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Housing Typologies of Mud Block Construction in Central Ethiopia: the Case of Three Selected Towns

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Architectural Engineering.

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June 2019

Addis Ababa, Ethiopia

Declaration

I declare that the research entitled as "*Housing typology of mud block construction in central Ethiopia: the case of three selected towns*" is my own original work that is not presented anywhere for a degree award and all the sources of material in this thesis have been acknowledged appropriately.

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Confirmation

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This Thesis is submitted to the School of Graduate Studies of Ethiopian Institute of Architecture Building Construction and City Development in Addis Ababa University for Partial Fulfillment of the Requirements for the Degree of Masters of Science in Architectural Engineering for obeying the Thesis Regulation of the University on the Originality and Quality of the Thesis.

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Dedication

I dedicate this work for my lovely father and mothers who support me in all my life by initiating me to learn successfully and God blessed them healthy & long life.

Acknowledgement

Nothing in our life is ever successful without the help of God, and I like to praise my biggest and endless gratitude for the massive God.

Next to God my special and endless thanks is for Dr. Dagnachew Adugna in giving full time advices and initiating me on this thesis to be successful and also I have great appreciation for Mr. Tesfaye Hailu in further thinking and developing ideas on this thesis. Also I have thanks for all my beloved friends and classmates who support me during site visiting and research development to finalize successful. At the last I have gratitude thanks for all EiABC, MTRC lab assistants in supporting the lab testing of the mud blocks. The most that I don't miss at any time in my life to thanks are my family for their support in giving idea and endless love for me to be successful.

Generally I have greatest thanks next God for all those who support me at any time and place on my life and during the development of this thesis.

Abstract

Earth as a construction material is the commonly available and worldwide usable material in rural and urban areas. In developing countries, this recyclable material of earth construction was used for economically efficient and sustainable Housing Projects. Thus, in Ethiopia the mud block construction is an essential in increasing sustainable solutions for the provision of shelter for every person. Weak use of locally developed building materials has resulted in huge housing shortage and expensive housing construction. The commonly used construction materials in Ethiopia are Chika/mud bet, hollow concrete block, brick, mud block and stone masonry. In investigating the housing typology of mud block construction in central Ethiopia on the three selected towns were studied through case study approaches using physical survey, interviews, and lab analysis on the compressive strength, water absorption capacity and shrinkage value of mud blocks. The findings of the present study revealed that mud block housing was affected by ingredients, climate, construction techniques and adaptability but mud block houses were more acceptable due to the use of local material & labor, economy, energy efficiency, comfortable and easy for construction. The present study recommends that researches were needed to investigate on the use of mud block construction as alternative walling material by substituting the uses of trees and other unsustainable construction material by adapting in different climatic zones of Ethiopia.

Keywords: mud blocks, typology, sustainable housing, construction material.

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Abbreviations/Acronyms

AAU	Addis Ababa University
CO ₂	Carbon dioxides
CS	Compressive strength
CSEB	Compressed Stabilized Earth Blocks
DV	Dry volume
EiABC	Ethiopian Institute of Architecture, Building and Construction
Lab	Laboratories
MD	Dry mass
MRTC	Materials Research and Testing Center
MW	Wet mass
TID	Total increased dimension
TL	Total load tones
TWA	Total water absorption
WV	Wet volume

Units

Cm	Centimeter
Cm ²	Square Centimeter
Hrs.	Hours
Kg	Kilogram
Km	Kilometer
Km/h	kilometer per Hour
Mm	Millimeter
Mpa	Mega Pascal
N/mm ²	Newton per Square Millimeter
PA	Press Area
°C	Degree Centigrade

Chapter One: Introduction

1.1. Background

Ethiopia is one of the developing countries and face lots of problems including high population growth rate, uncontrolled urbanization, low income of society, and deforestation resulted in erosion, drought, disease, hazards and desertification that caused huge housing shortage, unsustainable housing and expensive housing construction (Ann-Charlotte and Raffi, 2008).

In Ethiopia, adequate shelter is main problems that need studies for solving the problems of shelter and providing adequate houses for the society. In most parts of the country, earth material was widely used in the traditional construction of mud houses called “Chika bet” which was in turn unsustainable due to building surface wash by rain, unpleasant appearance, use of wood and continuous repair (Molla, 2012).

Building practices were the major consumer of resources, energy emissions and producing significant waste. The use of recyclable locally available raw materials of earth was a potential to explore different types of mud blocks such as Adobe block, Straw bale housing, Rammed Earth and Compressed earthen construction by improving the understanding of material behavior and construction practices (Molla, 2012).

Low cost housing projects have been carried out in Ethiopia for a long time by different countries and organizations with greater or lesser success. The oldest project have been in touch was a house that was erected/built with the Adobe technique, as early as 1954 by the Swedish Lutheran Mission in eastern Ethiopia. The German Hermann burg Mission has run Adobe technology projects mainly in western Ethiopia for about 20 years where the technique has been adopted by people in rural areas. Various attempts have also been made in parts of the country to introduce this construction technique and it seems like this material has been accepted but are mainly used for projects of a more costly character (Ann-Charlotte and Raffi, 2008).

In western Ethiopia especially in Ambo town the low cost housing projects have been actively present for over 20 years and the spread of the technologies were ongoing with a private enterprise within consulting and construction of mud block houses.

This Investigation was therefore, needed for analyzing the mud blocks, construction techniques, the housing typology and map out people's attitudes towards using of mud block houses for developing countrywide adaptations on the mud block construction. In the history of civilization the ecological factor initiate peoples in shaping their settlement and building typology and this housing typology is their symbol of existence. The major research gaps on mud block houses in Ethiopia are study on mud block housing typology in different climatic zones of Ethiopia, local peoples dependency on unsustainable chika-bet, mud blocks low acceptance than concrete block, difference in construction techniques of mud block house and low perception of people on adapting mud block housing in Ethiopia. Most of peoples around the world practice the historical, pragmatic and situational housing construction strategy of their ecological and environmental refecton for the construction process of environmentally sound mud block buildings by analyzing cost effectiveness, technology, durability and sustainability.

1.2. Statement of the Problem

A number of studies have been conducted to assess and evaluate the implementation of mud block houses that mainly focused on the ingredients, strength and construction technique of mud block houses to address the problems of shelter in Ethiopia. In this thesis the affordability for low income peoples, energy efficiency, adaptability, durability and environmental friendly of mud block houses need broad exploration. Weak & unstandardized construction technique, over deforestation, use of uneconomical and energy inefficiency material, weak perception of people about mud block houses for adaption, dependency on chika-bet are the major problems this research is going to solve.

The current studies has been solved the problems of wall that particularly focus on the contribution of mud block houses to combat problems linked with deforestation of trees, as considerable people in Ethiopia depends on trees for housing construction. Subsequently, such practices have been leading to severe problems of climate change, poverty, erosion,

disease and drought. Almost all the traditional construction materials in Ethiopia depends on wood as the main construction material of walling, roofing, and flooring that leads to the over deforestation of trees. Especially the dependency of low income and medium income peoples on 'Chika bet' (synonymous to mud house) leads to short life span of the houses due to moisture and termites.

In many parts of Ethiopia, mud block was used as a construction material and the housing typologies haven't common construction technique. Such difference in the construction techniques of mud block construction leads to the low adaptability of mud block for construction materials. Moreover, in Ethiopia, the mud block constructions have no guidelines on the construction technique, climatic zone, ingredients of blocks, building height, wall thickness, room area and the whole mud block constructions. Subsequently, various approaches were practiced throughout the country on the housing typology of mud block construction to adapt this low cost and ecofriendly materials in a durable ways for the society.

Therefore, this study is intended to address issues mainly focusing on the construction of mud block housing typology in central parts of Ethiopia. This also study analysis on what are the factors affecting the durability of mud block housing construction in adapting countrywide. This was helpful to forward a sound recommendation to follow some approaches during the construction of mud houses at least in the study areas. In addition it was necessary to identify the causes of poor performance of the mud block houses which contribute to low quality and adaptability of mud block housing that bring structural failure, discomfort and wall cracking that finally bring the failure to the houses.

1.3. Objective of the study

1.3.1. General objective

The general objective of the study is to identify the existing mud house typologies and investigate the durability of mud blocks in Ambo, Meki and Adama towns for adapting the houses in countrywide.

1.3.2. Specific objectives

The specific objectives of the study are to:

- ❖ identify the existing mud housing typologies in the case studies,

- ❖ analyze the Ingredients of mud blocks and its effect on the strength and durability of mud block houses,
- ❖ examine the economic benefits of mud blocks comparing with concrete blocks and
- ❖ Survey on the typology of mud block construction from the local community perceptions.

1.4. Research questions

The research questions of the study were;

- ❖ What types of mud block housing typologies were practiced in the three case study area?
- ❖ What were the Ingredients of mud blocks and the effect of the ingredients on the strength and durability of mud block houses?
- ❖ Why the mud blocks had been economical than concrete blocks?
- ❖ What were the local community perceptions on the housing typology of mud block construction?

1.5. Significance of the study

The shortage of housing was significant case in Ethiopia. The mud block housing provides a comfortable living environment by minimizing the deforestation of trees used for housing construction. This research helps to develop the people's awareness toward the uses of mud block houses and make the mud block construction adaptable to the countrywide for a physically sustainable and economical construction.

The durability of housing was affected by the climate, ingredients, construction techniques and housing typology thus the study helps to recommend the appropriate housing for the society. If mud block construction was designed accordingly of the climate condition, it was applicable in the overall parts of the country. Corrective measures were taken to ensure the sustainability, economy, eco-friendly, and adaptable construction material for the country. The ingredients used in the preparation mud block for adapting the houses needs analysis of the applicability of the mud block in different parts of Ethiopia.

In Ethiopia the high population growth rate, energy inefficient construction materials, uneconomical construction materials, weak use of local materials, housing shortage of urban

area and inadaptability of environmental friendly construction materials. These problems were solved by developing people's perception toward the uses of mud blocks by giving long-term and short-term training. Thus, this thesis helpful in developing the acceptability of mud block houses by teaching community about the mud blocks housing typology.

1.6. Scope and limitation of the study

1.6.1. Scope of the study

This study was used to analysis the ingredients of mud block (soil, stabilizers and water), molding & curing methods and lab tests on the compressive strength and water absorption of mud block to study on the durability of mud block houses. The thesis was helpful to analysis the effect of housing typology and construction technique on the durability of mud block houses. Narrating on the durability of mud block houses by analyzing the mud block houses wall height, thickness, and area were done in this study. But in this thesis the design, construction, other wall construction material and roofing material were not studied in this thesis.

1.6.2. Limitations of the study

The limitations of the study include the research populations were too large to cover in the limited given time thus sampling was required which had an impact on the general output of the study. Secondly, since the area was in a severe political problem, it was difficult to access and get some additional data. Third, the distances among the three case studies were far apart which imposed additional efforts to cover all the required data, which took long time and additional finance.

Chapter Two: Literature Review

2.1. Introduction

Mud is one of the oldest and most universally used construction materials. Even at the start of human development, people are built the building with mud. Mud construction occurs throughout the majority of the world. The raw earth construction materials are produced by using very low of energy and low emission of CO₂ (Thamizh and Dhanalakshmi, 2016).

Figure 2.1 shows the best and appropriate prepared clay soil for mud block construction;



Figure 2.1: Prepared clay soil used for mud block (Thamizh and Dhanalakshmi, 2016)

Building with earth is definitely an appropriate, economical and energy effective technology. Mud walls have been used for the buildings since ancient times. Mud wall buildings can be seen throughout the world and mud construction techniques are still in trend in many parts of the world. Cob wall, adobe, rammed earth, and wattle and daub are some of the common techniques of building mud walls (Vimala and Kumarasamy, 2014).

Modern earth building is alive and well spread over an enormous geographical area using numerous different methods of construction. The new earth buildings developing worldwide have generally utilized the good aspects of the traditional method by adding aspects and technologies. Today Adobe brick construction has been partially adapted to economical projects. In Mesopotamia, some cases of earth brick construction are as far as 10,000 BC.

Historically some of the building materials are new, while others are very old and started with human shelter (AL-sakkaf, 2009).

"According to UNESCO (Maïni, 2004); 15 % of the “world cultural heritage” is built with earth, 25 % of the “world heritage in danger” is built with earth and 14 % of the “100 most endangered world heritage” is built with earth”.

2.2. Mud block housing

The increment of the population growth mainly leads to the high problems of deforestation, joblessness, environmental impacts, industrialization and uncontrolled urbanization. The major cause of deforestation is conversion of the land to crop production and grazing, firewood, and traditional house building. The uncontrolled urbanization puts extremely high pressure on the land surrounding the towns and leads to the development of construction industry. All this problems leads to construction cost increment, unsafe environmental problems, unsustainable housing, housing shortage, and uncomfortable living environments (Ann-Charlotte and Raffi, 2008).

Some hundred years ago, the forest coverage of Ethiopia was about 30%, which was the main source of construction materials. However, currently it has reduced to 4% that it puts a greater burden on the availability of other construction materials (Molla, 2012). Conversely, the need of shelter rises with the rise of the Ethiopian population, as shelter is one of the most important basic human needs. Studies showed that about 25% of the world's population does not have any fixed home, and 50% of the urban population lives in slums. Indeed, 80% of urban settlements in developing countries consist of slums and spontaneous settlements made of temporary materials (Molla, 2012).

To reduce deforestation the world had investigated various alternative construction materials including mud block. Mud block has several advantages over conventional fired clay or concrete masonry. Mud blocks perform considerably better, in environmental terms compared to other construction materials. They have significantly less embodied energy, contribute fewer CO₂ emissions, and promote the local economy and local labor. At first glance they appear to be an ideal candidate for an economically viable sustainable

construction material (Vinu et al., 2016). The energy consumption of different material is shown in Table 1.1.

Table 2.1: Energy comparisons of different construction material (AL-sakkaf, 2009)

Building materials	Unit	Energy (kWh)
Cement	Sack	50
Concrete	Cubic meter	400 - 500
Fired brick	Cubic meter	1000
Adobe/mud block	Cubic meter	5

To solve such problems of housing there are different systems that are suitable for construction of sustainable, low-cost and environmental friendly building by using Adobe Blocks (mud blocks). Since these alternative construction materials potentially could contribute to a better standard of living for people and respond the environmental problems, there is reason to continue, broaden and deepen the knowledge about these possibilities of using mud block as construction materials (Ann-Charlotte and Raffi, 2008).

Housing transformations in a worldwide are the result of major demographic and socio-economic changes, technological advancements and sociopolitical interventions. In the case of vernacular settlements, housing has always been a direct expression of the state of know-how of construction techniques, available local construction materials as well as local climatic and cultural conditions (Remal et al., 2016).

Using mud for wall construction has distinct advantages. Mud is readily available locally, low cost, recyclable and environment friendly and it provides better thermal comfort than other materials. Major drawbacks of mud walls are larger wall thickness, loss of strength on saturation and erosion due to rain impact. These drawbacks can be minimized and/or eliminated by using soil stabilization techniques. Stabilized mud blocks are produced via soil stabilization processes (Vimala and Kumarasamy, 2014).

Earth/soil has been used in the construction of shelters for thousands of years and approximately 30% of the world's present population still lives in earthen structures. Earth is a cheap, environmentally friendly and abundantly available building material. It has been used extensively for wall construction around the world, particularly in developing countries (Hanifi et al., 2004).

2.3. Earth block technology

The new development of earth construction really started in the 1950's with the technology of the Compressed Stabilized Earth Blocks (CSEB). A research program for affordable houses in Colombia proposed the first manual press – the Cinvaram. Since then, considerable scientific researches has been carried out by laboratories. The knowledge of soil laboratories concerning road building was adapted to earth construction. Figure 2.2 shows the Soil ingredient, suitability and stabilization for CSEB productions (Maïni, 2004).

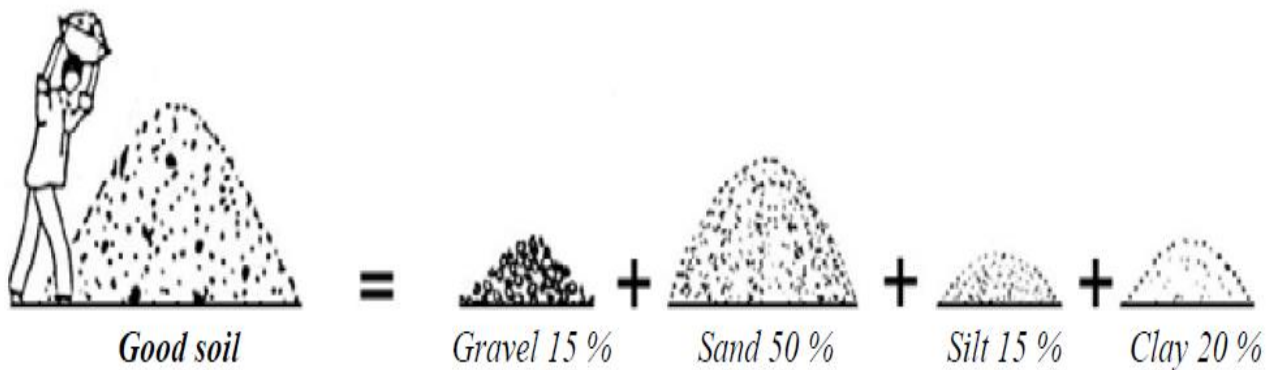


Figure 2.2: The soil used in good stabilized mud block (Maïni, 2004)

Mud blocks are more eco-friendly than fired bricks. The manufacture of mud block consumes less energy and pollute less than fired bricks. Here on the Table 2.2 there is the simple comparison of mud block and fired brick on their energy consumption and pollution emitted to the environment (Thamizh and Dhanalakshmi, 2016).

Table 2.2: Comparisons of mud block and fired brick (Thamizh and Dhanalakshmi, 2016)

Energy consumption	Pollution emission
4.9 times less than wire cut bricks	2.4 times less than wire cut bricks
15.1 times less than country fired bricks	7.9 times less than country fired bricks

Masonry is one of the most popular materials for housing construction due to its useful properties such as durability, relatively low cost, good sound and heat insulation, acceptable fire resistance, adequate resistance to weathering and attractive appearance.

The global interest about the environment has increased the use of earth as a building material (Baba et al., 2013).

The ingredients of earthen building systems include a binder soil typically clay, clay-silt mixture or loam and inorganic or organic tempering materials. Sand and gravel are the most commonly used inorganic tempers while straw and cow dung are the commonly used organic tempers. Soil may be stabilized using materials such as lime, cement, asphalt emulsion, calcite gypsum or cactus juice, or may be un-stabilized (Arooz and Halwatura, 2017).

In Ethiopia straw of teff, wheat, rice and Qacha are used as the best organic binders. The most commonly used organic binders in Ethiopia are teff straw while the usages of other binders are rare depending on the material access.

2.4. Molding of mud blocks

2.4.1. Material used for molding mud blocks

This portion covers about the materials required for production of mud blocks. It also includes classification, specifications, availability and properties of materials which are necessary for stabilized earth blocks production (such as soil, cement and straw).

2.4.1.1. Soil

Soil is a sediments or accumulation of mineral particles produced by the physical or chemical disintegration of rock, plus the air, water, organic matter, and other substances that may be included in the soil. In addition, soil is a non-homogeneous, porous, earthen material whose engineering behavior is influenced by changes in moisture content and density (Tadege, 2007).

