the most influential party in the material selection process. The client is vital for whether or not environmental goals are included in the project and exerts pressure on project participants to improve buildings' lifecycle performance (Gann and Salter, 2000 as cited by Akadiri, 2011).

The results of their response are presented on Table 17. The second ranked stakeholder are Architects & designers followed by product supplier.

4.1.7 Obstacles of Material Selection and Sustainability

4.1.7.1 Obstacles of Material Selection

The respondents were asked what obstacle are preventing them from selecting sustainable products, the Relative Importance Index (RII) of their response and their respective rank is presented on Table 18.

As can be shown from Table 18, respondents from both the consultants' and contractor' side identified Perception of extra cost being incurred as the main obstacle to selecting sustainable products. This indicates that economic factors are paramount.

Respondents from the academics' side identified "Problem in evaluating information" as the main obstacle to selecting sustainable products. This indicates that the paramount need for easier multi criteria assessment tool and justifies the need for this thesis research.

Table 18: Obstacles of Material Selection

Presumed Obstacles	**Consultant**		**Contractor**		**Academics**		**Overall Rank**	
	I	**R**	**I**	**R**	**I**	**R**	**I**	**R**
a. Problem in Evaluating information	0.82	2	0.75	8	1	1	0.86	1
b. Perception of extra time being incurred	0.82	2	0.81	4	0.88	2	0.84	2
c. Perception of extra cost being incurred	0.85	1	0.84	1	0.75	6	0.81	3
d. Lack of information on sustainable construction materials	0.79	9	0.81	4	0.81	5	0.8	4
e. Maintenance concern	0.78	11	0.75	8	0.88	2	0.8	4
f. Uncertainty in the liability for the final works	0.8	7	0.69	13	0.88	2	0.79	6

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g. Difficulties in balancing environmental, economic & social issues	0.82	2	0.81	4	0.75	6	0.79	6
h. Limited availability & reliability of suppliers	0.8	7	0.84	1	0.69	8	0.78	8
i. Low flexibility for alternatives or substitutes	0.78	11	0.78	7	0.69	8	0.75	9
j. Lack of tools and data to compare material alternatives	0.82	2	0.66	15	0.69	8	0.72	10
k. Possible delay due to sustainability requirement	0.79	9	0.84	1	0.44	12	0.69	11
l. building code restriction	0.81	6	0.72	11	0.44	12	0.66	12
m. perception that sustainable materials are low in quality	0.73	15	0.69	13	0.5	11	0.64	13
n. Unwillingness to change the conventional way of specifying	0.74	13	0.75	8	0.38	14	0.62	14
o. aesthetically less pleasing	0.74	13	0.72	11	0.25	15	0.57	15

4.1.7.2 Obstacles to Usage of Material Selection Tools

The respondents were asked what obstacle are preventing them from using material selection tools, the Relative Importance Index (RII) of their response and their respective rank is presented on Table 19.

As can be shown from Table 19, respondents from both the consultants' side identified High cost involved in its use as the main obstacle to using material selection tools. This indicates that economic factors are paramount.

Respondents from the contractors' side identified Lack of suitable programming software and Lack of adequate project information as the main obstacle to using material selection tools. While respondents from the academics' side identified Lack of skills in using technique as the main obstacle to using material selection tools.

The results are presented as follows:

Table 19: Obstacles to Usage of Material Selection Tools

Presumed Obstacles	Consultants		Contractor		Academics		Overall Rank	
	I	R	I	R	I	R	I	R
a. Lack of familiarity with the technique	0.87	2	0.78	4	0.88	2	0.84	1
b. Lack of skills in using technique	0.87	2	0.69	7	0.94	1	0.83	2
c. Poorly updated programs	0.85	4	0.84	3	0.81	3	0.83	2
d. Lack of suitable programming software	0.85	4	0.88	1	0.69	4	0.81	4
e. Lack of adequate project information	0.83	7	0.88	1	0.63	6	0.78	5
f. High time consumption in using technique	0.85	4	0.72	6	0.67	5	0.75	6
g. High cost involved in its use	0.88	1	0.78	4	0.5	7	0.72	7

Constraints are a reflection of the real world in which building professionals operate (Akadiri, 2011). As any design decision, designers and architects face obstacles when trying to implement sustainability and material selection in their designs. It was tried, in this research, to understand what kind of obstacles the practicing professional face when trying to implement sustainable building materials.

A question that inquired about this issue was presented to the respondents, their response is presented on Table 19. Out of the presented presumed obstacles, “Problem in evaluating information” was ranked first. This is an interesting finding, material selection can be an overwhelming procedure if there is no easy way of evaluating information. This ranking heavily justifies the need for this research. The second ranked obstacle is “Perception of extra time being incurred”. As Akadiri, (2011) put it, another design constraint is time. Good design, in all of its creative aspects, take time- and sufficient time is not always available to satisfy the inner needs of the architect.

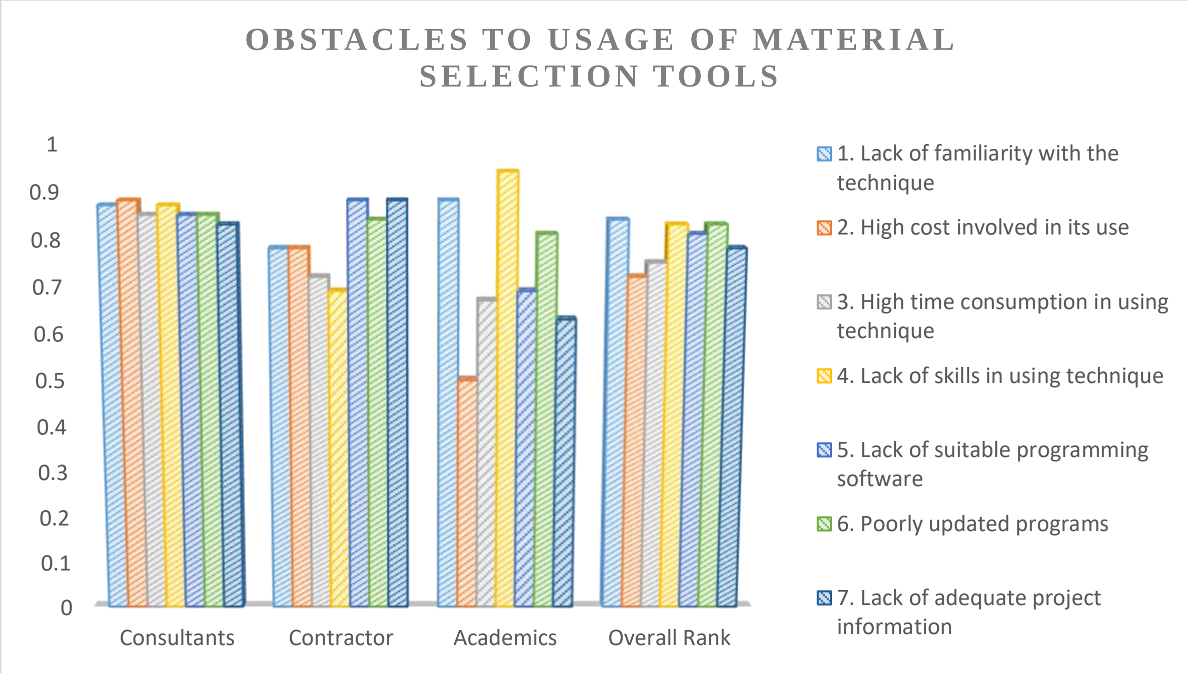

Chart 9: Obstacles to Usage of Material Selection Tools

The third ranked obstacle is “Perception of extra cost being incurred”. This is not only an Ethiopian problem as Williams and Dair (2006) as cited by Akadiri, (2011) in a survey of designers involved in a development schemes in England observed that in many instances, although cost differentials had not been thoroughly investigated, designers were certain that anything other than ‘business as usual’ would be more expensive.

Another question that inquired about the obstacles preventing from using material selection tools presented to the respondents, their response is presented on Table 19.”Lack of familiarity with the technique” was the highest ranked obstacle.

4.1.8 Criteria and Weightage for Material Selection

4.1.8.1 Criteria for Material Selection

The respondents were asked what criteria & factors they consider for building material selection during planning & design stage, the Relative Importance Index (RII) of their response and their respective rank is presented on Table 20.

As can be shown from Table 20, respondents from both the consultants' side identified Socio-economic factors as the most important factors in material selection process. Whereas, environmental factors such as "Environmental impact during material production" were identified as the least important factors.

Respondents from the contractors' side identified Technological Criteria as the most important factors alongside the group of factors. While respondents from the academics' side almost exclusively identified technological factors as the most paramount factors in the selection process.

Table 20: Criteria for Material Selection

Criteria	Consultants		Contractor		Academics		Overall Rank	
	I	R	I	R	I	R	I	R
1. Material availability	0.95	6	1	1	1	1	0.983	1
2. Life cycle cost (initial cost, maintenance cost, repair cost, disposal cost)	0.93	8	1	1	1	1	0.977	2
3. Aesthetics	0.96	2	0.97	10	1	1	0.976	3
4. Material Strength and Mechanical Properties	0.91	14	1	1	1	1	0.973	4
5. Maintainability	0.9	16	1	1	1	1	0.973	4
6.Service Quality	0.93	8	0.97	10	1	1	0.97	5
7. Land conservation	0.9	16	1	1	1	1	0.967	6
8. Minimize pollution (air, land, water etc)	0.92	12	1	1	1	1	0.967	6
9. Health and safety	0.93	8	0.97	10	1	1	0.967	6
10. Fire resistance	0.92	12	0.97	10	1	1	0.963	10
11.Life Expectancy/ Durability/Resistance to decay	0.91	14	0.97	10	1	1	0.96	11
12. protecting physical resources	0.94	7	1	1	0.94	15	0.96	11
13. Labor Availability	0.97	1	0.97	10	0.94	15	0.96	11
14. Energy saving and thermal insulation	0.9	16	0.97	10	1	1	0.957	14
15. Amount of transportation required	0.96	2	0.97	10	0.94	15	0.957	14

16. Ease of Construction/Technology	0.89	19	0.97	10	1	1	0.953	16
17. Water Conservation	0.93	8	0.97	10	0.94	15	0.947	17
18. Potential for recycling and reuse	0.88	20	0.94	24	1	1	0.94	18
19. Availability of environmentally friendly disposal options	0.86	21	1	1	0.94	15	0.933	19
20. Environmental Impact during material production	0.84	26	1	1	0.94	15	0.927	20
21. Method of Material Extraction	0.85	25	0.97	10	0.94	15	0.92	21
22 Material Conservation/ Amount of likely wastage in use of material	0.84	26	0.97	10	0.94	15	0.917	22
23. Impact of material on air quality	0.86	21	0.94	24	0.94	15	0.913	23
24. Environmental statutory compliance	0.86	21	0.94	24	0.94	15	0.913	23
25. Use of local material instead of imported material	0.96	2	0.97	10	0.81	26	0.913	23
26. Embodied energy within material	0.86	21	0.91	27	0.94	15	0.903	26
27. Cultural Aspects	0.96	2	0.97	10	0.75	27	0.893	27

4.1.8.2 Weightage for Material Selection Software Development

The respondents were asked to provide weightage of the criteria & factors with sustainability in mind when they evaluate them for building material selection during planning & design stage, the Relative Importance Index (RII) of their response and their respective rank is presented on Table 21.

The results are presented as follows on Table 21.

Table 21: Weightage for Material Selection software development

Criteria	Consultants		Contractor		Academics		Overall
	I	Wt.	I	Wt.	I	Wt.	Weight
Environmental criteria							

1. Potential for recycling and reuse	0.9	3.6	0.97	3.88	0.94	3.75	3.74
2. Availability of environmentally friendly disposal options	0.89	3.56	1.00	4.00	0.94	3.75	3.77
3. Impact of material on air quality	0.88	3.52	0.91	3.63	0.94	3.75	3.63
4. Material Conservation/ Amount of likely wastage in use of material	0.87	3.48	1.00	4.00	1.00	4.00	3.83
5. Environmental Impact during material production	0.87	3.48	1.00	4.00	0.94	3.75	3.74
6. Land conservation	0.9	3.6	1.00	4.00	1.00	4.00	3.87
7. Environmental statutory compliance	0.87	3.48	0.94	3.75	0.94	3.75	3.66
8. Minimize pollution (air, land, water etc)	0.9	3.6	0.97	3.88	0.94	3.75	3.74
9. Water Conservation	0.89	3.56	0.94	3.75	1.00	4.00	3.77
10. Method of Material Extraction	0.84	3.36	0.97	3.88	0.94	3.75	3.66
11. Embodied energy within material	0.84	3.36	0.94	3.75	0.94	3.75	3.62
Mechanical/Technical criteria							
1. Maintainability	0.85	3.4	1.00	4.00	1.00	4.00	3.80
2. Ease of Construction/Technology	0.84	3.36	0.97	3.88	1.00	4.00	3.75
3. Life Expectancy/ Durability/Resistance to decay	0.87	3.48	1.00	4.00	1.00	4.00	3.83
4.Service Quality	0.88	3.52	0.97	3.88	1.00	4.00	3.80
5. Fire resistance	0.86	3.44	0.97	3.88	1.00	4.00	3.77

6. Material Strength and Mechanical Properties	0.87	3.48	1.00	4.00	1.00	4.00	3.83
7. Energy saving and thermal insulation	0.9	3.6	1.00	4.00	1.00	4.00	3.87
Socio-economic criteria							
1. Life cycle cost (initial cost, maintainace cost, repair cost, disposal cost)	0.89	3.56	0.94	3.75	1.00	4.00	3.77
2. Health and safety	0.9	3.6	0.97	3.88	1.00	4.00	3.83
3. protecting physical resources	0.89	3.56	1.00	4.00	1.00	4.00	3.85
4. Use of local material instead of imported material	0.89	3.56	1.00	4.00	0.88	3.50	3.69
5. Aesthetics	0.85	3.4	0.94	3.75	1.00	4.00	3.72
6. Material availability	0.86	3.44	1.00	4.00	0.94	3.75	3.73
7. Labor Availability	0.85	3.4	0.97	3.88	1.00	4.00	3.76
8. Cultural Aspects	0.84	3.36	0.94	3.75	1.00	4.00	3.70
9. Amount of transportation required	0.88	3.52	0.97	3.88	0.94	3.75	3.72

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In material selection, there are numerous criteria to keep in mind in order to select the sustainable option. In this research, it was tried to understand what these criteria are and their respective weightage in the procedure.

A question that inquired about this issue was presented to the respondents, their responses are presented on Table 22. The most important criteria for the respondents of the questionnaire was “Material Availability”. This may be a reasonable option as a material has to be available to be selected by the designers and architects. These ranking were used for the development of the material selection software.

Some adjustment were made to initial questionnaire criteria list based on the response. Criteria that were ranked 1 up to 23 were used for the development of the software. Some adjustment was done assimilating some similar criteria to make the list more concise and to the point. The final list that was used in the development of the computer program is as follows:

Table 22: Criteria List used for the Software Development

Criteria	Overall Rank	
	RII	**Rank**
SE8. Material availability	0.983	1
SE1. Initial cost	0.977	2
SE2. Operational/Maintenance Cost	0.977	2
SE3. Disposal Cost	0.977	2
SE4. Recovery/Production Cost	0.977	2
SE7. Aesthetics	0.976	3
T6. Material Strength and Mechanical Properties	0.973	4
T1. Maintainability	0.973	4
T4. Workability/Service Quality	0.970	5
SE5. Health and safety	0.967	6
E5. Sustainable Site/ Land conservation	0.967	6
T5. Fire resistance	0.963	10
T3. Durability/ Life Expectancy//Resistance to decay	0.960	11
SE9. Labor Availability	0.960	11
T7. Insulation	0.957	14
T2. Ease of Construction/Technology	0.953	16
E1. Potential for recycling and reuse	0.940	18
E2. Availability of environmentally friendly disposal options	0.933	19

E4. Environmental Impact during material production	0.927	20
E6. Method of Material Extraction	0.920	21
E3. Amount of likely wastage in use of material	0.917	22
SE6. Use of local material instead of imported material	0.913	23

