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CHAIR OF CONSERVATION OF URBAN AND ARCHITECTURAL HERITAGE

Reinvigorating Traditional Wisdom: Conserving Earthen Construction Practice for the Revival of the Tradition in Addis Ababa

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Advisor

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March 6, 2025.

BOARD OF EXAMINERS

As a member of the team of board for Araya Abrham's master's thesis formal defense, we have studied and assessed Araya Abrham's final master's thesis, titled as ''*reinvigorating traditional wisdom: conserving earthen construction practice for the revival of the tradition in Addis Ababa*''. Additionally the Ethiopian institute of Architecture, Building Construction and City Development, Located at Addis Ababa University, approved this Thesis that meets the requirement for award of master's degree in conservation of urban and architectural heritage.

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DECLARATION

I hereby declare that this research is the product of my own independent efforts, free from direct intellectual influence or collaboration with others. All findings and contributions presented are my own, and any sources used have been properly acknowledged within the text.

Araya Abrham

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GLOSSARY

Aggregate Analysis- refers to a process in which individual data points, observations, or components are combined or summed up to form a larger, more comprehensive result.

Atterberg Limit Test- a set of measurements used to determine the Atterberg limits, which specify the necessary water content at which fine-grained soils, such clays change from being liquid to being plastic to being semi-solid to being solid.

Blow- in a Casagrande (liquid limit) device, it is the impact of a single drop of the brass cup on a hard rubber base.

Calcination- is a heat treatment process where a solid material is subjected to high temperatures, either in the presence of air or oxygen or in their absence.

Chiken mesh- is a Light weight wire mesh applied in earthen and other constructions to hold the mud in place.

Chikka- is a local term used to label earth or mud. It is abundantly used in traditional Ethiopian construction.

Clay- is a type of fine-grained natural soil material containing clay minerals phyllosilicates, e.g. kaolinite.

Compressive strength- the amount of pressure the material can resist without collapsing.

Control- is a neutral variable that is used for comparison in a laboratory experiment.

Conventional building material- are construction materials that are widely used by the main stream construction industry, like HCB.

Daub- is a mixture of materials such as mud, clay, sand, animal dung, and straw. This mixture is typically smeared onto the wattle framework to create a solid wall surface.

Dry Strength- the ability of a material, such as soil, brick, or concrete, to withstand compressive forces when it is in a dry state.

Embodying Energy- is the entire amount of energy needed for the extraction, manufacturing, processing, and transportation of building materials.

Enset (Ensete Ventricosum)- is a multipurpose crop that resembles a banana tree and yields building materials, fiber, and food. The fibers are used to make ropes and textiles, and the leaves are used to make mats and wrap food.

Feldspar- is a group of rock-forming minerals that are crucial components of many types of igneous, metamorphic, and sedimentary rocks.

Flexural strength- is the maximum stress a material can endure without failure when subjected to bending or flexural load.

Gravel- soil particles that is larger than 4.75mm.

Hidmo- traditional earth and stone complex that is abundantly found in *Tigrai* region of Ethiopia.

Hydrometer Test- is a method used in laboratories to measure the fine-grained soils' particle size distribution, especially those that are too small to be examined with a standard sieve.

Hygro-thermal- refers to the combined effects of moisture (hygro) and temperature (thermal) on a material, system, or environment.

Liquid Limit- is the water content at which a soil changes from a plastic state to a liquid state.

Malleable Mass- refers to a substance or material that can be easily shaped, molded, or deformed without breaking or cracking. This property is known as malleability.

Material Characterization- is a comprehensive examination of the physical, mechanical, thermal, chemical, and electromagnetic properties of materials to understand their structure, composition, and performance under various conditions.

Mechanical Properties- the mechanical properties of soil refer to its behavior and response to applied forces, which are crucial considerations in engineering and construction. Some key mechanical properties of soil.

Mechanical Property- refers to a behavior of soil under applied forces, such as strength, compressibility, and permeability.

Mica- is a group of silicate minerals known for their layered structure and physical properties.

MJ (Mega-joule)- is a unit of energy. One MJ is roughly equal to the energy needed to heat 2.4 liters of water by 1 degree Celsius.

Particle Size Distribution (PSD) - in soil testing it is the division of the soil into its constituent particles according to size, which aids in identifying the texture of the soil (e.g., sand, silt and clay).

Physical characteristics- are those characteristics that include texture, structure, density, porosity, moisture content, and color. They are related to the inherent qualities of the soil. These mostly static characteristics characterize the status of the soil in the absence of outside pressures.

Pise -refers to a traditional construction method called "rammed earth." Used to construct sturdy, long-lasting walls.

Plastic Limit- is the water content at which a soil changes from a semi-solid state to a plastic state.

Plasticity Index- is the range of water content over which the soil exhibits plastic behavior.

Quartering- in soil testing is a method used to reduce the size of a bulk soil sample to a smaller, representative sample by dividing it into four equal parts, discarding two opposite quarters, and repeating the process if necessary.

Quoins- external corner stones of a building or doors as a style or structural functioning elements.

Shrinkage Limit Test- the water content at which a soil transitions from a semi-solid to a solid state without experiencing additional volume loss is known as the shrinkage limit.

Sieve Analysis- is employed to ascertain the distribution of particles in a granular substance, such as crushed rock, gravel, sand, or soil.

Soil Auger- soil augers are versatile tools that play a crucial role in soil research, land management.

Specific Gravity Test- the ratio of a material's density to that of water at a particular temperature is known as specific gravity.

Stabilization- refers to the process of modifying and improving the engineering properties of soil.

The Atterberg limits test- is a technique for determining the critical water contents of fine-grained soils, which impact their physical properties and behavior.

Wattle- is a structure composed primarily of wood, with branches or sticks weaved together. The fundamental structure that daub is applied to is formed by this framework.

LIST OF ACRONYMS

ARSO- The African Regional Organization for Standardization.

ASTM- American Society for Testing and Materials.

CIS- Corrugated Iron Sheet

Cm- Centimeter.

Cm^3- Centi-meter cube.

CSEB- Compressed Stabilized Earth Blocks.

Dm^3-Deci-meter Cube.

ETB- Ethiopian Birr.

HCB- Hollow Concrete Blocks.

ILFI - International Living Future Institute.

Kg- Kilograms.

LCA- Life Cycle Analysis

LL- Liquid Limit.

MJ- Mega joule.

Mpa- Mega Pascal.

OMC-Optimum moisture content.

PI- Plasticity Index.

PL- Plastic Limit.

PSD-Particle size Distribution.

UNCHS- United Nations Centre for Human Settlements.

UNEP - United Nations Environment Programme.

UNESCO- United Nation Education Scientific and Cultural Organization.

ABSTRACT

Culture is a significant component of a society's identity embodying the distinctive traits, the techniques, methods and materials used to build the physical environment which is among the most common and identifiable aspects of the built interface. Utilization of indigenous building materials such as earth has long been a tradition in Ethiopia including the capital, Addis Ababa. However, in recent times it is visible that contemporary building materials are significantly replacing the more sustainable traditional materials. As a result it negatively impacts the culture of building with earth. Hence, this paper studies the issue from different dimensions to reinvigorate the use of the material and indicate ways to conserve the tradition. For this it relies on methods of contextual study around earth, discussion of underrated aspects, exploration of selected earthen sample with an innovative, local, cultural and affordable means to formulate experiment based proposition to particular and generic short comings of the material and indicate ways to secure continuity of the use of material.

By integrating these approaches and experiments, the thesis indicated that earth as traditional construction material can be enhanced and reinvigorated with study based solution to be used as a replacement in traditional and modern constructions to ultimately preserve the tradition in Addis Ababa. Moreover the paper portrayed the value of different components in the culture that contribute to the continuity of the tradition.

CHAPTER-ONE

1.1 BACKGROUND

In the sphere of culture along the context of the built environment, various byproducts emerged in tandem with the progression of construction tradition in Ethiopia. Among these products, earth as construction material coupled with its cultural attributes stands out as expression of the country's construction culture. Similarly this tradition manifested in Addis Ababa's construction during and after its emergence. Ethiopia's architectural legacy is tribute to the country's cultural identity which renders the physical environment and construction culture. Moreover, the construction exemplifies the socio-cultural result embedded in the context of a location, more so reflecting a site-specific construction technique unique to an area.[1]

This material, which represents traditional knowledge across generations, has been pivotal component of the built interface reflecting not only the architecture but also enticed traditions. From the northern regions, such as *Axum* and *Gondar*, to the southernmost parts, significant works of construction materials have been part of the nation's architecture.

Particularly in Addis Ababa, earth as a building material has been utilized extensively in various typologies since the formation of the city.[2] However, in recent times due to rapid urbanization it became largely overlooked and those elegant structures are at risk of being lost to the pressures of short-term economic interests.[3] Therefore, the back ground of the study area is to recognize the material, analyze the potential and identifies effective strategies to encourage its use.

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[1] *Gruber, Petra, and Kingshuk Datta. "Construction Aspects in Ethiopia's Architectural Traditions: A Comparative View." Journal of Traditional Building, Architecture and Urbanism 2 (2021): 318-33*

[2] *Nieder, Piet, ed. The Addis Ababa House: A Typological Analysis of Urban Heritage in Ethiopia 1886-1936. Dom publishers, 2024.*

[3] *Ibid.*

1.2 STATEMENT OF THE PROBLEM

Over the years, Ethiopia's rich tradition of earthen construction, which dates back to the country's earliest civilizations, has faced a steep decline due to various socio-economic and policy-driven factors.[4] Despite its historical significance and cultural value, earthen construction is increasingly being replaced by standardized building materials, driven by perceptions of its limited durability and fear of structural strength.[5] This shift is not unique to Ethiopia but reflects a broader global trend where wealthier nations tend to have fewer earthen structures, and developing countries are rapidly following suit.[6]

The Ethiopian government has identified the construction sector as a key driver of economic growth, for that it is prioritizing modern building methods that overwhelmingly favor conventional material. [7] Consequently, urban construction, particularly in Addis Ababa, is dominated by these materials, sidelining traditional techniques and marginalizing the cultural heritage they represent.[8] If this trend continues, the survival of earthen construction in Ethiopia will be at serious risk, raising concerns about the loss of indigenous building knowledge and the living heritage it upholds. Without intervention, the erosion of these time-tested practices may result in the irreversible disappearance of a sustainable and culturally significant architectural tradition. This calls for urgent research-driven efforts to modernize and reintegrate earthen construction into contemporary urban development while addressing concerns over its performance and adaptability.

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[4] *Nieder, Piet, ed. The Addis Ababa House: A Typological Analysis of Urban Heritage in Ethiopia 1886-1936. Dom publishers, 2024.*

[5] *Amede, Ermias A., Gebrella G. Aklilu, Helen W. Kidane, and Alemayehu D. Dalbiso. "Examining the viability and benefits of cement-stabilized rammed earth as an affordable and durable walling material in Addis Ababa, Ethiopia." Cogent Engineering 11, no. 1 (2024): 2318249.*

[6] *Marsh, Alastair TM, and Yask Kulshreshtha. "The state of earthen housing worldwide: how development affects attitudes and adoption." Building Research & Information 50, no. 5 (2022): 485-501.*

[7] *Ali, Mohammad Sujayath, Saliha Shukri, Mahaboob Patel, and Abdul Ahad. "Alternative Building Materials for Sustainable Development in Ethiopian Construction." International Research Journal of Engineering and technology 7, no. 6 (2020): 2899-2903.*

[8] *Ibid*

1.3 RESEARCH QUESTION

The main questions the paper answers are the following:

- How can conserving this old aged construction material and the technique associated with it be related to conserving the traditional value?
- How can earth as construction material and the practice be preserved?
- What integral topics can be incorporated to help preserve the material and the trend in the advent of globalization in construction?

1.4 OBJECTIVES

GENERAL OBJECTIVE

The main goal of the research is to support Addis Ababa's continued use of traditional earthen building materials and their preservation. Additionally, by offering methods to improve the utility of earthen building materials, they offer a feasible holistic approach for the preservation of the culture of earthen construction.