Classification of soil

Soils are classified in many different ways: by their use, origin, grain size, texture, color and density (Frederick et al., 2001).

A. Based on the origin of soil

Based on the origin soil can be divided to two basic types:

a. Residual soils: are caused by the weathering (decomposition) of rock by chemical or physical action. Residual soils may be very thick in areas of intense weathering such as the tropics, or they may be thin or absent in areas of rapid erosion such as steep slopes. Residual soils are usually clayey, and their properties are related to the climate and the location of the soil. Residual soils are usually preferred to support foundations, and they have better, more predictable engineering properties.

b. Transported or deposited soils: are derived by the movement of soil from one location to the other by natural means. The means are generally wind, water, ice, and gravity. The character of the resulting deposit often reflects the modes of transportation and deposition and the source material. Deposits by water include floodplains, coastal plains, and beaches. Deposits by wind include sand dunes and loess. Deposits by melting ice include glacial till and out wash. Each of these materials has behavioral characteristics dependent on geological origin, and the geological name, such as loess, conveys much useful information. Transported soils, particularly by wind or water, are often of poor quality in terms of engineering properties. In addition, topsoil or agricultural soil, which contains a high proportion of organic matter, forms a layer above the bed-rock and which may be more or less weathered. When the upper layers of earth are made up of loose material and contain little organic matter, they can be used for building purpose.

For building purpose soil can be generally characterized in two ways: by a particle size distribution analysis and by plasticity index. The particle size analysis will give information on the soil ability to pack into a dense structure and the quantity of fines present (combined silt and clay fraction), while the plasticity index gives an idea of cohesion of the fines. Cohesion is the molecular bonding or attraction between soil particles. It is a function of clay mineralogy, moisture content, particle orientation (soil structure), and density. Cohesion is associated with fine grain materials such as clays and some silt.

B. Classification by particle size distribution

Soils are made up of varying proportions of materials such as gravels, sands, fine (silts and clays). Each of these have different characteristic, for example, when they are exposed to variations in humidity, some will change in volume, while others will not. The first two of these materials are stable, the other two are unstable. Stability is the ability of the material

to withstand alternating of humidity and dryness without its properties changing. This is a fundamental importance property for a building material.

a) Gravels: are made up of pieces of rock of varying hardness, and their size ranges between approximately 2 and 20 mm. They form a stable constituent of the soil. Their mechanical properties undergo no detectable change in the presence of water.

b) Sands: are made up of mineral particles, and their size ranges between approximately 0.06 and 2 mm. They also form stable constituents of the soil. They lack cohesion when dry, but have a very high degree of internal friction between the particles which make them up. When moistened, however, they display apparent cohesion as a result of the surface tension of the water occupying the voids between the particles. Sand is used as a releasing agent during the molding of a block. It prevents the wet mud from sticking to the sides of the mold. It is also sometimes used as a stabilizer and mixed with very clayey soils to prevent the blocks from cracking when drying.

c) Silts: are made up of particles the size of which range between approximately 0.002 and 0.06 mm. They have little cohesion when dry. Since their resistance to movement is generally lower than that of sands. However, they display cohesion when wet. When they are exposed to different levels of humidity, they swell and shrink, changing clearly in volume. Gravels, sands, and to a lesser extent silts, are characterized by their stability in the presence of water. However, when they dry, they have little cohesion. Therefore, they cannot be used on their own as the principle materials of a building.

d) Clays: form the finest fraction of soils 0.002mm, and have completely different characteristics than those of the other particle types. They consist mainly of microscopic clay mineral particles. Clay particles are coated in a film of absorbed water. Since, they are so small in size; they are very light in weight compared with the surface tension forces occurring in the film of absorbed water. Thus volume forces (the particles weight) are low relative to surface forces. The film of absorbed water which sticks strongly to the clay layers, links the micro-particles of the soil together, and it is this which gives clay its cohesion and most of its mechanical strength. This can be eliminated only by very advanced desiccation. Desiccation is the state of extreme dryness, or the process of extreme drying. The desiccation process may result cracks for earth block that have large

amount of clay in the soil. A more useful range of particle sizes suitable for building with earth block is from 40 - 75% sand and from 25 - 60% fine (silt and clay). Gravel is not usually used in soil- cement mixture production, as the large particle size may lead to a poor (rough) surface finish. A suitable soil for building construction contains a mixture of sand and fine (silt and clay) particles. The properties of each of these fractions influence the properties of the stabilized earth block.

From the recommendation, there is no need of gravel particles in soil which is used for stabilized earth block productions. Therefore, the sieve that is used for filtering or screening the soil should have a diameter the same as the minimum diameter of the grave particle size (i.e. 2mm) (Molla, 2012).

C. Classification by plasticity (Fine content)

Soil plasticity is the ability of a soil to undergo irreversible deformation when it is subjected to an increasing load. It is indicated by the plasticity index. The plasticity index is the amount of water required for a soil to pass from a plastic to a liquid state. In addition, soil is a mixture of irregularly shaped mineral particles of various sizes containing voids between particles. These voids may contain water if the soil is saturated; water and air if partly saturated, and air if dry.

Under unusual conditions, such as sanitary landfills, gases other than air may be in the voids. The particles are a by-product of mechanical and chemical weathering of rock and described as gravels, sands, silts, and clays. Based on plasticity (fine content), the soil is classified as cohesive and non-cohesion soils.

(a) Cohesive soil. Cohesive soils are fine-grained materials consisting of silts, clays, and/or organic material. These soils exhibit from low to high strength when the air is dried in the voids. Most cohesive soils are relatively impermeable compared with non-cohesion soils. Some silt soil may have bonding agents between particles such as soluble salts or clay aggregates.

(b) Non-Cohesion Soil. Non-cohesion soil is composed of granular or coarse-grained materials with visually detectable particle sizes and with little cohesion or adhesion between particles. These soils have little or no strength when they dry and little or no

cohesion when they submerged. Strength occurs from internal friction when the material is confined. Apparent adhesion between particles in non-cohesion soil may occur from capillary tension in the pore water. Non-Cohesion soils are relatively free-draining compared with cohesive soils. The silt and clay content of a soil are responsible for soil cohesion and these fines provide fresh blocks with load bearing ability.

The degree of cohesion provided to the earth block production is dependent on both the fines present and the degree of compaction used to form the block. In addition, a low-pressure molding process requires higher fines content than a high pressure molding process. This is because increased compaction pressure will force the soil particles into more closed contact, thus strengthening the fresh (the first added particles) compact. And, by their nature fine particles can easily be compacted with low pressure since they are smaller in size.

Exploitation

Usable layers of soil are rarely found at the surface of the ground (except in dry areas), because at the surface soils contain too much organic matter. This organic top soil is rarely used for stabilized soil blocks and it is mostly found in the first 0.50 m depth of the soil layers. In addition, usable soil is rarely found at great depths, where there are too many stones, or even solid rock. Therefore, the depth or height of usable layers of soil varies greatly, from a few centimeters to several meters ranges (Molla, 2012).

2.4.1.2. Cement

Cement is a fine grey powder which is mainly composed of Lime (CaO) and Silica (SiO₂). When water is added, it forms combinations of Tri-calcium silicate and Di-calcium silicate referred to as C₃S and C₂S in the cement literature. The chemical reaction eventually generates a matrix of interlocking crystals that cover any inert filler (i.e. aggregates) and provide a high compressive strength and stability. Depending on their hardening property cements are divided into two types: hydraulic and non-hydraulic. Hydraulic cements (Portland cement) harden due to the chemical reaction of added water and cement which is called hydration, while the non-hydraulic cements harden without the need of water (Becky and Tom , 2001).

Earlier studies have shown that cement is a suitable stabilizer with soil in the production of compressed stabilized soil block. Portland cement is the most commonly used stabilizer and cheapest. The minimum amount of cement required to stabilize a block depends on the type of soil, the degree of compaction force and the final application of the blocks. Generally cement can be used with any soil type, but with clays it is uneconomical because more cement is required. The range of cement content needed for good stabilization is between 3% and 18% by weight according to soil type (Becky and Tom , 2001).

2.4.1.3. Straw

Straw is one of the finest and the renewable building material which is available around the world in abundance. It is the strong stalk of tall grain plants such as wheat, rye, hemp or rice that remains in the field after the seed grains have been harvested. Its chemical composition is primarily cellulose, just like trees. When the straw is bundled together into a bale, it becomes a solid block. That is highly resistant to decomposition in its dry form. The straw is used mainly for reinforcing wooden walls of mud house buildings and for livestock feed. It can also be used as stabilizer in stabilized earth block production. Straw is sometimes added to mud to prevent the brick from cracking when curing. In addition, straw is added to decrease drying shrinkage and prevent cracking in earth block constructions (Molla, 2012).

2.41.4. Water

The amount of water add in to mixture must be known in stabilized earth block production. The quality and quantity of the water plays a significant role in compressed earth block production. Impurities in water may interfere with the setting of the mixture, may adversely affect the strength of the block or cause staining of its surface, and may also lead to corrosion or decomposition of the reinforcement. For these reasons, the suitability of water for mixing and curing purposes should be considered (Tadege, 2007).

Combining water with a soil material forms soil paste by the process of hydration. The soil paste joins the aggregate together, fills the voids or gaps between soil particles and allows it to flow more freely. Less water in the soil paste will yield a stronger and more durable earth block, whereas more water will give a free-flowing block with a higher slump (Tadege, 2007).

Some very experienced people can judge the correct amount of water without measuring, but this is not recommended for first time producers. Because adding more water to the mixer make easier to work, however the blocks will have a poorer quality. The excess water can also cause the block to crack due to shrinkage and break during drying. Adding the correct amount of water during earth block preparation is critical for making good quality blocks. The less water used, the better the quality. If the amount of water is too much in the mixture, the blocks will (Tadege, 2007):

- Deform easily under its own weight after molding;
- Deform when placed on uneven or bumpy ground;
- Results shrinkage crack during drying;
- Take much more time to dry.

2.4.2. Mud block molding steps

In the production of mud blocks for the construction of mud block houses the below steps are the necessary and basic to be followed everywhere in molding the blocks (Molla, 2012).

A. Sieving

From many literature, a suitable soil for mud blocks construction contains a mixture of sand and fines (silt and clay) particles. There is no need of gravel in soil for earth block production, so the sieve that is used for filtering or screening the soil should have holes' diameter the same as the minimum diameter of the grave particles size (i.e. 2mm).Therefore, the dry soil is screened using this sieving machine.

B. Mixing

The materials which are used to manufacture the mud block are earth (soil), cement, straw and water. These materials are mixed together with specified proportion or ratio. The cement which was used in stabilized earth block sample preparation is Portland cement. The straw which was used in this work has been cut into a fiber of average length equal to 4cm (in a range between 2cm and 6cm).These natural fibers have 1 to 2 mm in diameter and a hollow structure.

And, never try to make a mixture more workable by just adding more water because this lowers the strength and durability of the mixture. Finally, this prepared mixture can also use as a mortar to connect the blocks each other during construction. Since the mixture has some amount of cement, it creates good joining property, as glue, between earth blocks.

C. Molding

The wooden formworks of block pattern with a dimension of width (cm) x length (cm) x depth (cm) are prepared and molded manually by hand. Molding framework was oil by lubricant during molding. This is because; the oil prevents sticking of the wet mud with the wooden pattern during casting.

D. Drying process

In the Laboratory, after molding, the samples can be dry using oven from 110⁰C -115⁰C for 24 hours. But when the sample dries using oven with high temperature, some crack may be occur. This is because of rapid drying process. In rapid drying process, evaporation rate is high. This causes the moisture in the inner part of the mud blocks to escape with force. This force pushes the outer surface apart to remove the moisture, which results cracking. From literature, drying should be take place with slow process with medium temperature (average 25⁰C) for 3 to 4 weeks, with uniform temperature distribution and in shielded area.

In general, the stabilized earth block production steps are:

- Sieving (dry soil using sieving machine) - Mixing (soil, stabilizer (cement and straw fiber and water) - Molding (using compressed block machine or manually by hand) – Drying (using sun in shielded area for 3 to 4 weeks).

2.5. Types of mud/adobe block

2.5.1. Stabilized mud Block

Stabilized mud blocks can be prepared by compacting moist mixture of soil and cement in a machine. A number of studies are available on the properties and use of soil cement blocks for building construction. The block making process consists of mixing the cement, screened soil, admixture and water (Vimala and Kumarasamy, 2014). Table 2.3 shows the general Property of stabilized mud block.

Table 2.3: Properties of stabilized mud blocks (Vimala and Kumarasamy, 2014)

Block size	240mm x 240mm x 90mm
Dry strength	8.2 N/mm ²
Wet strength	3.1 N/mm ²
Water absorption	12 %

2.5.2. Traditional adobe

Traditional adobe block is made out of soil and straw and it is found mostly in older homes. The straw prevents cracking and adds strength. Adobe buildings can last easily for about 100 years or more if the walls are dry and are kept away from wicking up water from the earth. Thus, maintenance is important since moisture can get in through cracks (AL-sakkaf, 2009).

2.5.3. Compressed earth blocks

The compressed earth block is made by compressing moist soil in a press and it is the modern descendent of the molded earth block. The earth-compressed blocks became widely used around the world in the last 30 years or more, not only in third world countries, but also in developed countries like the USA, France, Canada and Australia. Machines were first used to compress earth as early as the 18th century. In France, architectural purposes came into effect only in 1952 by Engineer Raul Ramirez of the CINVA, Centre in Bogota, Columbia, designed the CINVA-Ram press machine. This was used throughout the world especially in developing countries in Africa, South America and Asia (AL-sakkaf, 2009).

Compressed earth block technology offers an alternative kind of building construction which is more accessible and of high quality. The compressed earth block is one of the most important "modern building materials" which has enough production flexibility to let it be integrated into both formal and informal sectors of structural activities and also hydraulic machines were developed to get blocks similar to concrete blocks (AL-sakkaf, 2009).

2.5.4. Rammed earth

Rammed earth is the continuous walls formed by ramming moist mud between movable wooden shuttering (Namango, 2006). The availability of useful soil and appropriate local

climatic conditions are the factors for rammed earth construction. The soil for this technique is mostly a composition of clay and sand. Rammed earth walls are simple to construct, non-combustible, thermally massive, strong, and durable. However, they are susceptible to water damage if they are inadequately protected or maintained. Modern rammed earth techniques use heavy machinery to compress the soil. Walls tend to be at least a foot thick for stability and also thermal mass (Molla, 2012).

2.6. Mud block housing

The increment of the population growth mainly leads to the high problems of deforestation, joblessness, environmental impacts, industrialization and uncontrolled urbanization. The major cause of deforestation is conversion of the land to crop production and grazing, firewood, and traditional house building. The uncontrolled urbanization puts extremely high pressure on the land surrounding the towns and leads to the development of construction industry. All this problems leads to construction cost increment, unsafe environmental problems, unsustainable housing, housing shortage, and uncomfortable living environments (Ann-Charlotte and Raffi, 2008).

Some hundred years ago, the forest coverage of Ethiopia was about 30%, which was the main source of construction materials. However, currently it has reduced to 4% that it puts a greater burden on the availability of other construction materials. Conversely, the need of shelter rises with the rise of the Ethiopian population, as shelter is one of the most important basic human needs. Studies showed that about 25% of the world's population does not have any fixed home, and 50% of the urban population lives in slums. Indeed, 80% of urban settlements in developing countries consist of slums and spontaneous settlements made of temporary materials (Molla, 2012).

To reduce deforestation the world had investigated various alternative construction materials including mud block. Mud block has several advantages over conventional fired clay or concrete masonry. Mud blocks perform considerably better, in environmental terms compared to other construction materials. They have significantly less embodied energy, contribute fewer CO₂ emissions, and promote the local economy and local labor. At first glance they appear to be an ideal candidate for an economically viable sustainable

construction material (Vinu et al., 2016). The energy consumption of different material is different (refer Table 2.4).

Table 2.4: Energy comparisons of different construction material (AL-sakkaf, 2009)

Building materials	Unit	Energy (kWh)
Cement	Sack	50
Concrete	Cubic meter	400 - 500
Fired brick	Cubic meter	1000
Adobe	Cubic meter	5

To solve such problems of housing there are different systems that are suitable for construction of sustainable, low-cost and environmental friendly building by using Adobe Blocks (mud blocks). Since these alternative construction materials potentially could contribute to a better standard of living for people and respond the environmental problems, there is reason to continue, broaden and deepen the knowledge about these possibilities of using mud block as construction materials (Ann-Charlotte and Raffi, 2008).

Housing transformations in a worldwide are the result of major demographic and socio-economic changes, technological advancements and sociopolitical interventions. In the case of vernacular settlements, housing has always been a direct expression of the state of know-how of construction techniques, available local construction materials as well as local climatic and cultural conditions (Remal et al., 2016).

Using mud for wall construction has distinct advantages. Mud is readily available locally, low cost, recyclable and environment friendly and it provides better thermal comfort than other materials. Major drawbacks of mud walls are larger wall thickness, loss of strength on saturation and erosion due to rain impact. These drawbacks can be minimized and/or eliminated by using soil stabilization techniques. Stabilized mud blocks are produced via soil stabilization processes (Vimala and Kumarasamy, 2014).

Earth/soil has been used in the construction of shelters for thousands of years and approximately 30% of the world's present population still lives in earthen structures. Earth is a cheap, environmentally friendly and abundantly available building material. It has been

used extensively for wall construction around the world, particularly in developing countries (Hanifi et al., 2004).

2.7. Durability and strength of mud block

Buildings made from earth materials can be a way towards sustainable management of the earth's resources. After its production it can be placed in a place using simple machinery and human energy. Earth buildings avoid high-energy costs in the initial manufacturing and construction period, in their use as homes, and eventually in their recycling process (AL-sakkaf, 2009).

Thus, it is not surprising that many people value earth construction for the above reasons for their durability and for the following qualities (AL-sakkaf, 2009);

1. The principal reason for using earth is its excellent sustainability characteristics. These include, the efficient use of finite resources, minimizing pollution, waste and low carbon emissions especially in industrial countries. In comparison with other materials, earth buildings reflect the embodied energy required for the production and use of various materials. As shown in Table 2.5, mud blocks have the less embodied energy comparison to brick and concrete.

Table 2.5: Embodied energy required for the production of various materials (AL-sakkaf, 2009)

Common brick	13,570 BTU
Concrete block	29,018 BTU
Earth (Adobe) block (mechanized production)	2,500 BTU

2. Mud blocks do not use organic resources for firing and it does not consume any non-renewable energy. Thus, it has environmental advantages and does not contribute to deforestation.
3. Mud blocks have good economic advantages. It requires no major financial transport costs. It is often comparable in cost and more economical than other competing technologies. Mud blocks require only simple production and application tools (molds, presses, light shuttering and masonry tools, etc.).

Earth is a versatile material which finds application in construction industry as mud blocks for wall construction, mud mortar for binding and plastering and as tiles for flooring and roofing. It is universally accepted as an environment friendly and user friendly material for construction from time immemorial (Lekshmi et al., 2016).