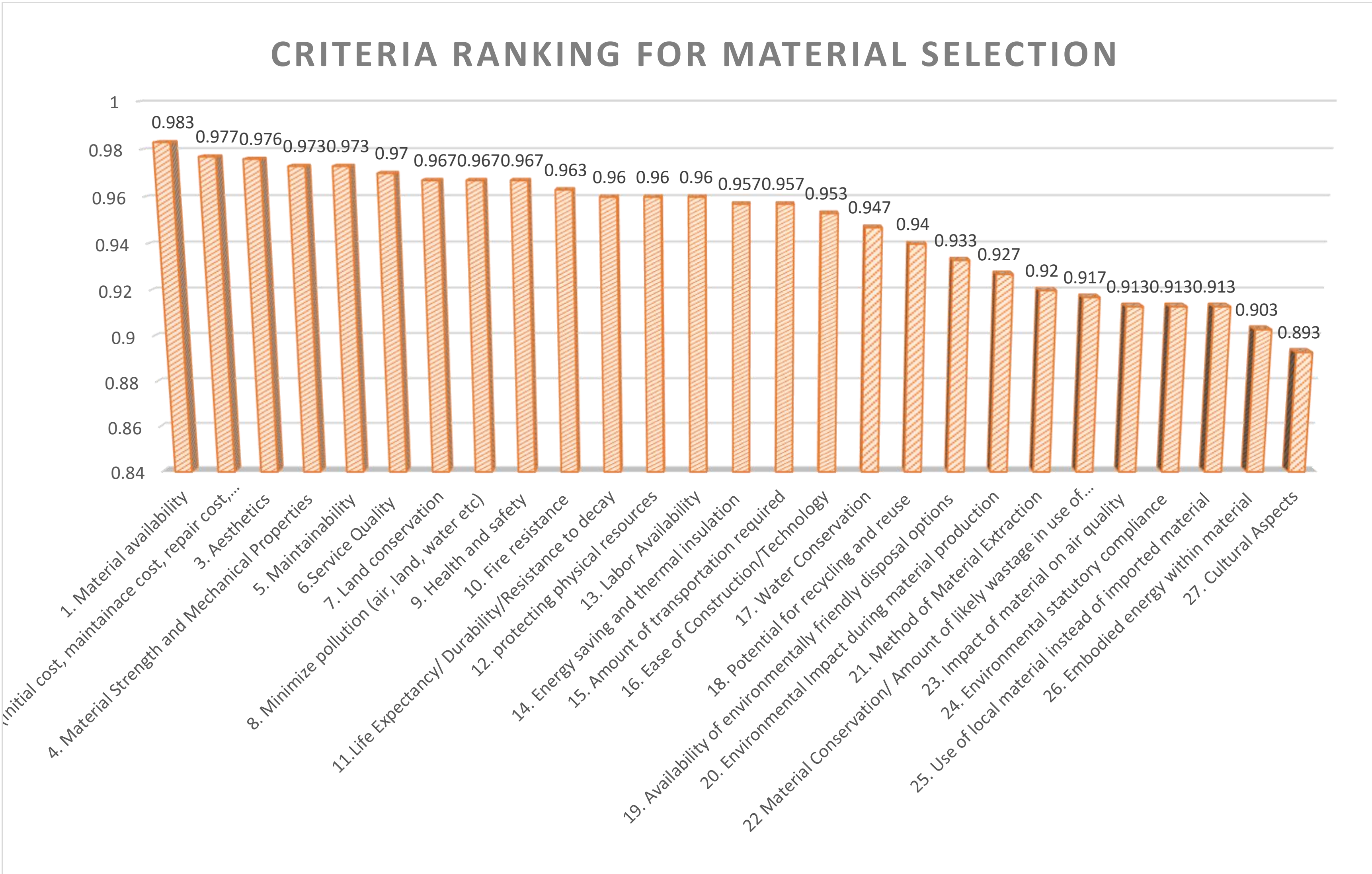

Chart 10: Criteria Ranking for Material Selection

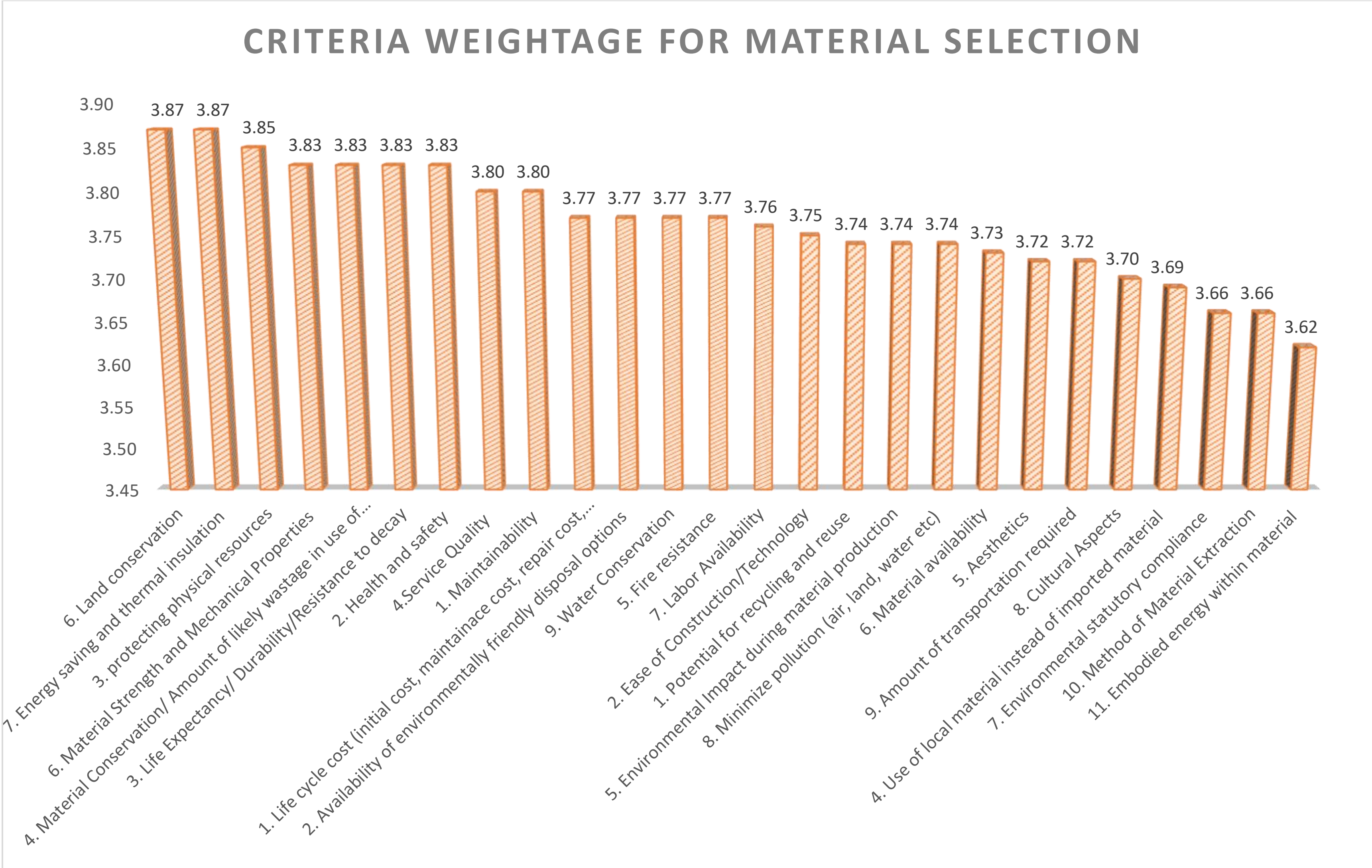

Chart 11: Criteria Weightage for Material Selection

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4.1.9 Spearman's Rank Correlation Coefficient

The Spearman's rank correlation coefficient is used to measure the degree of agreement or disagreement associated with the importance ranking of each of the two stakeholders on a single research questionnaire while ignoring the third party ranking (Werku & Jha, 2016).

The coefficient resultant values range from negative one (-1) to one (1). One (1) being perfect agreement with negative one (-1) perfect disagreement and zero (0) being neutral correlation. By using [Eq. 8], Spearman's correlation coefficient was calculated for each research question and presented on Table 23.

Table 23: Spearman's Rank Correlation Coefficient between stakeholders

Research Question	Consultant Vs Contractor	Consultant Vs Academics	Contractor Vs Academics	Avg.
Building Project Objectives in Building Construction	0.6	-0.35	-0.35	-0.04
Perceptions of Sustainability	0.67	0.49	0.51	0.56
Factors that Affect Material Selection practice	-0.29	0.18	0.34	0.08
Application of Existing Material Assessment Tools	0.55	0.71	0.60	0.62
Influence of Construction Stakeholders on Material Selection	0.87	0.55	0.62	0.68
Obstacles of Material Selection	0.11	0.52	0.14	0.26
Obstacles to Usage of Material Selection Tools	-0.50	0.21	-0.36	-0.22
Criteria For Material Selection	0.22	0.04	0.42	0.23
Average	0.28	0.29	0.24	

The highest degree of agreement, on specific research questions, is 87% (influence of construction stakeholders on material selection) between consultants and contractors whereas, the lowest degree of agreement is –50% (obstacles to usage of material selection tools) also between consultants and contractors. When see it on average value, consultant & academics have the highest degree of agreement with (29%), which is not that great. This result shows, even though the stakeholders are not in disagreement, the resultant values display insufficient level of agreement with the average values in the close to neutral correlation (0). This might indicate the disparity in awareness about sustainability and material selection among construction stakeholders. This might direct to work to be done to gain some sort of working awareness and understanding amongst the stakeholders.

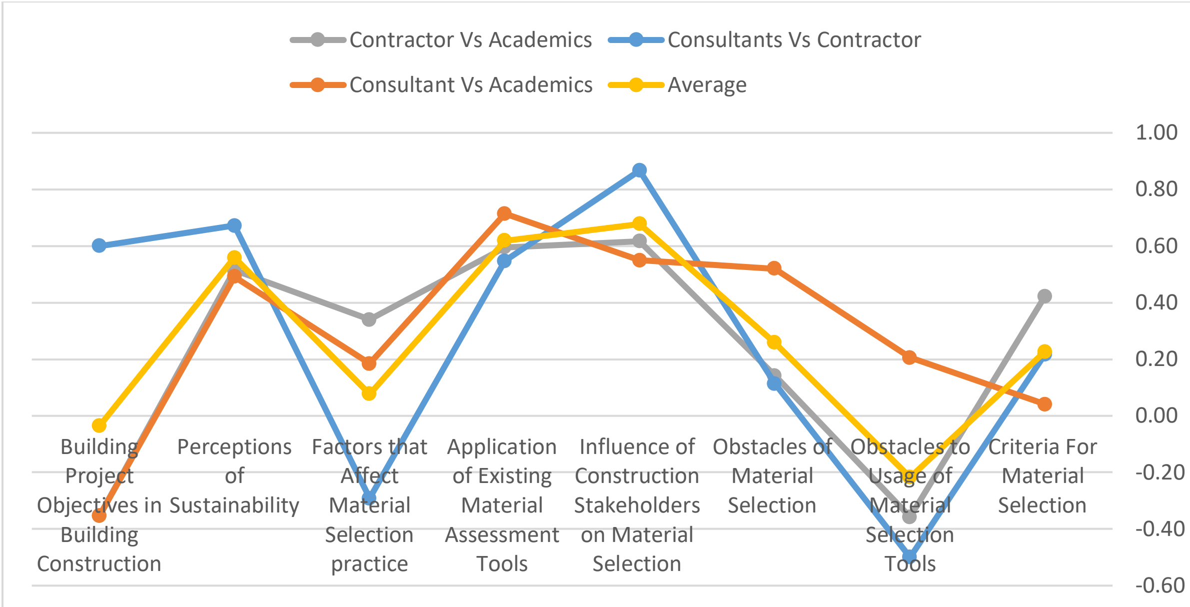

Chart 12: Spearman's Rank Correlation Coefficient between stakeholders

4.2 Analysis of the Design Document Review

4.2.1 Background of the Reviewed Design Documents

A Design Document review of 40 completed design drawings and Design Document were reviewed by the researcher to assess the current practice of building material usage and material selection trends.

This study covered selected Forty (40) public and private building design projects in Tigrai which were designed by different consultancy companies and has project costs in the range of 10 million birr up to 1 Billion birr. It was tried to assess the materials selected for the projects.

For the sake of simplicity and clear comparison, it was tried to compare direct alternative material usage in the drawings. And Finishing works specifically floor finish materials were selected as numerous alternatives are offered as compared to other activities such as structural elements and other portions of a construction process.

4.2.1.1 Building Function of Assessed Buildings

This section would help the researcher to know the different functions that were considered for design document review. This, as stated above, is important so as to know what type of building used what material and how different function influences material selection.

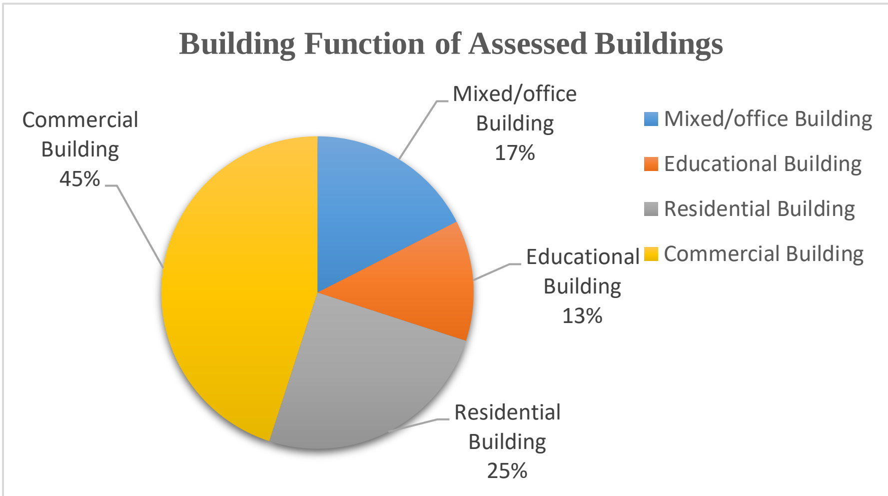

Chart 13: Building Function of Assessed buildings

4.2.1.2 Client Type of Assessed Buildings

This section would help the researcher to know the different types of ownership of the buildings assessed for Design Document review. This, as stated above, is important so as to know what type client used what material and how different ownership influences material selection.

4.2.1.3 Geographical Location of the Assessed Buildings

This section would help the researcher to know the different geographical location of the buildings assessed for Design Document review. This, as stated above, is important so as to know what geographical locations used what material and how different geographical locations influences material selection. It is illustrated on chart 14.

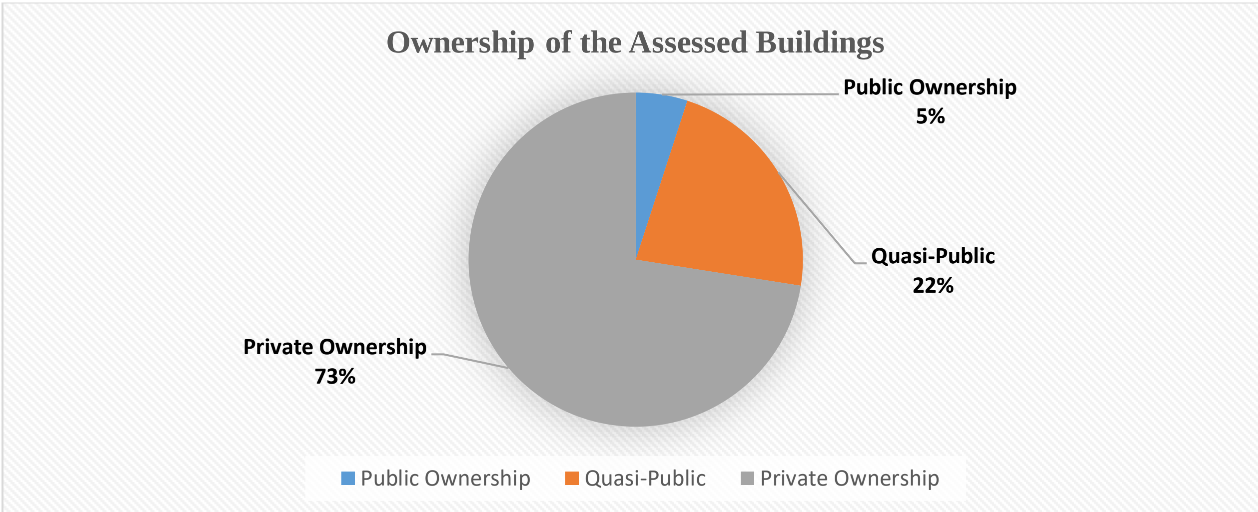

Chart 15: Building Ownership of Assessed buildings

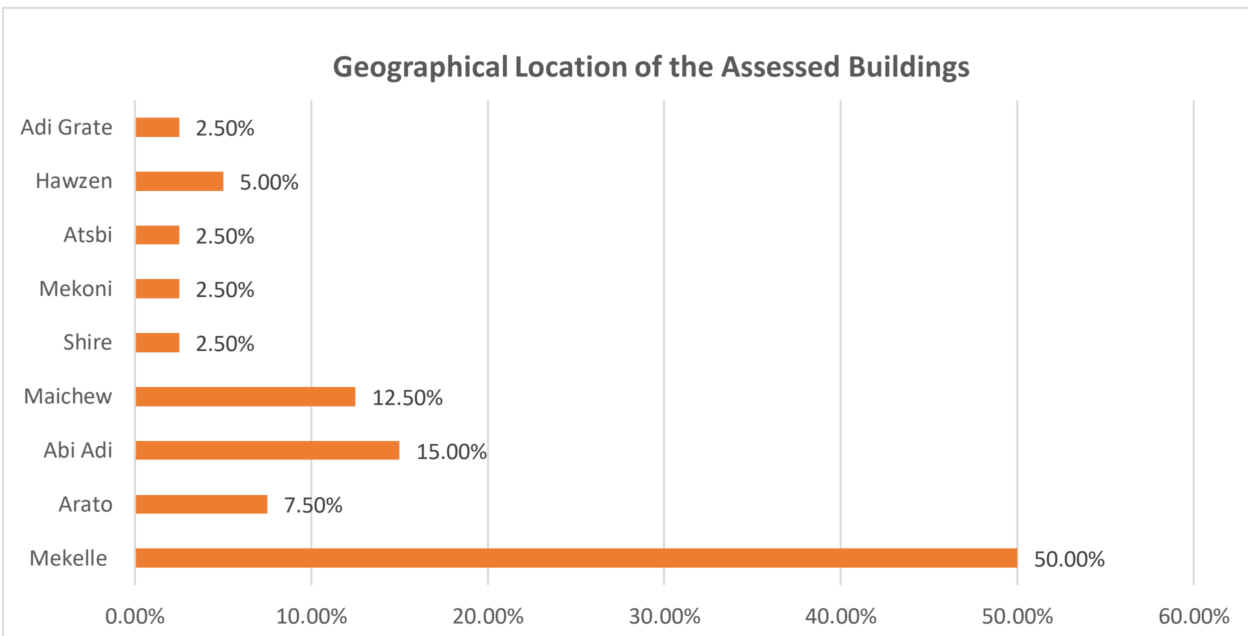

Chart 14: Geographical Location of Assessed Buildings

4.2.1.5 Budget of the Assessed Buildings

This section would help the researcher to know the estimated budget of the buildings assessed for Design Document review. This, as stated above, is important so as to know what range of budget used what material and how estimated budget of a building influences material selection.

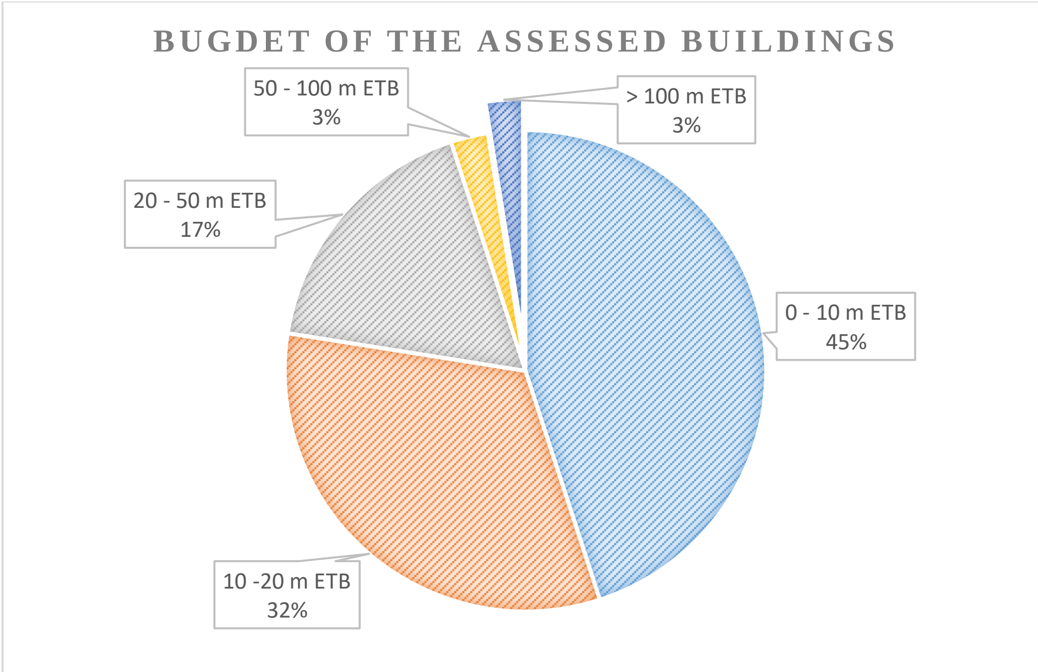

Chart 16: Budget of the Assessed Buildings

4.2.2 Floor Finish Material Information of the Assessed Buildings

Of the selected Forty (40) public and private building design projects in Tigrai, they were classified into different groups based on different criteria as to make the comparison and to show the correlation of the parameters. The classifications are attached on Appendices D.

In this design document review, 149,979.63 m^2 total floor area was assessed that compromise room function ranging from Office to Restaurant. It was tried to show correlation of different parameters such as the building function, budget of the building, the expertise of the designer.

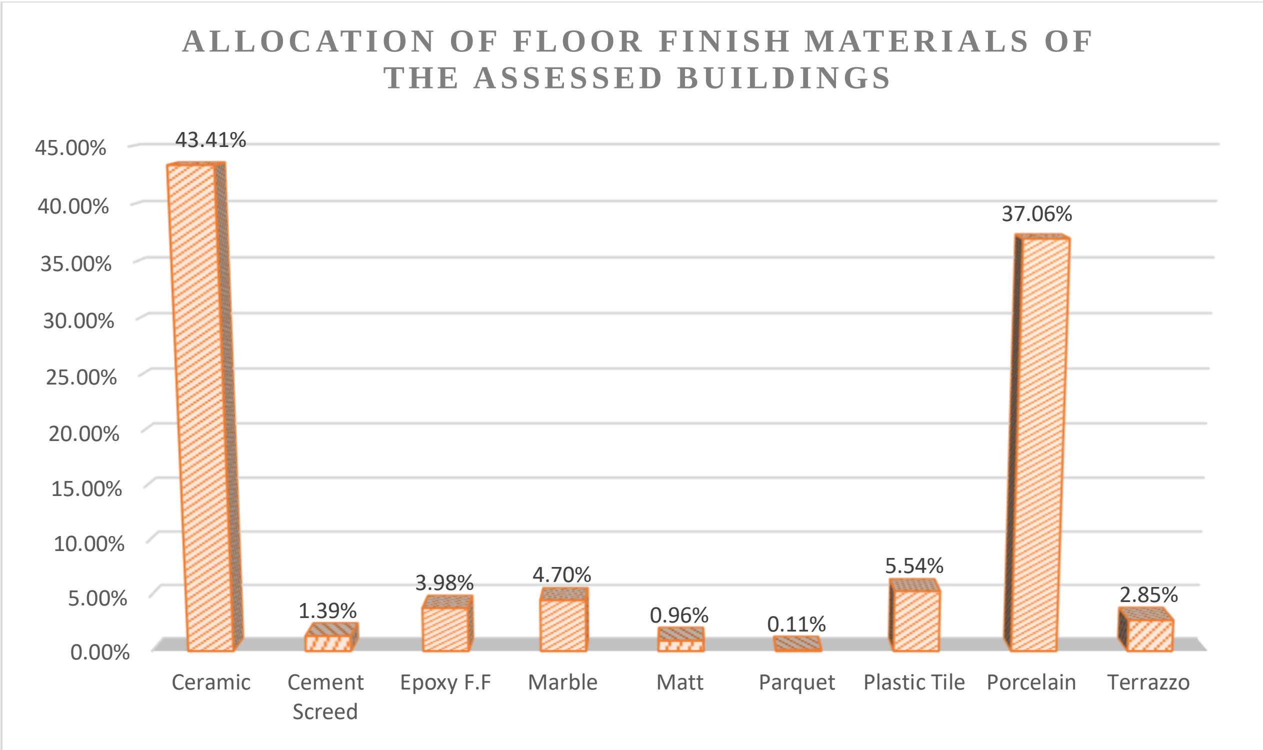

Chart 17: Allocation of Floor Finish Materials of the Assessed Buildings

4.2.3 Relationship between Room Function and Material Selection

Building Function refers to the purpose the infrastructure building is constructed for. Function can refer to intended uses and activities. In short, this is what engineers call description. Functions can be for commercial purpose, Educational or mixed use.