SPECIFIC OBJECTIVES

The specific objectives are;

- To experiment on earth as a construction material.
- Study the characteristics and behaviors to come up with responsive, replicable and local solutions for successful use of the material.
- To investigate and provide insight on undervalued components of the tradition and their influence on earthen construction culture.

METHODS

The research executes this through the use of laboratory testing, experimentation, innovative formulation, prototype preparation interviews, surveys, observations and literature reviews. Further details of the method will be discussed in Chapter Three.

1.5 SIGNIFICANCE OF THE RESEARCH

This research is critical in safeguarding and modernizing Ethiopia's as well as Addis Ababa's earthen construction heritage, which faces rapid decline due to the dominance of conventional materials. By developing scientifically tested methods to enhance the durability and structural integrity of earthen materials, it provides a practical pathway for their reintegration into construction. Without such advancements and study, Addis Ababa risks losing a century-old architectural tradition, along with the invaluable indigenous knowledge it embodies.

From an academic standpoint, this study is a pioneering contribution to sustainable architecture, material science, and heritage conservation. It bridges the gap between traditional wisdom and modern engineering, providing a vital resource for scholars, architects, and policymakers. The findings offer a research-backed foundation for further studies and curriculum development, solidifying its role in shaping future architectural discourse.

Beyond academia, the study holds economic and strategic significance for stakeholders and policy makers. It promotes cost-effective, locally sourced materials as a sustainable alternative to expensive, imported construction materials, reducing foreign currency outflows and enhancing national economic resilience. Additionally, it serves as a blueprint for urban policy and planning, ensuring that earthen construction is not just preserved, but systematically reintroduced as a viable, high-performance building material for Ethiopia's future development.

1.6 SCOPE

The bound of the research lies in the study of earth as a construction material in Addis Ababa, the general context around it and the means to reinvigorate its use to prioritize conservation of the practice. Additionally it also studies related components that are overlooked in the culture of earthen construction, but are key role players.

1.7 LIMITATIONS

The first shortcomings of the paper are that the findings may be limited to a particular geographic setting and cultural contexts studied within Ethiopia, Addis Ababa. The proposals and analysis presented in the paper work are effective for a specific material type in the city of Addis Ababa. The study and responsive solutions to the material are limited to the specific confinement. Secondly as there is different range of soil typology it is not the practical reach of the paper to go in depth and study the different types of soil and provides strategies for each typology.

Additionally one of the challenges in the research was, finding willing officials and respondents for the interview. Secondly laboratory testing and experimentation which required labor intensive and time taking tasks that often needed more than two individuals for execution. Moreover raw material transportation, access, pricing, availability (particularly *Dembaqie*), were difficult. More so the unavailability of *Dembaqie* at the time of the test coupled with requirement of more experimentation time limited the research from experimenting different proportions of it in the mix prototype formulation.

1.8 STRUCTURE OF THE THESIS

This thesis is divided into six chapters, each systematically addressing the research framework, literature, methodology, findings, and conclusions. Chapter One establishes the foundation by outlining the research problem, objectives, significance, and scope. It defines the study's framework and sets the direction for the subsequent chapters. Chapter Two presents a literature review on earthen construction, covering historical context, global and Ethiopian perspectives, and relevant building codes. This chapter highlights past research and explores methods for enhancing earthen materials locally. Chapter Three details the research methodology, including data collection techniques, sampling strategies, and study focus areas. It evaluates the tools and approaches applied for gathering and analyzing data. Chapter Four examines earthen construction in-depth, addressing its decline, benefits, challenges, and applications. It also discusses site selection, material characterization, and innovative formulations tested in the study. Chapter Five synthesizes key findings, analyzing their implications for the viability of earthen construction. It offers recommendations for integrating enhanced earthen materials into contemporary construction practices. Chapter Six concludes the research by summarizing the study's outcomes and reinforcing the cultural and practical significance of earthen architecture. The recommendations section provides strategies to expand its application and strengthen its conservation.

CHAPTER-TWO

2. LITERATURE REVIEW

This section examines articles on the historical use of earth in construction, its role as a cultural material and relevant building codes. The reviewed works, primarily local studies, emphasize optimizing earth for enhanced construction performance while ensuring sustainability and the preservation of its intangible values. The primary goal of this review is to gather academic insights that reinforce the core themes of this research.

2.1 EARTH AS A MORTARING MATERIAL

Earth as construction material has existed globally for long; the primitive human being applied it to construct early structures. For example it was used from the eastern part of the globe, during the construction of the Great *Ziggurat* of Iran and Iraq. The Granaries of the *Ramasseum* in Egypt, constructed of sun-dried bricks (adobes) are among the oldest earthen construction still surviving in the world.

Also the oldest earthen structure in India is the *Tabo* Monastery in *Himacha*, Since 996 AD; it has endured the Himalayan winters and was constructed using adobes as a wall.[9]

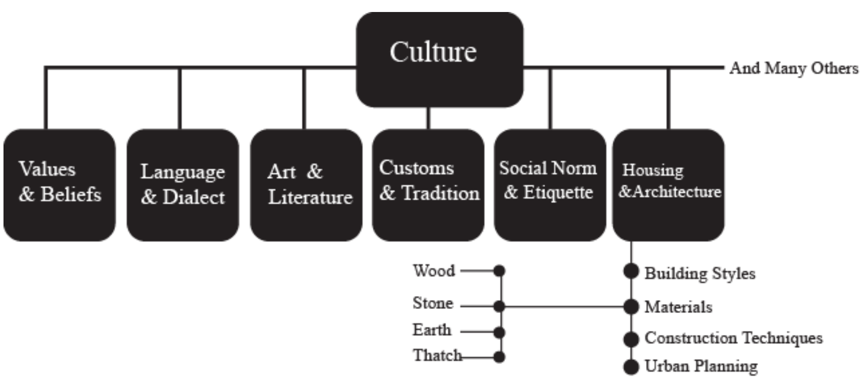

Figure 1-Earth and the material culture.

Moreover according to UNCHS statistics, 40% of world's population resides in earthen dwellings. Additionally the UNESCO heritage lists reveal that 15% of the world cultural heritage and 25% of the world heritage in danger are built with earth,

[9] *African Organisation for Standardisation. 2018. WD-ARS 1333:2018(E) Compressed Stabilized Earth Blocks — Requirements, Production and Construction. ARSO.*

while 14% of the 100 most endangered world heritage sites are constructed from earthen materials.[10]Most of these structures that are the results of these civilizations still exist, bearing witness to; first how earthen structures are resilient and possess perseverance to cope up with geo-climatic phenomenon that could have completely wiped other construction materials out, and second how earth as construction material are enticed with different cultures. Thus earth as a construction material is not a new trend but a very old tradition that is enticed not only to a particular geography but also many civilizations of the world. Likewise in Ethiopia earthen construction is deeply rooted in to the culture.

Figure 2-Najran Palace – Cob, Saudi Arabia; Ksar Villages – Rammed Earth, Dades Valley, Morocco; Tabo Monastery – Adobe, India, 996 AD. Source: Maïni, Satprem. "Earthen architecture for sustainable habitat and compressed stabilized earth block technology." The Auroville Earth Institute

However earth often times is considered short lived material. But these structures are the living testimonies to how earthen construction can be strong structure.

"Constructing with earth has a great history, but also a promising tomorrow all over in the world. Don't skip it! "[11]

[10]*Maïni, Satprem. "Earthen architecture for sustainable habitat and compressed stabilised earth block technology." The Auroville Earth Institute, Auroville Building Center-India 14, no. 4 (2005): 112-128.*

[11] *Maïni, Satprem. "Earthen architecture for sustainable habitat and compressed stabilized earth block technology." The Auroville Earth Institute, Auroville Building Center-India 14, no. 4 (2005): 112-128.*

2.2 EARTHEN ARCHITECTURE IN ETHIOPIA

Amidst the current advancement in technology and urbanization which has high impact on earthen construction tradition, the culture of earth as building material in Ethiopia's architecture is still prevalent, especially in suburbs and rural section of the country. [12] Also till to this day a proportion of buildings in Ethiopia are earthen construction and a couple of years ago about 40 percent of Addis Ababa's buildings interfaces were *kebele* houses, most of which are earth based.

The construction has been practiced from the *Axumite* civilization to the extents of *Gondar, Gojam, wollo, oromia* and the southern vernacular architecture and manifested itself as a cultural construction material of geographic confinements.

ADDIS ABABA

In the Capital where urban development was first sparked during *Menilik*'s period (1890's), earthen construction became one of the dominant technique to exist along with wooden construction methods, which later became character of the city's Architecture.[13] With some foreign architectural influences and design styles existing during that time, earthen construction was widely used. Also over time, Addis Ababa experienced synthesis of architectural styles, with pinched roofs and high detailing[14]as a result leading to the morphing of the former styles into newer typology, which later came to be the city's style.

Figure 3-Early Addis Ababa traditional houses. Source; F. Giorghis and D. Gérard, The City and Its Architectural Heritage: Addis Ababa (Addis Ababa: Shama Books, 2019).

[12] *Adegun, Olumuyiwa Bayode, and Yomi Michael Daisiowa Adedeji. "Review of economic and environmental benefits of earthen materials for housing in Africa." Frontiers of Architectural Research 6, no. 4 (2017): 519-528.*

[13] *Nieder, Piet, ed. The Addis Ababa House: A Typological Analysis of Urban Heritage in Ethiopia 1886-1936. Dom publishers, 2024.*

[14] *Ibid.*

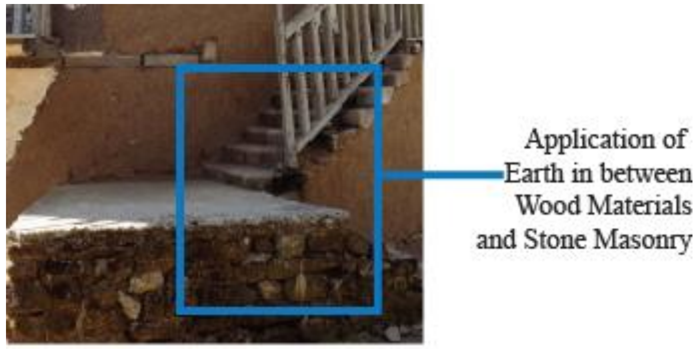

Figure 4-Figure 10-Complexes in the palace of emperor Menelik II in Entoto Park, Addis Ababa, by Trevor W. Hampel, (www.trevorstravels.com).

Also traditional earthen constructions in the city conveyed two story complexes. Moreover when compared to other typologies in Ethiopia, Addis Ababa style construction became modern like, through utilizing earth along with stone and wood, which could be due to exposure to the globalized trend of construction and cultural interchange. [15]

EVOLUTION OF TRADITIONAL HOUSES AND THE ALTERATION THROUGH TIME IN ADDIS ABABA

The city's changing architectural requirements and urbanization are reflected in Addis Ababa's shifting housing materials. Because earth, especially mud and clay, offered inherent insulation and durability in the local climate, traditional dwellings were first constructed utilizing this material. These durable, plentiful earthy elements were closely linked to the city's cultural legacy.

The usage of clay materials started to decrease as urbanization increased, giving way to more contemporary, industrialized building techniques. Although the basic material of rectangular earthen dwellings remained earth-based, the addition of corrugated iron sheet (CIS) roofs provided increased longevity and resistance to weather.

[15] *Ibid., abstract.*

Figure 5-Evolution of the city's construction trend. Sources: Addis Ababa: The City and its Urban and Architectural Heritage from 1886-1941, tripadvisor.com, allgebeya.com.

However, with rapid population growth and the demand for more robust, multi-story buildings, the shift to reinforced concrete and hollow block (HCB)-based structures became inevitable. HCB provided superior strength, fire resistance, and the ability to support higher and more complex buildings, making it the material of choice for modern urban development. This shift from earth to HCB marks a significant departure from traditional construction methods, driven by the need for increased durability and adaptability in a rapidly growing city. While HCB has become the standard for contemporary housing, it has also led to the diminishing use of earthen materials, signaling a disconnect from the city's architectural heritage.