2.8. Housing typologies in Ethiopia

The main concern of typology as a realm of investigation is to address the conceptual basis by which buildings can be classified and categorized into types. Typology is about the formal and spatial characteristics of buildings, which are rooted in culture and history. Typology in this sense is regarded as the “classification of models”. Typological process is defined as dynamic evolutionary paradigms of a certain type of buildings of a particular society, in order to provide a clear generative interpretation of form transformation. It is important to note that writings on typology emphasize that it should not aim at architectural styles; it is rather a set of descriptive categories that define the spatial characteristics of buildings over time. Typology has been used either as a basis for analyzing buildings and cities (analytical typology) or as a basis for designing buildings (generative typology).

2.8.1. Based on forms of houses

Basically in Ethiopia there are two major building forms (circular and rectangular) that are used in both rural and urban areas without any regard of the construction materials. In most of the urban areas; the rectangular building forms are used while in the rural areas both the circular and rectangular building forms are used as the major building forms. When we see the traditional housing form of Ethiopia the construction forms are circular and due to the influence of globalization they are directed toward the rectangular forms (Weldekidan, 2015).

The building height, room area, wall size/thickness, and over all building standardizations are not taken in to consideration and they use their own standardization which affect the building durability. Mud block constructions at different climatic zone and soil type have different construction technique, construction standards and building forms. So, analyzing the mud block construction at different climate and soil type is helping the researcher to give standardization and easy adaptability of mud block houses in the whole Ethiopia.

2.8.2. Based on material used

Based on material used for construction; Ethiopia construction industry is mainly classified in to the modern and traditional building material based building. The traditional building material based buildings are Chika-bet, mud block house, stone house and brick house while the modern building material based buildings are HCB building, glass, steel, and postmodern building material based buildings. When we compare this housing typology based on the construction materials; the traditional building material based are more sustainable in the case of economy, energy efficiency, material availability, local labor, environmental adaptability and construction technique. The mud blocks based buildings are constructed both in the traditional and modern construction industry in Ethiopia in some parts of the country (Ann-Charlotte and Raffi, 2008).

2.8.3. Based on function

It is well known that the mud block houses constructed in Ethiopia are mostly of residential or mixed and sometimes used for other building types of ware house and commercial buildings. The building function may or may not affect the form and material used for the construction of the houses.

Chapter Three: Materials and Methods

3.1. Study area

The study sites includes Ambo, Meki & Adama towns and the towns were located in the central part of Ethiopia (refer Figure 3.1). Ambo is located in the central parts of Ethiopia about 107km to the west of Addis Ababa, Whereas, Adama and Meki are located in the central Ethiopia, about 99km south east and 134.8 km south of Addis Ababa, respectively.

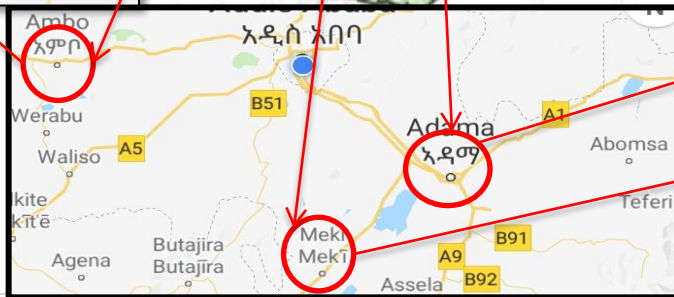
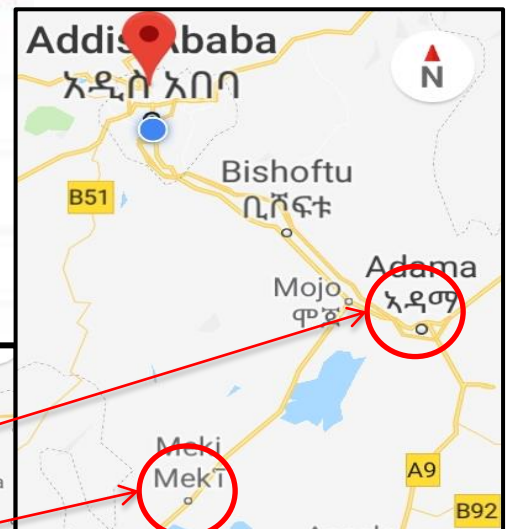
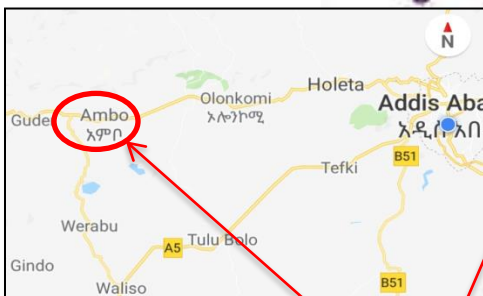
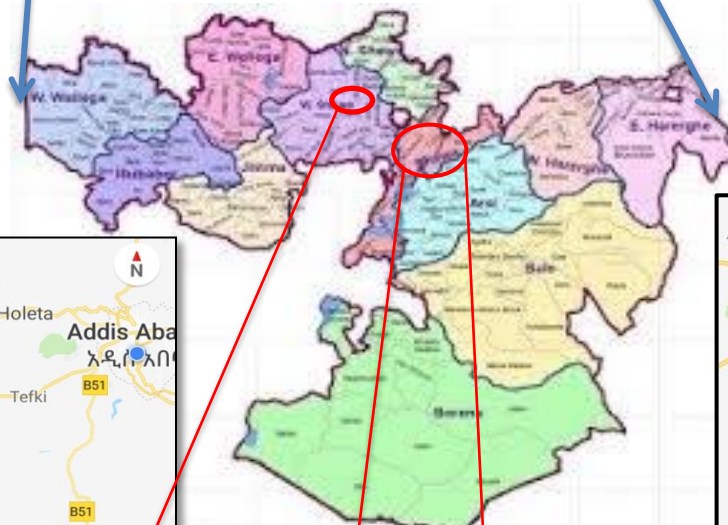
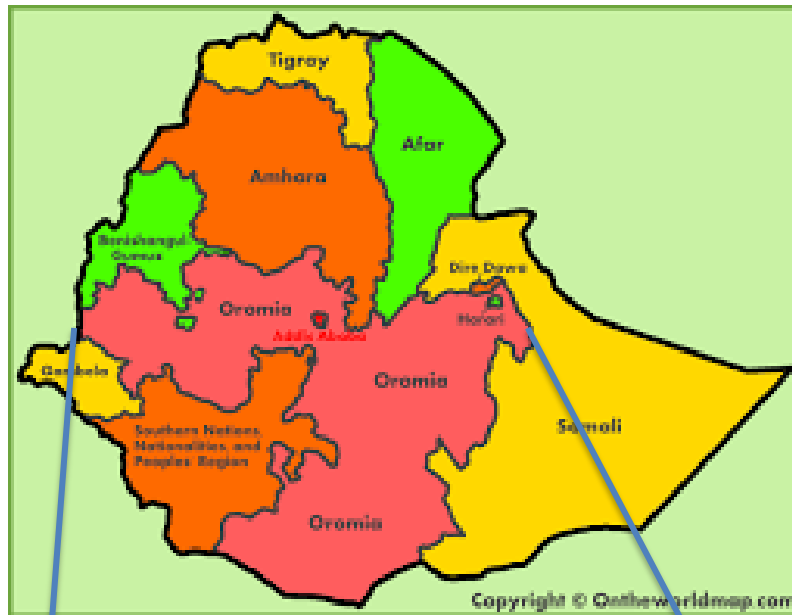


Figure 3.1: Location map of the study area (<http://Wikipedia.orh/wik.com>)

The three studied case sites are located under different climatic zones. Table 3.1 shows the climate of the study areas.

Table 3.1: The climate of the study area

location	Av. Temperature (°c)	Annual rainfall (mm)	Humidity (%)	Wind speed (km/hr.)
Ambo	18	1012	79	4.8
Meki	19.6	885	58	6.5
Adama	20.5	808	45	9.35

Source: Ethiopia meteorology agency

3.2. Sampling sites

In the three studied sites specific localities/kebeles were purposively selected where mud block houses have been practiced for longer periods of time. The number and location of these three sampling sites were selected based on soil type, building technique, and the abundance of construction that the three sites are the representative of the whole country. The kebeles/locality selected is a representative of the other sites in the town. In Ambo, the habitat village is selected which start the construction before 20 years. In Adama, Bole sub city mainly around bole madianalem church and in Meki, the whole town was surveyed by the present study.

In Ambo and Adama the selected sites are the best representatives of the other sites in the town and the mud block houses in the selected sites are exist in abundance. The sampling sites were designated as Ambo as S1, Meki as S2, and Adama as S3 (refer Figure 3.2). The buildings going to be surveyed are done by random sampling from the mud block houses constructed in the selected sites.



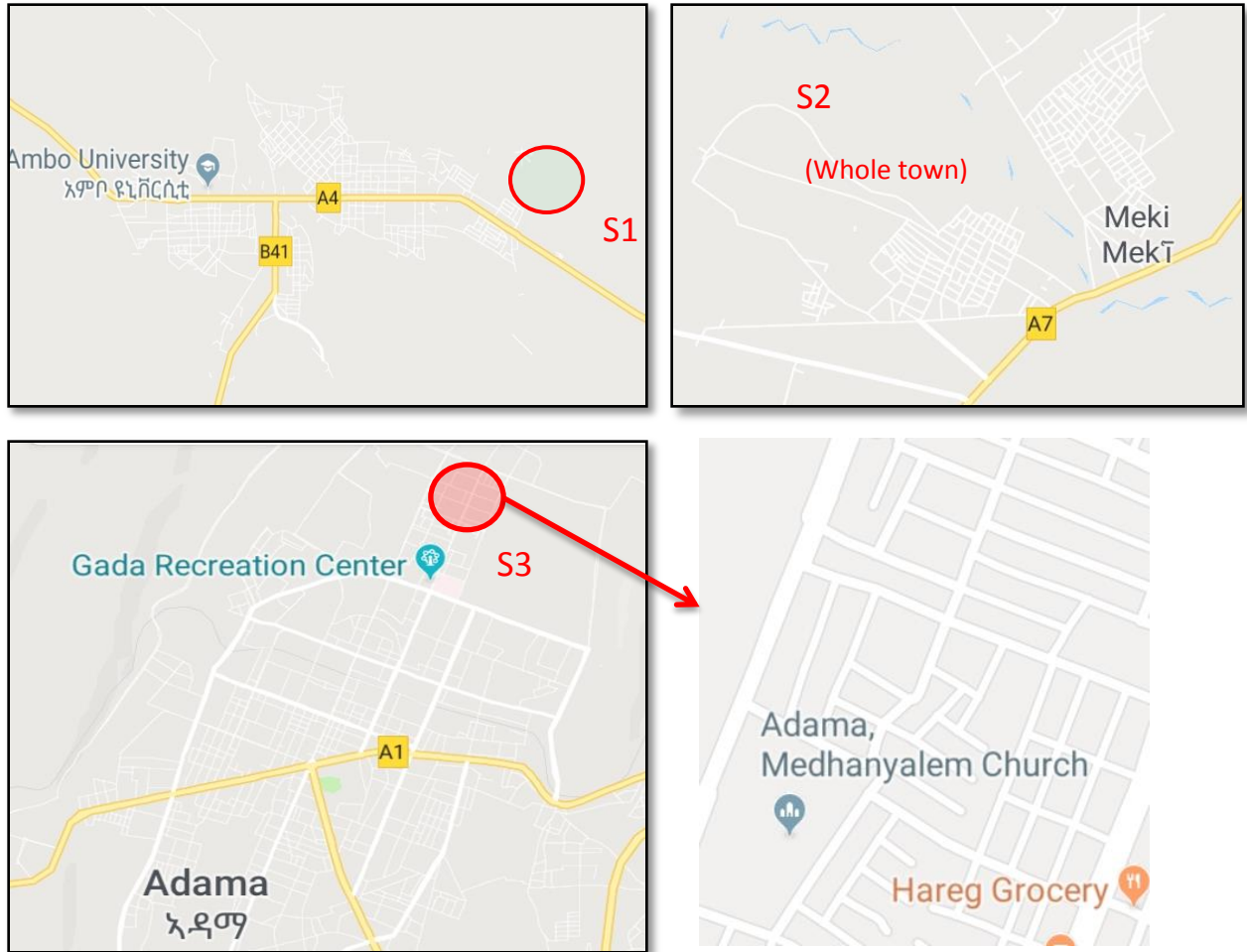


Figure 3.2: Sampling sites (<http://Wikipedia.orh/wik.com>)

3.3. Materials used

To conduct this study the materials described here under were employed:

- *Google earth* was used for analyzing the existence or the geography of the site and locating selected site of the study areas.
- *Lab machines* were used in measuring the compression, shrinkage and water absorption of the mud blocks collected the three sampling sites.
- *Mud block* were used to analyze the strengths (compression strengths and water absorption) of the mud blocks which were collected from the selected sites,
- *Tape meter* was the basic material for measuring the buildings height, area, width, and wall thickness any metric measurements of the mud block houses,
- *Soil* was used to analyze the soil type used for mud block molding.

3.4. Data sources

Data used for analyzing this thesis were collected from primary and secondary data sources. The primary data was collected from questionnaires, physical observation, and laboratory analysis. The secondary data was collected from written documents, and master plans and/or Google earth maps. Besides these Zonal and regional offices, reports, books, journals, internet, and other published and unpublished were used as the secondary data sources.

3.5. Data collection methods

The primary data was collected through personal observation, laboratory analysis and questionnaires. The questionnaire were conducted on prepared question by asking the society in the written ways and thirty (30) persons living in mud block houses were selected randomly for the questionnaires from each selected sites. The laboratory test was conducted at the EiABC, MRTC lab class on the compressive strength, water absorption and shrinkage. Physical survey was employed to survey on the ingredients, block size, constraints, construction techniques, and any metric measurements of the data on the mud blocks.

The secondary data was collected from written documents and master plans and/or Google earth maps. The written document was used to read and collect the necessary document about this study. This was performed on the local and international understanding of people's perception toward the mud block houses. The master plans and/or Google earth maps were used to indicate the location of the site and site geography, information about the study sites and the appropriate location, position, amount and arrangement of the buildings. Beside this, Zonal and regional offices, reports, books, journals, internet, and other published and unpublished sources were the sources of secondary data collection method in developing knowledge on the mud block and mud block housing.

3.6. Data analysis

3.6.1. Qualitative and quantitative data analysis

The quantitative and qualitative data were analyzed using SPSS and a spreadsheet. The data collected from different sources were analyzed systematically. The data collected from the three case study sites using questionnaires, physical survey and lab test were analyzed and presented by using the spread sheet and SPSS.

The analysis was done on the values obtained from the respondents of the three sites on the strength, durability, buildings height, wall thickness, moisture absorption, comfort, building function and other architectural property. This analysis on the selected areas and other parts of Ethiopia are helpful in developing and adapting the mud block housing and construction technique in to the country construction industry.

3.6.2. Laboratory data analysis & testing procedures

Mud block samples were collected from Ambo, Meki and Adama towns. Six samples of mud blocks were taken from the three study towns. The analysis was done on the mud block compressive strength, water absorption and shrinkage values. Two samples were taken from each site and one sampling block was used for compressive strength test while the other one sample was used for water absorption and shrinkage test. As shown in Table 3.2 during the lab analysis of mud block construction, the following affecting variables need considerations.

Table 3.2: The lab test affecting variables

No.	variables		
	Independent variables	Dependent variables	Extraneous variables
1	Soil type	Strength	Construction technique
2	Straw/ stabilizer	age	cultural habits
3	Moisture/water	Damp proofing	technology

3.6.2.1. Compressive strength test

The compressive strength of mud earth blocks (i.e. the amount of pressure they can resist without collapsing) depends upon the soil type, and the type & amount of stabilizer used to form the block. Maximum strengths are obtained by proper mixing of suitable materials and

good soil type. The compressive strength of a block is one of its most important engineering properties. It was established from the literature that the durability of mud blocks increases with increase in its strength. Knowledge of the compressive strength value of a block is used to:

- check the uniformity of block quality,
- compare a given block sample with a specified requirement,
- evaluate the blocks performance and durability,
- Classify a block in terms of its resistance to abrasive conditions.

Equipment list for compressive strength test are:

- Metric Scale
- Compression test machine
- Weight measuring scale

The average composition of sample that the blocks molded was prepared based on volume ratio of each ingredient as given below:

- ✚ 25% cements+25% sand +50% clay soil (A)/Ambo
- ✚ 3% teff straw + 97% silt soils (B)/Meki
- ✚ 3% teff straw + 97 % sandy soils (C)/Adama

General block production steps are: Excavation and Sieving of soil - Mixing (soil, and stabilizer (cement, sand and/or straw) and water) - Molding (using machine or manually by hand) - Drying.

The compressive strength tests procedure: compressive strength tests of blocks were carried out on three different blocks from the three sites that mean one block from one site.

The main procedures for compressive strength test are:

- Measure all the metric measurements and dry weight
- Put the samples on compression test machine and apply a vertical load on sample by lowering the plates of the machine.
- Record the applied vertical force and the resulting displacements at the breaking point, which is identified with the appearance of vertical cracks near the corners of blocks and in the middle of vertical surfaces. This method is for samples that have straw in the

mixture as they have larger elastic value and are not brittle. Whereas samples that have only cement, sand and soil have brittle character. Therefore, for those samples the maximum load record when the peak load gives signal in compression test machine.

The Compressive strength of mud block of the samples is expressed as in equation 3.1.

Compressive strength, $CS = \frac{TL}{PA} \times 1000$ Equation 3.1

Where: CS = Compressive strength (kg/cm²)

TL = total load tones (kg)

PA = press area (cm²)

3.6.2.2. Water absorption test

The aim of the water absorption test was to determine the percentage moisture absorption capacity of the mud block samples. Knowledge of the water absorption levels of blocks could serve as useful criteria for setting limits and for investigating possible ways of reducing the defects in order to improve the durability of mud blocks. Total water absorption test was carried out to determine the water absorption values of blocks and to compare their value with standard values.

Equipment's required for total water absorption test are:

- Drying oven
- Water Tanker for soaking the block
- Electronic weighing machine

The test procedures (steps) for total water absorption test are:

- Dry the specimens from each category of blocks in the oven at temperatures between 110°C and 115°C.
- When cool, weigh each specimen by electronic weighing scale.
- Immerse the specimens in a single layer tank for 24hrs after weighing so that water can circulate freely on all sides and bottom of the sample. Leave a space of about 10 mm between adjacent samples in the tank.

- Calculate the total water absorbed (TWA) for each for each sample which is expressed as a percentage of the dry mass using as shown in equation 3.2.

Remove the specimens after 24 hours, wipe off the surface water while shaking lightly with a damp cloth and reweight each specimen. Initially the weights of each of the mud block specimen from oven were taken (W1), and then mud block specimens were soaked in water. After 24 hours of water absorption, specimens were taken out, wiped and weighed (W2).The % water absorption can be Calculated as:-

% water absorbed, TWA = $\frac{MW-MD}{MD} \times 100$Equation 3.2

Where: TWA = total water absorption (%)

MW = wet mass (g)

MD = dry mass (g)

3.6.2.3. Expansion in wetting process

The shrinkage is contraction of a given block sample during drying. It gives an overall idea of the mixture behavior and suitability for construction. In other word, shrinking of soil is the opposite of swelling soils. A volume change soil swells with increasing moisture content, but it will shrink with decreasing moisture content. Soil expansion can cause serious distress to a foundation/structure and, the mechanism is the same as the shrinkage, but in the opposite direction.