The function of a building can heavily affect the material selection aspect of the design. As a simple example, Plastic tile, conventionally, will not be used for toilet floor finish material as water can damage the adhesive and the functionality of the material.

The researcher tried to show if these considerations are taken into contemplation during the planning and design phases of buildings. Rooms for various functions were assessed in the Design Document/drawings survey to see if these considerations were actually taken into account in the current practice of design and to see the most frequently applied floor finish material in the assessed room functions.

The results are tabulated on Table 24 and illustrated on Chart 18.

Table 24: Relationship between Room Function and Material Selection

Function	Ceramic	Porcelain	Plastic/PVC	Cement Screed	Epoxy F.F	Terrazzo	Marble	Matt Tile	Parquet	Total (m2)
Bedroom	16253.22	9060.26	5015.65	-	-	-	-	-	-	30444.13
	53.39%	29.76%	16.47%	-	-	-	-	-	-	100.00%
Basement Parking	1106.70	62.00	-	1845.04	5061.43	564.26	-	-	-	8639.42
	12.81%	0.72%	-	21.36%	58.59%	6.53%	-	-	-	100.00%
Basement/Others	916.09	1507.62	0.00	-	609.46	0.00	-	-	-	3033.17
	30.20%	49.70%	0.00%	-	20.09%	0.00%	-	-	-	100.00%
Café/Restaurant/Bar	5816.16	3131.48	0.00	-	-	135.36	952.12	-	-	10035.11
	57.96%	31.21%	0.00%	-	-	1.35%	9.49%	-	-	100.00%
Lobby/Circulation	12551.13	10411.10	733.58	-	-	616.68	3094.46	609.46	-	28,819.41
	43.55%	38.91%	2.62%	-	-	2.20%	11.06%	2.18%	-	100.00%
Class Room/Library/Lab	0.00	0.00	513.24	-	-	1173.24	-	-	-	1686.48
	-	-	30.43%	-	-	69.57%	-	-	-	100.00%
Kitchen	3965.94	82.00	-	-	-	-	-	-	-	4047.94
	97.97%	2.03%	-	-	-	-	-	-	-	100.00%
Store/Electrical Room	115.22	-	-	20.40	-	-	-	-	-	135.65
	84.94%	-	-	15.04%	-	-	-	-	-	99.98%
Shop/Gym/Spa	4044.43	1122.82	310.05	122.00	-	-	-	-	-	5599.30
	72.23%	20.05%	5.54%	2.18%	-	-	-	-	-	100.00%
Living & Dining Room	1285.36	4701.00	3002.40	-	-	-	-	-	41.00	9029.76
	14.23%	52.06%	33.25%	-	-	-	-	-	0.45%	100.00%
Meeting Hall	4020.94	2742.55	75.00	-	-	506.05	656.21	761.82	-	8762.57
	45.89%	31.30%	0.86%	-	-	5.78%	7.49%	8.69%	-	100.00%
Office	5183.19	19184.22	25.00	-	-	690.64	1776.04	-	-	26859.09
	19.30%	71.43%	0.09%	-	-	2.57%	6.61%	-	-	100.00%
Toilet	6032.33	-	-	-	-	-	-	-	-	6032.33
	100.00%	-	-	-	-	-	-	-	-	100.00%

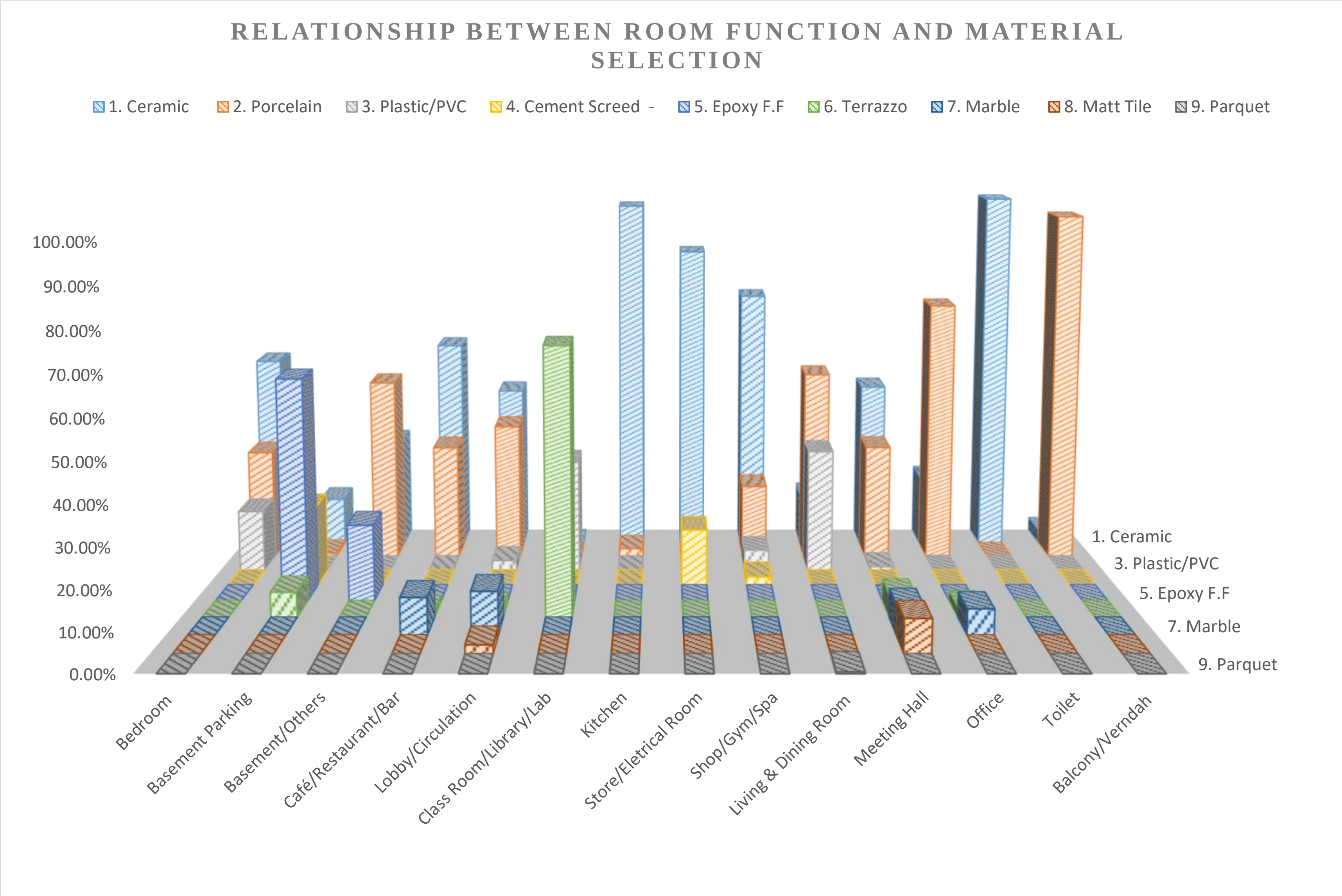

Chart 18: Relationship between Room Function and Material Selection

4.2.4 Relationship between Geographical Location and Material Selection

The geographical location of a building can heavily affect the material selection aspect of the design. As a availability of Materials will logically impact the designer's attitude of material selection. A simple example of this is, materials with high insulation capability will be more attractive for building in cold and low temperature areas.

The researcher tried to show if these considerations are taken into contemplation during the planning and design phases of buildings. Buildings in various geographical locations were assessed in the Design Document/drawings survey to see if these considerations were actually taken into account in the current practice of design and to see the most frequently applied floor finish material in the assessed geographical locations.

The findings are tabulated on Table 25 and illustrated on Chart 19.

4.2.5 Relationship between Budget of a Building and Material Selection

The estimated budget of a building can heavily affect the material selection aspect of the design. As economical features of Materials will logically impact the designer's attitude of material selection. A simple example of this is, materials with low initial cost will be more attractive for building in building and construction budget.

The findings are tabulated on Table 26 and illustrated on Chart 20.

The researcher tried to show if these considerations are taken into contemplation during the planning and design phases of buildings. Buildings in various budget range were assessed in the Design Document/drawings survey to see if these considerations were actually taken into account in the current practice of design and to see the most frequently applied floor finish material in the assessed buildings of different estimated budget range.

Table 25: Relationship between Geographical location and Material Selection

Geographical Location	Ceramic	Porcelain	Plastic/PVC	Cement Screed	Epoxy F.F	Terrazzo	Marble	Matt Tile	Parquet	Total (m2)
Mekelle	21516.74	44652.35	10648.72	842.98	4508.35	380.00	3944.58	1371.28	156.00	88020.99
	24.45%	50.73%	12.10%	0.96%	5.12%	0.43%	4.48%	1.56%	0.18%	100.00%
Hawzen	6061.23	-	-	-	-	282.13	-	-	-	6343.36
	95.55%	-	-	-	-	4.45%	-	-	-	100.00%
Mekoni	6037.62	-	-	610.59	-	-	-	-	-	6648.21
	90.82%	-	-	9.18%	-	-	-	-	-	100.00%
Abi Adi	13093.82	7340.78	-	311.00	1162.54	-	50.40	-	-	21958.54
	59.63%	33.43%	-	1.42%	5.29%	-	0.23%	-	-	100.00%
Atsbi	1066.38	-	-	-	-	-	-	-	-	1066.38
	100.00%	-	-	-	-	-	-	-	-	100.00%
Adi Grate	989.96	-	734.20	222.87	-	-	491.48	-	-	2438.51
	40.60%	-	30.11%	9.14%	-	-	20.16%	-	-	100.00%
Arato (25 Km East of Mekelle)	6530.80	814.91	-	-	-	-	-	-	-	7345.71
	88.91%	11.09%	-	-	-	-	-	-	-	100.00%
Shire	4669.00	-	-	-	-	-	-	-	-	4669.00
	100.00%	-	-	-	-	-	-	-	-	100.00%
Maichew	112.80	-	-	-	-	3121.97	-	-	-	3234.77
	3.49%	-	-	-	-	96.51%	-	-	-	100.00%

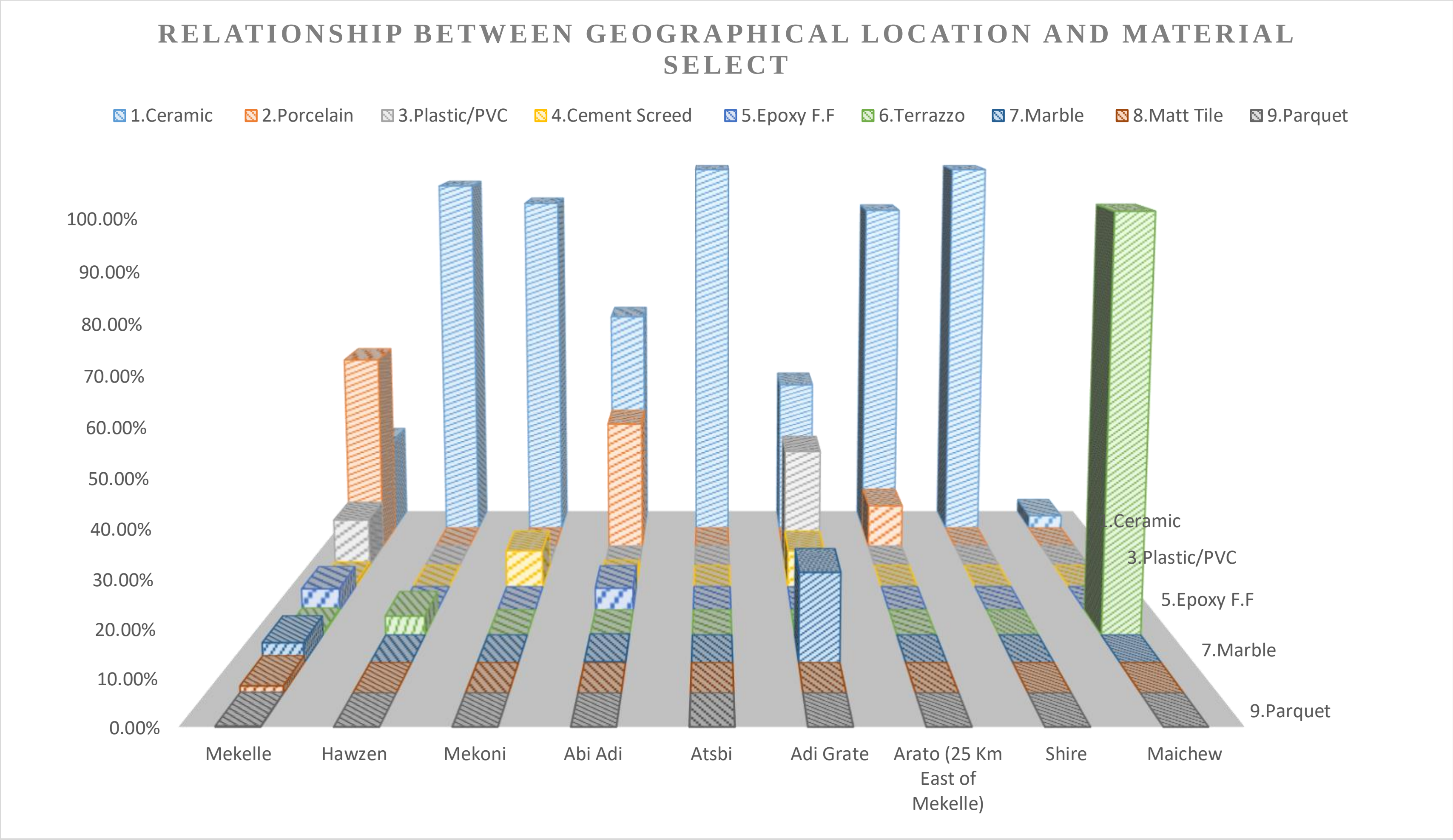

Chart 19: Relationship between Geographical location and Material Selection

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Table 26: Relationship between Estimated budget of a building and Material Selection

Estimated Budget	Ceramic	Porcelain	Plastic/PVC	Cement Screed	Epoxy F.F	Terrazzo	Marble	Matt Tile	Parquet	Total (m2)
0 - 10 Million Birr	4721.03	1191.46	684.32	-	215.25	3121.97	22.16	-	156.00	10112.19
	46.69%	11.78%	6.77%	-	2.13%	30.87%	0.22%	-	1.54%	100.00%
10 - 20 Million Birr	13520.08	8856.78	1396.70	533.87	930.00	380.00	565.45	-	-	26182.88
	51.64%	33.83%	5.33%	2.04%	3.55%	1.45%	2.16%	-	-	100.00%
20 - 50 Million Birr	38377.05	-	9301.90	1433.17	812.54	564.26	4278.24	-	-	54767.15
	70.07%	-	16.98%	2.62%	1.48%	1.03%	7.81%	-	-	100.00%
50 - 100 Million Birr	2654.60	20033.57	-	20.40	1580.00	-	1828.00	-	-	26116.57
	10.16%	76.71%	-	0.08%	6.05%	-	7.00%	-	-	100.00%
> 100 Million Birr	2590.19	22726.24	-	-	609.46	-	-	1371.28	-	27297.16
	9.49%	83.25%	-	-	2.23%	-	-	5.02%	-	100.00%

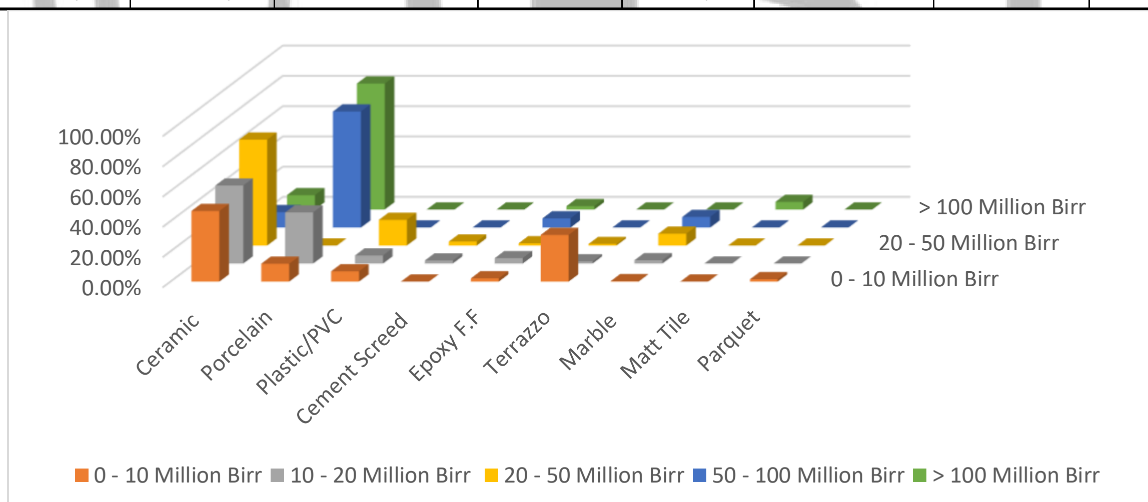


Chart 20: Relationship between budget of a Building and Material Selection

Chapter 5: Strategic Framework and Computer Program Development

The ultimate intended result of this thesis research is to develop a building material selection software that can facilitate, optimize and make the selection process comprehensive so that the designer can implement it easily. (Akadiri, 2011) suggested in order to protect the environment,

Sustainable development is essential for building design and construction. One of the ways that sustainable development can be achieved is to make the whole process simpler and more comprehensive so that material selection can be more attractive to implement.

Practicing designers and Academics were the primary respondents of the questionnaire survey and as a result their opinions and answers were significant.

5.1 Computer Program Development for Building Material Selection

5.1.1 Material Selection Criteria

A total of 22 criteria were obtained from the questionnaire survey. These criteria were further classified using three (3) parameters that can gauge the varying needs of the users of the software .Namely:

1. Based on Technical Consideration of the Factors
2. Based on the Importance of the Factors
3. Based on the ownership of the Project

These 22 criteria factors are brought together in developing the software to aid decision-making. The 22 criteria in the derived software are measured using Multi Criteria Analysis (MCA).