2.3 EXISTENCE OF TRADITIONAL DOUBLE-STORY BUILDINGS

One commonly perceived notion as disadvantage of traditional earth is its reputation as weak building material. Earth is the traditional sense is often deemed unsuitable for multi-story construction.

However, complexes such as these images serve as testimony to the notion that when skillfully applied, earth can be effectively used for double-story houses and could have extended longevity. Moreover *Tukul* houses in *Lalibela Lasta* (*Figure* ***6***) area, stone and *Chikka* complexes

Figure 6-Tukul house structure and their typologies in Lasta area. Source; earthen architecture on the Lalibela world heritage site, mission report.

in *Gondar* region are the other indicators to this capacity. This shows cases design harmony of earth, stone, wood and thatch at play.

As building material around the world, earth has profound cultural significance. Currently there is increasing global push to re-evaluate its use,[16] even though it is underappreciated in areas such as Addis Ababa. This trend is led by entities encouraging eco-friendly construction practices and preservation of cultural assets. Initiatives to research and use the material in are growing, as a result of its cultural significance and environmental advantages. Institutions such as international center for earth construction (CRATerre-EAG) are prime instance of the institutional push for scientific achievements. CRATerre-EAG has been instrumental in expanding technical understanding in this field since its foundation, which demonstrates not only the focus on earth as alternative construction material but also feasibility of mass production and sustainability.

2.4 LITERATURE REVIEW

Primary work that speaks highly of earthen construction in Ethiopia is the paper titled '*adobe in Ethiopia*', the author of the paper, *Kiessling, D* discusses an examination of earth and stabilized blocks that are locally produced for construction purposes.

Figure 7- A building constructed using stabilized earth as a wall. Source; Kiessling, D(2017).

The paper sought to analyze projects primarily in *Afar*, benefiting from direct involvement in the ongoing construction project in the complex and further in *Amhara* and southern Ethiopia to provide a summary of challenges in the execution process while indicating the ideal approach for projects of such kind. These projects are collaborative efforts executed to serve as prototypes rather than mass produced building projects, thus showcasing ways and mechanisms to construct replicas using earth and the means to enhance it.

[16] *Avila, Fernando, Esther Puertas, and Rafael Gallego. "Characterization of the mechanical and physical properties of unstabilized rammed earth: A review." Construction and Building Materials 270 (2021): 121435.*

In addition the article indicated the different techniques and effective strategies of locally constructing complexes with earth. Among which are the different stages of construction starting from primary to execution phase.

Primarily the paper conveyed that an analysis on the compatibility of the locally available soil should be carried out. After wards comprehension including; material properties, preparation mechanisms, location, climate considerations, historical, architectural importance along with regionally specific requirements is addressed. Moreover for the material understanding it relied on range of primary tests including soil sedimentation test to make sure the material was compatible. Following that the article discusses application of stabilizers to amend the qualities of the material. These are all primary steps in material analysis which ought to be carried.

The paper also emphasizes on the need to consider flexibility of stabilizers according to climate and local construction trends. Which means stabilizers should be context specific for instance in Afar where there is little rainfall the application of cement as stabilizers can be omitted and the raw material can be enhanced just by compression. Also among the presented stabilization techniques compaction of the raw soil, aggregate utilization and additive application are discussed. On the other aspect the research also addresses adobe bricks however it tries to inform the setbacks particularly in production phase. Additionally the application of sand stabilization is also brought to discussion and was seen in one of the projects implemented.

The biggest lesson that can be taken here is that the projects were implemented by local people living with in the area where in the due process they are being educated on the replicable ways of experimenting and designing a building material and constructing these prototypes with hands on experience. This endeavor can facilitate the interaction between research based efforts and the community where the locals learn ways to update the traditional construction.

Figure 8-Sustainable rural dwelling units. Source; Kiesling, D. (2017).

The other is application of enhanced earth in local construction traditions where the enhanced material was used as a replacement of traditional earth while respecting the culture, tradition and way of construction. This should be one of the ultimate goals of such projects and if possible enhancing traditional earth to replacing conventional materials. The third lesson that can be grasped from the article is that it indicated and documented step by step applications of how to locally enhance earth, bringing to light how these projects should be conducted and implemented with respect to local customs and scientific procedures.

Figure 9-Traditional technique of pressing and creating earthen mix, Source; Kiesling, D. (2017).

Additionally this research indicated not only ways to adapt the material and make it function in today's reality but also went to the construction phase of applying the enhanced material to produce prototypes which served as a standing testimony to the practicality of the application of such efforts.

Moreover, in finding ways to mix soil with stabilizers, there are several techniques mentioned by the article among these pressing is primarily used. While in traditional cases pressing is done to strengthen the fermentation[17] process of the earth, water and daub. However in one of the projects they used this method to mix the samples but the final result was used for the block production rather than daub.

And in the *Amhara* and southern region projects the application of straws was applied to create air and sun dried bricks. Also material wise the major weakness of earth is its permeability, which in the literature is mostly addressed by utilizing cement and other additives mentioned above as stabilizing agent.[18]Even though this method is effective technique in making earthen blocks more resistant to water, in terms of cost, eco-friendliness and utilizing indigenous raw materials, it is not the ideal solution [19] as there can be other organic suggestions to be explored

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[17] ***Fermentation:*** *a process of mixing soil with different agents, the likes of Teff straws, in a wet state and leaving it to further chemically combine in a granular level.*

[18] ***Stabilizing agent:*** *a material or mix applied to the main material (earth) to address demerits and change the engineering properties.*

[19] *Wilson, Alex. "Cement and concrete: environmental considerations." Environmental Building News 2, no. 2 (1993): 1-11.*

for additives, such as organic binders the likes of cow dung. While the research also recognizes cow dung as potential organic additive it does not explicitly address the scientific means to utilize it in stabilization. Therefore looking for other locally available alternatives specific to an area can also be cognizant of the local culture, its identity and a means to explore and experiment on materials.

Moreover, when stabilizing earth, the focus should not be limited to a single tested material like cement as the sole additive. Instead, various alternative materials should be explored for incorporation. In the article's case most of the mixture of the final result included two components; the stabilizer and the soil. But inclusion of different additives all together along with the main material could open doors to newer findings and discovery for instance an experimentation of two additives on the main material such as application of fibers and lime with earth. While lime works on granular stabilization, the fibers could be effective in reinforcement. Although further study and analysis should be carried out on how these components combine with one another.

Nevertheless, in cases mentioned in the article the soil is stabilized with only one additive alongside the main material sometimes the research recommends raw material compaction as another means of stabilization[20] which can be feasible in areas with no rainfall. But for locations with high rainfall it should be enhanced so that the blocks are water repellent.

All in all the purpose of the study is to determine methods and obstacles involved in carrying out building projects on enhancing local materials. The research went to execute one project in *Afar* utilizing earth according to the context to produce locally functional edifice that served the community afterwards. But the rest of the projects, the research only examined them from observer's point of view as they were executed without the researcher's first hand involvement.

The second paper for this literature section is an article by *Esayas, E., Agon, E. C., & Assefa, S, (2018),* which discusses earth as local traditional material and the indigenous means to enhance it. The research is an intensive experimental paperwork that indicated each steps in the effort of applying *Enset* as a stabilizer in the local construction material, earth. The experiment utilized two materials; clay and *Enset* and went to assess each material accordingly to come up with

[20]*According to the strength and quality of the material the compaction of the raw soil could also make it stabilized and stronger, especially in arid regions where rain cannot often challenge the surroundings.*

responsive solution. Moreover the intention of the paper resides in helping alleviate the local housing problem by providing affordable construction materials.

In selection process of raw material, the research underlines the input soil for construction is required to have parameters met, among which clay content is the primary one as it contributes to the strength of earthen material by serving as a binding agent especially when additives are applied.[21]

Figure 10-Enset fiber air drying at room temperature in laboratory. Source; Esayas, E., Agon, E. C., & Assefa, S. (2018)

Figure 11- Enset being studied in laboratory. Source; Esayas, E., Agon, E. C., & Assefa, S. (2018)

This article investigates the means to enhance structural performance of earth with low cost and eco-friendly material that is considered part of the local tradition. Also the organic material, *Enset* holds multi directional value for the local community, encompassing cultural, economic, environmental, and social dimensions. Its integration into various aspects of community life underscores its importance and contribution to culture of *Tarcha* Town.

[21] *Dixon, Joe Boris, and Sterling Barg Weed. Minerals in soil environments. 1989.*

Fiber properties	Test result	Implication
Cellulose (%)	62%	complex carbohydrate
Hemicellulose (%)	19%	
Moisture content (%)	15.47%	Absorbent
Density (Kg/m^3)	690	Light mater
Lignin (%)	5%	UV protective and non-decomposable
Single fiber Snap force (N)	15.44	Very strong material

Table 1-Granular composition of the stabilizer, material test for the organic Enset fibers and characteristic. (Source: Esayas, E., Agon, E. C., & Assefa,

As a result its fibers were used as stabilizing agent. The fibers were collected from *Enset* plants and processed into thread-like structures for reinforcement purposes. These fibers were then incorporated into the material to enhance its strength and durability. *Enset* fiber, in varying percentages was added to the soil. Also the research meticulously investigated the stabilizer's properties to predict how it blends in the mix. Based on the literature, it typically takes 45 days for the blocks to dry before undergoing compressive strength testing while for cement it is 28 days.

This is exemplary way of showing that locally available materials, possessing traditional value, can also be used as stabilizing agents. Moreover with further research this methodology can be applied in maintenance and conservation practice of earthen buildings. Also the paper investigated the stabilizing agent and contents inside the material. Thus *Enset* fibers were analyzed in terms of strength and internal molecular content in laboratory.

After soil samples were gathered from *Tarcha* town, in accordance with ASTM and ASHTO recommendations, range of tests were performed, including specific gravity, Atterberg limit, and grain size analysis. The results of these tests were used to assess soil's qualities and appropriateness for production of earthen blocks.

Afterwards process of mold[22] Preparation followed to produce consistent block sizes. These are wooden frames that served as a form work to retain the mix before it becomes dry.

In doing so the conservation of construction material can be seen in exploratory way where addition of newer material is tested to check the difference in strength while maintaining the primary material. To sum it up the following are some of the key points reflected on the literature.

A-Sustainable Reinforcement: The research provides sustainable substitute for conventional building techniques that mainly relies on non-renewable resources to produce non-biodegradable

[22] ***Mold:*** *is a formwork which is used to shape block forms. It is made from wood and metal.*

products, by investigating the use of *Enset* vegetable fibers as a reinforcement medium for clay bricks. This method encourages the use of ecologically friendly building materials.

B-Increased Durability: The strength and durability of clay blocks are all improved by addition of *Enset* fibers. The longevity of earthen blocks was increased by the enhancement, which also lessens the need for regular maintenance and repairs.

C-Cultural Preservation: Local customs, cultures, and building methods are frequently reflected in earthen construction. Through the creation of novel method for stabilizing earthen materials using *Enset* fibers, the research empowered the preservation of cultural legacy connected to earthen construction practices.

D-Cost-Effective Solutions: The study highlights *Enset* fibers' low cost ability to lower building expenses for rural dwelling units. It backs the economic viability of earthen construction by offering low-cost substitute for building materials, making it more affordable for communities with limited resources.