The expansion analysis of the mud block is done by:

- Drying mud blocks by insert in oven for 24 hours
- measure all the dimension of the mud block
- Immerse the block in water tanker for 24 hours
- Measure the moisten mud blocks.

The total dimensions for each for each sample which is expressed as a percentage of the increased dimension as shown in equation 3.3.

% increased dimension, TID= $\frac{Wv-Dv}{Dv} \times 100$Equation 3.3

Where: TID = total increased dimension (%)

WV = wet volume (cm³)

DV= dry volume (cm³)

3.6.3. Cost analysis

Cost are the key playing in house constructions as cost is the basic for standing any structure but the amount of cost needed for construction depend on the types of material used, the quality of material, location and the amount of material. The cost of construction of equal sized mud block and concrete block have very gap depending on the quality of material, transportation cost, production cost, material used for production, and the easy of construction.

To analysis the cost of mud blocks and concrete blocks:

- Select and list the raw material used for molding
- Measure the amount or ratio of each material used for single molding from the volume
- Measure the rate used per the given amount
- Calculate the overall cost needed for single blocks and then calculate the overall cost for multiple blocks
- Compare the cost of each blocks

3.7. Data presentation

The analyzed data were presented by using statistical tools including charts, tables, and figures in clear and legible ways. Further the statistical data's were explained briefly by the help of texts to provide clear information on the research.

Chapter Four: Results and Discussions

4.1. Introduction

The final samples of populations for questionnaires of the study were 90 survey respondents from the three geographic regions of Ambo, Meki and Adama. The respondents were permanent or temporary residents within the mud block house. Using the material and methods described in chapter three, this chapter attempts to answer the following objectives of the study: 1) the existing mud block housing typologies practiced in the study area, 2) the Ingredients of mud blocks and its effect on the strength and durability of mud block houses, 3) the economic benefits of mud blocks comparing with concrete blocks, and 4) the perception of local community on the typology of mud block housing.

Each of the research objectives were going to be addressed below separately. The themes were identified by analyzing the interviews conducted with community and experimental results of each selected sites. For interviews when a similar answers or insights were given by multiple interviewees, it was believed significant enough to be considered a theme and every interview question was linked to one of the four research objectives from which it is emerged.

Source of questionnaires information concerning the mud block housing construction on the central Ethiopia; in the case of three selected sites are done only on peoples living in mud block houses. The information gathered was used to improve the mud block housing construction by analyzing the durability, adaptability and construction techniques in the study areas especially on the perceptions of the respondents.

Total water absorption, shrinkage and compressive strength tests of the mud blocks were carried out on the mud blocks to make comparison of their results with standard recommended values and to examine their performance and durability. Beside this the cost analysis of mud block compared with concrete blocks are analyzed. For all the samples of mud block collected from the three sites, the compressive strength, water absorption, block size/shrinkage and overall related experimental results were analyzed to adapt the mud block houses in the countrywide.

4.2. Socio-Economics characteristics of respondents

The socio-economic factors have input on the mud block construction. The respondents from the three sites were asked to provide the socio-economics characteristics as these socio-economics characteristics have influence on the mud block houses (refer Table 4.1).

Table 4.1: Socio- Economics characteristics of the participants

description		Ambo		Meki		Adama	
		Freq.	%	Freq.	%	Freq.	%
sex	Female	14	46.7	7	23.3	12	40
	Male	16	53.3	23	76.7	18	60
Age	<20	3	10	2	6.7	1	3.3
	21-40	12	40	26	86.7	23	76.7
	41-60	13	43.3	2	6.7	6	20
	>60	2	6.7	-	-	-	-
Education status	No education	1	3.3	-	-	1	3.3
	Primary school	4	13.3	4	13.3	4	13.3
	Secondary school	3	10	8	26.7	7	23.3
	college/university	22	73.3	18	60	18	60
Occupation status	House worker	6	20	-	-	2	6.7
	Trading	8	26.7	4	13.3	7	23.3
	Government employee	16	53.3	6	20	13	43.3
	Farmer	-	-	11	36.7	1	3.3
	Daily laborer	-	-	2	6.7	6	20
	contractors	-	-	1	3.3	-	-
	Unemployed/student	-	-	6	20	-	-
	House rents	-	-	-	-	1	3.3
Income	<1000	2	6.7	9	30	2	6.7
	1000-1500	2	6.7	3	10	6	20
	1500-2000	2	6.7	5	16.7	4	13.3
	>2000	24	80	7	23.3	18	60
	No income	-	-	6	20	-	-
No. of children	No	1	3.3	9	30	12	40
	One	5	16.7	8	26.7	5	16.7
	two	11	36.7	6	20	7	23.3
	Three	4	13.3	4	13.3	5	16.7
	four	5	16.7	3	10	1	3.3
	>five	4	13.3	-	-	-	-
<i>Total</i>		<i>30</i>	<i>100</i>	<i>30</i>	<i>100</i>	<i>30</i>	<i>100</i>

Source: Figured from the surveyed site data of code 101-106/ Socio- Economics characteristics

4.3. The existing mud house typologies of the case studies

The primary concern of housing typology as a jurisdiction of investigation is to address the conceptual basis to classified and categorized buildings into types. Typology of the housing is about the formal and spatial characteristics of buildings for rooting in culture and history and the typology in this sense is regarded as the “classification of models”. Typological process is defined as dynamic evolutionary paradigms of a certain type of buildings of a particular society, in order to provide a clear generative interpretation of forms transformation.

The houses types that are used in the study areas during the past time were Chika bet/mud house, mud block, stone, brick, HCB, and wood as a dominating construction material. As shown in Figure 4.1, Chika bet/mud house, mud block, stone, brick, HCB, and wood were mentioned for the respondents on the types of the houses used for living in the past. From the types of houses used traditional building materials called Chika bet also called mud house was identified as the primary housing material for living in the study area during the past. Chika bet amounts about 58.9% from the total population of the three site and 76.7% from Ambo on the chika bet is selected by the participants.

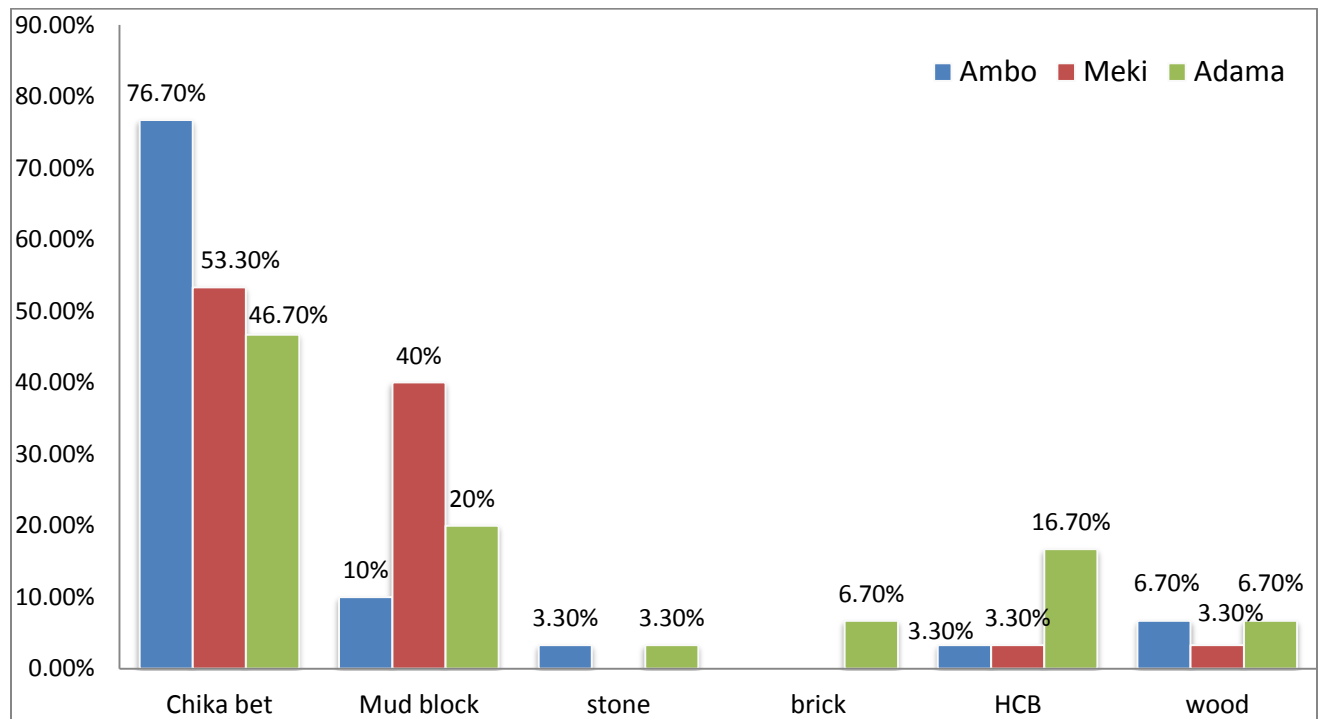


Figure 4.1: The houses types that respondents use in the past

The reason for the selections of Chika bet as the dominant building material in Ethiopia is due to the easy access and abundances of wood in past but now a day Ethiopia is under severe problems of deforestation. Beside this, the construction process of the Chika bet is simply from wood and filling the gap between the wood by mud. Compared to other construction material the use of chick bet is economical, simple and need local labor but it is the cause for deforestation and not durable. Generally the use of wood and wood product for construction of chika bet houses cause severe problems such as deforestation, discomfort and deterioration by moisture. Wood products were easily affected by termites that make the chika bets not durable.

The traditional mud block based constructions are more sustainable, economical, energy efficiency, environmentally adaptable, and recyclable that uses local material and labor as it is easy of the construction techniques. All the respondents are living in the mud block houses and the current age of the houses are varying from place to place. The age of the housing is dependent of the time the societies are taking the technology of mud block as it is taken from foreigners. The time taken for adaptations of mud blocks is varying from place to place based on the climatic zones. The age of the mud block houses existing in the study areas are varying between 0-30 years and are able to exist long time in the future without any failure (refer Table 4.2).

Table 4.2: The age of mud block houses

No.	age of the mud block houses(yr.)	Ambo		Meki		Adama	
		Freq.	%	Freq.	%	Freq.	%
1	0-5	-	-	7	23.3	10	33.3
2	6-10	-	-	9	30.0	11	36.7
3	11-15	-	-	9	30.0	3	10.0
4	16-20	25	83.3	5	16.7	3	10.0
5	>20	5	16.7	-	-	3	10.0

As studies show the major factors affecting the age of the mud block houses were soil, stabilizers, moisture/rain and the structural elements. For construction of durable mud block houses the material used for molding the blocks are the key playing. From this mud block houses are an ability to survive more than 40 years for the mud block molded from clay soil

and stabilized with cement and sand while for mud block molded from silt soil and sand soil stabilized with straw are able to survive for more than 30 years.

The housing typology doesn't emphasize on architectural styles, rather it is a set of descriptive categories that define the spatial characteristics of buildings over time. Typology has been used either as a basis for analyzing buildings and cities (analytical typology) or as a basis for designing buildings (generative typology).

The shape based housing typologies of the study area are both circular and rectangular form. The current housing forms are rectangular and the reasons for selecting the rectangular shapes are due to durability, easy of construction and climatic conditions. The easy of construction is the base for selecting the building shapes due to the difficulty of construction leads to high labor, economy and time of construction. As summarized in Figure 4.2, 66.8% from the respondents are agreed on the easy of construction is the case for the selection of rectangular shapes.

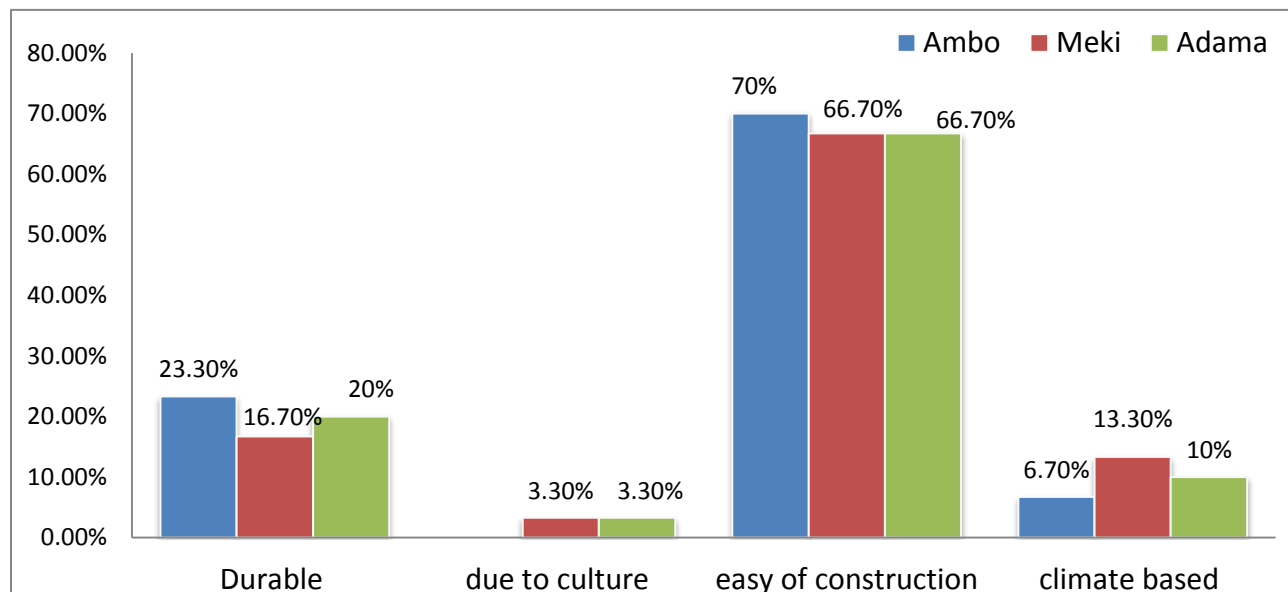


Figure 4.2: Reason for selection of rectangular shape

Rectangular shapes are very easy of construction due to easy of material arrangement or positioning and setting. When constructing rectangular shapes the construction technique is very easy that doesn't need any skill. Rectangular shapes are very easy for construction and dominating forms in the world. As our Ethiopia is developing country and majority of

the community is under low income, the housing construction needs low skilled labor due to the fact that rectangular shapes are appropriate for simple construction.

Now a day in Ethiopia the dominant roofing materials of the houses are iron sheet as iron sheets are resistant to climate, durability and easy of construction. In the whole study area the roofing material used was iron sheet. The roof shape, eave and materials are affected by the climatic zones. The roof eave is varying from place to place due to wind and rain (refer Table 4.3). In Ambo as the area is rainy, majority of the respondents (50%) are using 1-1.5m eave while in Meki and Adama as the area is dry and high wind blowing, high percent of the respondents are using <0.5m eave which is 40% and 63.3% respectively.

Table 4.3: Roofs soffit length

No.	Roof soffit or eaves (m)	Ambo		Meki		Adama	
		Freq.	%	Freq.	%	Freq.	%
1	<0.5	-	-	12	40	19	63.3
2	0.5-1	3	10	10	33.3	4	13.3
3	1-1.5	15	50	6	20	6	20
4	1.5-2	12	40	2	6.7	1	3.3

To conclude, the soffit length of the roofs in rainy area must be eave over wall to protect the walls from vertical rain while in dry area increasing the roofs soffits leads to an easy removal of the roofs by wind. From the literature and this study the length of soffit is dependent of the climatic conditions mainly rain and wind.

The building height, room area, wall thickness, and other building standardizations are the leading in affecting the durability of the mud block houses. Each of the sites has its own housing standardization which affects the building durability. Mud block constructions of the study sites are in different climatic zone with different soil type which leads to difference in construction technique, construction standards and building forms. Analyzing the mud block construction in different climatic zone and soil type helps the researcher to give adaptability of mud block houses in solving the housing problem of Ethiopia.

The effect of housing shape on durability of mud block houses is varying according to the climates. The selection of rectangular or circular shape in different site is different

depending on the climate, soil type and the society attitude toward mud block construction. The numbers of respondent agreed on the fact that shape affects the durability is very low which is about 32.2% (refer Figure 4.3).

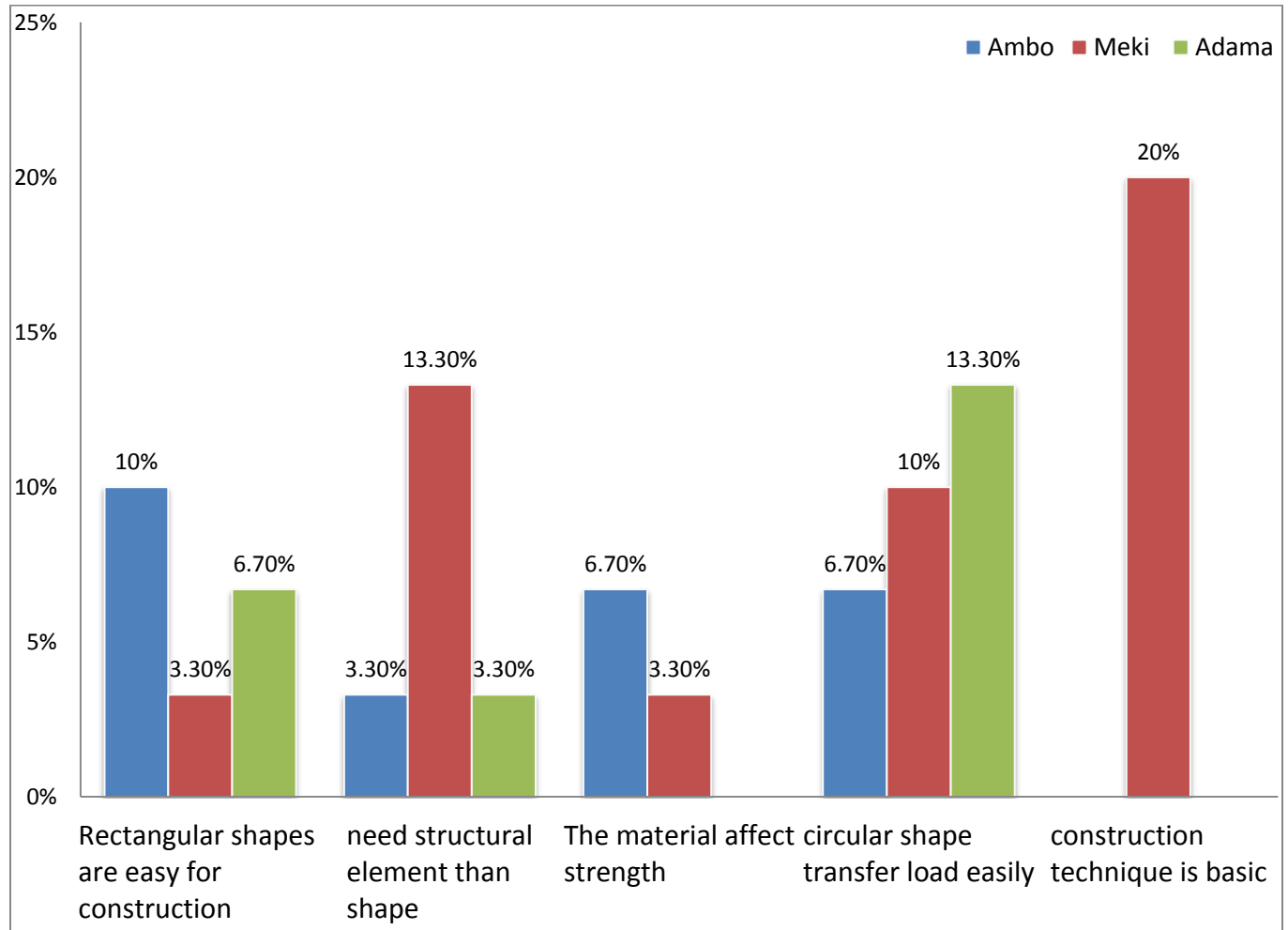


Figure 4.3: Housing shape effect on the durability of mud block houses

For a mud block houses to be durable using of different shapes were not problem rather construction technique, material ability and use of structural elements influence the strength and durability of mud block houses. In the construction of mud block shapes have little influence on the durability.