1. Based on Technical Consideration of the Factors

Table 27: Based on Technical Consideration of the Factors

Factors Governing Material Selection
Classification Based on Technical Considerations

	Technical Criteria	**Environmental Criteria**	**Socio-Economic Criteria**
Quantitative	Strength	Amount of wastage in use of material	Initial Cost
	Durability		Operational/Maintenance cost
	Workability		Disposal Cost
	Fire Resistance		Production Cost
	Insulation		
Qualitative	Ease of Construction	Method of Extraction	Health and Safety
	Maintainability	Environmentally Sound Disposal	Aesthetics
		Environmental impact during harvest	Use of local Material
		Potential for reuse and recycling	Labor Availability
		Sustainable Site	Material Availability

2. Based on the Importance of the Factors

Table 28: Based on the Importance of the Factors

Factors Governing Material Selection			
Classification Based on level of importance			
	Primary Criteria	**Secondary Criteria**	**Tertiary Criteria**
Quantitative	Strength	Amount of likely wastage in use of material	
	Initial Cost	Insulation	
	Operational/Maintenance cost		
	Disposal Cost		
	Recovery/Production Cost		
Qualitative	Material availability	Environmentally Sound Disposal	Method of Material Extraction
	Durability	Environmental impact during harvest	Use of local material
	Workability	Potential for reuse and recycling	
	Sustainable Site	Ease of Construction	
	Health and Safety	Labor Availability	
	Maintainability	Aesthetics	

	Fire Resistance		

3. Based on the ownership of the Project

Table 29: Based on the ownership of the Project

Factors Governing Material Selection			
Classification Based on Building Ownership			
	Public Buildings	**Common Factors**	**Private Buildings**
Quantitative		Strength	Insulation
		Durability	
		Workability	
		Initial Cost	
		Operational/Maintenance cost	
		Disposal Cost	
		Recovery/Production Cost	
		Amount of wastage in use of material	
		Fire Resistance	
Qualitative	Method of Extraction	Aesthetics	
	Labor Availability	Health and Safety	
	Environmental impact during harvest	Ease of Construction	
	Sustainable Site	Maintainability	
	Potential for reuse and recycling		
	Environmentally Sound Disposal		
	Material Availability		
	use of local material		

5.1.2 Choice of Multi Criteria Analysis (MCA) Technique

As it is illustrated in literature review (Chapter two), there are numerous MCA techniques that can be applied in various multi attribute problems like this one. However, the issue remains as to which of these MCA methods are suitable as a theoretical framework for the construction of a composite criterion. The selected method for composite criteria formulation must allow for the weighted aggregation of quantitative individual indicators, which requires that the method is utility or value based, quantitative in format and provides a cardinal measurement of the weighted differences amongst indicators and not merely ordinal difference (Nijkamp *et al.*, 1990 as cited by Akadiri, 2011).

(Akadiri, 2011) reviewed numerous techniques for multi-criteria or multi-attribute decision-making have emerged. Some of the simpler and more useful techniques include Scoring Multi-Attribute Analysis (SMAA), Multi-attribute utility theory (MAUT), Multiple Regression (MR), Linear programming (LP), Cluster analysis (CA), Multivariate discriminant analysis (MDA), Weighted sum method (WSM) and the Analytical hierarchy process (AHP).

Multi-attribute utility theory (MAUT) was chosen for this software development and selection due to its relative simplicity and linear equation evaluation method as compared to the other MCA techniques.

5.1.3 Multi-attribute Utility Theory (MAUT)

In this technique subjective components of the attributes are quantified using “utility”. The term “utility” is used to refer to the measure of desirability or satisfaction of an attribute of the alternative under consideration (Akadiri, 2011). The “Utiles” is more of a gauge of the criteria in relation to the alternative under consideration. “Utiles” are used to changes or equates real life units such as years, dollars and Mpa into a series of commensurable units (utiles) on an interval scale of zero (0) to one (1) (Holt, 1998 as cited by Akadiri, 2011). (Akadiri, 2011) suggested that Utility values can be used in conjunction with weightings, W_i, to give a more reliable aggregate score for the various alternatives.

The working procedure and mathematical expression for this technique is illustrated in the literature review (chapter 2) section of this thesis; for further detailed elaboration, the reader can refer to page tweleve (pp.12) on this thesis paper.

5.1.4 The Flowchart of the Computer Program

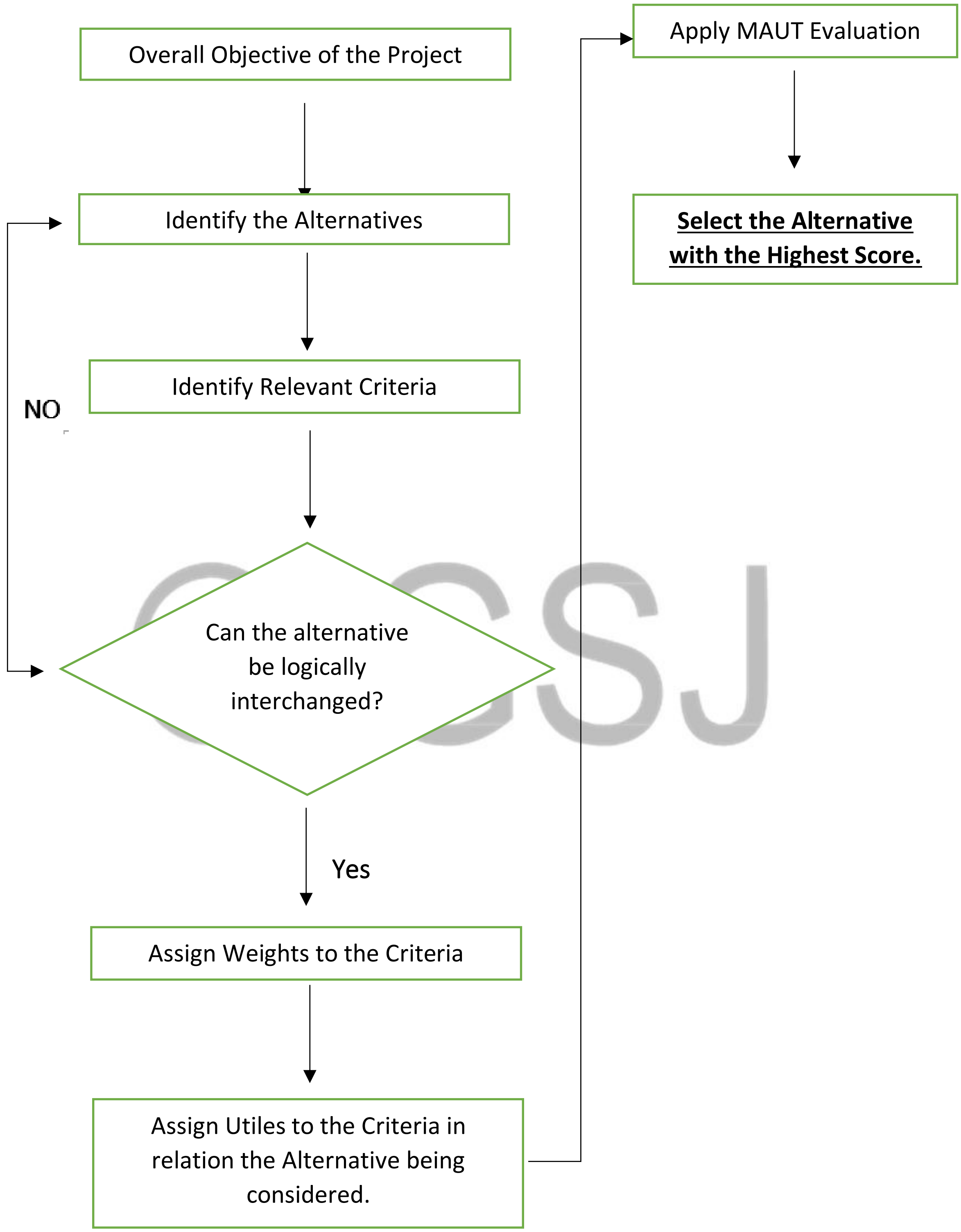


Chart 21: Flowchart of the proposed strategic approach

5.1.5 Programming Language

A programming language is a vocabulary and set of grammatical rules for instructing a computer or computing device to perform specific tasks. The word programming language typically refers to high-level languages, such as BASIC, C, C++, COBOL, Java, FORTRAN, Ada, and Pascal (Beal V, n.d.).

Since the advent of the computer in the 50s, human kind has been trying ever since to utilize the invention to new levels. This has led to new ways of communicating with the machine. From command oriented Ms-DOS in the 80s to Graphical User Interfaces of now-a-days such as Windows OS series and Mac OS series.

The problem of which language is paramount one that consumes a lot of time and energy among computer professionals. Every language has its strengths and weaknesses. For example, FORTRAN is a particularly good language for processing numerical data, but it does not lend itself very well to organizing large programs. Pascal is very good for writing well-structured and readable programs, but it is not as versatile as the C programming language. C++ embodies powerful object-oriented features, but it is complex and difficult to learn (Beal V, n.d.).

According to Institute of Electrical and Electronics Engineers (IEEE) Spectrum interactive list, Python is the top programming language of 2019, followed by Java, C and C++. Python has an immense popularity, especially within the artificial intelligence domain, with the library being heavyweight among deep-learning developers: Keras provides an interface to the deep-learning system, CNTK and Theano deep-learning kits (Cass, 2019). Of course, the choice of the language to use depends on the type of machine the program is to run on, what sort of program it is, and the skill of the programmer.

Python is an interpreted, high-level, general-purpose programming language. Designed by Guido van Rossum and first published in 1991, Python's design philosophy emphasizes code readability with its prominent use of large whitespace. Its language constructs and object-oriented approach aim to help programmers write clear, logical code for small and large-scale projects (Kuhlman, 2012).

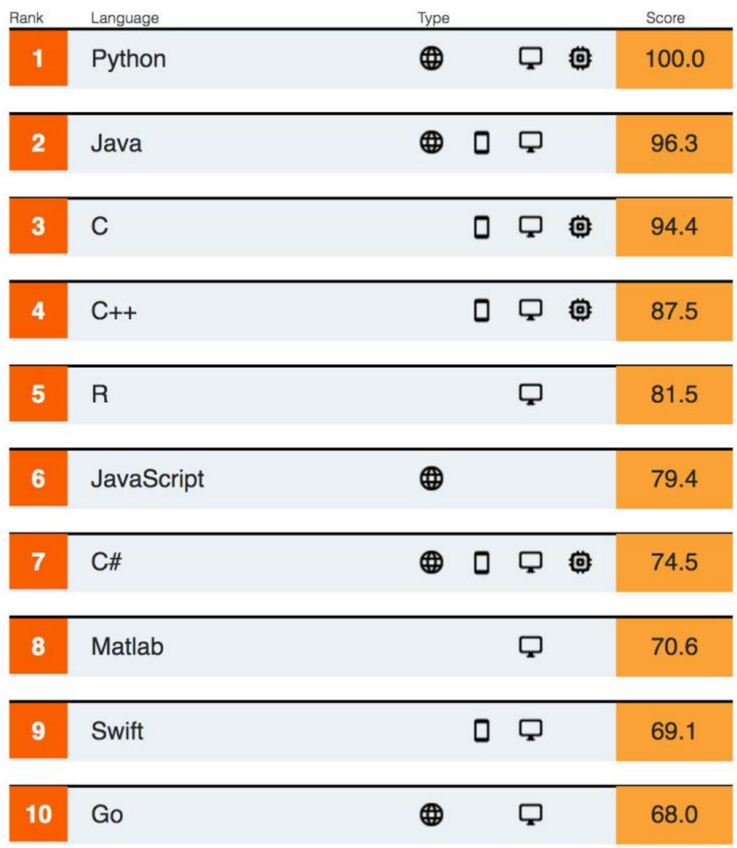


Chart 22: IEEE Spectrum Interactive ranking (2019) adopted from (Cass, 2019)

Specification of the employed programming language and Computer:

1. Computer: LENOVO Laptop PC Intel Core i7 CPU 2.60 GHz
2. RAM: 16 GB with 64-bit OS Architecture
3. Programming Language: Python Programming Language 3.8.1
4. Integrated Development Environment (IDE): Pycharm Community Edition 2019.3.2

The computer program was developed to help designers make the building material selection process more streamlined and efficient. To accomplish this a computer program called “Prime Building Material Selection Software” was developed by the Author.

5.2 Description of the Computer Program

As stated above, the developed computer program's main objective is to make the selection process more streamlined and efficient. Python programming language was used to develop the computer program. Python was chosen because for its clear, logical, and readable code. The computer program uses Multi attribute utility theory (MAUT) as Multi Criteria Analysis (MCA) to evaluate the multiple criteria for building material selection.

The evaluation process of the computer program contains five (5) main phases:

I. Determination of the project objectives
II. Determination of the alternatives
III. Determination of the Criteria
IV. Determination of Weights and Utiles of the criteria
V. Computation of the Score

5.2.1 Working Manual

In this section the five (5) main phases of the computer program will be discussed in detail. The working manual will describe each of the phases in detail starting with installation of the computer program.

5.2.1.1 Installation

Pycharm community edition 2019.3.2 was used as integrated development environment (IDE) for python programming language. The computer program doesn't need installation as it's in executable (.exe) format already. Python has a feature to turn the written software to executable (.exe) format, which makes the language more useful for programmers.

5.2.1.2 Determination of the project objectives

The first step in any building material selection process is determining the project objectives and the client's requirement. The computer program allows the user, in this case the designer, to choose different classifications of the criteria based on the objectives of the project.

In the first window, the user is greeted with a brief message about the objective of the computer program. The user is given the choice of different classifications. These are:

I. Based on Technical Considerations: In this classification, the criteria are further grouped into:

    i. Mechanical/Technical Criteria
    ii. Environmental Criteria
    iii. Socio-economic Criteria

This grouping helps the user to identify and evaluate the criteria more easily and efficiently based on the project objective. The grouping was done based the questionnaire analysis and literature review done on this thesis.

II. Based on Importance of the criteria: In this classification, the criteria are further grouped into:

    i. Primary Criteria
    ii. Secondary Criteria
    iii. Tertiary Criteria

This grouping helps the user to identify and evaluate the criteria more easily and efficiently based on the project objective. The grouping was done based the questionnaire analysis done on this thesis.

III. Based on Ownership of the project: In this classification, the criteria are further grouped into:

    i. Public Building
    ii. Private Building

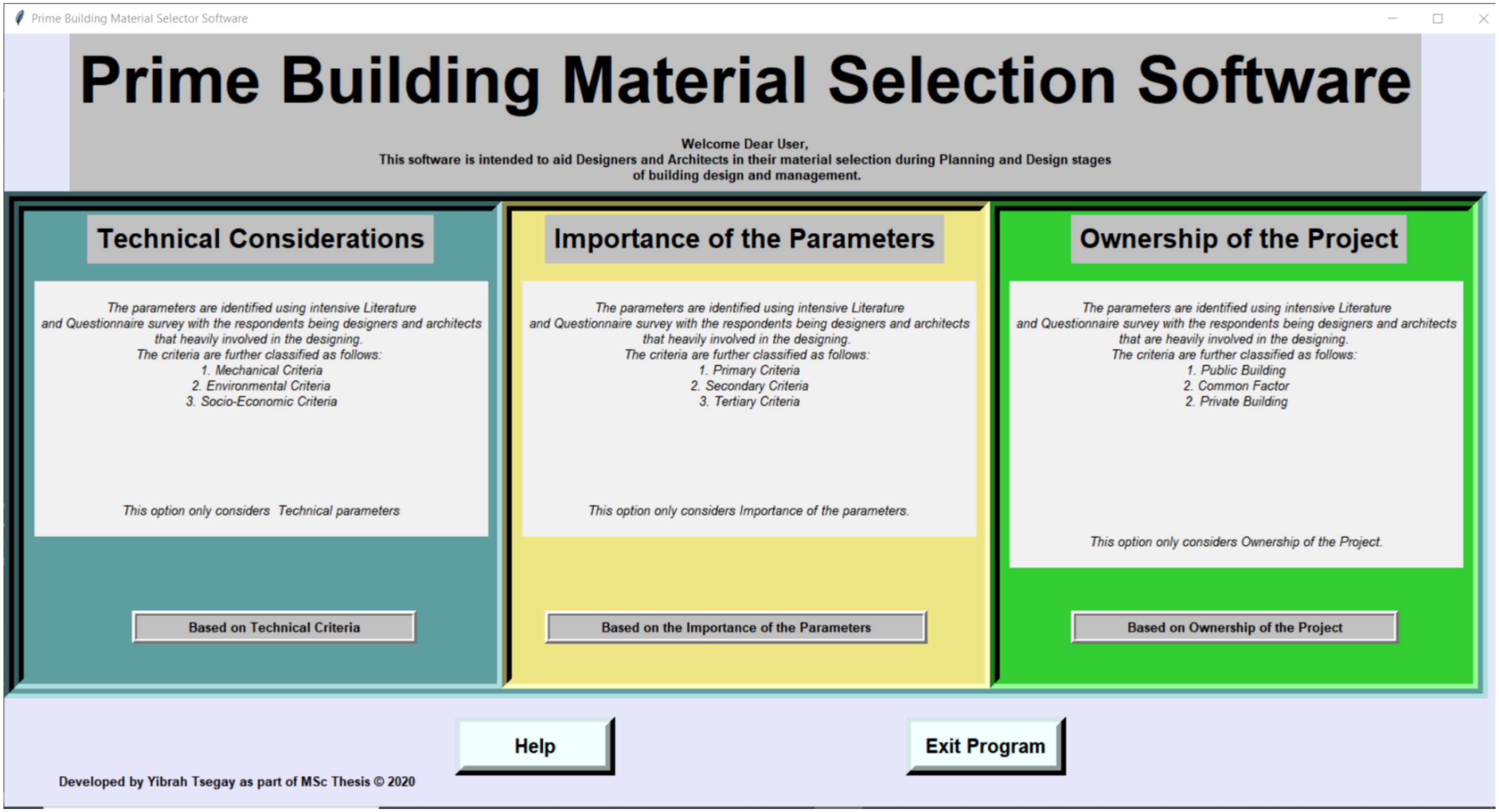


Figure 1: Computer Program Top Window

iii. Common Factors

This grouping helps the user to identify and evaluate the criteria more easily and efficiently based on the project objective. The grouping was done centred around the questionnaire analysis done on this thesis.

Once the user clicks on a button of his choice on the bottom of each of the classifications, the program opens two windows (window 2 and window 3) based on his/her choice.

5.2.1.3 Determination of the alternatives

The user then has to identify the alterative building materials that he/she wants to evaluate. This will be done at the top of the second window. The alternatives are listed in the dropdown menu next to each alternative (figure 2).

5.2.1.4 Determination of the Criteria

The user then has to identify the criteria list that he/she wants to evaluate. The criteria list is obtained through comprehensive literature review and questionnaire survey.

5.2.1.5 Determination of Weights and Utiles of the criteria

The user then has to input weights to each criteria, on a scale of zero (0) – four (4), that indicates their relative importance based on the project objective and client's requirement. The user also has to input Utiles to each criteria that indicates how much each criteria satisfies each alternative. This will be illustrated in Chapter later in the paper using an illustrative example. This will be done over two windows (window 2 and window 3).

5.2.1.6 Computation of the Score

After inputting the necessary data, the program will calculate the MAUT score once the user clicks the "subtotal" for each alternative and "Total" for each alternative. In computation, the user has to click "subtotal' on window 2 (figure 2) and window 3 (figure 3), then the program adds them up once the user clicks on "Total" for each alternative.

The building material with the highest score is the most sustainable material based on the project objectives and the client's requirements.