Although the research was focused mainly on reinforcing the material to enhance its intactness, the challenge arises when the mixture is exposed to water, which is potential shortcoming that the paper fails to address. The area *Tarcha* is located in a high rainfall geographic confinement where the rain and exposure to water could affect the earth and the *Enset* thread itself.[23] Hence for this specific case the paper only suggested to add more fibers and strengthen the compaction. But adding a proportion of cement, lime or other stabilizers and exploring chemicals for instance silicon based sealants would help enhance its strength and resistance to water.[24]Stabilizing earth with additives in composition might not be practiced in the traditional sense but in some local constructions earth is used with other materials. Also in some parts of Addis Ababa the utilization of earth alongside new materials has become visible local practice in some areas. Although not as a stabilizer but mixing of traditional and modern building material has become a subtle trend. For example in some houses cement is added as plastering agent and is effective in

[23]*Esayas, Eshetu, Elmer C. Agon, and Sintayehu Assefa. "Development of wall construction material stabilized with Enset vegetable fibers for rural housing units." American Journal of Civil Engineering and Architecture 6, no. 2 (2018): 54-62.*

[24] *Tian, Yupeng, Penggang Wang, Tiejun Zhao, Zhiming Ma, Zuquan Jin, and Haitao Zhao. "Influence of Water-Repellent Treatment with Silicon Resin on Properties of Concrete." Advances in Materials Science and Engineering 2019, no. 1 (2019): 5743636.*

diminishing water permeability and overall strength of earth.[25] However the cement is not mixed with daub but rather applied on top of it as protective layer. Never the less the case of cement reacting with earth is a concern. Because in some cases cement layer collapsed off of the earthen material.[26] However, culture wise cement is not an indigenous material to Addis Ababa while *Enset* is part of the community's culture and has intimate affiliation to *Tarcha* area. Thus by tapping in to the cultural materialism[27] study the research presented the cultural value and methodology to utilize it in the area's construction context. The objective of the research was to pioneer innovative approach to construct non-structural earthen walls, particularly tailored to meet housing needs of rural communities residing in southern Ethiopia, *Tarcha* town.

Figure 12-Figure 11-Cement and sand mix used as a finishing. Photo by author, [june,2024].

Accordingly through structured framework, the study aimed to look into incorporating *Enset* to the fabrication process which also encompassed observation of earthen blocks' compressive and flexural strength, density profiles, water absorption characteristics, and overall suitability for practical construction applications.

By examining how materials interact and carrying out thorough assessments, the study aimed to offer insightful information for creation of locally adaptive, sustainable housing solutions. In doing so, it aimed to empower communities, fortify their habitats against environmental challenges, and catalyze positive socio-economic transformations within the targeted rural landscapes.[28]

As a result the material produced not only replaces traditional construction methods but also ended up being sustainable, cost effective and context specific cultural material, which is well

[25] *Author's Visual Investigation, August 2024.*

[26]*Ibid.*

[27] ***Cultural materialism:*** *is an anthropological theory that emphasizes the material aspects of culture.*

[28] *Esayas, Eshetu, Elmer C. Agon, and Sintayehu Assefa. "Development of wall construction material stabilized with Enset vegetable fibers for rural housing units." American Journal of Civil Engineering and Architecture 6, no. 2 (2018): 54-62.*

aligned with objectives of international living future institute (ILFI) and United Nations Environment Programme (UNEP), which promotes local and lower impact materials on the environment.

Also according to UNESCO globally earthen construction is deemed to be found in the state of extinction thus currently existing earthen structures require special attention. Moreover approximately 25% of the sites listed as endangered on the world heritage list are earthen construction building sites. And earthen construction and the enhanced means to utilize it in modern way is given attention by organizations like International Centre for Earth Construction. For that matter the research strengthens the ideas pushed by these organizations and contributes to the protection of the tradition.

Another notable work that focuses on preserving and enhancing earth by conjoining it with stabilizers, is an article titled '*Examining the viability and benefits of cement-stabilized rammed earth as an affordable and durable walling material in Addis Ababa, Ethiopia*' by Amede, Ermias A., Gebrella G. Aklilu, Helen W. Kidane, and Alemayehu D. Dalbiso. This paper discusses the sand and cement stabilized earthen blocks to enhance earthen construction and the construction of walls that utilize the updated earth blocks in Addis Ababa. The research aims at making affordable and environment-friendly construction material that is context specific. Stabilized blocks (CSEB)[29] serve as bridge between traditional earthen construction and modern construction techniques, offering sustainable and cost-effective solution that respects and preserves cultural heritage. This article shares insight on propositions, where earthen construction technique is designed to fit current construction requirements. Besides the study compares stabilized earth with other widely used walling techniques and explores its potential as economical and long-lasting walling material in Addis Ababa. Additionally the study assesses mechanical and physical properties of red clay soil (refer to *Figure **67)*** both before and after cement stabilization.

Earth-based building materials have ability to scale efficiency together with production volume, resulting in 80–90% reduction in manufacturing energy.[30] Additionally, the study examines physical and mechanical properties of red clay soil before and after cement stabilization, testing

[29] ***CSEB:*** *compressed stabilized earthen blocks.*

[30] *Preciado, C. E., & Santos, S. D. (2020). Rammed earth construction in Latin America: Current panorama and perspectives.* Materials Research*, 23, e20200381.*

cement contents of 0%, 5%, 10%, and 15%. Results reveal increased compressive strength and erosion resistance with higher cement content, achieving strengths of 1.766 MPa to 7.61 MPa. The material demonstrated significant durability at 10% and 15% cement content, resisting rainfall erosion effectively, highlighting its viability for regional construction needs. However the paper experimented above the recommended cement proportion by ARSO and when compared to other stabilized blocks cement usage here is higher.

2.5 GOVERNMENT CODES AND REGULATIONS

Among major variables that directly or indirectly impact construction materials are policy and construction codes, because in order to realize the utilization of earth as building material, there has to be legal landscape that allows its usage in the context of the city. This legal landscape includes collection of current standards and working policies. Accordingly the research brought to discussion existing codes and documents regarding earthen construction.

The first document is Ethiopian building proclamation (624-209) by federal government of Ethiopia which is legal framework intended to guarantee sustainability, safety, and high standards of building practices across the country The document does not specifically forbid the use of earth as construction material in urban areas; neither does it give directions on earthen construction. But rather it emphasizes on quality control and the need to refer to local inspection officers and authorized bodies to check for qualities of materials in general which might favor modern materials as earth is not traditionally designed for such tests.

The other construction standard is ‘compulsory Ethiopian standard for building spatial design’ (CES 164) by Ethiopian standards Agency (ESA) which also fails to address earth as building material and give directions to spatial guide in earthen construction, but rather focuses on spatial design and building standards.

Another particular code is Es C.D3.301-1973-5000, which solely conveys minimum dry strength of all grades of HCB for construction and does not address earth in any shape or form. Further investigation of construction code and responses from construction authority officials is presented in chapter Four.

CHAPTER-THREE

3.1 METHODOLOGY

The study applied quantitative and qualitative data acquisition methods to collect data, and phase based processes[31] to analyze earth as cultural construction material. First general contextual information[32] including reasons for decrement in the use of earth is discussed along with historical back ground of the tradition. Later on topics such as; application, shortcomings and advantages are discussed. Afterwards site analysis and strategic location mapping[33] of selected area is addressed. Moreover information, from experienced expert who possesses considerable traditional knowledge of earthen construction is presented. Next, laboratory experiments are carried to give insight on properties of selected sample to eventually test different propositions and produce prototypes.

3.1.1 FOCUS OF THE STUDY AREA

Primary Focus Areas

Material analysis and study involved selection of earthen sample to be studied in a laboratory. This study focuses on the materialistic properties of earth and its characteristics as inferred from the particular sample. As a result the research utilized more than 95 kg of particular clay type, around 13 kg of *Dembaqie* and 5kg of cement. However this is including the inputs for material characterization, prototype production and wastage in all accounts.

Additionally innovative formulation is another area, which is experimental phase that devises to enhance the material qualities and recommends by using the information gathered from the characterization section. This section sets proportions of the composition to check the results of three tests with constant and variable inputs. In this case the constant variable for the testing was

[31] ***Phase based process:*** *a sequential process where material characterization, innovative formulation, and prototype production are carried out.*

[32] ***Contextual information:*** *a data acquired from previous documents and direct acquisitions regarding the given topic such as advantages of traditional earthen construction and public opinion.*

[33] ***Strategic location mapping:*** *a scientific approach of locating a potential site with suitable clay in a given confinement.*

the amount of *Dembaqie,* which was fixed at 30% and the variables were cement and clay content which varied in each tests.

Moreover traditional earthen construction expertise and the skills they possess are discussed as a defining framework for the overlooked integral components that has influence on the tradition. In this section the research assesses some of the key aspects of traditional earthen construction in Addis Ababa as described by Ato Angasso Urgessa.

Secondary Focus Area

Impacts, merits and demerits of earth in relation conventional building materials along with reasons for the decrement of earth as construction material in Addis Ababa is presented.
Furthermore public perceptions of earthen construction in the city aims to highlight reasons behind public views and how they influence the utilization of earthen construction, positively or negatively is discussed, which is also another study area.

Moreover examination of legal documents and drafts pertaining to building codes to indicate its influence and importance on the trend is discussed as study area within the reasons for the decrement of earthen architecture. Additionally discussion of selected site and method of location pining provides information on the site.
Along with the above areas, the research presents contextual information[34] concerning other aspects of earthen construction materials.

3.1.2 DATA TYPES

Primary data such as information that was acquired directly from the sources included; information from earthen construction expert, Ato Angasso which was collected three times between June and August 2024, through surveys and interviews, in Addis Ababa and *Jimma* city. On top of that the surveys were written in English then translated to the respondent. While in *Jimma* to exhibit the traditional construction practice at play in the reconstruction of the palace of *Abba Jifar* the researcher acquired first hand observation and investigation of the construction site.

[34] ***Contextual Information:*** *information presented to discuss other generic aspects about the topic.*

Furthermore responses from ; seventeen individuals for community perception (which took three weeks), responses from three officials in Ethiopian Construction Authority (which took a day), information from observations around *Qechenie Medhanialem* (which took about a week) ,verbal interviews with pottery association workers, measurements from material study, innovative formulation (which took three weeks) and testing were used as a primary data inputs.

Following that is secondary data, which is information that the research acquired from publications and documents, and was used in the literature review section. These included; former related academic works, back ground of earthen construction, geological map of the city codes and standards.

From the nature of these data they are classified into two. The first is qualitative data which covers information on public perception, observations, and local earthen construction expert views, interviews from pottery association and responses from Ethiopian Construction Authority. While the last data is quantitative data which covers material characterization[35], innovative formulation[36] , prototype production and material test of the selected earth.

3.1.3 POPULATION SIZE

The study comprised 17 participants who were representative of the Addis Ababa general population in order to collect data on public perception and dynamics surrounding earth as construction materials. In addition, three officials were specifically chosen to provide insights from the Construction Authority. These authorities were selected from among the institutions estimated above 500 employees because they have a direct impact on construction codes and standards. And due to the lack of information to estimate the entire sample population and the lack of professionals in the field, the research relied on only one expert to provide comments on earthen construction. Also verbal interviews with pottery workers was conducted it relied on

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[35] ***Material Characterization:*** *refers to the process of analyzing and determining the physical, chemical, and mechanical properties of soil*

[36] ***Innovative formulation:*** *refers to the process of developing new or improved materials, mixtures, or methods that enhance the performance of the former material.*

three individuals out of more than 30 people where the information was applied in the innovative formulation part of the paper in deciding the proportion of *Dembaqie.*

3.1.4 SOURCES OF DATA

The research used data sources from different areas of study to render its argument. Among those questionnaires, interviews and Surveys were the first categories and were used in collecting information from public opinion respondents, construction authority officials, pottery workers and earthen construction expert through open and close ended questions.

Additionally as controlled examinations in which the researcher modifies one or more factors to see how it affects other variables experiments were carried out. Subsequently it served as the source of data in used in innovative formulation section.