The building height affects the age/durability of the mud block houses. 63.3% of the respondents agreed that the building height affect the durability of mud block houses. The building heights of the three study areas are different and the cause for the difference of the mud block houses from place to place is based on rain/moisture, hotness and wind (refer

Table 4.4). The selection of the building height was greatly influence the durability of the building as the climatic conditions mainly wind and rain affects the durability of mud block houses.

Table 4.4: The building height of the selected sites

Description		Ambo	Meki	Adama
Height (m)	Min. height	2.75	4.5	2.75
	Max. height	3.25	5	3

The building height affect the age/durability of the mud block houses unless structural elements are used to support the vertical loads, Wind blows take the roof covers, rain wash the wall surface, failure due to high Load of the mud block houses (refer Figure 4.4). In the construction of mud block houses, the building heights were varying from place to place based on the external factors and the climatic conditions.

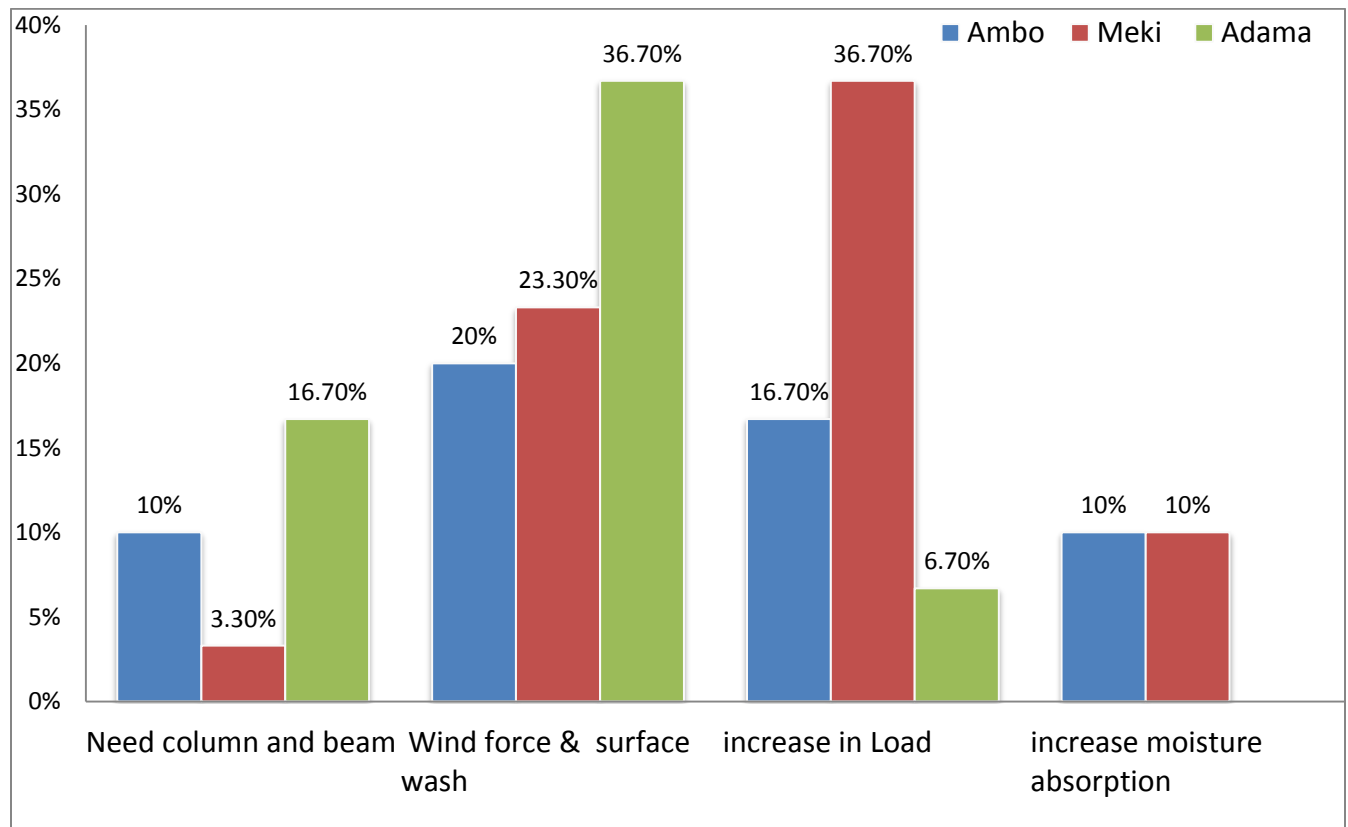


Figure 4.4: Housing height versus age/durability of mud block houses

Increasing the height of the building has influence on the mud block houses as soil has high weight and weak strength that facilitates the failure of mud block houses. From this study and literatures, the increments of exposure of wall surface to rain and winds are the key factors in affecting the mud block houses durability.

An increase in the room area affects the durability of the houses and about 47.8% of respondent are agreed on the fact that building area affects the durability of mud block houses. The increase in the room area affects the durability of the mud block houses unless it needs vertical structural elements to support loads, failure of the houses due to increase of load with surface area and exposure to wind increase with area (refer Figure 4.5).

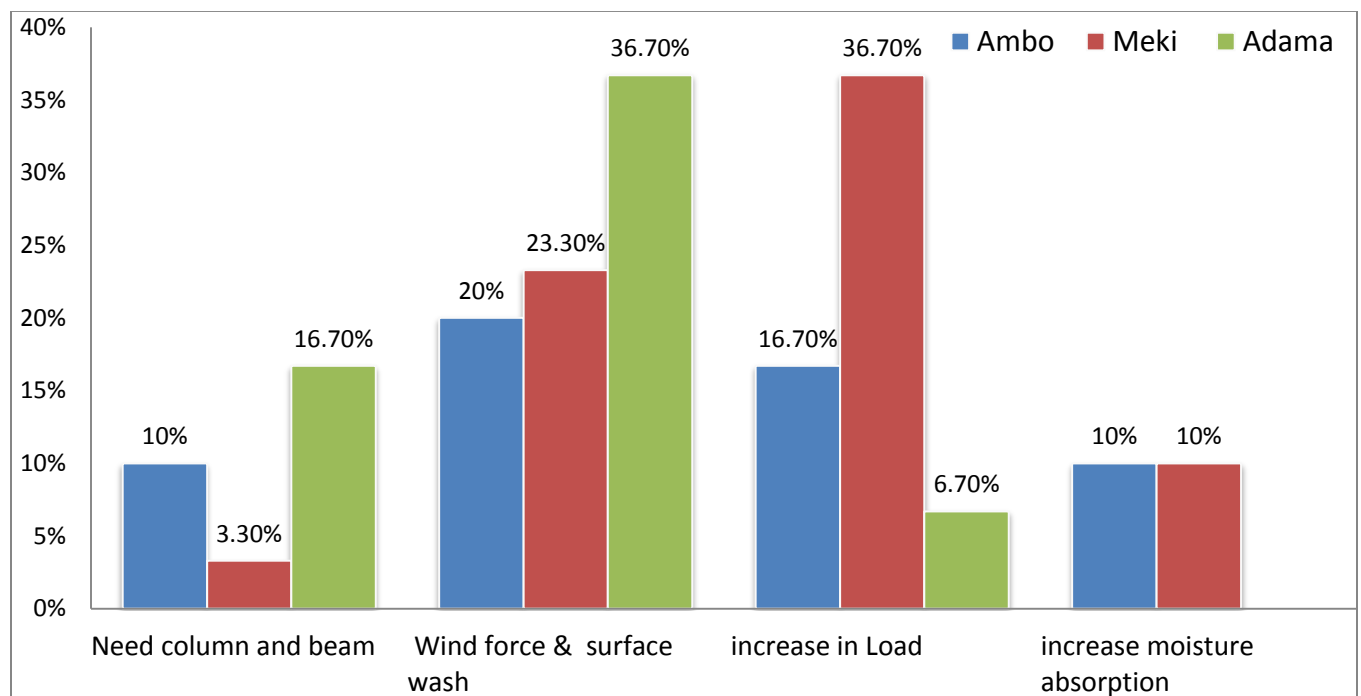


Figure 4.5: Effects of increases in the room area on the durability

Mud block houses were constructed from soil and stabilizers by molding into the blocks. Soils by nature have high weight and the weight of the building increase with the room area that leads the building to miscarry. When increase the building areas it is mandatory to use structural elements to support the loads of the building and minimize the building exposure to the wind and rain.

The wall thickness has influence on the durability of mud block houses. This study shows that about 71.1% of respondent agreed on the fact that the wall thickness has influence on the durability of the mud block houses. As shown in Figure 4.6 below the increase in the wall thickness has influence on the durability of the mud block houses due to the fact that Wall thickness increases the loads of the building.

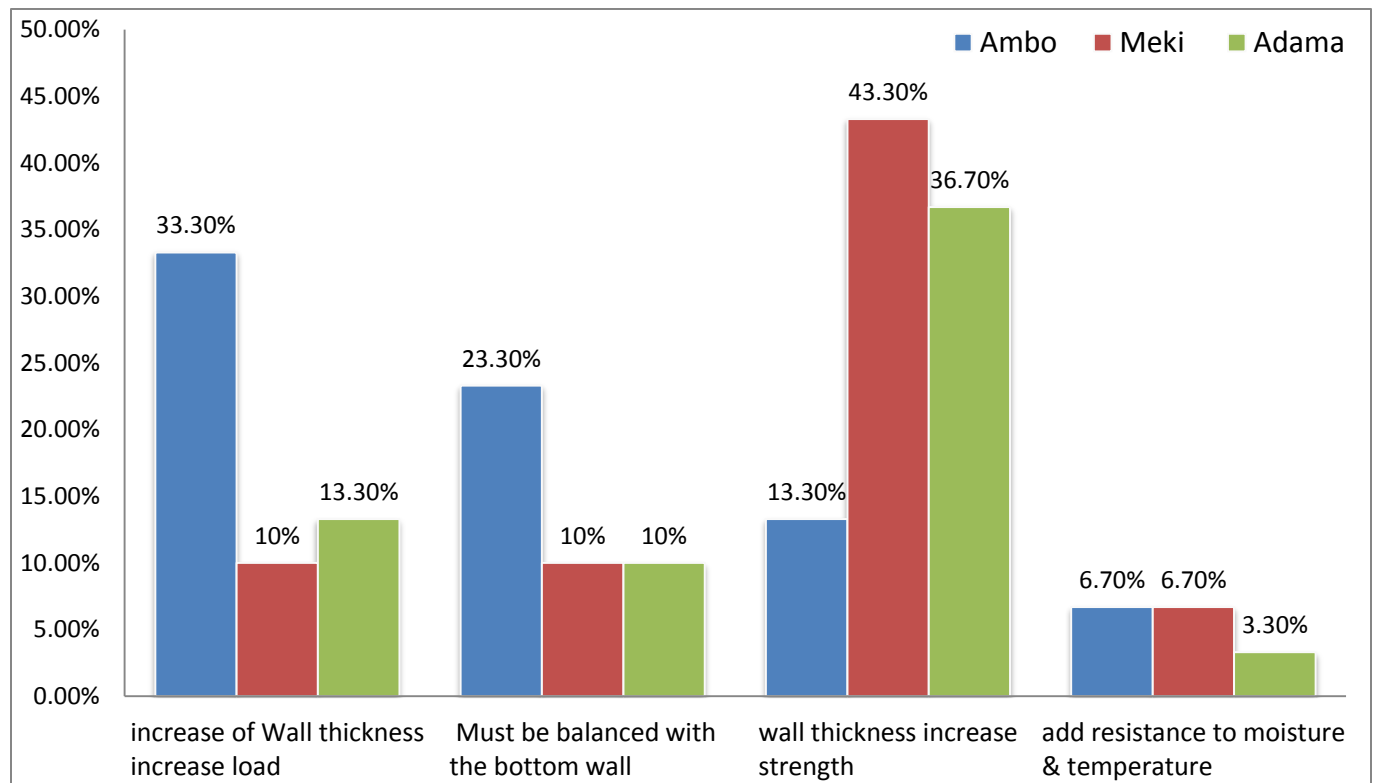


Figure 4.6: Wall thickness influence on the durability of mud block houses

In other direction increasing the wall thickness add resistance to moisture and temperature. In the construction of mud block houses, using large and loaded mud block increase the building to failure.

From this study and literatures, the construction of mud block houses wind, rain/moisture, building height, wall thickness, room area, soil type, admixture and the use of structure affects the building durability. The natural behavior of mud block was taken from the soil and the soil was high load, water absorption and non-adhesive.

4.4. The Ingredients of mud blocks and their effects on durability

The main ingredients used in molding mud block are soil material and stabilizers. The types of soil and stabilizers used for molding mud block houses are different from site to site (refer Table 4.5). The mud blocks are made up of varying proportions of soils materials like gravels, sands, fine (silts and clays). Each of the soils have different characteristic and the materials are capability to resist humidity, change in volume, and binding.

Stability and un-stability is the ability of the material to withstand alternating of humidity and dryness without its properties changing which is a fundamental importance property for a building material.

Table 4.5: The main ingredients used

No.	Description	Ambo	Meki	Adama
1	Soil type	Clay soil	Silt soil	sandy soil
2	stabilizers	Sand & cement	Teff straw	Teff straw
3	dimension/cm	30x15x12.5	37.5x20x17.5	35x20x12.5
4	Av. Weight/kg	9.17	16.5	10.2

The most commonly used soil materials in the selected sites are clay soil, silt soil and sandy soil. Besides the soil type different types of stabilizers are used for stabilizing the mud blocks. The most commonly used stabilizers used for molding mud blocks in three sites are teff straw, sand and cement and it have influences on the durability of mud block houses.

From the soil type used for molding of mud block, clay soil is more efficient for production of a durable mud block houses. An increase in the amount of cement and straw increase the stability of the mud block that bring excellent compressive strength, water absorption and shrinkage values by binding the ingredients together. From the mud block used in the three sites, the mud block molded from cement and clay soil is good in compressive strength (refer Table 4.6). In different sites different types of soil and stabilizers are used for molding mud block depending on the products accessed in the construction sites. The mud block houses from Adama and Meki are not acceptable according to the experimental results but

acceptable the local society. The main cause for acceptability of mud block in Adama and Meki is mainly due to small amount of rain per year that support the mud block houses in these areas to be durable.

Table 4. 6: Compressive strength of mud blocks

location	Comp. strength/Mpa	Soil type
Ambo	2.4	Clay soil
Meki	0.46	Silt soil
Adama	0.42	Sand soil

(Mpa= kg per cm² divide by 10.197)

As explained above, stabilizers greatly affect the mud blocks strengths. The stabilizers affect the blocks strengths by binding the ingredients, add water resistance and protect from crack (refer Figure 4.7). From the advantages that the stabilizers bring on the mud block, the leading for the durability of mud block houses are stabilizers add strength of the mud blocks by binding the ingredients.

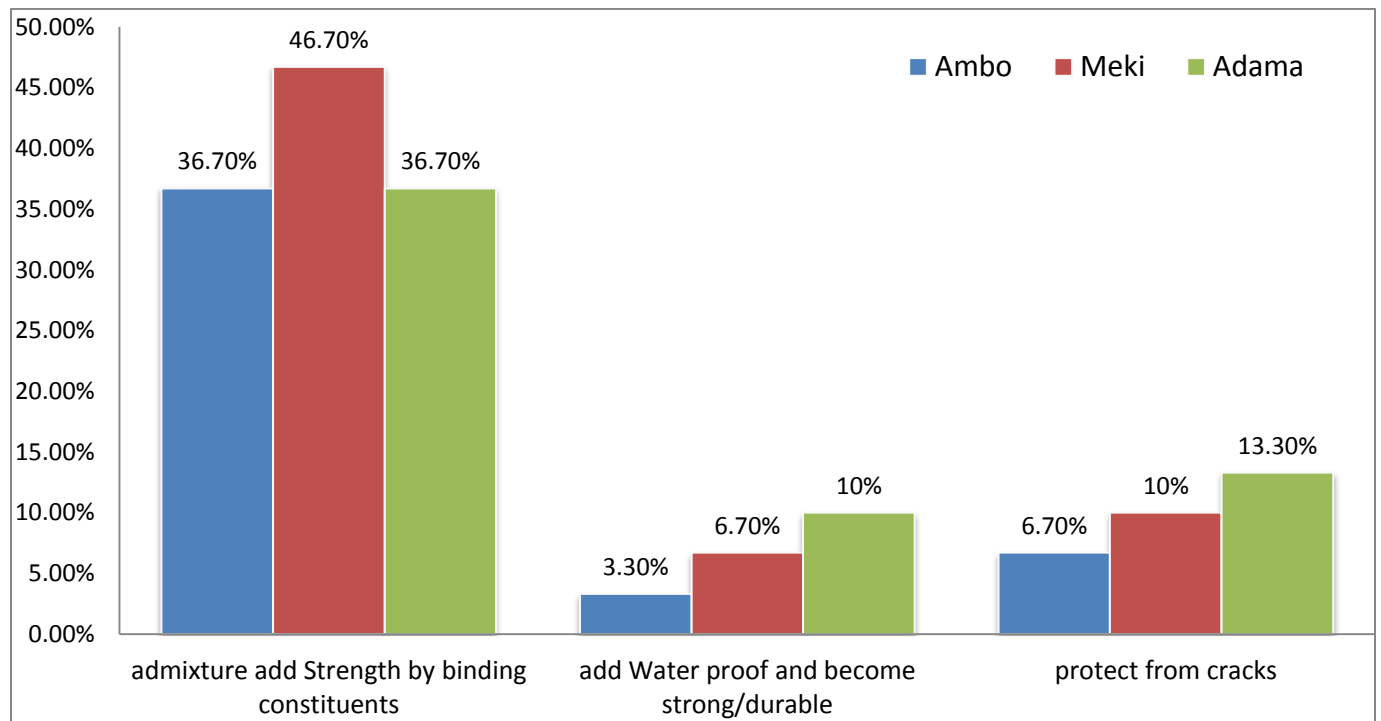


Figure 4.7: Uses of the stabilizers in mud block

The stabilizers have greatest impact on blocks strengths. The types of stabilizers used for molding mud blocks is different from one place to another place depending on the local accesses of material, economy of the society and peoples attitude toward the mud block housing. For example in Ambo cement and sand are broadly used while in Meki and Adama teff straw is used as the binding material to add strength of mud blocks.