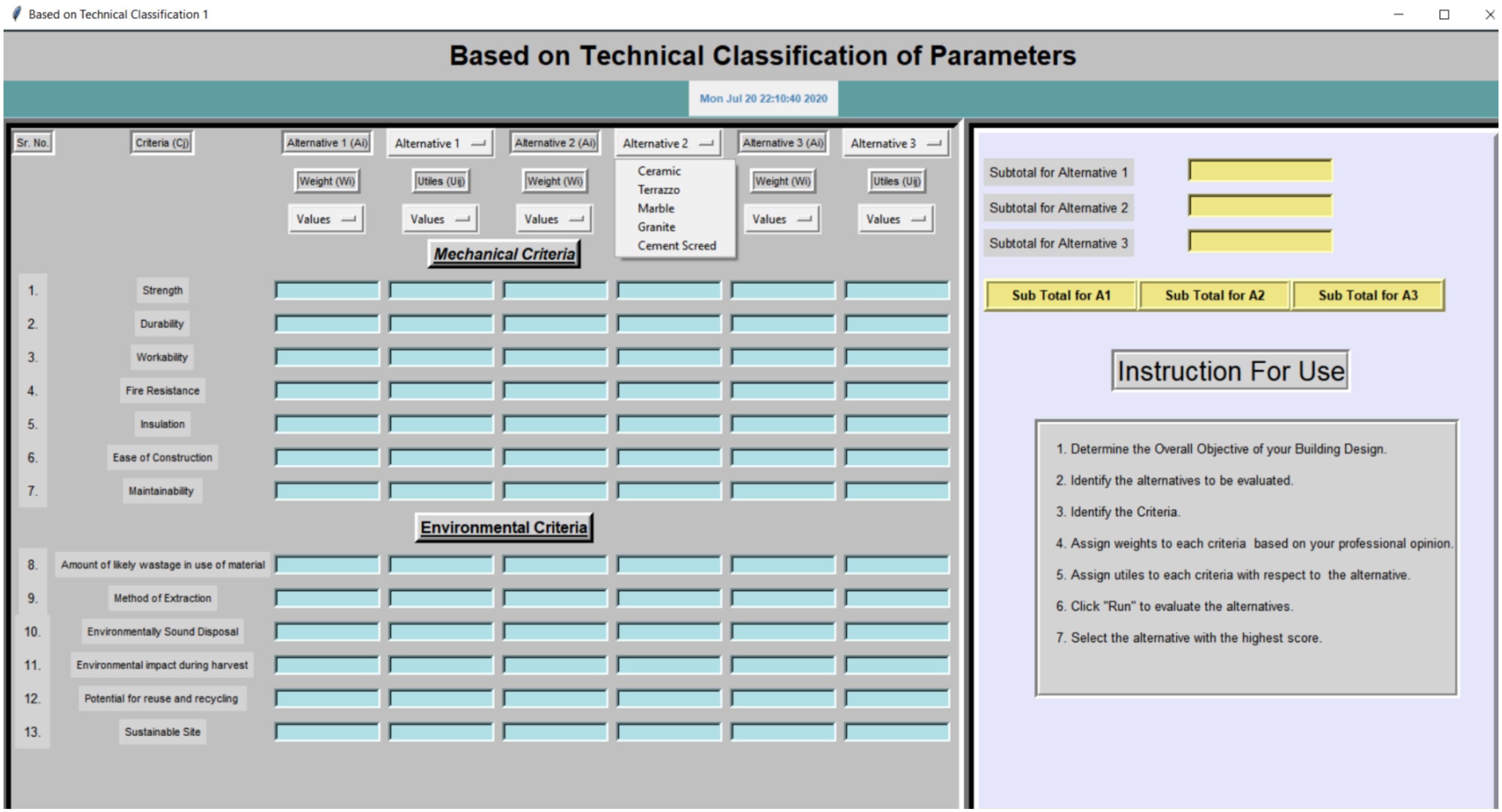


Figure 2: Window 2 of the computer Program

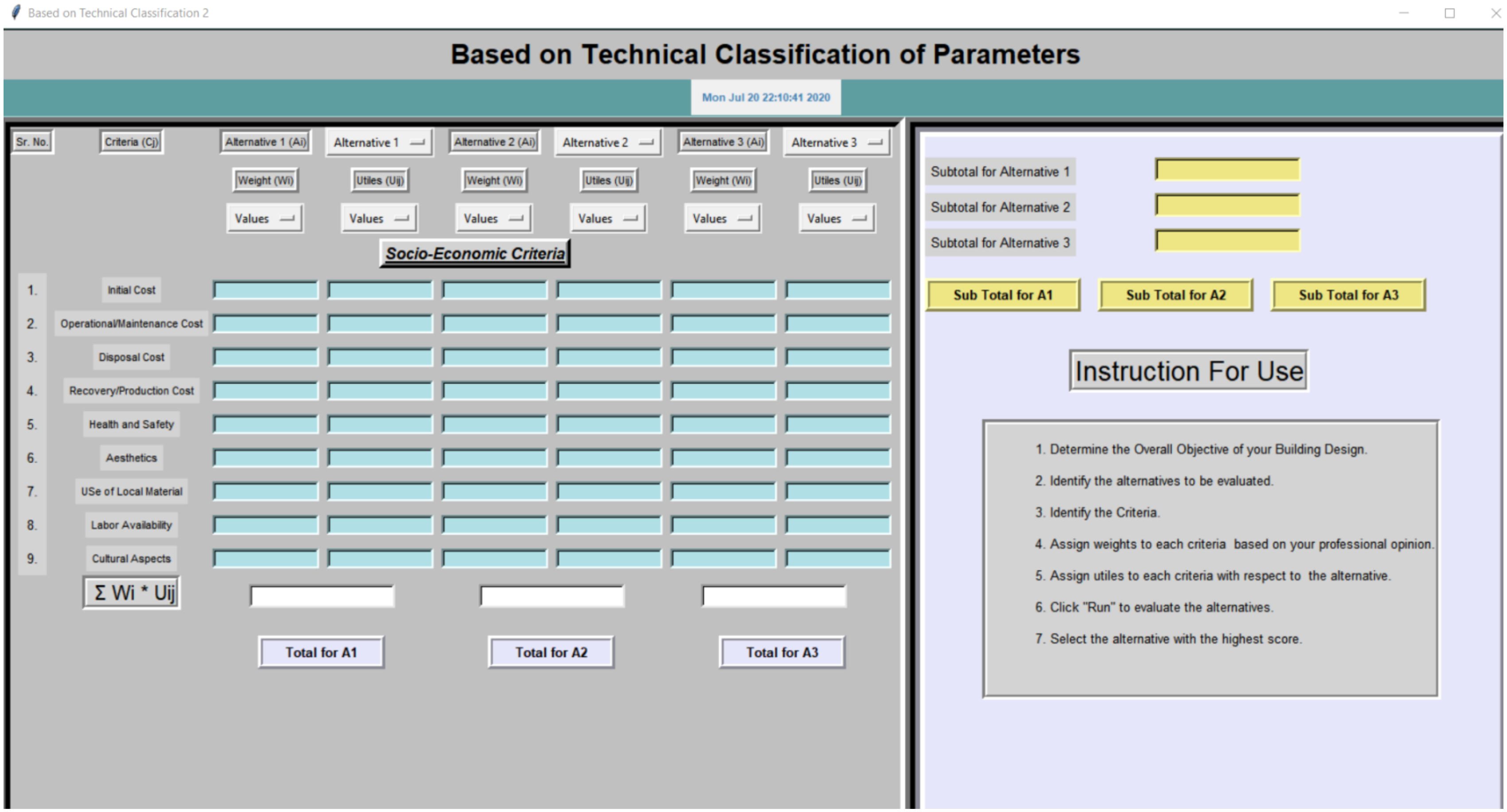


Figure 3: Window 3 of the computer program

5.2.2 Limitation of the Computer Program

Since this is the author's first endeavor into the programming world and this version also is the first version of the computer program, there is considerable limitation to the program,

a) The computer program only has capability to evaluate three (3) building materials at one time.
b) The computer program can only evaluate floor finish materials in its current capacity.
c) The user interface window is a bit unimaginative.
d) The evaluation is done on two separate windows.
e) The program requires a lot of inputs from the user.

5.2.3 Potential for Improvements

The computer program has a lot of potential for improvement. The capability is numerous and the practicability is astounding.

a) There is a potential to increase the evaluation capacity of the program.
b) Other materials other than floor finish materials will be added.
c) The evaluation will be on 1 window after some rearrangement and adjustment.
d) The author is considering adding data sheet to the program so that the user can have information or data of the material he/she is evaluating right from the program.
e) A feature can be added whereas the user is only asked to input few information and project particulars such as location, project type, project objectives, project budget, and few information about the weightage of the criteria in qualitative form. Consequently, the program fetches the relevant data from the built-in data sheet and optimizes the building material for that project.

5.2.4 Comparative Advantage of the Computer Program

1. The Computer Program can be used in the design of Ethiopian buildings by local designers with relative ease.

2. The computer program uses locally sourced criteria list, which makes it more relevant to be used in the design of Ethiopian buildings as compared to the existing tools.

3. Most of the foreign assessment tools reviewed in the literature review, put much more focus on the environmental performance (ENVEST, EPM), as well as economic aspects (BEES). But what makes this program unique is – it evaluates all aspects with weights from the designer.

5.3 Software Testing

5.3.1 Illustrative Example

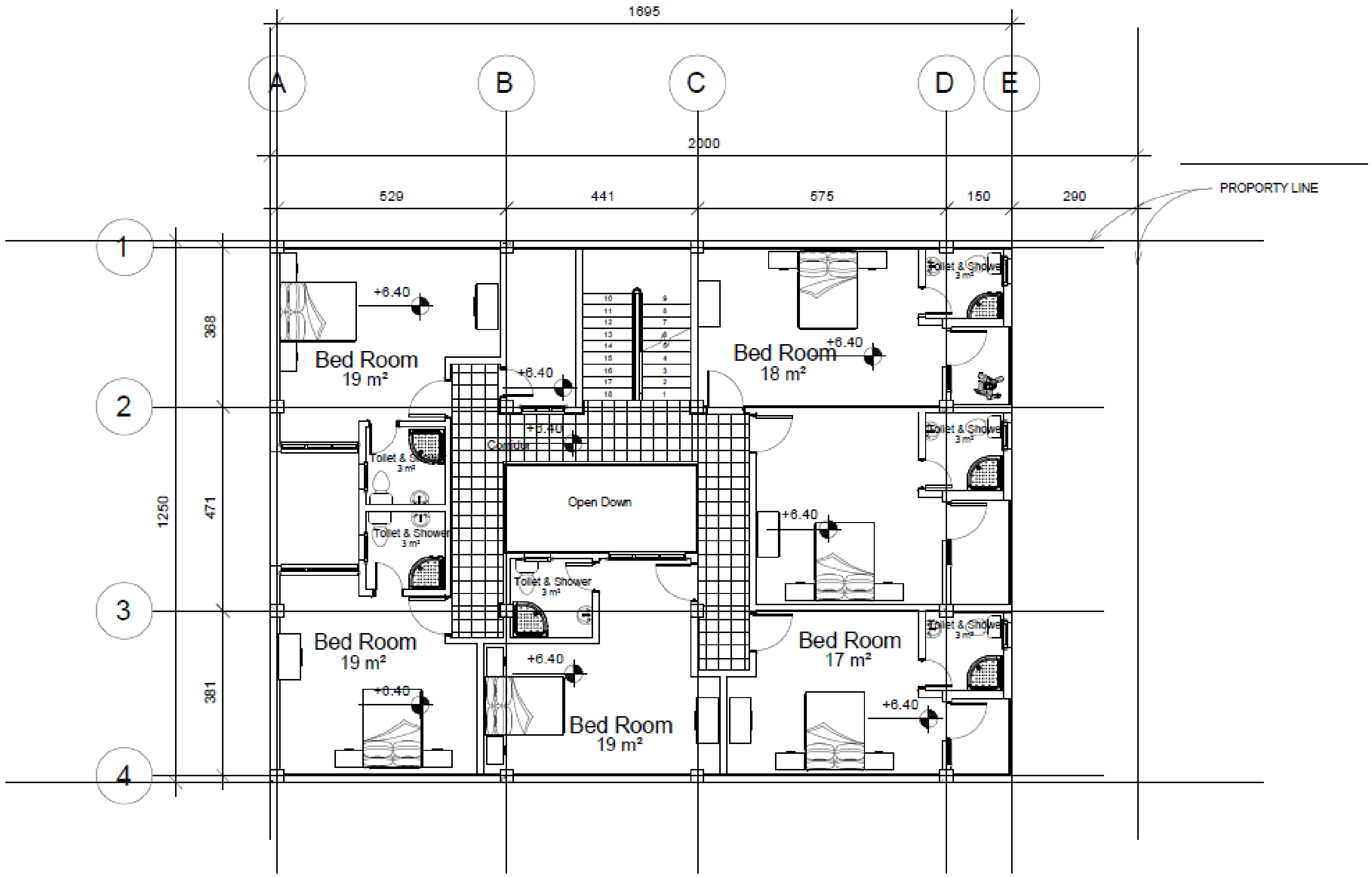
The aim of this validate to test and demonstrate the developed computer program in practical and real life application. . This chapter first provides the background to the selected case study. In view of the complex nature of the research, case study was chosen as the best means to validate the software/model and show how the material selection process can be made easier using this software.

To test the applicability of the software, three commonly used floor finish materials in Ethiopian private buildings were selected as a sample for the case study. Private building was chosen for the case study because majority of respondents in the questionnaire survey specialize in private buildings and have adequate experience in private building floor finish materials.

The case study used intends to provide an indication of the use of the Multi-attribute Utility Theory (MAUT) as Multi Criteria Analysis (MCA) model for selection of sustainable and best building material.

The proposed hypothetical case study taken as study case is a hypothetical design of a B+G+4 private commercial building located in Mekelle, Tigray. The designer is working with a client to select materials (in this case floor finish material) for the proposed private commercial building.

The client informs the designer that he wants a cost effective building made of economical and cost conscious building materials. He goes on to say that, while he is willing to compromise the aesthetics on materials to achieve a “sustainable building,” Environmental issues is still a consideration.



Second Floor @ 6.40
Sc 1:100

Figure 4: Illustrative Example

5.3.2 Working Steps

In this section, it was tried to illustrate the steps that have to be taken to evaluate the alternatives using the software. It is a step by step illustration of the software.

5.3.2.1 Step 1: Overall Objective of the Project/Client

As it is stated above, the client informed the designer that he wants a cost effective building made of economical and cost conscious building materials. He goes on to say that, while he is willing to compromise the aesthetics on materials to achieve a "sustainable building," Environmental issues is still a consideration.

With this consideration in mind, the designer decided to implement the building material selection software. Since the client has emphasized on the cost effectiveness and economic aspect of the design, the designer has decided to further classify the criteria/factors based on the technical considerations. This classification gives the user, in this case the designer, more freedom to manipulate the weightage and importance coefficient specifically based on the client needs. Also, the designer has decided to use the weightage values surveyed in this thesis paper.

5.3.2.2 Step 2: Identify the Alternatives

The Second step in this material selection process is to identify the alternatives. The designer has alternatives in mind for floor finish material. Considering the type of building and function of the building, the designer has narrowed down the alternatives to 3, which the designer will further select the most sustainable option using the software. The description and information of the three options was based on the standard practices and construction details commonly used in Ethiopia (figures 2 & 3).

Table 30: Identify Alternatives

Description/Information	Alternative 1	Alternative 2	Alternative 3
Material Name	Ceramic	Marble	Terrazzo
Material Type	Floor Finish	Floor Finish	Floor Finish
Material Tile Size	40 cm * 40 cm	40 cm * 40 cm	40 cm * 40 cm
Building Type	Private Commercial	Private Commercial	Private Commercial

5.3.2.3 *Step 3: Identify the Criteria*

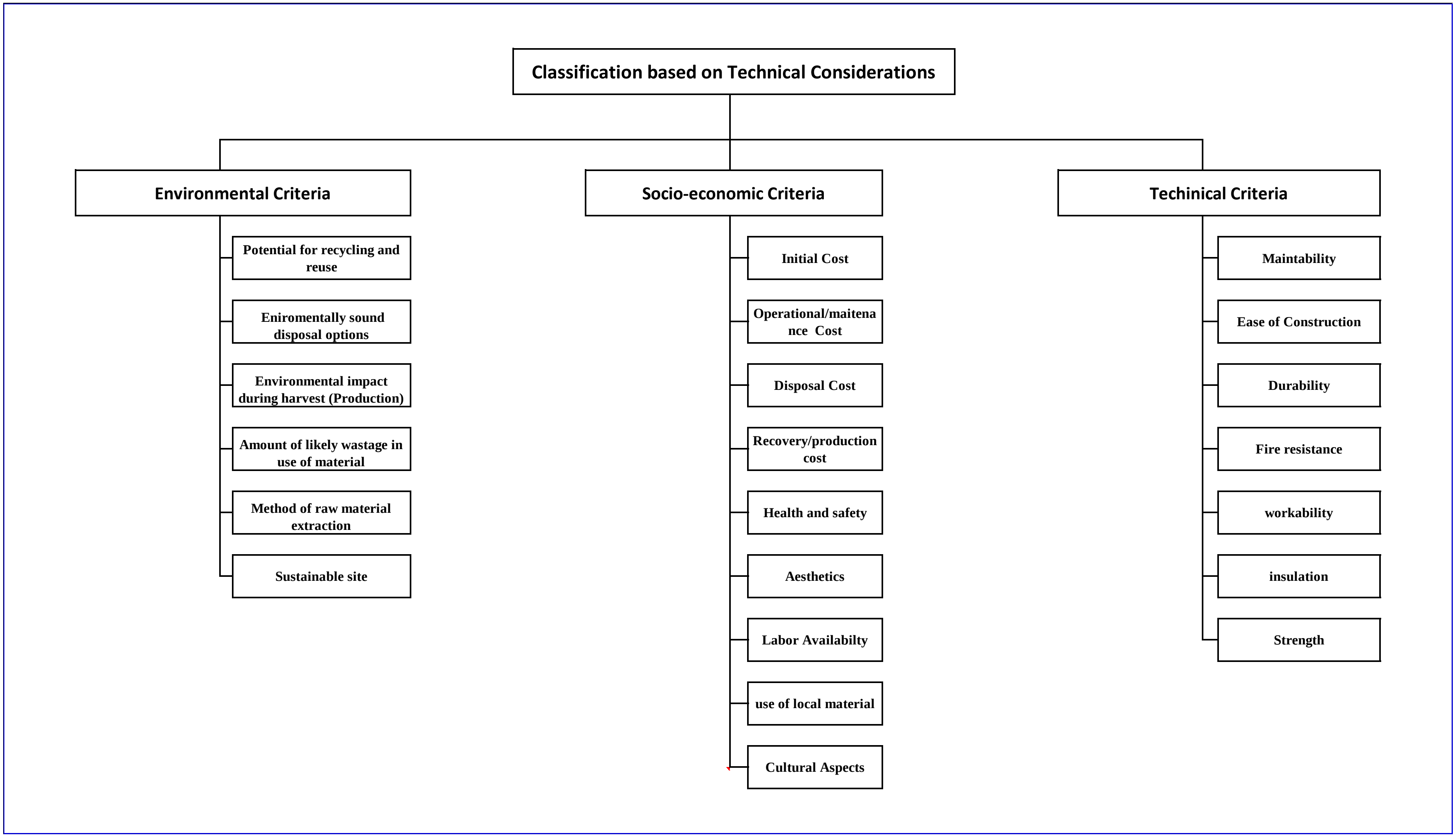


Chart 23: Identify the Criteria

5.3.2.4 Step 4: Assign Weights (W_j) to Criteria

The following step in material selection process will be to assign weights to each criteria. Having the priorities set by the client, the designer has to determine weightage of the criteria keeping in mind the priorities of the client, his professional knowledge and for the greater good.

5.3.2.5 Step 5: Assign Utiles (U_{ij}) to criteria

The following step in material selection process will be to assign utiles to each criteria. Utiles are commensurable units (utiles) on an interval scale of zero (0) to one (1) used to equate unrelated units into measurable and comparable units.

The designer will have to assign utiles (U_{IJ}) based on how much each alternative satisfies each criteria. The more the alternative satisfies the criteria, the closer the value of the utiles has to be to one. For example, if Alternative 1 satisfies the criteria of strength better than Alternative 2, Alternative 1 will be assigned 0.9 and Alternative 2 will be assigned 0.7.