The behavior of the material *Dembaqie* was also examined using this data source in order to assess its pozzolanic qualities using the roll test method. Additionally, the primary inspection experiment method was used to evaluate the material's compatibility. Furthermore when collecting visual information on earthen construction around *Qechenie Medhanialem* area such as; urban context, construction trends, observation was applied. More so it was used in the overview of earthen construction at *Jimma* Abba *Jifar.*

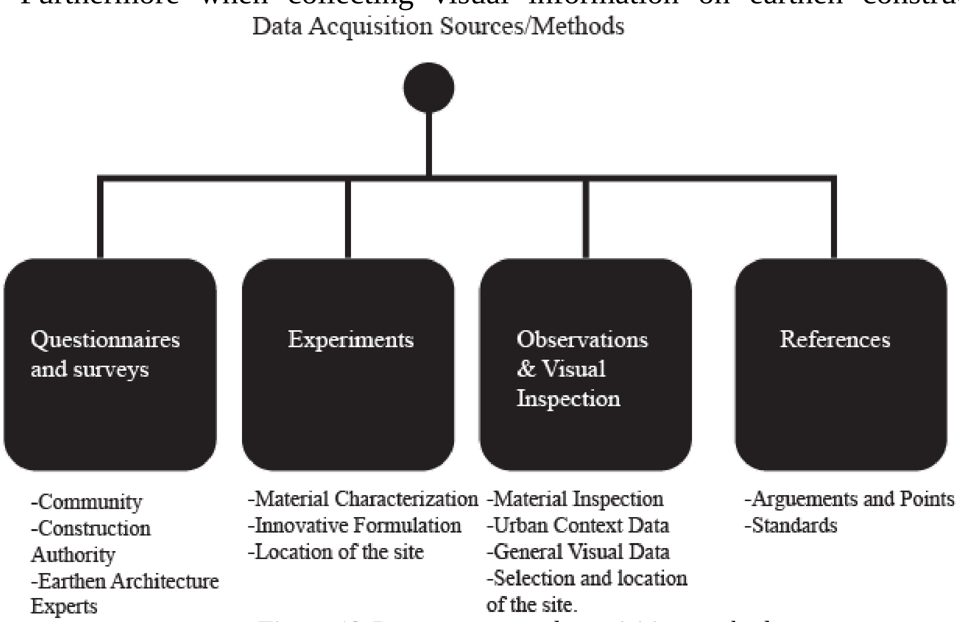

Figure 13-Data sources and acquisition methods.

3.1.5 SAMPLING TECHNIQUE

When selecting the research subjects the paper used two sampling methods where the first involved selecting random individuals for the survey and interviews example when selecting respondents from the community. This is called random sampling, while the other is Purposive (judgmental) sampling which targets specific individuals or samples in collecting data. As a result it was applied in the research when selecting officials from Ethiopian construction authority (ECA), earthen construction experts whom the researcher chose particularly for the study and soil samples from *Qechenie Medhaniealem* area.

3.1.6 METHOD OF DATA COLLECTION

In order to locate the potential site with suitable earthen samples for construction a geological map of Addis Ababa was used. Later upon the selection of location, primary sample inspection methods were applied to affirm the material for further suitability.

The next method is characterization where laboratory tests and analysis to understand properties of extracted earthen material is conducted. This method uses a range of tests to provide information and measurements about the sample which the research bases innovative formulation and prototype production on. Accordingly this stage took more than two months from June to August 2024.

Figure 14-Tools utilized for the material study.

For the conduction of the laboratory experiment, tools (*Figure* ***14***) that are test specific were used. Additionally for the Atterberg limit test tools such as; grooving tool, plastic plate, spatula, balance, shrinkage dishes, washing bottles were applied. Also for the specific gravity test de-aeration device, thermometer, evaporation dish and oven were applied. As well as for the hydrometer test standard ASTM 152H, washing bottles, dispersing agent, balance, thermometer, electric stir and glass bakers were utilized. While for the standard compaction effort test; proctor mold, extruder, balance, canisters, rammer and sieve were used.

Besides universal testing machine (UTM) was applied for dry compressive strength test. On top of that, the research utilized the laboratory facilities at the material testing center of EiABC, as well as library resources and internet platforms, for the overall execution of the study.

Generally, for the research the method of material characterization was applied which used a range of step-based tests to understand traits of the sample to address them with responsive designs. This includes the Atterberg limit test, specific gravity, hydrometer test, and compaction effort test and sieve analysis.

Afterwards based on findings from material characterization, the research experimented with variations in compositions and additives where the aim was to enhance material's desirable properties while addressing its weaknesses (both generic and specific).[37] This step involves examination and application of stabilizers. As opposed to the literatures presented the experimentation here utilized two stabilizers on the main material; cement and *Dembaqie*. The experimentation of three variations was conducted where the behavior of the mixtures is recorded and analyzed in the context of standard the like of ARSO and local proportions such as recommendations by the pottery workers. This method is called innovative formulation which later devised an ideal proportion to produce the prototype with. Following the development of novel ratio for creating the ideal mix, the next step was prototype production[38], where the ideal mix recommended by the formulation is produced in the form of a model against a control.[39] And later on through a Section tests selected material and creates prototype that lessens its shortcomings.

In addition strategies of location selection, to pin point potential site with suitable earthen sample, was executed using geological map and possible indicators. On top of that primary

[37] *Generic refers to the general soil characteristics and specific means to particular soil typology. In this case the extracted sample.*

[38] ***Prototype**: refers to a model produced to showcase the material in a sample type.*

[39] ***Control:** is a sample or product used for comparison where its components are kept pure or constant as opposed to the other product.*

***Integral discussion:** is used to refer to the overarching discussion related to the subject that is presented in the paper.*

examination steps and inspection were applied to affirm the sample further. Additionally for the inspection of the pozzolanic trait of the *Dembaqie* the ball and crush test was conducted.

3.1.7 METHOD OF DATA ANALYSIS

The analysis method applied for this paper is a mixed data analysis method, which primarily utilizes a convergent parallel design. In this approach, multiple data inputs are analyzed separately, ensuring that qualitative and quantitative findings retain their distinct analytical integrity. The results from these independent analyses are then merged to produce an intersectional output, where the convergence of different data sources enhances the credibility and reliability of the study's conclusions. This methodological approach strengthens the argument by integrating diverse perspectives, allowing for a more comprehensive understanding of the research problem.

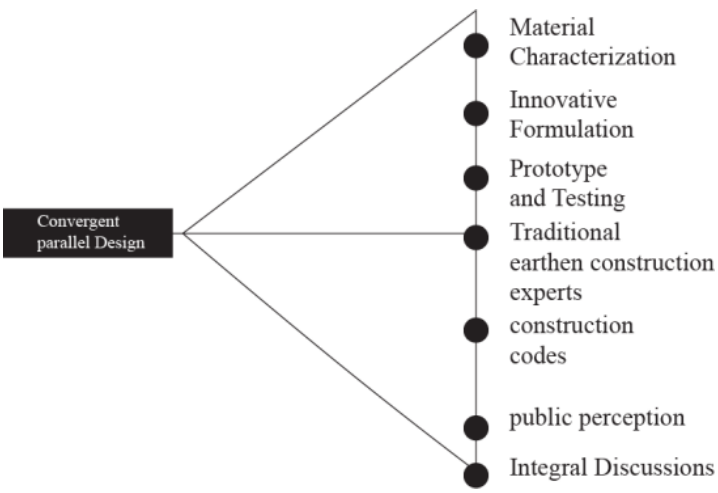

Figure 15Method of data analysis.

In order to improve study depth, validity, and reliability, this paper integrates qualitative and quantitative data utilizing a convergent parallel design and mixed data analysis method. The method guarantees a balanced viewpoint by combining statistical precision with contextual insights by examining various data kinds independently and combining the results. By overcoming the constraints of single-method studies, minimizing biases, and cross-verifying results, this approach improves the scientific argument. In the end, this methodological approach's use in this work supports the findings of the research, making it an effective instrument for generating comprehensive and perceptive scholarly investigation.

CHAPTER-FOUR

4.1 DATA PRESENTATION

This discussion provides overview of contextual information related to earth as construction material, afterwards examines particular soil archetype[40] and its index properties to later produce prototypes that addressee its shortcomings. But prior to that, investigation of the city's declining use of earthen construction is discussed to put insight on prevalent challenges on the field.

4.1.1 REASONS FOR THE DECLINE OF EARTHEN CONSTRUCTION IN THE CITY

Ethiopia has seen significant shift in building materials from traditional to conventional. Particularly in Addis Ababa the use of conventional construction is in a state of increment[41] which is indirectly impacting earthen construction. This in part can be due to expanding population and rapid urbanization which required a construction that makes conventional materials more advantageous than traditional ones. In summary, however, the following are presented by the paper as culminating factors contributing to the general decline of the tradition;

PHYSICAL DEMERITS

Even though in some areas earth as building material possesses strong properties, traditional methods in most cases exhibit physical demerits due to lack of proper enhancement[42] like its susceptibility to weather condition and permeability.

It is widely held belief that modern building materials provide more structural integrity and longevity than earthen construction.[43] Hence by preference people tend to choose materials they

[40] ***Architype:*** *sample or specimen that is taken out to be studied as a model.*

[41] *Nieder, Piet, ed. The Addis Ababa House: A Typological Analysis of Urban Heritage in Ethiopia 1886–1936. Berlin: Jovis Verlag, 2019.*

[42] *Bailly, Gabo Cyprien, Yassine El Mendili, Athanas Konin, and Eliane Khoury. "Advancing Earth-Based Construction: A Comprehensive Review of Stabilization and Reinforcement Techniques for Adobe and Compressed Earth Blocks." Eng 5, no. 2 (2024): 750-783.*

believe to be safer and more stable. Additionally, traditional construction technique and application of clay structures may be more vulnerable to damage or collapse in extreme conditions.[44] Such experiences typically perpetuate this notion which can have impact on the tradition.

INFLUENCE OF GLOBALIZATION AND CULTURAL IMPOSITION

Exposure to global trends and new construction materials can influence local cultures to adapt to new construction materials such as cement, which is reflection of the desire to adopt worldwide trends.[45] Also in the city of Addis Ababa, it is projected that this tendency could lead the construction sector to be dominated by conventional building materials.[46] And currently the city is being overwhelmed by the use of HCB;[47]as a result this phenomenon could contribute to decline in the use of earth as construction material.

ACCESSIBILITY OF MATERIALS

Because these days' typical building materials such as concrete, steel, and HCB are widely available in market supply chains, they may be easier to acquire. On the other hand finding earth for construction is challenging, because locating fit and high-quality materials could be harder, particularly in urban areas such as Addis Ababa. Even though earth is abundant, extracting it is not always simple as some earthen typologies may be scarce due to the particular traits needed for building, such as high engineering qualities.[48]

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[43] *Domone, Peter, and John Illston. Construction materials: their nature and behaviour. CRC press, 2018.*

[44] *Mileto, Camilla. Earthen Architecture: Past, Present and Future. Edited by Fernando Vegas, L. García Soriano, and Valentina Cristini. CRC press, 2014.*

[45] *Hubbard, Phil. "Concrete cities: why we need to build differently: by Rob Imrie, Bristol, Bristol University Press, 2021, 298 pp.,£ 19.99 (paperback), ISBN 978 1529220520." (2022): 506-508.*

[46] *Gossaye, A. "Inner-city renewal in Addis Ababa: The impact of resettlement on the socio-economic and housing situation of low-income residents (Ethiopia)." (2003): 0034-0034.*

[47] *Ibid.*

[48] ***Engineering qualities:** refer to physical, mechanical, and chemical properties of soil that determine its suitability for construction and infrastructure projects.*

COMMUNITY PERCEPTION

Earth as material could be adopted by the national code and construction law; but it would be futile endeavor unless the general public has positive attitude toward it. Usually the community regards earth as material for the poor, Moreover the decline of earthen housing is associated with unfavorable perceptions and a growing preference for 'modern' construction materials in developing nations.[49] In this part the research went to assess the study of what view against earthen construction is held by subjects representing the general public. This follows random sampling technique of selecting respondents for their response.

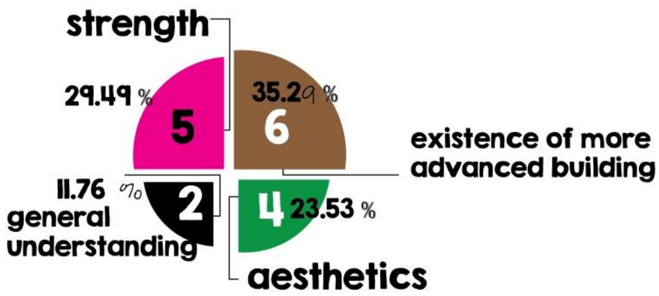

Figure 16- Community perception response illustration.