To conclude, the ingredients used for molding mud block and their effect on the strength of mud block houses, detail analysis were done. The ingredients used are different types of soil and stabilize (cement, sand and straw) and the types of the soil and stabilizers have greatest impact on strength of mud blocks. Beside the ingredients used for molding mud block houses, the external factors that affect the strength of the buildings are moisture, function it provide, climate and construction technique. From the information collected from this study and literatures, moisture has influential effect on the durability of the mud block house even if the ingredients used have impacts on the durability.

4.5. The economic benefits of mud blocks compared to concrete blocks

Mud block construction is economical for the low income local community as about 88.9% of the respondents were decided. The block house was more economical due to use of local material, local labor, save time, simple for construction, efficient non-industrial product, and use of small amount of materials for construction. Depending on the data collected from the respondent the leading factor for economical of mud block is use of local material, local labor and save of time (refer Figure 4.8).

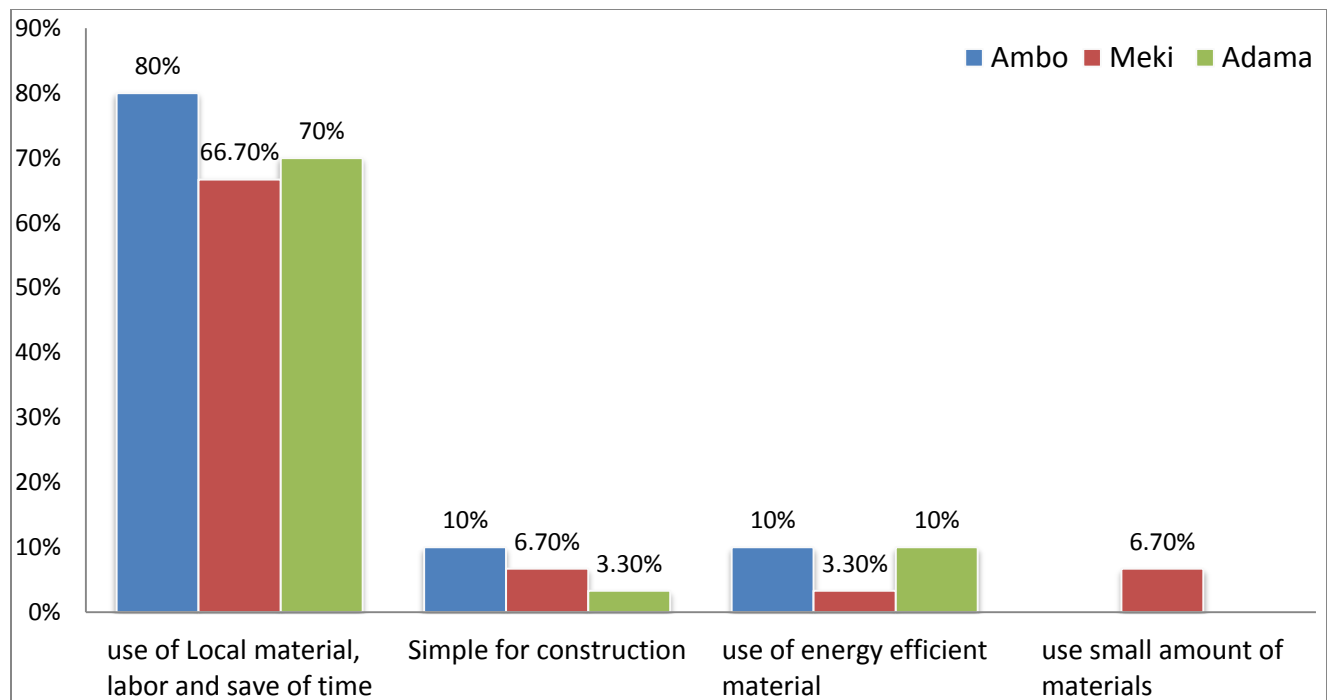


Figure 4.8: factors that make mud blocks economical

Mud blockhouses are economical to be constructed by every person especially low income peoples. Due to materials are locally accessible and need local labor mud blocks are more economical.

When compare mud block construction with concrete blocks on its economy. About 71.1% of the respondents from the three sites agreed on the fact that mud block have economic benefit than concrete. The mud block houses are more economical over concretes due to use of local material, local labor, simple for construction, saves of time, and use of non-industrial stabilizers. From the three studies, about 40% of respondent agreed that mud block house was economical due to the use of local material and labor(refer Table 4.7). The major ingredients of concrete blocks are cement, aggregate and sands that the cost needed for these ingredients are not economical.

Generally concrete block constructions were high cost of construction due to high production energy and transportation cost of concrete. The mud block constructions is not only economical but also there is high gap of cost between concrete and mud blocks as mud block construction uses non-Local material, energy inefficient material and unsustainable materials.

Table 4.7: Mud block constructions economic benefit over concrete block

No.	Reason of economical	Ambo		Meki		Adama	
		Freq.	%	Freq.	%	Freq.	%
1	use of local material and labor	7	23.3	14	46.7	15	50
2	Simple in construction and save of time	5	16.7	4	13.3	2	6.7
3	use of non-industrial local and economical stabilizers like straw	6	20	6	20	5	16.7
	Total	18	60	24	80	22	73.3

To calculate the cost of the concrete block and mud block knowing the basic ingredients used, the cost of the ingredients and the size/volume of the ingredients are the basic things. The mud blocks are stabilized with cement, sand and straw while concrete block are made from cement, sand and aggregate and mud block molded from soil and straw is more economical (refer Table 4.8).

Table 4. 8: The costs of mud block and concrete block

Block type	materials	Rate (birr)	Ratio	Weight	Cost	Remark
Mud block	Teff straw	20 per kg(approx.)	1:32	15kg	<3 ETB	labor force
	Soil					
Mud block	Cement	190 per bag (50 kg)	1:3	8.83 kg	10 ETB	labor force
	Soil					
Mud block	Cement	190 per bag (50 kg)	1:1:3	8.83 kg	12 ETB	labor force
	Sand	400 per m3				
	Soil					
Concrete block	Cement	190 per bag (50 kg)	1:2:3	7kg	20 ETB	
	Sand	400 per m3				
	Aggregate	400 per m3				

The costs of mud block and concrete block have great difference. Mud block is cheaper than concrete block and the average cost of one straw stabilized mud block is 3 birr and cement and sand stabilized mud block is 10 birr while the average cost of hollow concrete block is about 20 birr per block if the construction is taking place in Addis Ababa. From this the cement is the most influential in affecting the cost of the blocks (refer Figure 4.9).

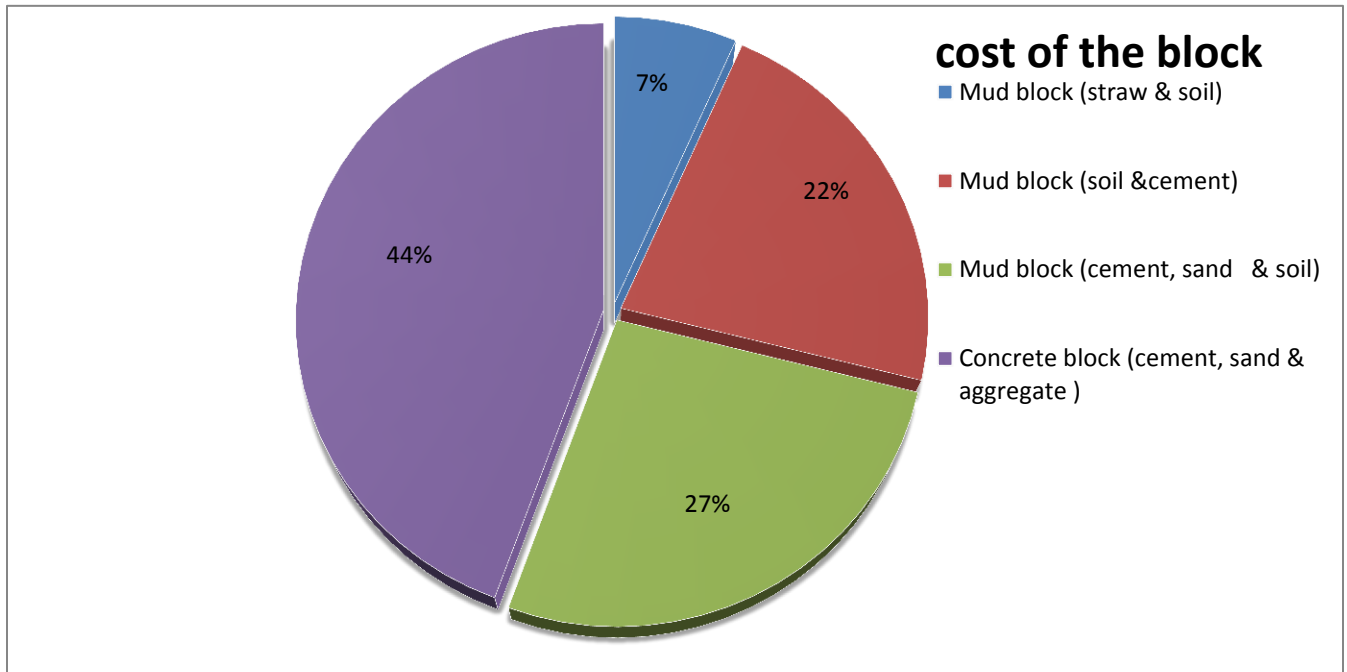


Figure 4.9: The cost comparison of mud and concrete block

The construction cost needed for construction of mud block houses were very small compared to concrete due to use of locally available material, local labor, easy of construction, and time saving. Mud block houses were economical, energy efficient, recyclable, and good in cooling effect that make mud block more acceptable compared to concrete blocks.

4.6. The perception of the local community on mud block housing

4.6.1. Comfort and sustainability of mud blocks

The mud block houses were comfortable and sustainable for living especially in warm areas. Form the questionnaires about 60% of the respondents agreed on the fact that mud block construction is comfortable for living due to cooling effect, sound proofing, simple for

construction, beauty houses, recyclable waste material, economical material and save construction time (refer Figure 4.10). About 37.8% of the respondents agreed that mud block houses provide best cooling effect and sound proof which is the major problem for peoples live in warm areas.

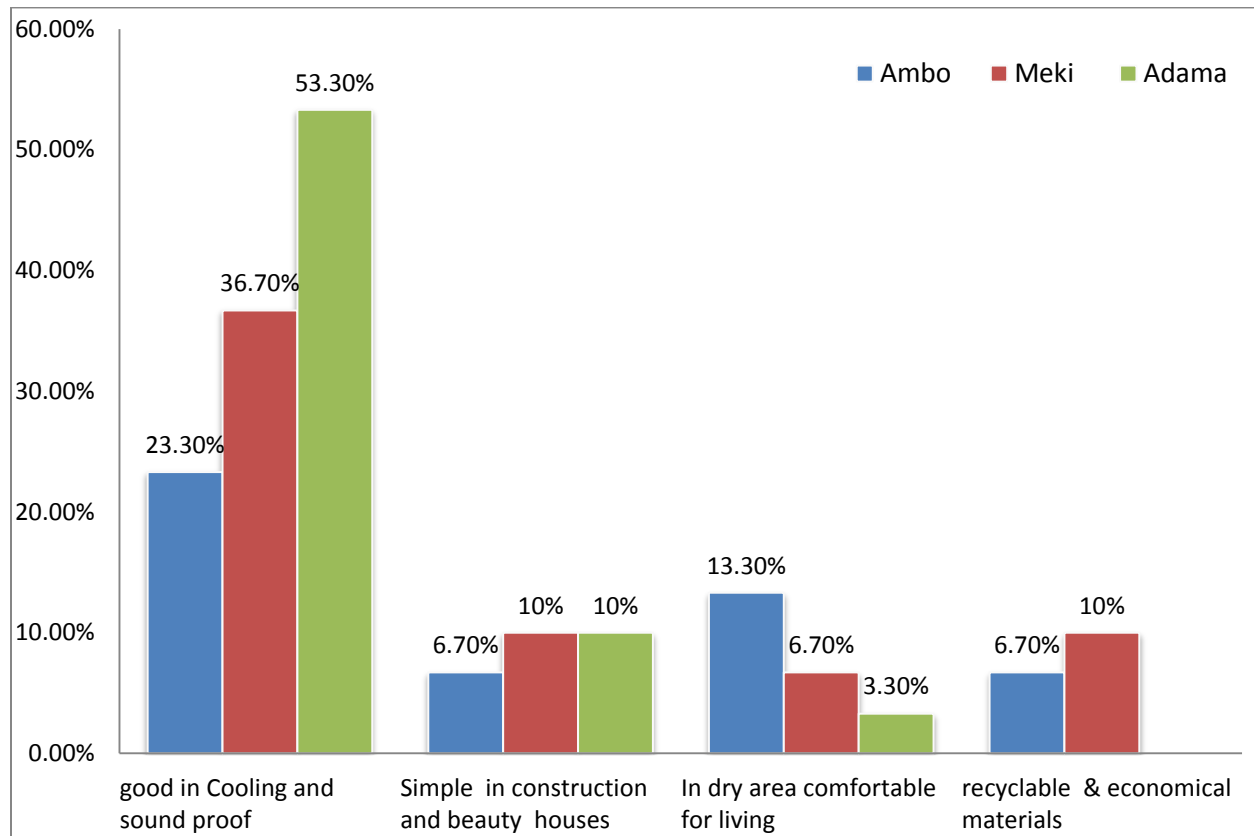


Figure 4.10: Comforts that mud block houses provide

From this investigation and written documents, mud block construction is basic and necessary in dry and desert areas for the user to live as the mud block houses provide comfortable living microclimate. The mud block constructions are the basic for desert areas as there is low amount of rain that affect the strength of mud blocks houses and the resistance of mud blocks to severe climate.

Mud block construction technique is easy compared to concrete. The construction technique of mud block house is different from concrete block houses. The material used, molding technique and labor needed for mud block make mud block very easy and simple compared to concrete. The constructions of mud block houses are economical and simple

due to use of local material, local labor, save time, and don't use structural elements (refer Figure 4.11).

From this study, we generalize that mud block houses are comparatively easy for construction due to the use of local material and local labor. In the construction of mud blocks houses there is no need of any extra skills but it is constructed by local labor. Beside local labor the construction of mud block didn't use structural elements and this simplify the constructions of mud block houses.

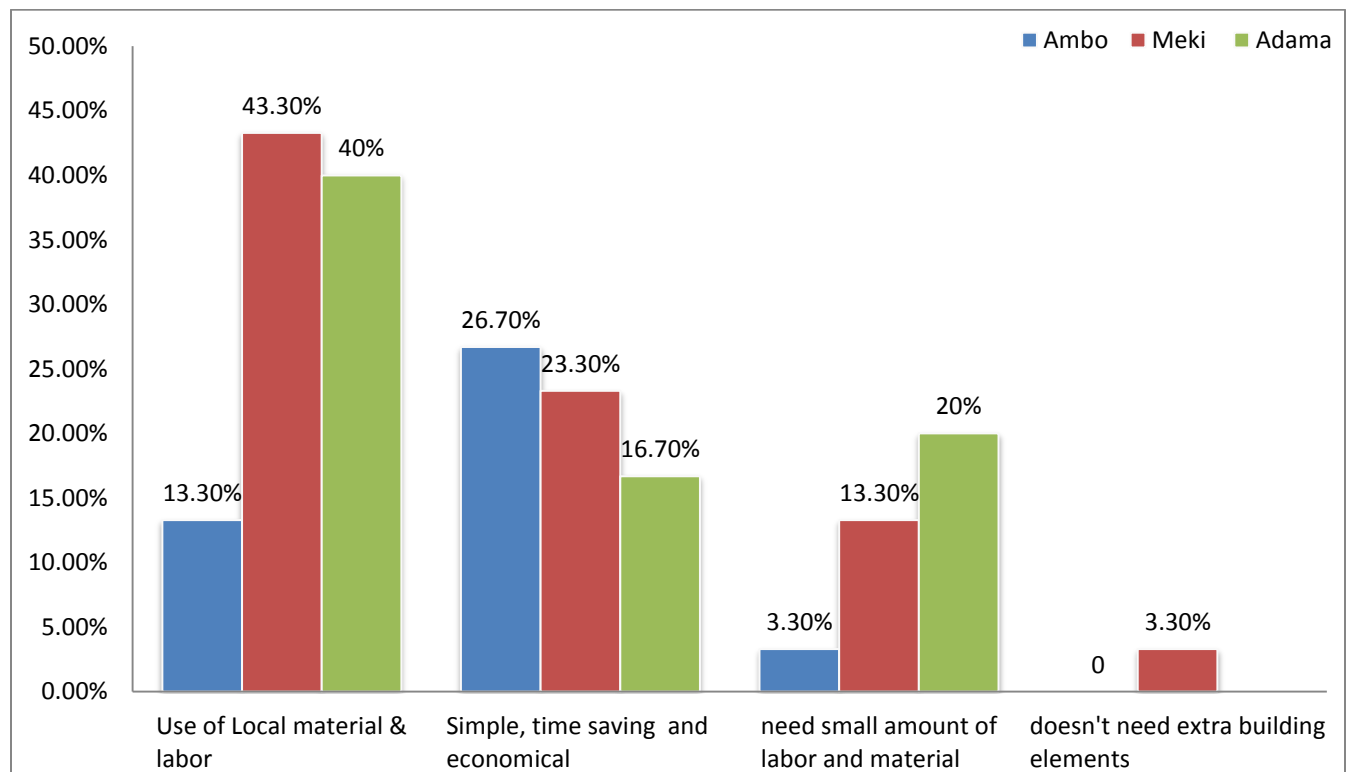


Figure 4.11: Causes for mud block construction technique to be easy

The durability and sustainability of Mud block houses are different from site to site depend on the climate and soil type. Even if majority of the respondents are disagree on mud block houses durability and sustainability, the key and leading factors that affect the durability and sustainability of mud block houses are termite, moisture, over load, and construction technique (refer Figure 4.12). The mud block houses are free from termite and environmental.