Step 4 and Step 5 will be summarized in the following table:

Table 31: Assign weight and utiles for the Alternatives

Item	Criteria (C_J)	Weight (W_J)	Ceramic	Marble	Terrazzo
			Utiles (U_{ij})	Utiles (U_{ij})	Utiles (U_{ij})
Mechanical/Technical Criteria					
1	Strength	3.83	0.9	0.9	0.8
2	Durability	3.83	0.8	0.9	0.7
3	Workability	3.80	0.9	0.7	0.8
4	Fire Resistance	3.77	0.9	0.9	0.7
5	Insulation	3.87	0.7	0.7	0.6
6	Ease of Construction	3.75	0.8	0.6	0.8
7	Maintainability	3.80	0.8	0.6	0.7
Environmental Criteria					
8	Amount of likely wastage in use of material	3.83	0.6	0.5	0.5

9	Method of Extraction	3.66	0.3	0.2	0.3
10	Environmentally Sound Disposal	3.77	0.3	0.2	0.3
11	Environmental impact during harvest	3.74	0.3	0.2	0.2
12	Potential for reuse and recycling	3.74	0.3	0.4	0.2
13	Sustainable Site	3.87	0.4	0.2	0.3
Socio-economic Criteria					
14	Initial Cost	3.77	0.4	0.3	0.6
15	Operational/Maintenance cost	3.77	0.4	0.4	0.6
16	Disposal Cost	3.77	0.3	0.2	0.6
17	Recovery/Production Cost	3.77	0.4	0.3	0.6
18	Health and Safety	3.83	0.8	0.7	0.7
19	Aesthetics	3.72	0.8	0.9	0.5
20	Use of local Material	3.69	0.7	0.7	0.8
21	Labor Availability	3.76	0.8	0.6	0.8
22	Material Availability	3.73	0.5	0.6	0.6

5.3.2.6 Step 6: Apply MAUT Evaluation using the Software

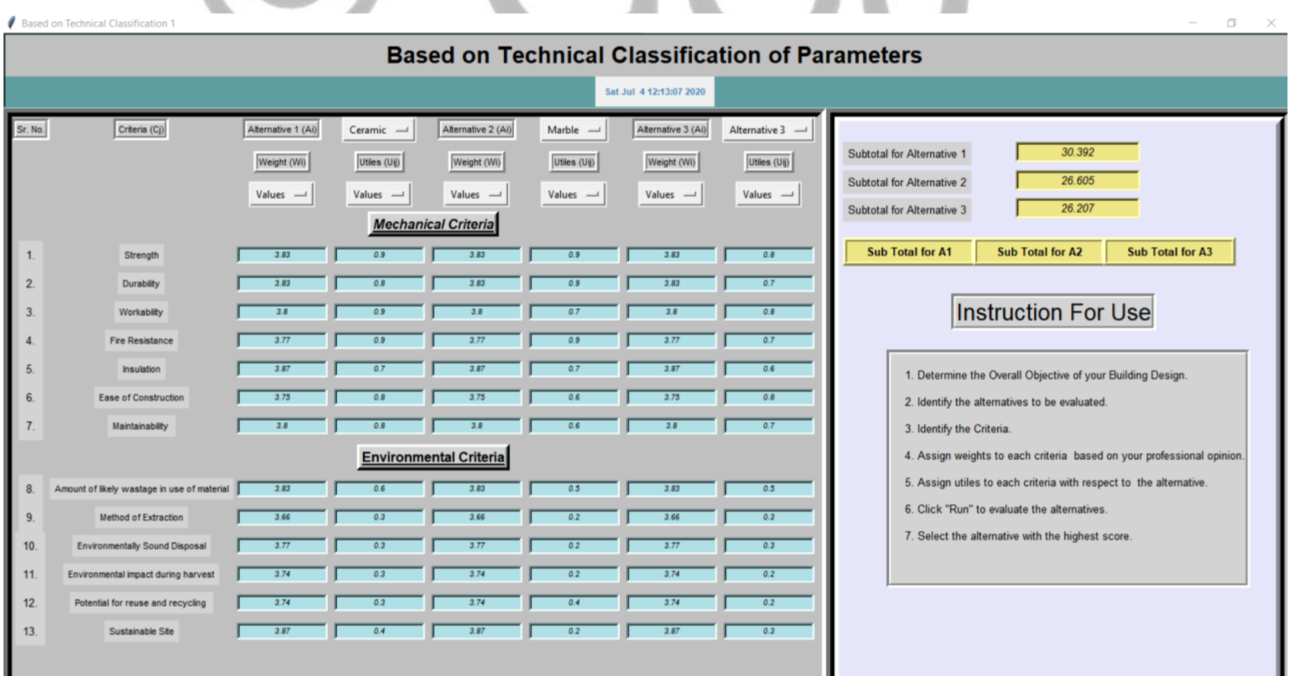


Figure 5: Apply MAUT using the program (Window 2)

After the weights and utiles for each alternatives are input in the software, subtotal for each alternative should be clicked so that it evaluates the inputs in the first window and links it to the second window so that it can be totaled with the other inputs.

According to the developed software, Ceramic is the most Sustainable material for this specific project given the priorities and weight given by the designer.

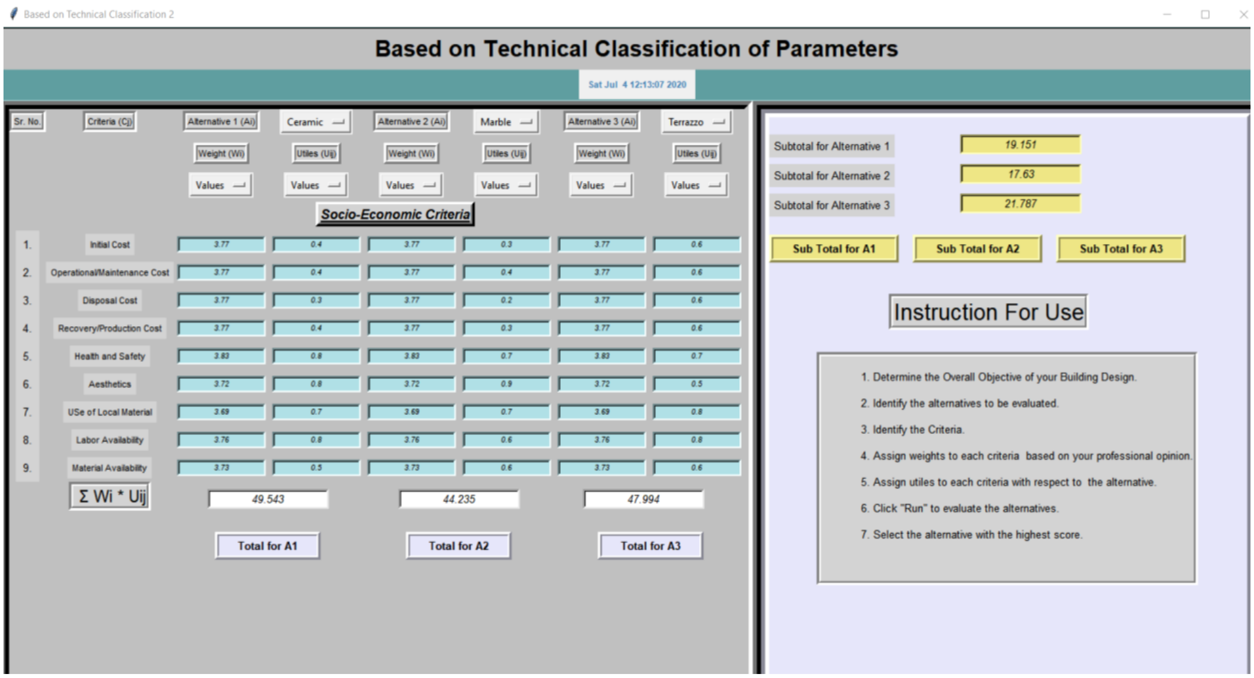


Figure 6: MAUT Evaluation using the program (window 3)

5.3.3 Results of the Computer Program

The results are as follows:

Table 32: Results of the computer program

Item	Alternative	MAUT Score (S_j)
1	Ceramic	49.54
2	Marble	44.24
3	Terrazzo	47.99

- ❖ Hence, Ceramic is the most sustainable material (the highest score) and is selected for this project.

Chapter 6: Conclusion and Recommendations

This chapter presents conclusion of the research and recommendation for further research and for a way to streamline and simplify the building material selection process.

6.1 Conclusion

In this section, conclusion based on the findings of the thesis will be forwarded in objective oriented manner.

I. *First objective of the research was to evaluate the Ethiopian building material selection practice:* The evaluation was done through literature review, Design Document review, and a questionnaire survey that inquired about the level of awareness about sustainability and the material selection practice. The findings of the research showed that majority of the construction stakeholders are somewhat aware about sustainability and environmental issues. Likewise, majority of the stakeholders (91%) agreed or strongly agreed that the design decision they make has an impact on environment which shows that the stakeholders would be open to material selection with sustainability as a driving concept, if given the right tools.

Even though, the somewhat acceptable level of awareness about sustainability, the material selection practice is not a satisfactory one. As results show, few stakeholders (mostly consultants) use existing assessment and selection tools. This findings leads the reader to wonder what presumed obstacles might hold the stakeholders from practicing material selection. These presumed obstacles, ranked based on their Relative Importance Index (RII), are – Problem in evaluating information, perception of extra cost being incurred, and perception of extra time being incurred.

II. *Second objective of the research was to assess the important factors for building material selection process:* To assess the important factors for building material selection, literature review and questionnaire survey was conducted. The results show that the stakeholders rank technical criteria as the most important for material selection followed with socio-economic criteria and with environmental criteria in the last place. The full list of the criteria are tabulated on Table 20.

III. *Third objective of the research was to propose a strategic material selection approach for Ethiopian building design:* Criteria ranked 1-23 were used for the proposal of the strategic approach and the computer program. Since twenty two (23) criteria were assessed to be important, multi criteria analysis (MCA) technique was used to evaluate the criteria. After reviewing numerous MCA techniques, multi attribute utility theory (MAUT) was chosen due to its relative simplicity and straight forward linear evaluation method. In the proposed strategic approach, After identifying the relevant criteria, the user has to assign weights (w_i) to each criteria based on the criteria's relative importance and assign "utiles (u_{ij})" based on how well each building material satisfies the criterion. To get the MAUT score, use Equation 2 and select the building material with the highest score.

The flowchart of the proposed strategic approach is presented on Chart 21.

IV. *Fourth objective of the research was to develop building material selection computer program for Ethiopian building design:* The computer program was developed using Python Programming language. Python programming language was used because after thorough literature review, it was found to be the most applicable and fastest growing programming language globally. The computer program was developed using the strategic approach flowchart as a basis and has multiple windows based on different classification of the criteria. The screens of the computer program are presented on Figures 1 up to 6.

In conclusion, this research tried to evaluate the current building material selection practice with respect to the level of awareness in regards to sustainability and material selection practices. After the evaluation, a strategic approach flowchart was proposed alongside a computer program.

6.2 Recommendation

In this section recommendation based on the research findings and identified gaps will be forwarded. Providing useful and practicable recommendations will be the ultimate goal of this research as all research should aim for.

i. Level of awareness about sustainability is an acceptable one as results show. However, the application of material selection is very low. As the country is going into green economy, the construction industry should be at the forefront of this push. For this goal to be a reality, the construction industry should seriously raise the level of sustainability awareness and knowledge about material selection.

ii. Tools such as Life Cycle Assessment (LCA), LEEDS, and BREAM should be integrated into the planning and design phases of building projects. As the results show, the usage of these tools is very low.

iii. Universities and Educational Institutions should do extensive research into sustainability and construction. As the literature review shows not much is done on this front.

iv. Universities and Educational Institutions should do researches into computer aided engineering such as Machine Learning in construction & design, Automating tedious tasks in construction sites, and Data science in construction.

6.3 Need for Further Research

i. Further and more extensive research into sustainability and environmental research should be done.

ii. Further research into Sustainability assessment tools and their possible application in the design of Ethiopian buildings should be done.

iii. Environmental parameters of building materials should be studied further. Parameters such as embodied energy, CO_2 emissions should be researched further as knowing these values will help us in material selection.

iv. There is a glaring gap of full data sheet for building materials. These data sheets should include the technical parameters (Strength, Durability), socio-economic parameters (initial cost, disposal cost), and environmental parameters (embodied energy, CO_2 emissions). Further study should be done to provide the aforementioned data sheet.

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Appendices

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Appendix B: Questionnaire

To Whom It May Concern

Dear Sir/Madam,

Research into Sustainability Practices in the Ethiopian Construction Industry and Proposal of a Strategic Model and a Computer Program

I am presently pursing a Master of Science Degree in Construction Technology & Management (COTM) Chair at Mekelle University, Ethiopian Institute of Technology.

This questionnaire is aimed at investigating sustainable construction practices of Ethiopian architects and designers, with focus on sustainable building material selection. This questionnaire is designed in a way that you can make suggestions as part of your invaluable contributions to this work. We would very much appreciate if you could please spare few minutes to complete the questionnaire. There are no correct or incorrect responses, only your much-needed opinion. All answers will be treated in absolute confidence and used for academic purposes only. Extra space is provided to enable you expand your answers to the questions where necessary.

We do appreciate that the questionnaire will take some of your valuable time but without your kind and expert input these research objectives aimed at improving sustainability implementation cannot be realized. To this end, we would like to thank you very much for your valued and kind consideration and the research findings will be disseminated to you.

Thank you in advance for your time and kind cooperation.

Yours Sincerely,

Yibrah Tsegay Berhe
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Construction and Technology Management (CoTM)
Ethiopian Institute of Technology (EiT-M)
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SECTION 1

SECTION 1A: BACKGROUND OF RESPONDENT (Optional)

Name of Company/Respondent: ([Respondent] if freelancer)
Position in company: (leave if freelancer)
Work Experience in the construction industry…..………… (Years) Address:
Nature of Experience (Select as (a) Design (b) Construction (c) Construction Management (d) other……………………..
Telephone:
E-mail:

SECTION 1B. GENERAL INFORMATION (Please tick □ options where applicable)

1. What type of organization do you work for? (Please tick □ box as appropriate).

a. Architecture & design office	□	b. Engineering	□	c. Quantity surveying	□	d. Project management	□
e. Education	□	f. Real Estate	□	g. Government agency	□	h. Contractor	□
Others (Please specify)							

2. Please specify the number of employees in your organization? …………………
3. What type of building project do you specialize in? (Please tick □ box as appropriate).

a. Commercial	□	b. Residential	□	c. Institutional	□	d. Industrial	□
e. Leisure	□	f. Other	□				

4. Age of organization? ……………….
5. Please specify annual turnover? ……………….
6. Your regular client type? (Please tick □ box as appropriate)

a. Public sector	□	b. Private sector	□	c. quasi-Public (Eg. SUR)	□	d. Industrial	□

SECTION 2

Section 2A: Sustainability Awareness and Related Action

❖ Legend:

- NI= No Idea
- DK= Don't Know
- NA= Not Applicable

7. Please indicate your level of awareness of sustainability and environmental issues in building construction (Please tick □ box as appropriate).

a. Extremely Aware	□	b. Moderately Aware	□	c. Somewhat Aware	□	d. Slightly Aware	□
e. No Idea	□	e. Not Applicable	□				

8. Please indicate the extent of your agreement with the following statements about environment and sustainability issues in building design and construction (Please tick □ box as appropriate)

Statements	Strongly Agree				Strongly Disagree
	5	4	3	2	1
a. Environmental assessment is an important issue in building project	□	□	□	□	□
b. Construction activities contributes to negative environmental impact	□	□	□	□	□

c. It is important to include environmental issues at the conceptual stage of building project	☐	☐	☐	☐	☐
d. It is important to understand the environmental impacts of design decision	☐	☐	☐	☐	☐
e. It is important to be conscious that some of the materials have impacts on the environment	☐	☐	☐	☐	☐
f. Environmental consideration need to be incorporated into material selection decision making	☐	☐	☐	☐	☐
g. It is important to consider the full range of environmental impacts of construction materials by assessing their entire life cycle	☐	☐	☐	☐	☐

9. Please rate on a scale of 1-4 the following project objectives when embarking on a building project (Please tick ☐ box as appropriate).

	Highest				Lowest
	5	4	3	2	1
a. Minimize cost	☐	☐	☐	☐	☐
b. Meet project deadline	☐	☐	☐	☐	☐
c. Meet building regulations	☐	☐	☐	☐	☐
d. Satisfy client specification	☐	☐	☐	☐	☐
e. Minimize project impact on the environment	☐	☐	☐	☐	☐
Others (Please specify)	☐	☐	☐	☐	☐

SECTION 3

Section 3A: Application of Existing Sustainable Principles in Building Design and Material Selection Process:

10. How will you rate your knowledge of material selection? (Please tick □ box as appropriate).

a. Excellent	□	b. Good	□	c. Sufficient	□	d. Insufficient	□
e. Don't Know	□	f. Not Applicable	□				

11. Do you consider sustainability assessment of building material an important issue for building development? (Please tick □ box as appropriate).

a. Yes	□	b. No	□	c. Can't Say	□

If Yes or No, Please give reason(s)

…………………………………………………………………………………....

……………………………………………………………………………………

12. Which of the following categories of stakeholders will be more attuned/aware to sustainability in a building project? (Please tick □ box as appropriate).

a. Public	□	b. Private	□	c. No difference	□	d. Can't tell	□
d. Other	□						

13. Overall percentage (%) of projects you've handled involving sustainability considerations? (Please tick □ box as appropriate).

a. Above 80%	□	b. Above 60%	□	c. Above 40%	□	d. Above 20%	□
e. Can't Say							

14. Which of the following sustainable construction practices have you implemented to show your commitment to sustainable and to what extent? (Please tick □ box as appropriate).

	Highest				Lowest
	5	4	3	2	1
a. Having obtained ISO 14001 certification	□	□	□	□	□
b. Having obtained the code for sustainable homes standard	□	□	□	□	□

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c. Investing in Research & Development (R&D) for implementing sustainable construction	□	□	□	□	□
d. Investing resources for improving sustainable equipment & technology	□	□	□	□	□
e. Implementing comprehensive energy saving plan	□	□	□	□	□
f. Implementing comprehensive material saving plan	□	□	□	□	□
g. Implementing comprehensive water saving plan	□	□	□	□	□
h. Implementing comprehensive land saving plan	□	□	□	□	□
i. Implementing comprehensive noise controlling plan	□	□	□	□	□
i. Implementing comprehensive waste abatement plan	□	□	□	□	□
k. Implementing comprehensive e air pollution controlling plan	□	□	□	□	□
Others (Please specify)	□	□	□	□	□

15. Below is a list of sources of information on new building products. Kindly indicate on a scale of 1-4 how often you consult the sources (Please tick □ box as appropriate).

	Highest				Lowest
	5	4	3	2	1
a. Trade journals & Magazines	□	□	□	□	□
b. Catalogue brochures	□	□	□	□	□
c. Trade representatives	□	□	□	□	□
d. Colleagues	□	□	□	□	□
e. Exhibitions & fairs	□	□	□	□	□
f. Web based information (e.g. internet)	□	□	□	□	□
Others (Please specify)					

16. Please rate the following (on a scale of 1- 4) as they affect your material selection practices.

	Highest				Lowest

	5	4	3	2	1
a. Budget Constraints	□	□	□	□	□
b. Lots of manpower and time in analyzing & selecting proper material	□	□	□	□	□
c. Problem in determining priorities	□	□	□	□	□
d. Lack of access to current and relevant information	□	□	□	□	□
e. Inadequate current construction techniques	□	□	□	□	□
f. Inadequate instructions about materials	□	□	□	□	□
g. Building regulation(codes & ordinances)	□	□	□	□	□
h. Consideration of sustainable materials	□	□	□	□	□
Others (Please specify)	□	□	□	□	□

17. Rate the following statements that best represents your perception of sustainability in building projects.

	Strongly Agree				Strongly Disagree
	5	4	3	2	1
a. Material specification should include sustainability considerations	□	□	□	□	□
b. Guides for selecting sustainable materials can be easily found in Ethiopia	□	□	□	□	□
c. Sustainability considerations are mainly for satisfying mandatory requirements	□	□	□	□	□
d. Adopting sustainable material should be voluntary	□	□	□	□	□
e. Use of environmentally friendly materials and sustainable construction methods will help to preserve natural resources.	□	□	□	□	□
f. I am aware that sustainability is getting more recognition among my colleagues and co-workers.	□	□	□	□	□
g. I believe that using environmentally friendly materials and will increase construction cost and time.	□	□	□	□	□
h. On the contrary, the use of environmentally friendly materials	□	□	□	□	□

would reduce construction cost and time.					
i. Even if there is an increase in the construction cost and time, I have noticed that my colleagues and co-workers intended to incorporate sustainability in material selection	☐	☐	☐	☐	☐
j. Even if there is an increase in the construction cost and time, I have noticed that my clients intended to apply sustainable construction methods in pro ects	☐	☐	☐	☐	☐
k. Important for architects to be conscious that some of the materials they specify have an impact on the environment	☐	☐	☐	☐	☐
l. Important for architects to consider the full range of environmental impacts of construction materials by assessing their entire life cycle	☐	☐	☐	☐	☐

18. As a practicing professional in the construction industry, how often do you use the following techniques/tools for material and building assessment? (Please tick ☐ box as appropriate).