To extract the information from individuals in Addis Ababa, questionnaire has been distributed. Thus among the volunteers five of them believed that the strength of earthen material is what made it to be lowly perceived by the public. Also six of the subjects believed that it is due to the existence of more advanced building materials in the market. Additionally four of them claimed that it is aesthetics which earthen materials produce which does not allow it to compare with other construction materials. While two volunteers underlined the public general understanding that had influenced the phenomenon; they stated it is considered as primitive material which indicates poor stature of residents.

Additionally the survey showcased that perception of primitiveness and unattractiveness along with different derogatory understandings are commonly held by the public. This coupled with abundance of modern conventional materials driven by the rising infrastructural demand in the city could highly contribute to the decline of usage in earthen construction.

[49] *Marsh, Alastair TM, and Yask Kulshreshtha. "The state of earthen housing worldwide: how development affects attitudes and adoption." Building Research & Information 50, no. 5 (2022): 485-501.*

GOVERNMENT POLICIES AND REGULATIONS

Construction codes and standards impact construction materials as they pave the way for the material's use in the legal landscape.[50] As a result relevant documents are presented in the literature section of the paper and they fail to incorporate or recognize earth as construction material which can marginalize earthen construction tradition by indirectly encouraging the use of conventional materials.

Hence the inexistence of any codes regarding earth as construction material could make it difficult for the trend to survive in the ongoing influence of conventional building materials. This phenomenon could highly contribute to decrease in the utilization of earth in the city and further loss of the tradition. Additionally to get more insight on the issue, the researcher has asked concerned officials on the matter, using questionnaires that targeted officials of the Ethiopian Construction Authority who are responsible for drafting of codes and policies on construction materials in Ethiopia. As a result the research went to extract information regarding existing code and regulation on materials particularly earth and sought if there are pending researches on development.

The information gathered from Ethiopian Construction Authority officials about earthen construction, is discussed below to add more insight on the legal sphere regarding earth as construction material. The responses from officials provide understanding of current regulatory landscape and their professional opinions.
All three officials confirmed that there are no specific codes or standards for earthen construction in Addis Ababa or Ethiopia at large. This absence of formal regulations and guidelines creates a regulatory vacuum, indirectly restricting the use of earthen materials in construction. For the anonymity they insisted their names are not disclosed.

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[50] *Ali, Mohammad Sujayath, Saliha Shukri, Mahaboob Patel, and Abdul Ahad. "Alternative Building Materials for Sustainable Development in Ethiopian Construction." International Research Journal of Engineering and technology 7, no. 6 (2020): 2899-2903.*

Informant 1[51] highlights the lack of research on earthen construction, which makes it difficult to develop standardized codes that ensure the safety and viability of using these materials. Informant 2[52] also cites the unknown load-bearing capacity of earthen materials as a reason for the exclusion of such methods. The absence of recognized standards prevents the legal and formal incorporation of earthen materials into urban construction. This regulatory gap discourages builders and developers from using earth, as it is seen as non-compliant with the current building regulations. There is a clear institutional preference for modern construction materials.

Informant 2 emphasized that earthen materials are not classified as engineering structures, and urban areas are particularly resistant to their use due to perceived inadequacies in structural integrity. This mindset is echoed in informant 3's concerns over load-bearing capacity, space optimization, and urban development pressures. The government's favoring of modern materials over traditional earthen materials, combined with skepticism about the engineering reliability of earthen structures, contributes to the marginalization of earth as a construction material. This discourages its use, especially in urban areas where higher-density, multi-story buildings are prioritized.

Moreover the respondents, particularly informant 1 and informant 2, pointed out the lack of detailed research and empirical data regarding earthen materials. This absence of scientific and technical validation hinders the development of specific standards or codes as there is no experiment and data to base the regulations on.

Informant 3 [53] mentioned ongoing studies into stabilized earthen blocks, as the absence of comprehensive research continues to be a major barrier. Without research proving the safety, durability, and structural viability of earthen materials; policymakers remain hesitant to integrate them into official regulations. This, in turn, restricts the material's use, contributing to the decline in earthen construction.

[51] ***Informant 1-*** *Code and standard preparation (Ethiopian construction authority).*

[52] ***Informant 2-*** *Team leader* ***(****Ethiopian construction authority).*

[53] ***Informant 3-****Desk executive, department of infrastructure code and standards (Ethiopian construction authority).*

Moreover, the officials recognized the general perception of earthen materials as primitive, non-engineering, and low-quality materials. Particularly informant 2 cited the poor construction quality and old structures as reasons for discouraging earthen construction. Additionally, informant 1 indicated that there is little institutional interest in revisiting or revising policies regarding earthen materials, signifying institutional reluctance to endorse them.

Also informant 2's remark that there is no significant value placed on the expertise of specialists in earthen construction underscores the broader undervaluation of traditional building knowledge.

As a result this negative perception translates into regulatory neglect, where earthen materials are not seen as suitable for modern construction. Thus the lack of value placed on traditional building material reinforces the marginalization of earth-based methods in favor of modern materials, accelerating the decline in its usage.

Furthermore, there is a mixed response regarding the cultural and heritage value of earthen construction from the respondents. Informant 1 recognized the cultural importance of preserving traditional architecture; whereas informant 2 did not view cultural preservation as a priority. Informant 3 offered a more balanced view, recognizing that earthen materials should be considered if they can be enhanced and upgraded to meet modern standards. From their responses lack of a unified approach to cultural preservation of earthen construction can be seen which means that it’s historical and heritage value is not prioritized in policymaking. This contributes to the erosion of traditional building practices, further reducing the utilization of earth in construction.

On top of that informant 2 was opposed to considering scientifically enhanced earthen materials, even if they could be stabilized. This skepticism contrasts with informant 1's and informant 3 's more optimistic views, where they indicated that if earthen materials could be upgraded to meet modern standards, they could be integrated into construction codes. While there is some openness to enhanced materials, the general institutional reluctance to accept earthen construction regardless of potential advancements further contributes to its decline in usage. And without a concerted effort to legitimize and promote enhanced earthen materials, the traditional practice of earthen construction remains sidelined.

Informant 2 also raised concerns about the environmental impact of extracting earth for construction, specifically regarding land degradation and erosion. Furthermore, he emphasized zoning regulations which, according to him, play a role in prohibiting earthen construction in urban areas, as they are perceived to conflict with modern urban planning and the need for higher-density structures.

These environmental and zoning concerns, while valid, can be used as additional justifications for excluding earthen materials from modern construction. This leads to fewer opportunities for earthen construction to be considered in urban development projects.

As among the top tier institution that concerns codes and standard, the Ethiopian construction authority, through its officials' responses, appears to play a significant role in the decrease of earthen construction in Addis Ababa. The key factors contributing to this decline include:

The lack of specific codes and standards for earthen construction, which not only denies its material status as construction input, but also marginalizes it into extinction. Secondly strong preference for modern construction materials over traditional methods, this is indirect avoidance of the material by not giving it priority in researches and standardizations. Additionally negative perceptions and undervaluation of earthen materials as viable for modern engineering standards was reflected from the responses.

Moreover from the responses there is insufficient empirical research to support the inclusion of earthen materials in official construction regulations. Also mixed and often low regard for cultural preservation was conveyed, which could otherwise support the use of earth in construction. In addition the responses underlined that it would be hard for the material to be used in the CBD areas of the city which can be riskier.

In general the collective impact of these factors creates an institutional barrier to the continuation of earthen construction in Addis Ababa. Together with the data gathered the research was able to corroborate existence of impactful bias against the trend.

4.1.2 LOCATION AND CONTEXT

Having that put to perspective earth as a mortar in Ethiopia has long existed. Particularly in the city of Addis Ababa half century ago a big proportion of buildings were comprised of earth based construction[54] where the material had been utilized as a mortaring agent that was applied along with wood and stone, rather than a standalone building element. Also in developing countries globally buildings that account for 20-25% in proportion are of earthen construction,[55]and according to a study carried out in 2019 the rural population of the country accounted for 83.4% of total population and the urban demographics sits at 16.6% of total population.[56] In Ethiopia considering significant rural population, that dwells in earthen houses, these numbers may even be higher, which conveys the surplus existence of earth based constructions in the country. This is what makes earth relevant to discussion.

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[54] *Nieder, Piet, ed. The Addis Ababa House: A Typological Analysis of Urban Heritage in Ethiopia 1886–1936. Berlin: Jovis Verlag, 2019.*

[55] *Marsh, A. T. M., and Y. Kulshreshtha. "The State of Earthen Housing Worldwide: How Development Affects Attitudes and Adoption." Building Research & Information 50, no. 5 (2021): 485–501. https://doi.org/10.1080/09613218.2021.1953369.*

[56] *OECD. 2020. "Rural Population (% of Total Population) - Ethiopia." OECD Data. Accessed July 27, 2024. www.oecd-ilibrary.org/sites/8f129f69-en/index.html?itemId=/content/component/8f129f69-en.*

4.1.3 RAMIFICATION FOR SELECTING THE AREA

For the material characterization a soil sample is needed to be studied, and selecting an area with soil type suited for earthen construction is a primordial step in understanding the material's properties. This incorporates points to why the researcher capitalized on earthen buildings material of specific context. As a result this phase gave the research clarification on how and why particular site was selected in correlation to the study. But before that this section discusses the importance and value of earth.

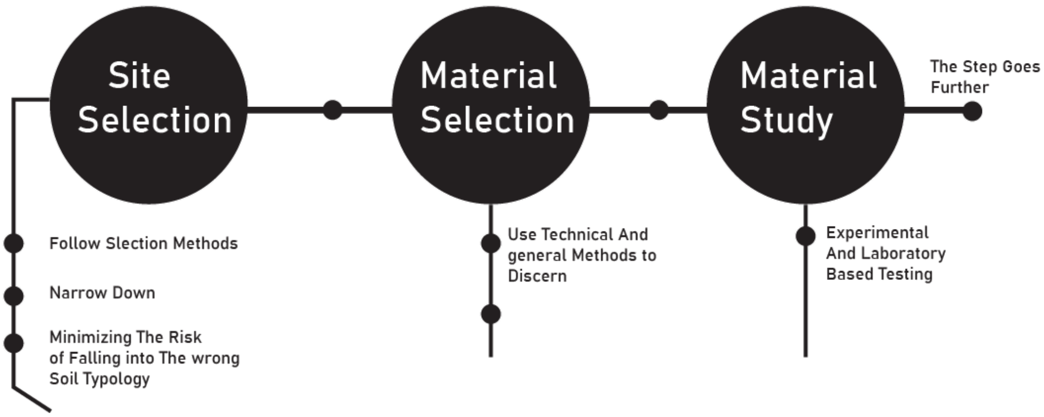
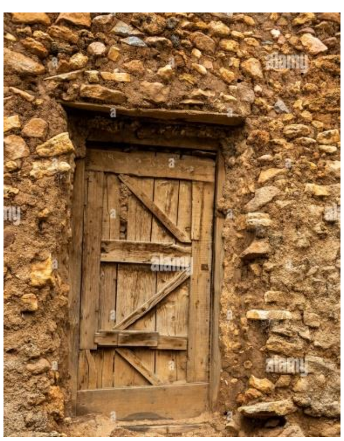


Figure 17-Diagram of the primary stage outlines of material characterization.

4.1.4 APPLICATION OF EARTH

Although earth is used as construction material the applicability of it can vary according to the requirements and the geographical needs. Accordingly the following are some of the known applications of earth as traditional construction material.



In most of traditional stone masonry buildings earth is applied as a sticking element between aggregates. The method is applied to strengthen connection between stones. This instance is seen in the

Figure 18-Earth as a conjoining material in between stone in Hararge region, (Source: Alamy.com).

Tigrian early religious and residential architecture. When compared to wattle and daub construction this technique yields a good strength because of stone’s has higher resilience and wood is most often suitable to insects and vermin.

Traditionally earth serves as plastering material after the main structure is finished and in other cases cow dung is applied.[57] The finishing is executed after the gap filler daub is applied. When compared to the daub the mixture for the finishing material could attain difference in fermentation level, thatch proportion and soil looseness.[58]

Figure 19- Earth as plastering element. Source: Endakmachin Charitable Association, October 28, 2021, https://shorturl.at/hzFTX.