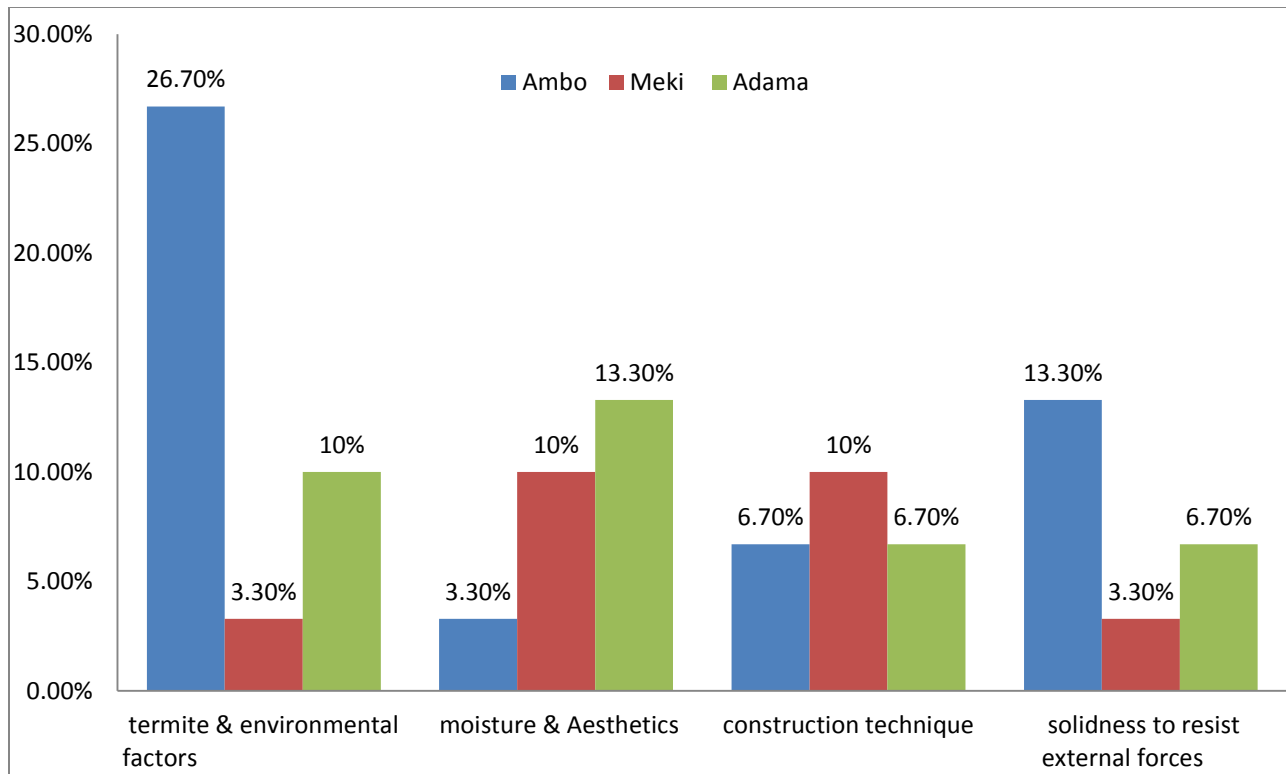


Figure 4.12: Factor affecting mud block houses durability and sustainability

The effects of rain on mud block houses are high. Soils are unable to resist moisture that makes the mud block houses easy for failure. The rain affects mud block houses by washing the wall surface, cracking of the wall due to moisture, and the ground swell or compressed even if the construction technique are useful in minimizing the influences of rains on the building. Mainly the rain affect the building by washing of the wall surface and this captured rain make the houses fail easily (refer Figure 4.13).

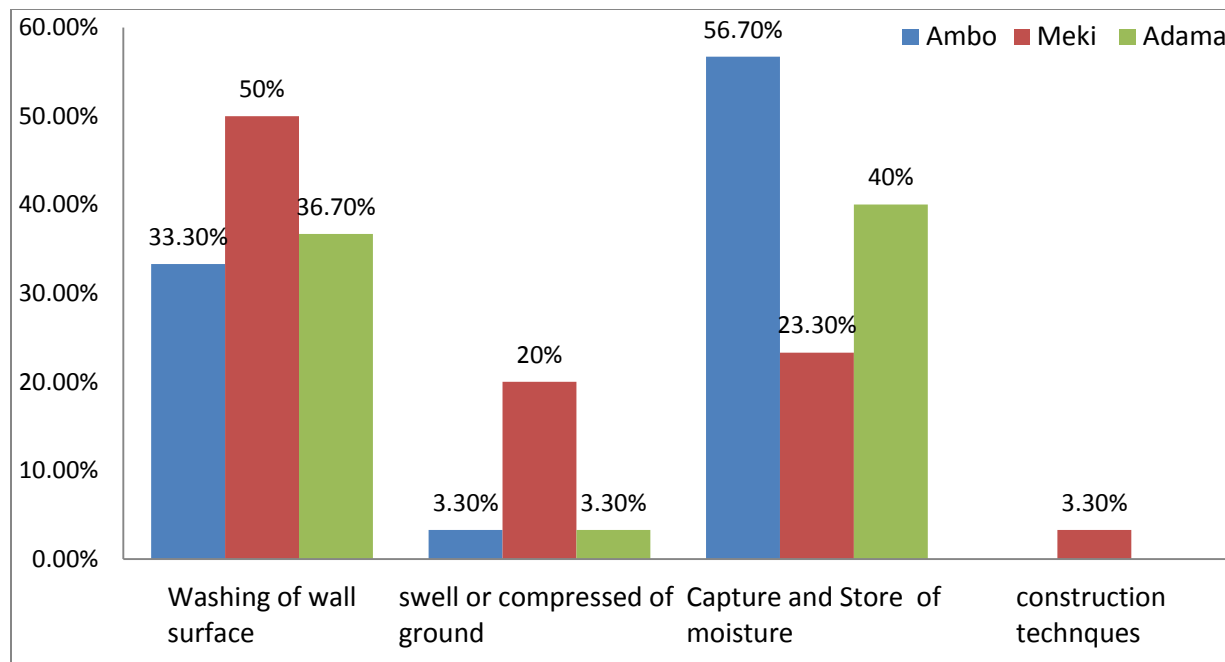


Figure 4.13: Effects of rain on mud block houses

The construction of mud block is very simple compared to concrete block and comfortable in warm areas as it provide good cooling effect for the user as mud blocks are full ability in producing microclimate. In dry and desert areas the construction of mud block houses are more recommended as the amount of rain/moisture in this area is very low while in rainy area due to high amount of rain the wall surface are washed by rain.

4.6.2. Compressive strength and durability of mud blocks

The amount of pressure the mud blocks can resist without collapsing depends upon the soil type, the stabilizer used to form the block and molding technique. Maximum strengths are obtained by proper mixing of suitable materials and proper soil type in appropriate ways as compressive strength of a block is one of the most important engineering properties.

In practical, compressive strength value for mud blocks may be less than 4MPa. When building loads are small (e.g. in the case of single store constructions), a compressive strength value from 2MPa to 4MPa may be sufficient for building purposes. Many building authorities around the worlds recommend values of compressive strengths are within 2-4Mpa. Figure 4.14 shows that the compressive strength of the mud blocks is varying from site to site depend on soil type and stabilizers.

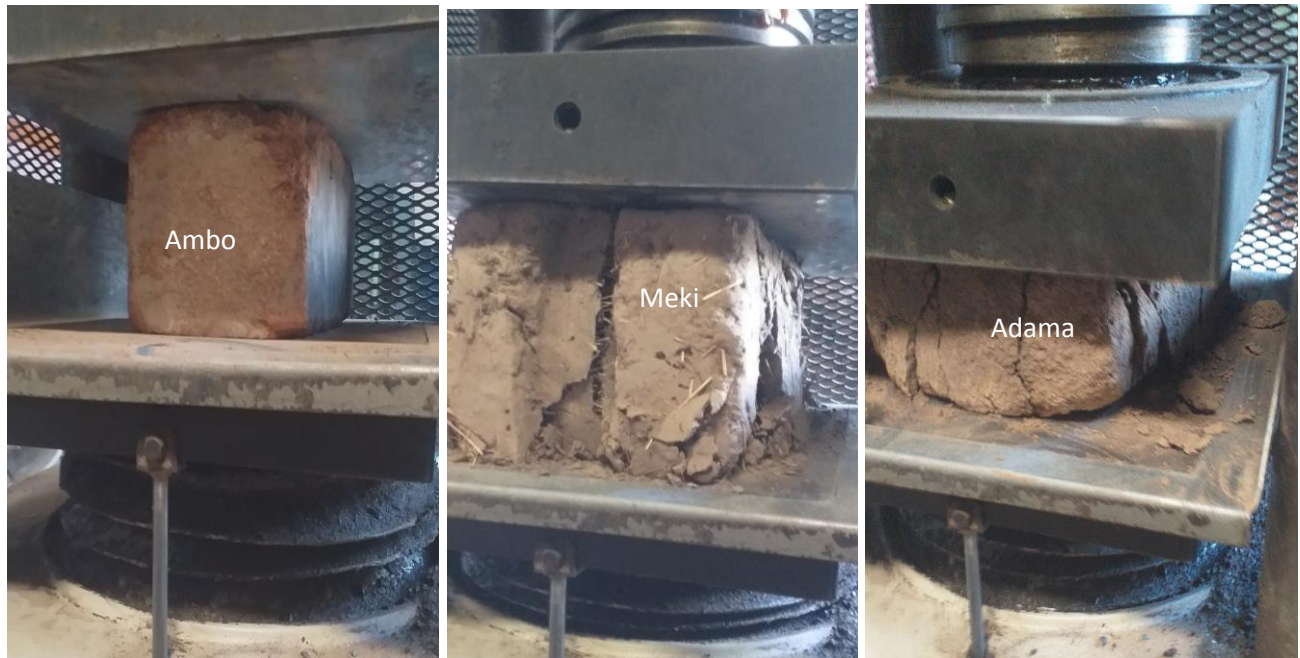


Figure 4.14: Mud blocks in compressive testing machine

In general, the compression stress results are obtained by dividing the maximum force by the area of the specimen, and the strain calculated by measuring the vertical displacements of the block during compressive test. The presence of teff straw in the mixture provides the plastic property of the mud block. The tension performances of the blocks are influenced by the teff straw content. As the straw content increases, the stain value increase and the same cement. The cement and the straw content increase in the mixture that results an increase in compressive strength value.

Based on the results obtained in this test, it was found that the three block samples from three different sites have different compressive strengths. The compressive strength of the mud blocks from Adama and Meki are under the recommended value while mud block from ambo which is 2.4Mpa is recommended according to countries building authorities around the world were their recommend values are within 2-4Mpa (refer Table 4.9). From this study and literatures the soil type and stabilizers have great impact on the compressive strength of the mud blocks. Clay soil is good and acceptable for adding the compressive strength of mud blocks.

Table 4.9: Compressive strength of mud blocks

location	Soil type	stabilizers	Mold size (cm)	Av Weight (kg)	Comp. strength (Mpa)	Results	
						Local views	Experi mental
Ambo	Clay soil	Cement & sand	30x15x12.5	9.17	2.4	agreed	Durable
Meki	Silt soil	Teff straw	37.5x20x17.5	16.5	0.46	agreed	Not
Adama	Sandy soil	Teff straw	35x20x12.5	10.2	0.42	agreed	not

(mpa= kg per cm² divide by 10.197)

The amount of straw and cement in the mixture has effect on the shape and the width of cracks that is created during compressive strength test (refer Figure 4.15). In fact, the increase of straw decreases the size and the number of cracks. This is because the straws have good plastic property that keeps the composite particle close together while an increment of cement causes few but large size cracks in the block during test. This is because the cement has good glue and compactness property. However, when it is exposed to compressive force, it results large crack within limited width.

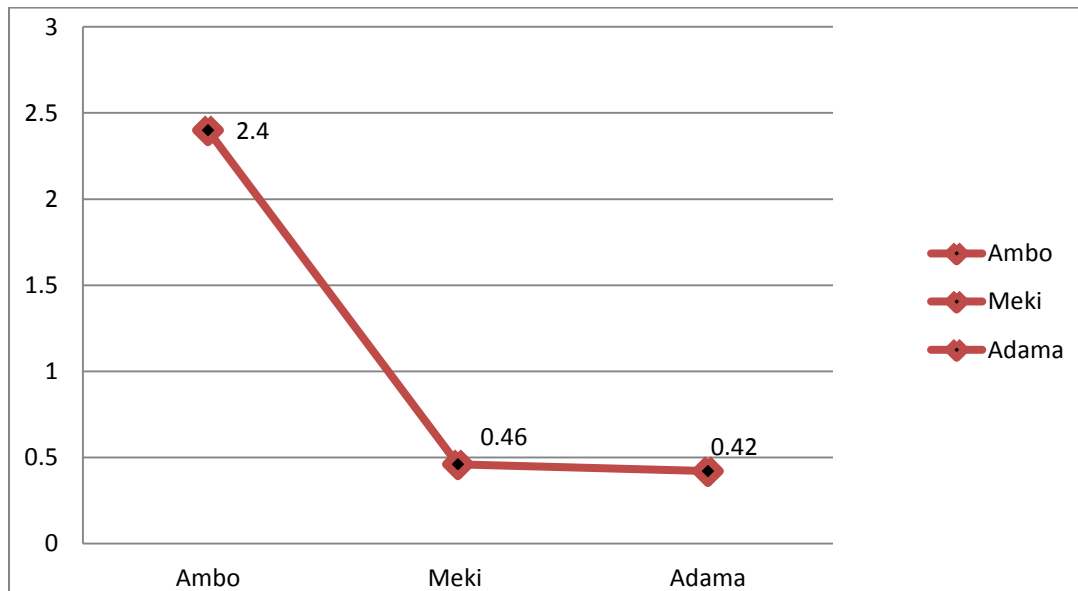


Figure 4.15: Compressive of different mud block (Mpa)

From this study we understand that mud blocks compressive strengths are affected by the types of soil and amount of stabilizers used in molding the blocks. The use of clay soil the

main ingredient and cements as stabilizers help the mud blocks more durable by adding the binding value of the ingredients.

4.6.3. Water absorption value and its effect on mud block houses

Almost all mud blocks can absorb water in high amount. The existence of pores of varying magnitudes in these materials deliberates marked passageway that the total amount of water absorbed is a useful measure of bulk quality. The reason for water absorption is the total volume of voids (pore) in a block which is estimated by the amount of water it can absorb. Figure 4.16 shows the mud blocks from the three sites soaked in water after 24hrs.



Figure 4.16: Mud block after soaked in water for 24hrs

Knowledge of the value of the total water absorption (TWA) of a block is important because it can be used for:

- Quality checks on blocks
- Comparison purposes with set standards and values for other like materials
- The classification of blocks according to required durability and structural use
- Approximation of the voids content of a block

Generally, the less water absorbs of a block and retains the better its performance. Reducing the TWA capacity of a block has often been considered as one of the ways of improving its quality and durability. Total water absorption test was conducted on all the three sampling

types and the average value of each sample value are the dependent of the soil type and stabilizers (refer Table 4.10).

Table 4.10: Total water absorption test

Descriptions	Ambo	Meki	Adama
Soil type	Clay soil	Silt soil	Sand soil
Admixture	Cement & sand	Teff straw	Teff straw
Dry weight(g)	8829.5	14905.8	11953.6
Wet weight(g)	10030.1	-	-
Increased weight(g)	1200.6	-	-
% of increase	13.6%	100%	100%

The experimental results of the water absorption test show the effect of cement and straw content on the water absorption capacity of the blocks. According to the tabulated results the mean water absorption values for ambo is approximately 13.6% while for Meki and Adama the water absorption is 100%. The mud block from Meki is changed in to mud while the mud block from Adama is cracked in to small blocks. From the literature the recommended maximum water absorption value for suitable blocks is below 15% in which the mud block of ambo is durable while mud block from Meki and Adama doesn't resist total water absorption that it is not durable in moist areas (refer Figure 4.17).

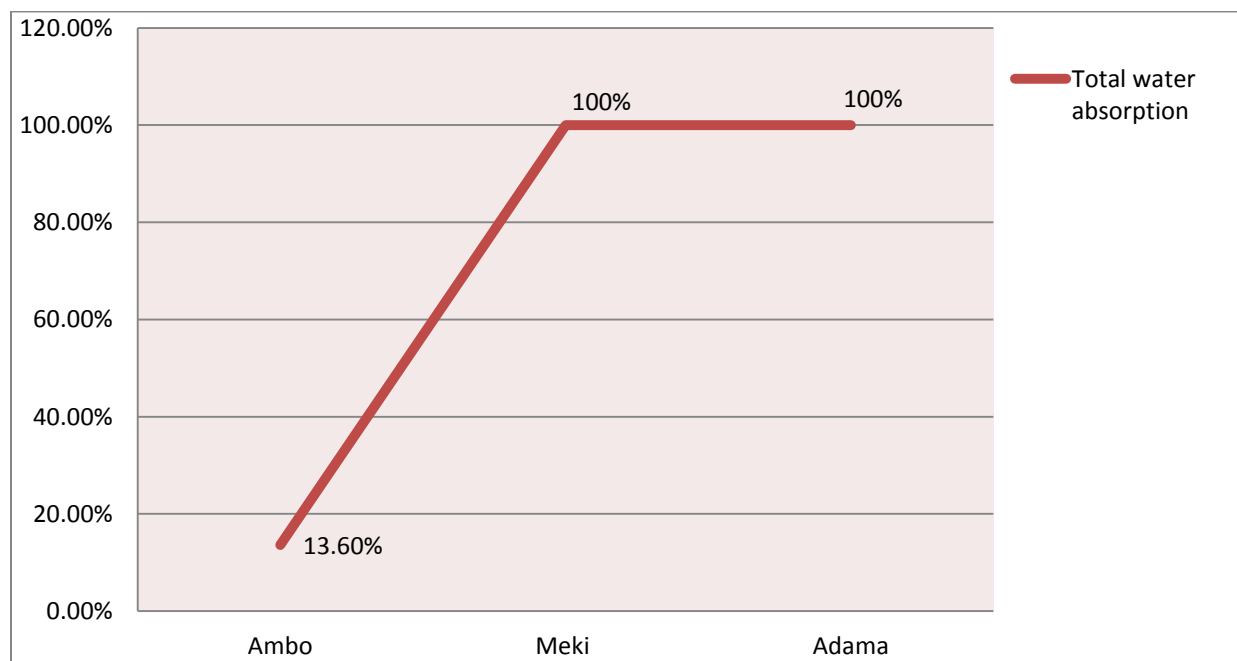


Figure 4.17: Total water absorption for mud block

Presence of cement decreases the water absorption value of the mud blocks. In contrary, the small straw content results in high water absorption. Beside the stabilizers, as shown from literatures and this study, the soil types have great impact on the total water absorption and clay soil have well resistant of water absorption than sandy soil and silt soil.

4.6.4. Expansion in wetting process and the effect of stabilizers

The expansion is swelling of a given block sample during soaking in water and after it takes in water its body is swelling. A volume change soil swells with increasing moisture content but it shrink with decreasing moisture content.

The shrinkage is contraction of a given block sample during drying. It gives an overall idea of the mixture behavior and suitability for construction. Soil shrinkage/expansion can cause serious distress to a foundation/structure and, the mechanism is the same but in the opposite direction. The presence of cement in the block has great impact on the shrinkage value as cement add the binding value of the ingredients (refer Table 4.11).

Table 4.11: Average value of shrinkage after moisten of the mud blocks

Size(cm)	Ambo	Meki	Adama
Dry size	29x14x12.5	37.5x20x20	40x18x15
Wet size	29.5x14.25x12.7	-	-
Increased size	0.5x0.25x0.2	-	-
% of expansion	5.2%	Not determined	Not determined

During moistening process there is volume change or shrinkage. The shrinkage value differs from sample to sample depends on their composition. From literature, the recommended range of percentage of shrinkage is less than 6 %. From the three samples (S1, S2 and S3), S1 values is within the recommended ranges which is 5.2% while S2 & S3 are difficult to measure the values of water absorption and shrinkage as the blocks loose its physical shape.

The shrinkage (volume change) value depends on the composition of mixtures in the samples. When the amount of the cement and the straw fiber is increased, the shrinkage value will decreases or vice versa. Compaction and the amount of water added in the

mixture also affect the block shrinkage value. If the amount of water added is increase, the shrinkage value will also increase. This is because, during drying process, the evaporated water will create openings (voids) between particles and that results shrinkage to fill the openings. Compaction is removing the air from blocks and fills the gap between particles. Proper compaction in blocks results dense structure which is stronger and more durable by reducing shrinkage cracks. The shrinkage has effect on the output blocks dimension.