	Highest				Lowest
	5	4	3	2	1
a. Multi-Criteria Analysis (a decision-making tool)	☐	☐	☐	☐	☐
b. Building for Environmental and Economic Sustainability (BEES)	☐	☐	☐	☐	☐
c. BRE Environmental Assessment Method (*BREEAM*)	☐	☐	☐	☐	☐
d. ATHENA^{TM} impact estimator for buildings	☐	☐	☐	☐	☐
e. Environmental Preference Method (EPM) – developed in Netherland	☐	☐	☐	☐	☐
f. Building Environment Assessment Tool (BEAT 2001)	☐	☐	☐	☐	☐

g. Leadership in Energy and Environmental Design (LEED)	☐	☐	☐	☐	☐
h. Building Environmental Performance Assessment Criteria (BEPAC)	☐	☐	☐	☐	☐
Others (Please specify)	☐	☐	☐	☐	☐

SECTION 4

Section 4A: Influences of Stakeholders in Material Selection and Obstacles of Sustainability

19. For each of the following professionals, indicate how much influence each has in material Selection.

	Highest				Lowest
	5	4	3	2	1
a. The client / client representative	☐	☐	☐	☐	☐
b. Architects & designers	☐	☐	☐	☐	☐
c. Quantity surveyors	☐	☐	☐	☐	☐
d. Project Managers	☐	☐	☐	☐	☐
e. Site Managers	☐	☐	☐	☐	☐
f. Contractors	☐	☐	☐	☐	☐
g. Technical consultants	☐	☐	☐	☐	☐
h. Suppliers of products	☐	☐	☐	☐	☐
i. Product manufacturers	☐	☐	☐	☐	☐

20. Please select obstacles and their degree currently preventing you from specifying sustainable products and materials in your design?

	Highest				Lowest
	5	4	3	2	1
b. Lack of information on sustainable construction materials	□	□	□	□	□
c. Problem in Evaluating information	□	□	□	□	□
d. Uncertainty in the liability for the final works	□	□	□	□	□
e. Maintenance concern	□	□	□	□	□
e. building code restriction	□	□	□	□	□
f. Lack of tools and data to compare material alternatives	□	□	□	□	□
g. Perception of extra cost being incurred	□	□	□	□	□
h. Perception of extra time being incurred	□	□	□	□	□
i. Difficulties in balancing environmental, economic & social issues	□	□	□	□	□
l. perception that sustainable materials are low in quality	□	□	□	□	□
k. aesthetically less pleasing	□	□	□	□	□
l. Possible delay due to sustainability requirement	□	□	□	□	□
m. Limited availability & reliability of suppliers	□	□	□	□	□
n. Low flexibility for alternatives or substitutes	□	□	□	□	□
o. Unwillingness to change the conventional way of specifying	□	□	□	□	□
Others (Please specify)					

21. Most practitioners/commentators have sought to explain the relatively low use of the tools by pointing out perceived obstacles to their successful usage. Please indicate how frequently each of the following factors has been an obstacle to the use of the tools in practice (Please tick □ box as appropriate).

	Highest				Lowest
	5	4	3	2	1

a. Lack of familiarity with the technique	□	□	□	□	□
b. High cost involved in its use	□	□	□	□	□
c. High time consumption in using technique	□	□	□	□	□
d. Lack of skills in using technique	□	□	□	□	□
e. Lack of suitable programming software	□	□	□	□	□
f. Poorly updated programmes	□	□	□	□	□
g. Lack of adequate project information	□	□	□	□	□
Others (Please specify)					

SECTION 5

Section 5A: Sustainability Criteria and Development Of Material Selection Model/Flowchart:

22. Rate on a scale of 1 to 5 your degree of agreement, if the following criteria's/factors should be included in the development of Material selection Model/Flowchart/Software. (Please tick □ box as appropriate).

	Strongly Agree				Strongly Disagree
	5	4	3	2	1
Environmental criteria					
1. Potential for recycling and reuse	□	□	□	□	□
2. Availability of environmentally friendly disposal options	□	□	□	□	□
3. Impact of material on air quality	□	□	□	□	□
4. Material Conservation/ Amount of likely wastage in use of material	□	□	□	□	□
5. Environmental Impact during material production	□	□	□	□	□

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6. Land conservation	☐	☐	☐	☐	☐
7. Environmental statutory compliance	☐	☐	☐	☐	☐
8. Minimize pollution (air, land, water etc)	☐	☐	☐	☐	☐
9. Water Conservation	☐	☐	☐	☐	☐
10. Method of Material Extraction	☐	☐	☐	☐	☐
11. Embodied energy within material	☐	☐	☐	☐	☐
Technological criteria					
1. Maintainability	☐	☐	☐	☐	☐
2. Ease of Construction/Technology	☐	☐	☐	☐	☐
3. Life Expectancy/ Durability/Resistance to decay	☐	☐	☐	☐	☐
4.Service Quality	☐	☐	☐	☐	☐
5. Fire resistance	☐	☐	☐	☐	☐
6. Material Strength and Mechanical Properties	☐	☐	☐	☐	☐
7. Energy saving and thermal insulation	☐	☐	☐	☐	☐
Socio-economic criteria					
1. Life cycle cost (initial cost, maintainace cost, repair cost, disposal cost)	☐	☐	☐	☐	☐
2. Health and safety	☐	☐	☐	☐	☐
3. protecting physical resources					
4. Use of local material instead of imported material	☐	☐	☐	☐	☐
5. Aesthetics	☐	☐	☐	☐	☐
6. Material availability	☐	☐	☐	☐	☐
7. Labor Availability	☐	☐	☐	☐	☐
8. Cultural Aspects	☐	☐	☐	☐	☐
9. Amount of transportation required	☐	☐	☐	☐	☐

23. Rate on a scale of 1 to 4, the weightage and importance of the following criteria's/factors during material selection with respect to sustainability as a driving concept. .

	Highest				Lowest
	5	4	3	2	1
Environmental criteria	☐	☐	☐	☐	☐
1. Potential for recycling and reuse	☐	☐	☐	☐	☐
2. Availability of environmentally friendly disposal options	☐	☐	☐	☐	☐

3. Impact of material on air quality	□	□	□	□	□
4. Material Conservation/ Amount of likely wastage in use of material	□	□	□	□	□
5. Environmental Impact during material production	□	□	□	□	□
6. Land conservation	□	□	□	□	□
7. Environmental statutory compliance	□	□	□	□	□
8. Minimize pollution (air, land, water etc)	□	□	□	□	□
9. Water Conservation	□	□	□	□	□
10. Method of Material Extraction	□	□	□	□	□
11. Embodied energy within material	□	□	□	□	□
Technological criteria					
1. Maintainability	□	□	□	□	□
2. Ease of Construction/Technology					
3. Life Expectancy/ Durability/Resistance to decay	□	□	□	□	□
4.Service Quality	□	□	□	□	□
5. Fire resistance	□	□	□	□	□
6.Material Strength and Mechanical Properties	□	□	□	□	□
7. Energy saving and thermal insulation	□	□	□	□	□
Socio-economic criteria					
1. Life cycle cost (initial cost, maintainace cost, repair cost, disposal cost)	□	□	□	□	□
2. Health and safety	□	□	□	□	□
3. protecting physical resources	□	□	□	□	□
4. Use of local material instead of imported material	□	□	□	□	□
5. Aesthetics	□	□	□	□	□
6.. Material availability	□	□	□	□	□
7. Labor Availability	□	□	□	□	□
8. Cultural Aspects	□	□	□	□	□
9. Amount of transportation required					

This is the end of the Questionnaire. Thank you very much for your time.

Feedback Form

1. How many minutes did it take you to complete the Questionnaire?
………………..minutes

2. Did you find any questions ambiguous or difficult to answer?

Yes [ ]
No [ ]
Can't Say [ ]

3. If you answered 'Yes' above, can you please list those questions here or specify their numerical order?

4. Are there any specific questions that you consider irrelevant and should be omitted from the Questionnaire?

5. Are there any other issues that you think could be considered in the Questionnaire? (Please give details below).
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
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NB: Confidentiality and anonymity are guaranteed.

Appendix C: Previous Research Works

Intensive literature survey was conducted on numerous literatures of which the outcome played the primary role in shaping the questionnaire design and questions.

Table 33: Previous Research works

Research Topic	Frequency	Overall Frequency	Author(s)/Literature
Period (1990-2000)			
1. Multi Criteria Analysis	1	13	E. Triantaphyilou & Mann S., (1995)
2. Analytical Hierarchy Process (AHP)	1	1	E. Triantaphyilou & Mann S., (1995)
Period (2000-2010)			
3. Sustainability	7	27	Ding G., (2002); Ahmed et. al., (2009); Bhatt R. et. al., (2010); Florez L. et. al., (2010); Florez L., (2010); Larcouture et. al., (2008); Azhar S., (2010)
4. Material Selection	8	25	Ferrante et. al., (2000); Brechet Y. et. al., (2001); Larcouture et. al., (2008); Wateils et. al., (2009); Pavuluri, (2009); Bhatt R. et. al., (2010); Florez L. et. al., (2010); Florez L, (2010)
5. Multi Criteria Analysis	3	13	Cheung et.al., (2002); Bhatt R. et. al., (2010); Larcouture et. al., (2008)
5. Sustainable Building Assessment Models/tools	6	23	Azhar S. et al., (n.d.); Larcouture et. al., (2008); Ding G., (2002); Ferrante et. al., (2000); Bhatt et. al., (2010); Florez L., (2010)
6. Impact of Construction Materials	1	2	H. Lomite & S. Kare (2009)

Research Topic	Frequency	Overall Frequency	Author(s)/Literature
Period (2010-2020)			
7. Multi Criteria Analysis	9	13	Akadiri, (2011); Haroutlugil et. al. Medineckiene et. al.,(2011); Akadiri et al., (2012); Medneckiene et. al., (2014); Zhang et. al., (2017); Erdogan et. al., (2019); Reddy et. al., (2019); K. D. Gospel, (n.d.)
8. Material Selection	17	25	Akadiri, (2011); Ibuchim O. and Junli Y.,(2012); Akadiri et al., (2012); Zin R. et. al., (2012); Shirazi et. al.,(2013) Kanniyapan G., (2015); Hariyo Ban Program, (2016); Sorensen et. al., (2016); Karaskor A., (2017); Zhang et. al., (2017); Okun A. and Gulser C., (2018); Prima et. al., (2019); Morini et. al., (2019); Marques et. al., (2019) Roy et. al., (2019); Rahman et. al., (n.d.); Pearece A.et. al., (n.d.)
9. Sustainability	20	27	Akadiri, (2011); Medineckiene et. al.,(2011); Akadiri et al., (2012) Hebel D., (2012); Akadiri et al., (2012); Zin R. et. al., (2012); Medneckiene et. al., (2014); Criterion Planners /crit.com, (2014); Broun R. et. al., (2014); Kanniyapan G., (2015) Riascos et. al., (2015); Khaled et. al., (2016); Karaskor A., (2017); Zhang

			et. al., (2017); Erdogan et. al., (2019); Marques et. al., (2019); Khoshanava et. al., (n.d.); Pearece A.et. al., (n.d.) Biswas & Krishnamurti, (n.d.); Esumeh E., (n.d.)
10. Sustainable Building and Material Assessment tools	17	23	Akadiri, (2011); Medineckiene et. al.,(2011); Akadiri et al., (2012) Medneckiene et. al., (2014); Sahamir S., (2014); Criterion Planners /crit.com, (2014); Broun R. et. al., (2014); Slumpf A. et. al., (2011); Riascos et. al., (2015); Serrano & Alvaraez, (2016); Khaled et. al., (2016); Karaskor A., (2017); Sabuis & Pranesh, (2017); Atanda, (2018) Tafesse and Abegaz, (2019); Reddy et. al., (2019); Reddy et. al., (n.d.)
11. Impact of Construction Materials	1	2	Tafesse and Abegaz, (2019)
12. BIM for Sustainability	7	7	Slumpf A. et. al., (2011); Eleftheriadis S. et. al., (2016); Lu Y. et. al., (2017); Chong et. al., (2017); Eleftheriadis S. et. al., (n.d.); Azhar et. al., (n.d.)
13. Life Cycle Assessment (LCA)	11	11	Medineckiene et. al.,(2011); Akadiri et al., (2012); Shirazi et. al.,(2013); Broun R. et. al., (2014); Rashid & Yusoff, (2015); Serrano & Alvaraez, (2016); Lassio J. et. al., (2016); Eleftheriadis S. et. al., (2016); Sabuis & Pranesh, (2017); Gerasio &

			Dimova, (2018); Kashkooli et. al., (n.d.)
14. Green Building	8	8	Ibuchim Ogunkah and Junli Yang, (2012); Hebel D., (2012) Sahamir S., (2014); Broun R. et. al., (2014); Haileleul T., (2015); Zhang et. al., (2017); Lu Y. et. al., (2017); Khoshanava et. al., (n.d.)

Note: All the authors and literatures listed above can be found on References and/or Bibliography.

Appendix D: Assessed Buildings

Item	Project	Designer/Consultant	Client	Location	Project Budget	Remark	Total Floor Area (m2)
1	PVC Project Employee Residence	CEC FDG JV	Dejenna Chemical Engineering PLC	Arato (25km East of Mekelle)	18,438,600.00	G+4	3,112.00
2	PVC Project Administration Building	CEC FDG JV	Dejenna Chemical Engineering PLC	Arato (25km East of Mekelle)	19,111,087.50	G+4	3,225.50
3	PVC Project Canteen	CEC FDG JV	Dejenna Chemical Engineering PLC	Arato (25km East of Mekelle)	7,850,980.50	G+0	1,325.06
4	Selam Bus HQ	Studio EK Consulting PLC	Selam Busline Share Company	Mekelle	31,679,612.25	2B+G+10	5,346.77
5	SUR Real State	Gretta Consulting	SUR Construction PLC	Mekelle	97,975,800.00	2B+G+17	16,536.00

6	Ato Berhe G/hiwot Project	Misigna Kiflom Consulting PLC	Ato Berhe G/hiwot	Abi Adi	36,919,030.50	B+G+7	6231.06
7	G+4 Commercial Project (Lachi)	AZU Consulting	Ato Berhe G/hiwot	Mekelle	15,464,250.00	B+G+4	2,610.00
8	Ato Muez Project	AZU Consulting	Ato Muez G/Tinsae	Mekelle	4,024,971.00	G+2	679.32
9	SUR Construction PLC Mekelle HQ	Tollen Consulting PLC	SUR Construction PLC	Mekelle	59,088,840.00	G+7	9,972.80
10	TDA Special High school Project (Class Room)	Fasil Giorgis Consulting PLC	Tigrai Development Association (TDA)	Maichew	4,054,596.00	G+1	684.32
11	TDA Special High school Project (Meeting Hall)	Fasil Giorgis Consulting PLC	Tigrai Development Association (TDA)	Maichew	4,283,360.25	G+0	722.93
12	TDA Special High school Project (Adminstration Building)	Fasil Giorgis Consulting PLC	Tigrai Development Association (TDA)	Maichew	5,346,720.00	G+1	902.40

13	TDA Special High school Project (Laboratory & Library)	Fasil Giorgis Consulting PLC	Tigrai Development Association (TDA)	Maichew	5,214,000.00	G+1	880.00
14	Kalamino Real Estate Project AR 15 Diaspora	Kibrom Hagos Consulting PLC	Kalamino Real State	Mekelle	3,555,000.00	G+2	600.00
15	Kalamino Real Estate Project Block F	Kibrom Hagos Consulting PLC	Kalamino Real State	Mekelle	3,826,068.75	B+G+2	645.75
16	Kalamino Real Estate Project G+2 B 20	Kibrom Hagos Consulting PLC	Kalamino Real State	Mekelle	3,396,802.50	G+2	573.30
17	Kalamino Real Estate Project Block C	Kibrom Hagos Consulting PLC	Kalamino Real State	Mekelle	3,199,500.00	G+2	540.00
18	Shire Kebele 03 Administration Office Building Project	Studio EK Consulting PLC	Shire Kebele 03 Administration Building	Shire	27,900,825.00	G+3	4,709.00

19	70 Kare Cooperative Housing	Promis Consulting PLC	Housing Cooperative	Mekelle	25,026,015.00	G+3	4,223.80
20	G+0 Project	Kibrom Hagos Consulting PLC	Ato Kahsu Mesele	Mekelle	711,000.00	G	120.00
21	G+2 Project	ADO Architecture Studio	Ato Birkity Tesfay	Mekelle	1,848,600.00	G+2	312.00
22	B+G+4 Project	ADO Architecture Studio	W/ro Hadas	Abi Adi	11,944,800.00	B+G+4	2,016.00
23	B+G+5 Project	ADO Architecture Studio	Solohateg PLC	Abi Adi	19,888,092.00	B+G+5	3,356.64
24	B+G+7 Project	Misigna Kiflom Consulting PLC	Ato Hayelom	Mekoni	41,345,835.00	B+G+7	6,978.20
25	Maichew Municipality Office Building	Maichew Town Road, Transport and Construction Office (Building Design and Cont. Dept.)	Maichew Town Road, Transport and Construction Office	Maichew	25,921,875.00	G+4	4,375.00
26	B+G+7 commercial Building	Wendifraw Hadgu Consulting PLC	Ato Biniam Amelake	Adi-Grate	15,098,227.20	B+G+7	2,548.22

27	B+G+2 Project	AZU Consulting PLC	Ato Siye Hailu	Mekelle	3,888,281.25	B+G+2	656.25
28	G+4 Project	Ataklti Kiflom Consulting PLC	Ato G/Michael Tadel	Atsbi	6,382,010.06	G+4	1,077.13
29	Ato Haile Hotel Project (Block A)	Misigna Kiflom Consulting PLC	Ato Haile Getesilasie	Abi Adi	32,960,775.00	2B+G+10	5,563.00
30	Ato Haile Hotel Project (Block B)	Misigna Kiflom Consulting PLC	Ato Haile Getesilasie	Abi Adi	11,613,000.00	B+G+1	1,960.00
31	Zewdu Hotel Project	Hiwot Hadush Consulting PLC	W/ro Zewdu Teshome	Mekelle	16,293,750.00	B+G+9	2,750.00
32	70 Kare Zeftrate	Wendifraw Hadgu Consulting PLC	ZEFTRATE self support housing association	Mekelle	25,026,015.00	G+3	4,223.80
33	B+G+M+5 Aro Gere Project	Ergo Consulting PLC	Ato Gere	Hawzen	20,978,220.90	B+G+M+5	3,540.63
34	Ato Girmay Project	Ergo consulting PLC	Ato Girmay	Hawzen	20,978,220.90	B+G+M+5	3,540.63
35	B+G+8 Project	Misigna Kiflom Consulting PLC	Ato Fishatsion Kasahun	Mekelle	21,756,600.00	B+G+8	3,672.00
36	B+G+7 Project	AZU Consulting PLC	Ato Awet Hailu Bilhatu	Abi Adi	19,070,560.50	B+G+7	3,218.66

37	B+G+5 Commercial Project	Studio EK Consulting PLC	Ato Hagos Birhane	Mekelle	12,569,887.50	B+G+5	2,121.50
38	Lion Bank Mekelle HQ Project	Geretta Consulting PLC	Lion Bank SC	Mekelle	171,523,773.00	2B+G+16	28,949.16
39	G+7 Mixed Use Project	EDGE Consulting Enterprise	Ato Yirdaw Mekonnen	Mekelle	28,295,430.00	G+7	4,775.60
40	Lola School	ADO Architecture Studio	Lola	Mekelle	4,178,310.00	G+0	705.20
						Total (m^2)	**149,979.63**

Appendix E: Sample of the software Source Code

File - C:\Users\User\PycharmProjects\GUI\Thesisfinal(all window).py

```
from tkinter import *
import time;

root = Tk()

def window1(main):
    main.title("Prime Building Material Selector Software")
    width = main.winfo_screenwidth()
    height = main.winfo_screenheight()
    main.geometry('%dx%d+0+0' % (width, height))
    main.configure(background='lavender')

    def new():
        pass

    my_menu = Menu(root)
    root.config(menu=my_menu)

    file_menu = Menu(my_menu)
    my_menu.add_cascade(label="File", menu=file_menu)
    file_menu.add_command(label="New", command=new)
    file_menu.add_separator()
    file_menu.add_command(label="Exit", command=root.quit)

    edit_menu = Menu(my_menu)
    my_menu.add_cascade(label="Edit", menu=edit_menu)
    edit_menu.add_command(label="Copy", command=new)
    edit_menu.add_command(label="Cut", command=new)
    edit_menu.add_separator()
    edit_menu.add_command(label="Paste", command=root.quit)

    help_menu = Menu(my_menu)
    my_menu.add_cascade(label="Help", menu=help_menu)
    help_menu.add_command(label="Help", command=new)
    help_menu.add_separator()
    help_menu.add_command(label="About the Software", command=new)

    lbl_copyright = Label(root, font=('arial', 10, 'bold', 'italic'),
                          text="Developed by Yibrah Tsegay as part of MSc Thesis © 2020"
                          , bd=8,
                          anchor='n',
                          fg='black', bg="lavender", width=50)
```