According to Ato Angasso fermentation and mixing process takes time before application. However mixing process of the layering earth takes longer time than the filler daub. When earth is applied in between standing wooden structures, rather than serving as conjoining material its application lies in filling spaces that the wattle is unable to occupy. The earth is mixed with water and stabilized with locally harvested straws to yield highly sticky walling material that is applied in between the space of erected wooden posts.

Moreover the image below shows updated version of rounded thatch house construction in the shape rectangle. However in the earliest instances of traditional construction the plan modality of these structures used to be circular which now has changed to rectilinear, due to the adoption of CIS.[59]

Figure 20-Earth being used as an insulating and gap-filling element in a wooden house. Source: Ralph Dubienski, Construction Rural Style in Ethiopia, 2014, screenshot from [0:02–0:44].

[57] *Gruber, Petra, and Kingshuk Datta. "Construction Aspects in Ethiopia's Architectural Traditions: A Comparative View." Journal of Traditional Building, Architecture and Urbanism 2 (2021): 318-332.*

[58] *Angasso, Urgessa.* Personal communication, *June 2, 2024.*

[59] *Cherenet, Zegeye, and Helawi Sewnet. "Building Ethiopia." (2012).*

Earth can also be used as flooring, where layered format is applied. According to Ato Angasso the lower section is filled with aggregates of bigger radius followed by smaller ones on the top. Each step is conducted by application of compaction to strengthen the material.

Figure 21-Example of flooring styles in local construction. Source: www.ranchomastatal.com.

OTHER APPLICATIONS

Earth is substantially used input for traditional pottery that has a firm affiliation to local culture and the country in general.[60]

Figure 22-Pottery production in Qechenie Medhanialem women's pottery association, Addis Ababa. Photo by author, [August, 2024].

Soil possessing high clay content usually is preferable as it exhibits elastic qualities, which make it fit for traditional practice such as pottery. And there are about two types of the same soil when extracting it in a given location: The first is accumulated on the top of the sedimentation which is characterized by organic content and mixture. Whereas the other is found around 50 cm below the ground surface (also known as sub-soil).

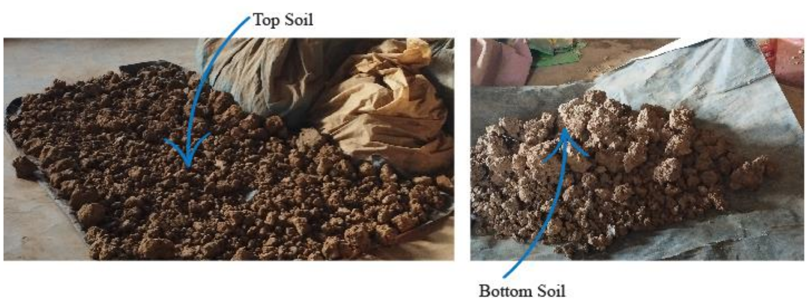


Figure 23-Soil variation with in the same confinement. Photo by author, [August, 2024].

[60] *Arthur, John W. "Pottery use-alteration as an indicator of socioeconomic status: An ethnoarchaeological study of the Gamo of Ethiopia." Journal of Archaeological Method and Theory 9 (2002): 331-355.*

The difference is that the material that is extracted underneath is uniform in terms of compositions where as the top is different. Overall, earth is prominently utilized by locals for pottery, serving as a source of income.[61]

4.1.5 DEMERITS OF TRADITIONSL EARTHEN CONSTRUCTION

Generally earth as construction material can exhibit disadvantages such as its need for routine care since it is prone to erosion and water damage, particularly in places with high rainfall.[62] Besides, in many cases traditional earth might not be as strong as contemporary building materials, which would restrict its application in high-rise structures and in regions vulnerable to earthquakes.[63] Earth is a sustainable option; however it needs to be carefully tailored to local environments and studied contextually. These along with the following are some of the general shortcomings of earth as traditional construction material.

One of the primary challenges of earth and studying it as construction material is the range of typologies it exhibits. Even though it can be very cheap and sustainable construction material earth exists in different spectrum, composition and variation. As a result making it difficult to analyze and study the material to come up with generic solution for its demerits, and provide a universal standard.

Moreover in the traditional architecture, the practice is conducted unprofessionally where there are less replicable methods and standard procedures.[64] One example of this challenge is identification of the ideal soil for construction. As mostly the selection process is done traditionally, materials characteristics are not studied and the steps are not documented. While

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[61] *Budhu, Muni. Soil Mechanics and Foundations. 3rd ed. Hoboken, NJ: John Wiley & Sons, 2010.*

[62] *Hall, Matthew R., Rick Lindsay, and Meror Krayenhoff, eds. Modern Earth Buildings: Materials, Engineering, Constructions and Applications. Cambridge: Woodhead Publishing, 2012.*

[63] *Ibid.*

[64] *Angasso, Urgessa.* Personal communication*, June 2, 2024.*

also new problems enticed with the soil are not addressed during construction, making the tradition hard to create enhanced materials and challenging for other experts to replicate and refer information from.

Figure 24- Inconsistency and lack of surface formation in traditional earthen construction, Bisidimo village. Source; the peace traveler.

Mostly in the application of earth as a walling material in traditional constructions the wall thickness is not even. This according to Ato Angasso can be due to lack of measurement and random implementation procedure. The local earthen construction is mostly executed by traditional experts.

Additionally when exposed to water and rain, traditional earthen materials tend to be degraded. This is due to permeability of soil and lack of stabilizing ingredients that can enhance the materials characteristics to resist water. Additionally, apart from being fermented, the earth is not enhanced in its composition to resist water. And the traditional construction uses no other material as an agent except in some cases where thatch, burnt ash and cow dung is applied.[65]

As well as earth can be exposed to high humidity levels which can lead to growth of mold and mildew on earthen walls that not only affect material's integrity but can also pose health risks to occupants. This is due to earth's suitability for plants and seeds to grow and once it is exposed to water these plants could make the material suitable place to grow,[66]which can later affect the material and degrade its physical makeup, leaving it functionless.

Also in traditional construction where the other components applied alongside earth are either stone or wood, the consumption of structural material comes at high cost to the environment. In

[65] *Tassew, A. The Role of Indigenous Knowledge in Ethiopian Vernacular Architecture: Case Study of Wattle and Daub Construction in Gurage Zone. Master's thesis, Addis Ababa University, 2005. Addis Ababa University Repository.*

[66] *Othman, Nur Liyana, Mastura Jaafar, Wan Mariah Wan Harun, and Fuziah Ibrahim. "A case study on moisture problems and building defects." Procedia-Social and Behavioral Sciences 170 (2015): 27-36.*

wattle and daub construction which utilizes wood extensively, raw material is extracted directly from the environment, as a result damaging the ecosystem by allowing deforestation to take place.

4.1.6 ADVANTAGES OF EARTH

Ethiopia, As well as Addis Ababa has abundant sources of clay-rich soil, which is primary raw material for traditional earthen construction. This availability makes earthen construction a cost-effective option, as it reduces reliance on imported and expensive building materials. But it has to be noted in areas such as Addis Ababa possible open locations where this material can be found, has been influenced by the urbanization.

Moreover earthen structures have excellent thermal properties, providing natural insulation against both heat and cold. The thermal mass of earth helps regulate indoor temperatures; keeping interiors cool in hot climates and warm in cooler weather conditions.[67] This contributes to enhanced comfort and energy efficiency, reducing reliance on artificial heating and cooling systems.

Also earthen construction is inherently sustainable and eco-friendly, as it utilizes locally available material that has minimal environmental impact. Building with earth reduces carbon footprint associated with manufacturing processes, contributing to environmental conservation.

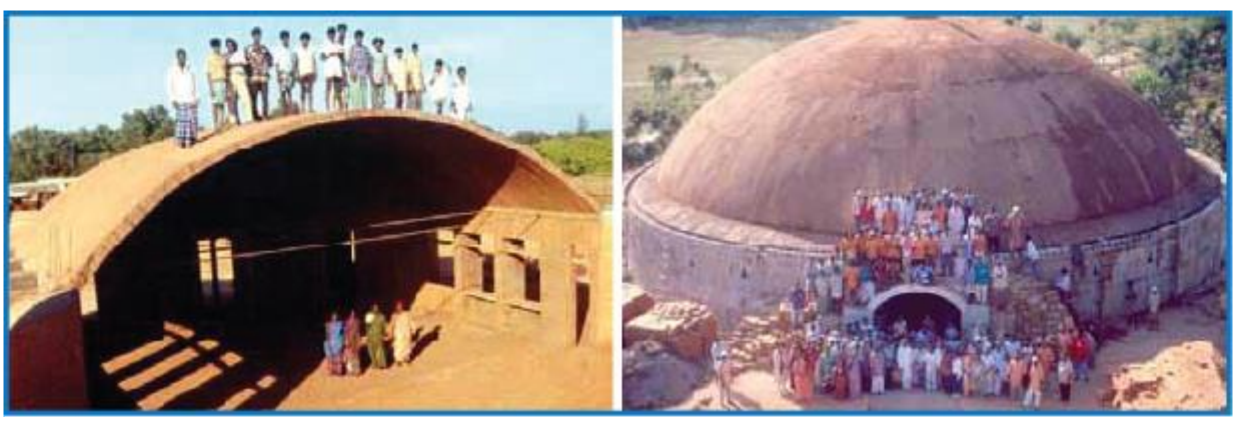

Figure 25-Vault of Mirramukhi school at Auroville, 10.35m span, 30 tons – Built in 3 weeks(Left) and the Dhyanalinga dome near coimbatore spans 22.16m in diameter 570 tons constructed in just 9 weeks(Right). Source; Maïni, S. (2005).

[67] *Adegun, Olumuyiwa Bayode, and Yomi Michael Daisiowa Adedeji. "Review of economic and environmental benefits of earthen materials for housing in Africa." Frontiers of Architectural Research 6, no. 4 (2017): 519-528.*

More so traditional earthen construction techniques are deeply rooted in Ethiopia's culture and heritage. These techniques reflect indigenous knowledge, craftsmanship, and architecture that has been passed down through generations. Building with earth preserves cultural identity and fosters a sense of pride and connection to local heritage.

Besides earthen construction techniques offer flexibility in design and construction, allowing for creativity and adaptation to diverse architectural styles. With proper study, the use of specially shaped adobe blocks enabled the creation of load bearing; detailed and unconventional forms vaulting structures such as in *Figure* ***25*** can be constructed, portraying earthen construction's capacity to construct complex geometric forms.[68]

Although rare in traditional constructions, Well-built earthen buildings, using methods such as reinforced adobe[69] or rammed earth with appropriate engineering and design considerations, can exhibit significant resilience to seismic activity, often outperforming conventional masonry structures in earthquake-prone areas.[70]

4.1.7 ENVIRONMENTAL IMPACT OF CONVENTIONAL BUILDING MATERIAL: CEMENT

The most widely used construction material in the world is cement, which comes at a cost of impacting the environment and contributing to increment global warming. It's the primary input for materials such as HCB and RC structures. As mentioned above cement industry contributes about 8% of global warming, making it one of the most detrimental construction materials aside from being an industry that affects traditional earthen construction.

Cement production is major contributor to greenhouse gas emissions, primarily due to high energy consumption involved in manufacturing process and chemical reactions that occur during clinker production. Also cement production relies heavily on finite natural resources such as

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[68] *Easton, David, and Cynthia Wright. The rammed earth house. Chelsea Green Publishing, 2007.*

[69] ***Reinforced adobe :*** *refers to a construction method where traditional adobe (sun-dried earth bricks) is strengthened by incorporating reinforcing materials.*

[70] *Houben, H., & Guillaud, H. (1994). Earthen Buildings: Materials, Engineering, Constructions and Applications. Intermediate Technology Publications.*

limestone, clay, and sand. Extraction of these resources can lead to habitat destruction, soil erosion, and loss of biodiversity, especially in ecologically sensitive areas.