In conclusion, the general perception of the respondents on the mud block housings durability, construction technique and adaptability are different from place to place depending on the climate, soil type, stabilizers, adaptability, resource availability and economy. In the construction of mud block houses the structural elements such as column & beams and balancing the building heights are the mandatory for construction of durable sustainable houses (refer figure 4.18).



Figure 4.18 : Mud block houses without any structural elements

Depending on the data collected from the perception local community of the three sites, performing researches to construct the mud block houses, improve the existing construction technique of mud block, saving of time & economical of mud block construction, simple for construction of mud block, recyclable of mud blocks and minimize

deforestation are the key playing element for analyzing the durability, construction technique and adapting of mud block houses (refer Figure 4.19). Other respondents disagreed on the mud block housing as mud block houses are not too durable to recommend for living. Generally, mud block construction are durable if constructed in dry areas with the support of structural elements that make a mud block house durable, sustainable, & comfortable.

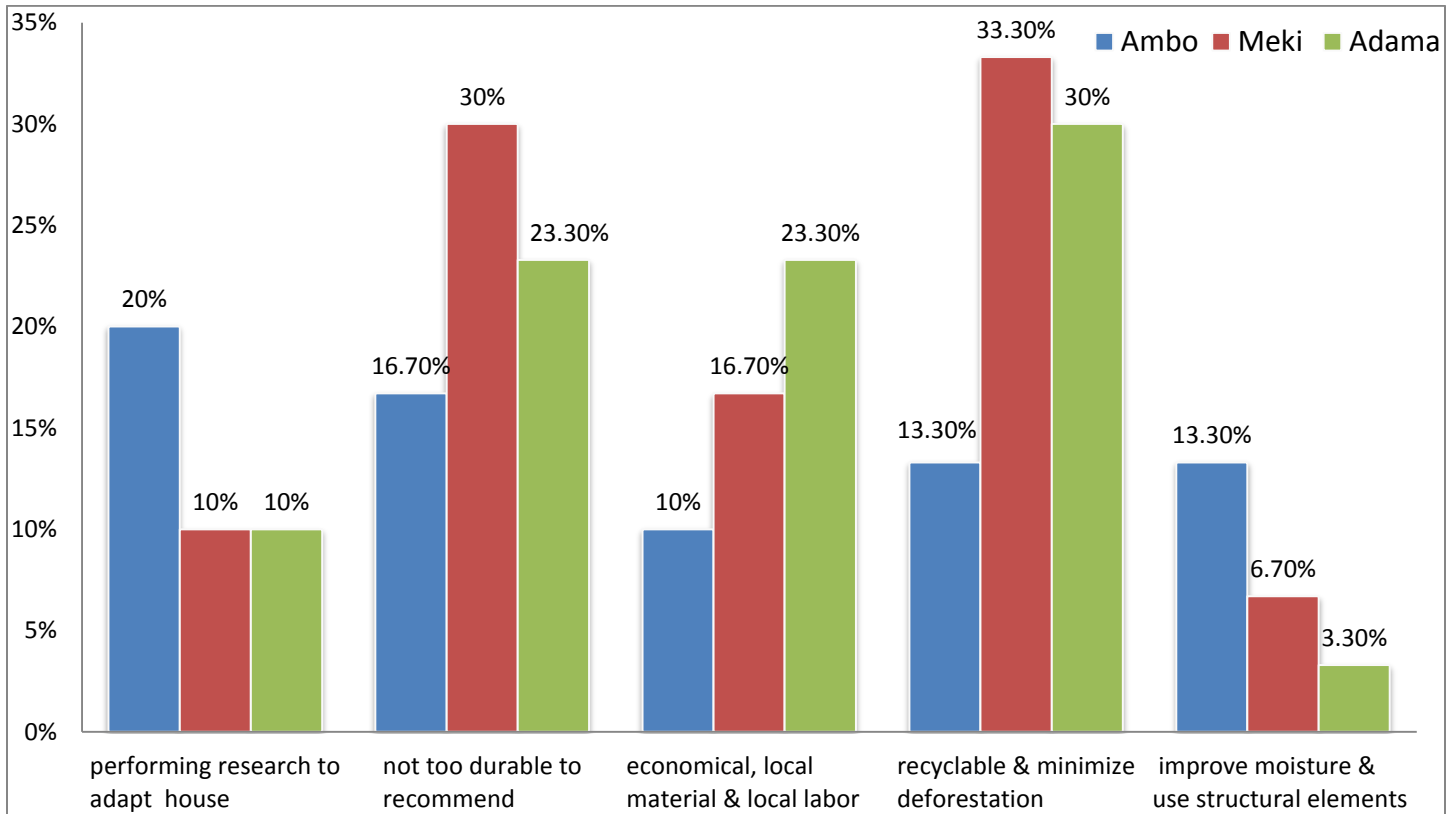


Figure 4.19: Local community perception towards mud block housing

Generally, the existing mud block house typologies in the study areas were molded from different types of soil and stabilizers (cement, sand & straw). Mud block houses are easy for construction, comfortable for living, economical, and minimize deforestation. The ingredients and climatic zones are the key factor in affecting the durability of the mud block houses for adapting the mud block houses in countrywide. The mud block houses are acceptable in the local community especially in desert areas as mud block houses are not resistant of moisture but best cooling effects.

Chapter Five: Conclusion and Recommendation

5.1. Conclusion

This study briefly discussed on the housing conditions, construction methods and local community perception on the mud block houses typology and durability in three cases sites namely Ambo, Adama & Meki which were located under different climatic zones. The factors that affect the housing condition were moisture, ground soil swelling and shrinkage, lack of structural column and beam and surface wash of wall by rain. The influential things for environmental resistance and durability of mud block houses are the soil type, amount and types of admixture and the climatic zone where the houses are constructed. Excessive uses of wood as a building materials contributes to deforestation, air pollution and other environmental issues while the modern construction materials such as burned brick, and HCB are energy inefficient, environmentally unsustainable and uneconomical to use.

In the study areas the mud block type practiced are molded from different types of soil and stabilized from straw, sand and cement. From literature and the case studies, stabilizers are the key playing elements in adding strength of the blocks by making the block good in compressive strength, water resistant, and cohesive. Beside the admixtures, the soil type used in the three areas are clay soil, sand soil and silt soil and from the soil types, clay soil is good for construction due to in compressive strength, water resistant, and cohesive. Even if the strength of mud block depend on the soil type and admixture, any soil type having admixture of different proportion is appropriate in dry areas.

Mud block houses are more economical and environmentally sustainable compared to concrete block. Soil which is the main ingredient for molding Mud blocks are accessed from local and the cost used for converting soil in to block is very low compared to the cost used for molding concrete block or brick. In addition to the main ingredient used, the amount and types of admixture used in molding mud block is economical. In mud block constructions the most commonly used admixture is teff straw which is accessed from local and waste organic materials. Cement as admixture is used for production of durable and environmental resistant mud block but cement stabilized mud blocks are inaccessible for low income peoples.

According to many literature and this study Mud block construction is more suggested for warm/desert areas due to low access to wood, warm climate/cooling effect, and no extreme moisture. The key elements that affect mud block houses are wind, climatic condition, rain and the soil. In warm areas the increase of wall height up to 5m for increasing the cooling effects of the rooms, while in windy areas the short wall height and short eave roof over wall were used. In rainy areas the most recommended roof soffit of mud block housing was up to 1.5m, minimizing wall height less than 3m and plastering of the wall help to protect the building from surface wash by rain. Beside this the ground soil helps the building to be durable and comfortable. If the soil is swell and compressed by moisture, it causes the building to crack easily and the structural elements like column and beam are used it add the building durability by protecting the wall from moisture, and carrying of the main elements.

The uses of mud block for construction have environmental advantage in minimizing the usage of wood and industrial products. The usage of trees for construction increases the deforestation that results in erosion, drought, disease, hazards and desertification. The industrial products are the cause for land degradation, uneconomical, energy inefficient, and ozone depletion that is resulted due to production and transportation cost.

Generally this thesis promotes the rural community's housing construction materials problems in economical and environmentally friendly way by improving the existing mud block. To advance the mud block construction technique and adaption, this study had valuable contributions, as most necessary data related to mud blocks have been generated. This includes the analysis of compression strength, water absorption and ingredients of the blocks of three case study areas. Moreover, the present study suggests that developing public awareness and educating the local community to use mud blocks for housing construction helps to reduce deforestation, and minimize environmental impacts imposed due to climate changes.

5.2. Recommendation

The present study suggests the following recommendations:

- The use of mud block houses should be taken and strengthened as alternative walling material in Ethiopia.
- The local community shall use the locally available, affordable and environmental friendly mud blocks as construction materials to reduce the ever increasing deforestation and environmental problem.
- The mud block construction is more appropriate in desert and dry areas due to its weak resistance to moisture, cooling effect, and economy. But the practices of constructing the mud block houses in the warm area are not consistent. This needs additional research to standardize the mud block construction techniques/practices.
- The present study also recommends that further studies need to be performed to select best mud block ingredients which could fit to the different climatic zones.

6. References

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7. Appendix

Appendix I: questionnaires

The questionnaire is on Housing typology of mud block construction in the central Ethiopia; in the case of three selected towns.

Location/town: _____

Prepared by; **Dejene Birku Gobena** Interviewee code/name: _____

Interviewer name: _____ Date of interview: _____

“Encircle letter of choice for the following question”

Part I: Socio-demographic characteristics of the study area.

Code	Question	Possible answer for the question	Skip
101	Sex	1) Female 2) male	
102	Age	1) under 20 2) 20 -40 3) 40-60 4) above 60 5) not remember	
103	Education status of the participant	1) No education 2) Primary school 3) Secondary school 4) college/university	
104	Occupation status of study participant	1) House worker 2) Trading 3) Farmer 4) Daily laborer 5) Government employee 6) renting house if others _____	
105	Income of the study participant per month	1) <1000 2) 1000-1500 3) 1500-2000 4) >2000 if other _____	
106	How many children do you have?	1) no children 2) one 3) two 4) three 5) four 6) > five	

Part II: source of information concerning the mud block housing construction

Code	Question	Possible answer for the question	Avoid
201	In what type of houses did you live in the past?	1) chika bet 2) mud block 3) stone 4) brick 5) HCB 6) wood If other; _____	
202	Now you live in mud block house, how long is the age of the houses?	1) 0-5 2) 5-10 3) 10-15 4) 15-20 5) > 20	
203	Why you select rectangular shape houses?	1) durability 2) culture 3) easy of construction 4) climate in other _____	
204	How long does the iron sheet roof eaves?	1) <50cm 2) 50cm-1m 3) 1m-1.5 m 4) 1.5m-2m If other; _____	
205	What are the main ingredients or raw material	1) clay soil 2) sandy soil 3) loam soil 4) silt clay	

	used for molding the blocks?	In other list; _____	
206	What are the stabilizers used?	1) straw/teff 2) straw/wheat 3) qacha 4) cow dung 5) cement 6) lime 7) sand 8) gravel In other list _____	
207	What are the effects of stabilizers on the strengths blocks?	1) admixture add Strength by binding constituents 2) add Water proof and become strong/durable 3) protect from cracks if other; _____	
208	From stabilizers, which ingredients which admixture increase the strength?	1) straw/teff 2) teff straw and sand 3) cement 4) Cement and steel 5) Cement and sand 6) Cement, sand & steel 7) Straw and cement In other list _____	
209	Beside the stabilizers what are the factors that affect the strength of the buildings?	1) moisture 2) animals 3) function it gives 4) climate 5) soil type 6) technique if other; _____	
2010	Would you think that mud block is economical?	1) Yes 2) No	
2011	If yes, explain why it is more economical?	1) Economical due to use of Local material, local labor and save of time 2) Simple for construction 3) no use of energy inefficient industrial production and transportation cost 4) use small amount of materials if other; _____	
2012	Would you think that mud block have economic benefit over concrete?	1) Yes 2) No	
2013	If yes, explain the reasons?	1) use of local material and labor 2) Simple in construction and save of time 3) use of non-industrial local and economical admixtures like straw if other; _____	
2014	Why concrete have high cost gap over mud block?	1) Due to high production and transportation cost of concrete 2) Concrete use extra materials 3) use of accessible Local material and labor if other; _____	
2015	Do you think that the mud block houses are comfortable?	1) Yes 2) No	
2016	If yes, In what perspective?	1) Cooling, and sound proof 2) Simple in construction and beauty houses 3) If free from moisture it become comfortable production and transportation cost 4) recyclable, economical and construction	

		time are potentials if other; _____	
2017	Does mud block construction technique is easy compared to concrete?	1) Yes 2) No	
2018	If yes, why it is easy for construction?	1) Use of Local material and labor 2) Simple, time saving and economical of construction 3) need small amount of labor and material if other; _____	
2019	Would you think that mud block houses are durable and sustainable?	1) Yes 2) No	
2020	If yes, why?	1) Free from termite and environmental 2) If free from moisture the house is durable, comfortable and Aesthetical houses 3) it depend on the construction technique production and transportation cost if other; _____	
2021	Does rain affects mud block houses?	1)Yes 2) No	
2022	If yes, Explain?	1) Wash the wall surface 2) the ground swell or compressed and mixed 3) Capture and Store moisture easily and become crack/fall if other; _____	
2023	Does the housing shape have impact on houses durability?	1)Yes 2) No	
2024	If yes, Why?	1) Rectangular shapes are easy for construction & durable 2) piled properly with structural element and considered the environment than shape 3) The binding material affect the strength 4) circular shapes are stronger due to easy load transfer than rectangular if other; _____	
2025	Does the building height influence on the age of the house?	1)Yes 2) No	
2026	If yes, Why?	1) Need column and beam to support load 2) Increase in height leads to Lateral force/Wind and surface wash by rain 3) increase with height that leads to fall, so make it balanced 4) as the height increase it is affected by rain if other; _____	
2027	Does the room area affect the durability of the houses?	1)Yes 2) No	

2028	If yes, why?	1) Need vertical structural elements to support loads 2) Not strong enough to be joined together 3) load increase with surface area that leads to fall 4) As the area increase the exposure to wind/lateral force and rain also increase if other; _____	
2029	Would you think that the wall thickness have positive relation on the durability?	1)Yes 2) No	
2030	If yes, why?	1) thickness increase only the loads that leads to falling 2) Must be balanced with the bottom wall 3) wall thickness increase strength 4) add climatic resistance to moisture and temperature if other; _____	
2031	What attitude do you have toward mud block construction?	Explain; _____ _____ _____ _____	

Darlingly thanks for your great support!

Appendix II: Photographs of mud Block and mud Block houses

Prepared soil

mud block

Ambo



Meki



Adama



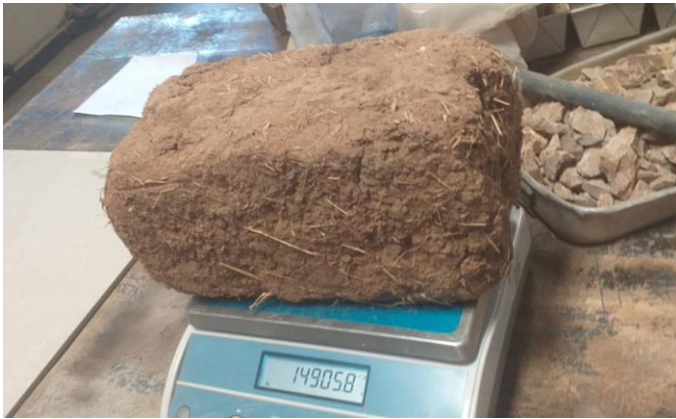
Dry weight

after soaking in water

Ambo



Meki



Adama



Waste material

Housing

Ambo



Meki



Adama



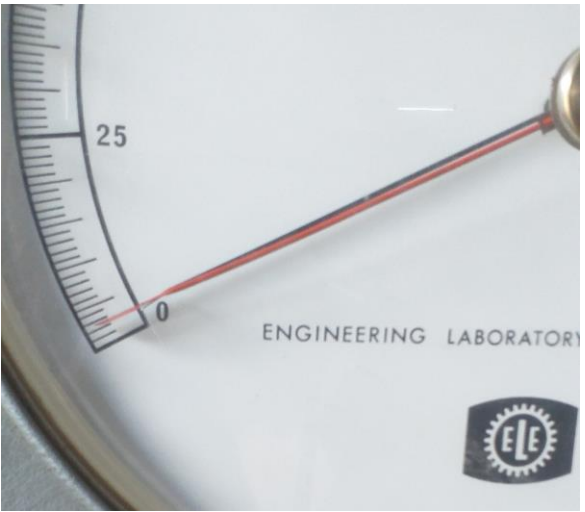
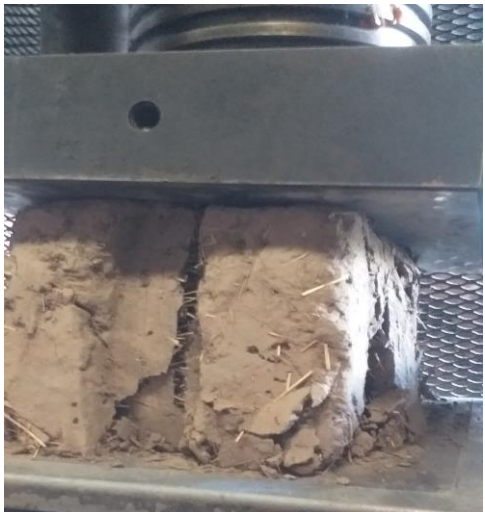
Compressive strength test machine

Compressive strength test scale

Ambo



Meki



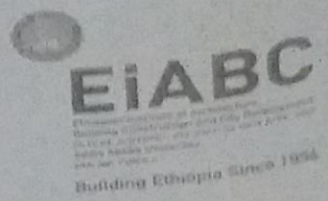
Adama



Appendix III: letters for the sites visits, lab test and compressive strength values



ሰ. MRTC



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CIADU
MATERIALS RESEARCH AND TESTING UNIT

Certificate No. _____

Client: _____
 Test Objects: _____
 Sampled by: _____
 Date received: _____
 Working site: _____

Kind of Test Compressive Strength
 Material information received from the client

Mould No _____ Batch No _____ Cons slump cm _____

Cement: (Source) _____ () Bag
 Sand: (Source) _____ Box size (. . . x . . . x . . .) Boxes
 Coarse Aggregate (source) _____ Box size (. . . x . . . x . . .) Boxes
 Slump _____
 Water _____ Sampled by _____

Remarks: The concrete was used for _____
 The above information's certified _____

TEST RESULTS

Sample No	Marking	Date Poured	Date Tested	Age In Days	Dimensions (cm)			Vol. (dm ³)	Weight (Kg.)	Unit Weight (Kg/dm ³)	Press area (cm ²)	Total Load Tons	Compressive Strength (Kg/cm ²)
					L	B	H						
1/Ambo	A	19 4r	23-04-2019		30	15	12.5	5625	9.17	163	450	11	24.45
2/meki	B	3 months	23-04-2019		37.5	20	17.5	13.125	16.5	1.257	750	3.5	4.67
3/Adama	C	12 4r	23-04-2019		35	20	17.5	8.75	10.2	0.86	700	3	4.29
Average													
Average													
Average													
Average													

Tested by: _____ Signature _____ Date _____
 Calculated by: _____ Signature _____ Date _____
 Checked by: _____ Signature _____ Date _____