File - C:\Users\User\PycharmProjects\GUI\Thesisfinal(all window).py

```
    lbl_copyright.place(x=30, y=750)

    Tops = Frame(root, width=1920, height=100, bg="silver", relief=SUNKEN)
    Tops.grid(row=0, column=0)

    mylabel_description = Label(Tops, text='Prime Building Material Selection Software', font=("arial", 50, 'bold'),
                                bg='silver',
                                fg='black', bd=8, anchor='n')
    mylabel_description.grid(row=0, column=0)

    mylabel_description2 = Label(Tops, text='''Welcome Dear User,
       This software is intended to aid Designers and Architects in their material selection during Planning and Design stages
        of building design and management.''', font=("arial", 10, 'bold'), bg='silver', fg='black', bd=8, anchor='w')
    mylabel_description2.grid(row=1, column=0)

    # ==================================== Frame ===========================================================================
    f1 = Frame(root, bg="cadet blue", width=1500, height=900, bd=10, relief=SUNKEN)
    f1.grid(row=2, column=0)

    technical_F = Frame(f1, bg="cadet blue", width=500, height=500, bd=10, relief=SUNKEN).grid(row=0, column=0)

    importance_F = Frame(f1, bg="khaki2", width=500, height=500, bd=10, relief=SUNKEN).grid(row=0, column=1)

    ownership_F = Frame(f1, bg="lime green", width=500, height=500, bd=10, relief=SUNKEN).grid(row=0, column=2)

    # ==================================== Label ===========================================================================
    technicaltitle_lbl = Label(technical_F, text='Technical Considerations', font=("arial", 20, 'bold'), bg='lavender',
                               fg='black', bd=8, anchor='n', relief=RIDGE, width=20)
```

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File - C:\Users\User\PycharmProjects\GUI\Thesisfinal(all window).py

```
    technicaltitle_lbl.place(relx=0.055, rely=0.23)

    technical_lbl = Label(technical_F, text='''
       The parameters are identified using intensive Literature
        and Questionnaire survey with the respondents being designers and architects
       that heavily involved in the designing.
       The criteria are further classified as follows:
       1. Mechanical Criteria
       2. Environmental Criteria
       3. Socio-Economic Criteria








       This option only considers  Technical parameters
       ''', font=("arial", 10, 'italic'), anchor='n')
    technical_lbl.place(relx=0.01, rely=0.3)

    importancetitle_lbl = Label(technical_F, text='Importance of the Parameters', font=("arial", 20, 'bold'),
                                bg='lavender',
                                fg='black', bd=8, anchor='n', relief=RIDGE, width=25)
    importancetitle_lbl.place(relx=0.36, rely=0.23)

    importance_lbl = Label(importance_F, text='''
       The parameters are identified using intensive Literature
        and Questionnaire survey with the respondents being designers and architects
       that heavily involved in the designing.
       The criteria are further classified as follows:
       1. Primary Criteria
       2. Secondary Criteria
       3. Tertiary Criteria





```

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File - C:\Users\User\PycharmProjects\GUI\Thesisfinal(all window).py

```



        This option only considers Importance of the parameters.
        ''', font=("arial", 10, 'italic'), anchor='n')
    importance_lbl.place(relx=0.336, rely=0.3)

    Ownershiptitle_lbl = Label(ownership_F, text='Ownership of the Project', font=("arial", 20, 'bold'), bg='lavender',
                               fg='black', bd=8, anchor='n', relief=RIDGE, width=20)
    Ownershiptitle_lbl.place(relx=0.70, rely=0.23)

    Ownership_lbl = Label(ownership_F, text='''
        The parameters are identified using intensive Literature
         and Questionnaire survey with the respondents being designers and architects
        that are heavily involved in the designing.
        The criteria are further classified as follows:
        1. Public Building
        2. Common Factor
        2. Private Building








        This option only considers Ownership of the Project.
        ''', font=("arial", 10, 'italic'), anchor='n')
    Ownership_lbl.place(relx=0.660, rely=0.3)

    # ====================================Buttons on the first window=================================================================

    Btn_technical = Button(technical_F, text="Based on Technical Criteria", font=("arial", 10, 'bold'), padx=50,
                           command=Second_Win, relief=
```

```
                              fg='black', bg="silver", width=90).grid(row=0, column=0)

    f1_window2 = Frame(window2, bg="silver", width=1500, height=900, bd=10, relief=SUNKEN)
    f1_window2.pack(side=LEFT, fill=BOTH, anchor='n')

    f2_window2 = Frame(window2, bg="silver", width=1500, height=900, bd=10, relief=SUNKEN)
    f2_window2.pack(side=RIGHT, fill=BOTH, anchor='n')

    f21_window2 = Frame(f2_window2, bg="lavender", width=1500, height=900, bd=10, relief=RAISED)
    f21_window2.pack(side=TOP, fill=BOTH, anchor='n')

    f22_window2 = Frame(f2_window2, bg="silver", width=1500, height=900, bd=10, relief=GROOVE)
    f22_window2.pack(side=BOTTOM, fill=BOTH, anchor='n')

    text_Input1 = StringVar()
    text_Input3 = StringVar()
    text_Input5 = StringVar()
    text_Input7 = StringVar()
    text_Input9 = StringVar()
    text_Input11 = StringVar()

    text_Input1_2 = StringVar()
    text_Input4_2 = StringVar()
    text_Input6_2 = StringVar()
    text_Input8_2 = StringVar()
    text_Input10_2 = StringVar()
    text_Input12_2 = StringVar()

    text_Input1_3 = StringVar()
    text_Input4_3 = StringVar()
    text_Input6_3 = StringVar()
    text_Input8_3 = StringVar()
    text_Input10_3 = StringVar()
    text_Input12_3 = StringVar()

    text_Input1_4 = StringVar()
    text_Input4_4 = StringVar()
    text_Input6_4 = StringVar()
    text_Input8_4 = StringVar()
    text_Input10_4 = StringVar()
    text_Input12_4 = StringVar()
```

```
        entry_subtottalA2T1.insert(0, result2T1)

    def subtotalA3T1():
        global result3T1
        z1 = float(entry9_1.get()) * float(entry11_1.get()) + float(entry10_2.get()) * float(entry12_2.get())
        z2 = float(entry10_3.get()) * float(entry12_3.get())
        z3 = float(entry10_4.get()) * float(entry12_4.get()) + float(entry10_5.get()) * float(entry12_5.get())
        z4 = float(entry10_6.get()) * float(entry12_6.get()) + float(entry10_7.get()) * float(entry12_7.get())
        z5 = float(entry10_8.get()) * float(entry12_8.get()) + float(entry10_9.get()) * float(entry12_9.get())
        z6 = float(entry10_10.get()) * float(entry12_10.get()) + float(entry10_11.get()) * float(entry12_11.get())
        z7 = float(entry10_12.get()) * float(entry12_12.get()) + float(entry10_13.get()) * float(entry12_13.get())

        intz = float(z1) + float(z2) + float(z3) + float(z4) + float(z5) + float(z6) + float(z7)

        result3T1 = round(intz, 3)
        entry_subtottalA3T1.delete(0, END)
        entry_subtottalA3T1.insert(0, result3T1)


# ==============================================================================================================================
    lbl_SubtotalA1T1 = Label(f21_window2, text='Subtotal for Alternative 1', font=("arial", 10), bg='light grey',
                             fg='black',
                             bd=5,
                             anchor='w')
    lbl_SubtotalA1T1.place(relx=0, rely=0.03)

    entry_subtottalA1T1 = Entry(f21_window2, font=('arial', 10, 'italic'), textvariable=text_Input_st1, bd=3,
                                insertwidth=1,
                                bg="khaki2",
                                justify='center')
    entry_subtottalA1T1.place(relx=0.4, rely=0.03)

    lbl_SubtotalA2T1 = Label(f21_window2, text='Subtotal for Alternative 2', font=("arial", 10), bg='light grey',
```

File - C:\Users\User\PycharmProjects\GUI\Thesisfinal(all window).py

```
==================================================================

    lbl_Instruction = Label(f21_window2, text='Instruction For Use', font=("arial", 20), bg='light grey', fg='black',
                            bd=5,
                            anchor='n', justify='center', relief=GROOVE)
    lbl_Instruction.place(relx=0.25, rely=0.3)

    lbl_Instructionlist = Label(f21_window2, text='''
    1. Determine the Overall Objective of your Building Design.

    2. Identify the alternatives to be evaluated.

    3. Identify the Criteria.

    4. Assign weights to each criteria  based on your professional opinion.

    5. Assign utiles to each criteria with respect to  the alternative.

    6. Click "Run" to evaluate the alternatives.

    7. Select the alternative with the highest score.


    ''', font=("arial", 10), bg='light grey', fg='black',
                                    bd=5,
                                    anchor='n', justify='left', relief=GROOVE)
    lbl_Instructionlist.place(relx=0.1, rely=0.4)
    # ======================================Entry Widget=====================================================================

    entry1_1 = Entry(f1_window2, font=('arial', 7, 'italic'), textvariable=text_Input1, bd=3, insertwidth=0.5,
                     bg="powder blue",
                     justify='center')
    entry1_1.grid(row=4, column=2, padx=4)

```

File - C:\Users\User\PycharmProjects\GUI\Thesisfinal(all window).py

```
    entry3_1 = Entry(f1_window2, font=('arial', 7, 'italic'), textvariable=text_Input3, bd=3, insertwidth=1,
                     bg="powder blue",
                     justify='center')
    entry3_1.grid(row=4, column=4, padx=4)

    entry5_1 = Entry(f1_window2, font=('arial', 7, 'italic'), textvariable=text_Input5, bd=3, insertwidth=1,
                     bg="powder blue",
                     justify='center')
    entry5_1.grid(row=4, column=6, padx=4)

    entry7_1 = Entry(f1_window2, font=('arial', 7, 'italic'), textvariable=text_Input7, bd=3, insertwidth=1,
                     bg="powder blue",
                     justify='center')
    entry7_1.grid(row=4, column=8, padx=4)

    entry9_1 = Entry(f1_window2, font=('arial', 7, 'italic'), textvariable=text_Input9, bd=3, insertwidth=1,
                     bg="powder blue",
                     justify='center')
    entry9_1.grid(row=4, column=10, padx=4)

    entry11_1 = Entry(f1_window2, font=('arial', 7, 'italic'), textvariable=text_Input11, bd=3, insertwidth=1,
                      bg="powder blue",
                      justify='center')
    entry11_1.grid(row=4, column=12, padx=4)

    entry1_2 = Entry(f1_window2, font=('arial', 7, 'italic'), textvariable=text_Input1_2, bd=3, insertwidth=1,
                     bg="powder blue",
                     justify='center')
    entry1_2.grid(row=5, column=2, padx=4)

    entry4_2 = Entry(f1_window2, font=('arial', 7, 'italic'), textvariable=text_Input4_2, bd=3, insertwidth=1,
                     bg="powder blue",
                     justify='center')
    entry4_2.grid(row=5, column=4, padx=4)

    entry6_2 = Entry(f1_window2, font=('arial', 7, 'italic'), textvariable=text_Input6_2, bd=3, insertwidth=1,
                     bg="powder blue",
                     justify='center')
```

File - C:\Users\User\PycharmProjects\GUI\Thesisfinal(all window).py

```
    dropa1 = OptionMenu(f1_window2_2, alternatives, "Ceramic", "Terrazzo", "Marble", "Granite", "Cement Screed")
    dropa1.grid(row=0, column=4, columnspan=2)

    lbl_alternative_2 = Label(f1_window2_2, text='Alternative 2 (Ai)', font=("arial", 8), bg='light grey', fg='black',
                              bd=5, relief=GROOVE,
                              anchor='w')
    lbl_alternative_2.grid(row=0, column=6, columnspan=2)

    lbl_w2 = Label(f1_window2_2, text='Weight (Wi)', font=("arial", 8), bg='light grey', fg='black', bd=5, relief=RIDGE,
                   anchor='w')
    lbl_w2.grid(row=1, column=6, columnspan=2)

    alternatives = StringVar(f1_window2_2)
    alternatives.set("Values")

    dropdvw2 = OptionMenu(f1_window2_2, alternatives, "Default Value", "User Entry")
    dropdvw2.grid(row=2, column=6, columnspan=2)

    lbl_u2 = Label(f1_window2_2, text='Utiles (Uij)', font=("arial", 8), bg='light grey', fg='black', bd=5,
                   relief=RIDGE,
                   anchor='w')
    lbl_u2.grid(row=1, column=8, columnspan=2)

    alternatives = StringVar(f1_window2_2)
    alternatives.set("Values")

    dropdvu2 = OptionMenu(f1_window2_2, alternatives, "Default Value", "User Entry")
    dropdvu2.grid(row=2, column=8, columnspan=2)

    alternatives = StringVar(f1_window2_2)
    alternatives.set("Alternative 2")

    dropa2 = OptionMenu(f1_window2_2, alternatives, "Ceramic", "Terrazzo", "Marble", "Granite", "Cement Screed")
    dropa2.grid(row=0, column=8, columnspan=2)

```

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```
    dropdvw1 = OptionMenu(f1_window3, alternatives, "Default Value", "User Entry")
    dropdvw1.grid(row=2, column=2, columnspan=2)

    lbl_u1 = Label(f1_window3, text='Utiles (Uij)', font=("arial", 8), bg='light grey', fg='black', bd=5,
                        relief=RIDGE, anchor='w')
    lbl_u1.grid(row=1, column=4, columnspan=2)

    alternatives = StringVar(f1_window3)
    alternatives.set("Values")

    dropdvu1 = OptionMenu(f1_window3, alternatives, "Default Value", "User Entry")
    dropdvu1.grid(row=2, column=4, columnspan=2)

    alternatives = StringVar(f1_window3)
    alternatives.set("Alternative 1")

    dropa1 = OptionMenu(f1_window3, alternatives, "Ceramic", "Terrazzo", "Marble", "Granite", "Cement Screed")
    dropa1.grid(row=0, column=4, columnspan=2)

    lbl_alternative_2 = Label(f1_window3, text='Alternative 2 (Ai)', font=("arial", 8), bg='light grey', fg='black',
                              bd=5, relief=GROOVE,
                              anchor='w')
    lbl_alternative_2.grid(row=0, column=6, columnspan=2)

    lbl_w2 = Label(f1_window3, text='Weight (Wi)', font=("arial", 8), bg='light grey', fg='black', bd=5, relief=RIDGE,
                        anchor='w')
    lbl_w2.grid(row=1, column=6, columnspan=2)

    alternatives = StringVar(f1_window3)
    alternatives.set("Values")

    dropdvw2 = OptionMenu(f1_window3, alternatives, "Default Value", "User Entry")
    dropdvw2.grid(row=2, column=6, columnspan=2)

    lbl_u2 = Label(f1_window3, text='Utiles (Uij)', font
```

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```
    Btn_totalA1_Importance = Button(f1_window3_2, text="Total for A1", font=("arial", 10, 'bold'),
                                    command=total_A1I2, relief=RIDGE, bg='lavender', bd=5, padx=20)
    Btn_totalA1_Importance.place(relx=0.28, rely=0.7)

    entry_totalA2_Importance = Entry(f1_window3_2, font=('arial', 10, 'italic'),
                                     textvariable=text_Input_total_A2_Importance, bd=3,
                                     insertwidth=2,
                                     bg="white",
                                     justify='center')
    entry_totalA2_Importance.place(relx=0.53, rely=0.63)

    Btn_totalA2_Importance = Button(f1_window3_2, text="Total for A2", font=("arial", 10, 'bold'),
                                    command=total_A2I2, relief=RIDGE, bg='lavender', bd=5, padx=20)
    Btn_totalA2_Importance.place(relx=0.54, rely=0.7)

    entry_totalA3_Importance = Entry(f1_window3_2, font=('arial', 10, 'italic'),
                                     textvariable=text_Input_total_A3_Importance, bd=3,
                                     insertwidth=2,
                                     bg="white",
                                     justify='center')
    entry_totalA3_Importance.place(relx=0.78, rely=0.63)

    Btn_totalA3_Importance = Button(f1_window3_2, text="Total for A3", font=("arial", 10, 'bold'),
                                    command=total_A3I2, relief=RIDGE, bg='lavender', bd=5, padx=20)
    Btn_totalA3_Importance.place(relx=0.8, rely=0.7)


def Fourth_Win():
    # define a 'Fourth window' object
    window4 = Tk()
    window4.title("Based on Ownership of the Project 1")
    window4.geometry("1920x1080+0+0")

    Tops_window4 = Frame(window4, bg="cadet blue", width=1500, height=100, bd=2, relief=SUNKEN)
    Tops_window4.pack(side=TOP)
```

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```

                7. Select the alternative with the highest score.


                ''', font=("arial", 10), bg='light grey', fg='black',
                                        bd=5,
                                        anchor='n', justify='left', relief=GROOVE)
    lbl_Instructionlist.place(relx=0.1, rely=0.4)


# ===========================================================================================================================


# ===============================================================================================================================
    def total_A1O2():
        global result_total_A1_Ownership
        t1 = float(entry_subtotalA1O1.get())
        t2 = float(entry_subtotalA1O2.get())

        intt = float(t1) + float(t2)

        result_total_A1_Ownership = intt

        entry_totalA1_Ownership.delete(0, END)
        entry_totalA1_Ownership.insert(0, result_total_A1_Ownership)

    def total_A2O2():
        global result_total_A2_Ownership
        s1 = float(entry_subtotalA2O1.get())
        s2 = float(entry_subtotalA2O2.get())

        ints = float(s1) + float(s2)

        result_total_A2_Ownership = ints

        entry_totalA2_Ownership.delete(0, END)
        entry_totalA2_Ownership.insert(0, result_total_A2_Ownership)
```

```python

    def total_A3O2():
        global result_total_A3_Ownership
        r1 = float(entry_subtottalA3O1.get())
        r2 = float(entry_subtottalA3O2.get())

        intr = float(r1) + float(r2)

        result_total_A3_Ownership = intr

        entry_totalA3_Ownership.delete(0, END)
        entry_totalA3_Ownership.insert(0, result_total_A3_Ownership)


# ==============================================================================================================================

    lbl_Summation = Label(f1_window4_2, text=' Σ Wi * Uij ', font=("arial", 15), bg='light grey', fg='black',
                                bd=5,
                                anchor='n', justify='center', relief=GROOVE)
    lbl_Summation.place(relx=0.1, rely=0.63)

    entry_totalA1_Ownership = Entry(f1_window4_2, font=('arial', 10, 'italic'),
                                           textvariable=text_Input_total_A1_Ownership, bd=3,
                                           insertwidth=4,
                                           bg="white",
                                           justify='center')
    entry_totalA1_Ownership.place(relx=0.27, rely=0.63)

    Btn_totalA1_Ownership = Button(f1_window4_2, text="Total for A1", font=("arial", 10, 'bold'),
                                          command=total_A1O2, relief=RIDGE, bg='lavender', bd=5, padx=20)
    Btn_totalA1_Ownership.place(relx=0.28, rely=0.7)

    entry_totalA2_Ownership = Entry(f1_window4_2, font=('arial', 10, 'italic'),
                                           textvariable=text_Input_total_A2_Ownership, bd=3,
                                           insertwidth=2,
```

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```
                                            bg="white",
                                            justify='center')
    entry_totalA2_Ownership.place(relx=0.53, rely=0.63)

    Btn_totalA2_Ownership = Button(f1_window4_2, text="Total for A2", font=("arial", 10, 'bold'),
                                           command=total_A2O2, relief=RIDGE, bg='lavender', bd=5, padx=20)
    Btn_totalA2_Ownership.place(relx=0.54, rely=0.7)

    entry_totalA3_Ownership = Entry(f1_window4_2, font=('arial', 10, 'italic'),
                                            textvariable=text_Input_total_A3_Ownership, bd=3,
                                            insertwidth=2,
                                            bg="white",
                                            justify='center')
    entry_totalA3_Ownership.place(relx=0.78, rely=0.63)

    Btn_totalA3_Ownership = Button(f1_window4_2, text="Total for A3", font=("arial", 10, 'bold'),
                                           command=total_A3O2, relief=RIDGE, bg='lavender', bd=5, padx=20)
    Btn_totalA3_Ownership.place(relx=0.8, rely=0.7)


def qExit():
    root.destroy()


# =========================Creating First Window===============================================================================

window1(root)
root.mainloop()

```