As well as cement production requires significant amounts of water for quarrying, processing, and cooling purposes. High water consumption can exacerbate water scarcity issues, particularly in regions already facing water deficiency as Ethiopia. For instance producing and utilizing one quintal of cement involves significant water usage across different stages. The production process uses an estimated 0.14 to 1.28 liters of cement per kilogram.[71]

By the same token cement manufacturing plants emit various pollutants into the air, including particulate matter[72], sulfur dioxide (SO2), nitrogen oxides (NOx), and volatile organic compounds (VOCs).[73] These pollutants can have adverse effects on air quality, human health, and ecosystems, leading to respiratory problems, acid rain, and damage to vegetation.

In Ethiopia cement is relatively a new construction material, when compared to the history of the country. It was first invented in England by Joseph Aspdin In 1824. Particularly in the country the first factory was established in the city of *Diredawa* in 1936, built by Italian Government, [74] this portrays the material to the city and the country as a whole is imposed than indigenous. Consequently, buildings are reduced to basic vertical and horizontal forms made of concrete blocks, which, due to their unattractiveness and lack of appeal, become harmful to society and contribute to environmental harm. Additionally, they result in a complete disconnection from traditional values and cultural norms.[75]

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[71] *Nydrioti, Ioanna, Melina-Margarita Moutsaki, Nikolaos Leounakis, and Helen Grigoropoulou. "Implementation of the water footprint as a water performance indicator in industrial manufacturing units located in Greece: challenges and prospects." Environmental Science and Pollution Research 31, no. 1 (2024): 803-819.*

[72] ***Particulate matter:** refers to small droplets suspended in the air which could be solid or liquid in nature.*

[73] *Zeb, Khaqan, Yousaf Ali, and Muhammad Waseem Khan. "Factors influencing environment and human health by cement industry: Pakistan a case in point." Management of Environmental Quality: An International Journal 30, no. 4 (2018): 751-767.*

[74] *Mulatu, Dure, Lulit Habte, and Ji Whan Ahn. "The cement industry in Ethiopia." 에너지공학 27, no. 3 (2018): 68-73.*

[75] *Ali, Mohammad Sujayath, Saliha Shukri, Mahaboob Patel, and Abdul Ahad. "Alternative Building Materials for Sustainable Development in Ethiopian Construction." International Research Journal of Engineering and technology 7, no. 6 (2020): 2899-2903.*

Also cement production requires large land area for plant, which includes allocation such as production facilities, raw material Storage, auxiliary facilities, logistics and other infrastructures. Combining all these spaces, the minimum area required for medium seized cement factory would be approximately about 27-55 hectares.[76]As a result, it is nearly impossible to find such a large area in the city center of Addis Ababa given the current shortage of land.

And energy wise cement can be a high energy consuming construction material. For instance upon the production of conventional building materials such as HCB, the estimate of the energy produced considering cement as an input is around 1.3-3.0MJ/kg.[77] For perspective one hundred kilograms of low-grade wood chips (10 MJ/quintal) burned can potentially heat up to two to three hundred liters of water by 2-3 degrees Celsius. This can translate in to a degrading environmental problems and costly construction materials. Cement is highly utilized construction material globally and in Ethiopia as well. The cement industry is responsible for around 7-8% of global CO2 emissions, making it significant contributor to climate change. [79] approximately 75–80% of the raw materials used in production of cement is limestone which is irreplaceable material. Apparently after its production cement is also not re-usable and none bio degradable material.

[76] *Alsop, Philip A. Cement plant operations handbook: for dry process plants. Tradeship Publications Ltd, 2007.*

[77] *Asdrubali, Francesco, Gianluca Grazieschi, Marta Roncone, Francesca Thiebat, and Corrado Carbonaro. "Sustainability of building materials: Embodied energy and embodied carbon of masonry." Energies 16, no. 4 (2023): 1846.*

[78] *Adams, Paul, Tony Bridgwater, Amanda Lea-Langton, Andrew Ross, and Ian Watson. "Biomass conversion technologies." In Greenhouse gas balances of bioenergy systems, pp. 107-139. Academic Press, 2018.*

[79] *Transition Pathway Initiative. Carbon Performance Assessment of Cement Producers: Note on Methodology*. 2022, *https://www.transitionpathwayinitiative.org/publications/uploads/2022-carbon-performance-assessment-of-cement-producers-note-on-methodology.*

4.2 SITE DATA

In the process of studying the means to conserve earthen construction tradition, it is helpful to study the material closely, discern its compatibility for construction.[81]to really understand the

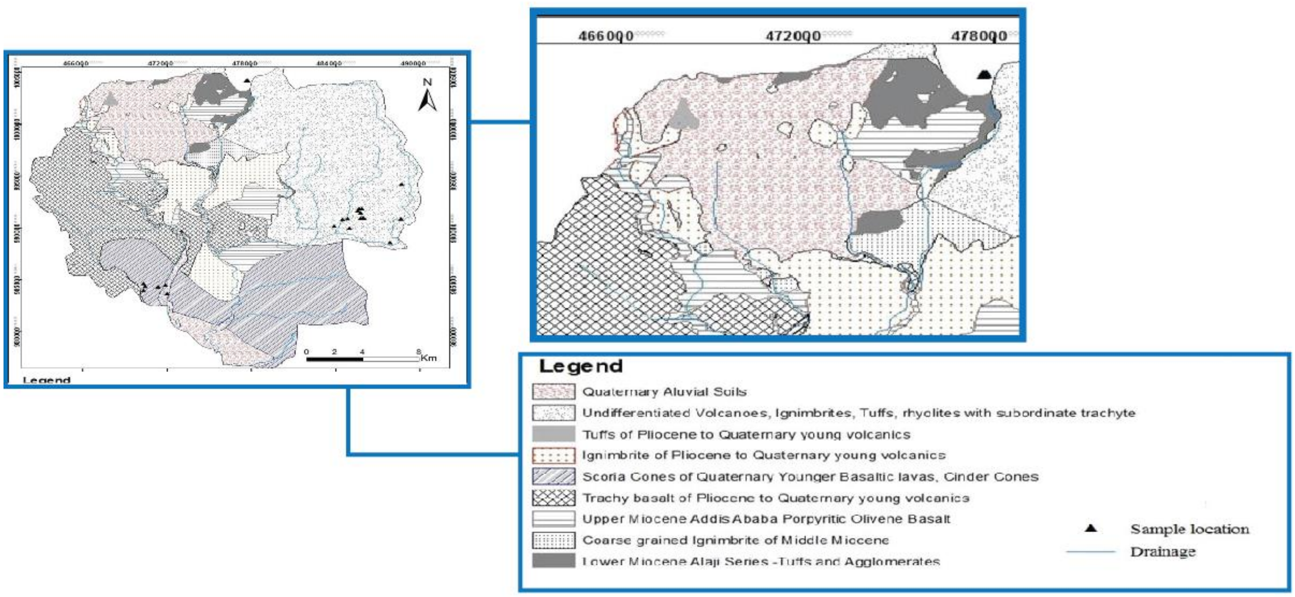

Figure 26-Modified geological map of Addis Ababa city, Source; (BCEOM, 1996).

material one needs to have hands on experience.[82] Moreover the focus of choosing earth and the approach to conserve the construction material is mainly due to its intertwinement with culture and location of the city. Hence to study the material, it is important to first identify specific locations where the required soil typology for construction is available, which helps provide feasible insight on sourcing raw materials.

As a result soil sample was extracted with in the city, Furthermore to narrow the search for location different indicators were followed. Resultantly the information about location selection and primary material inspection step is discussed.

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[81] *Avila, Fernando, Esther Puertas, and Rafael Gallego. "Characterization of the mechanical and physical properties of unstabilized rammed earth: A review." Construction and Building Materials 270 (2021): 121435.*

[82] *Kiesling, Denise. "Adobe in Ethiopia-implementation of earth building projects in the development context: problems/strategies von Denise Kießling." PhD diss., Wien, 2017.*

4.2.1 SITE AND LOCATION

Identifying suitable earthen material for construction can be labor-intensive and time-consuming process. Normally to discern and target potential location for ideal soil, certain indicative approaches are used. Among these the following are the predominant ones;

A-VISUAL INSPECTION- In this approach the color, consistency, and texture of the soil is checked.[83]Generally speaking, cohesive and fine-grained clay is considered of high grade.[84] However this will require seeing different locations and different soil topologies.

B-GEOLOGICAL SURVEY- When geological survey based on given map is followed it is highly likely to find areas and soil type that are suitable for construction, thereby narrowing the area to more specified confinement. For instance geological map (*Figure **26***) indicates the existence of quaternary alluvial soil in the region surrounding *Entoto*, [85] As a result it was used by the research. But the challenge is that it is a general map which sometimes don't pin point the exact locations where the soil type exist due to limited data, interpretational errors, changes over time and urban congestion.

C- SAMPLING METHOD- In this method soil samples from designated area and various depths is gathered. Take numerous samples from each place to ensure the samples are representative of the sites.[86]

This requires a lot of budget, time and samples to be studied in laboratory which unfortunately the research fails to attain.

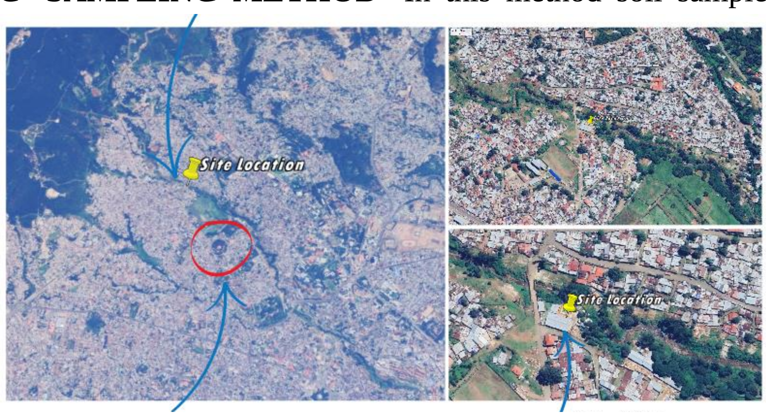

Figure 27-Aerial view of the location, Qechenie Medhanialem area and the local pottery workshop, Source; google earth.

[83] *Das, Braja M. Principles of Geotechnical Engineering. 9th ed. Stamford, CT: Cengage Learning, 2014.*

[84] *Bergaya, Faiza, Maguy Jaber, and Jean-François Lambert. "Clays and clay minerals." Rubber-Clay Nanocomposites: Science, Technology, and Applications (2011): 1-44.*

[85] ***Alluvial soil:*** *is created when river sediments are deposited. Because of its well-balanced composition of sand, silt, and clay, it is frequently appropriate for creating earth-based building materials such as Blocks of Compressed Stabilized Earth.*

[86]*Craig, Robert F. Soil mechanics. Springer, 2013.*

D- USING INDICATORS

Pottery is old traditional craft in Ethiopia, exercised for many centuries. As a result this field has brought certain skillsets and technical expertise that were passed down to generations. By design traditional workshops find suitable earth for production and base their locations with in close proximity to the area.[87] Furthermore it was proven that the raw material extraction sites that provided soil for local pottery workers turned out to possess soil input that is ideal for earthen construction.

Figure 28-Incense pots and storage pithos being produced at Qechenie women's pottery association workshop site. Photo by author, [August, 2024].

One instance of this was in Saudi Arabia *Najran*, where earthen samples used for pottery were tasted in laboratory and turned out to be effective construction material input for earth based building.[88] Consequently following the above indicators the research looked around *Entoto* mountain neighborhood of Addis Ababa, which according to the profile map, features rich variety of natural soil hues, such as reds, yellows, browns, and black. This region is notable for providing soil that suits rammed earth production because of its red soil.[89] Later on using profile map the researcher came to find local pottery workshop which is located around *Qechenie Medhanialem* church, where the raw supply quarry for it was located in proximate areal confinement around *Entoto* Mountain.

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[87] *Qechenie Women's Pottery Association, personal communication, July 7, 2024.*

[88] *Al-Sakkaf, Yaser Khaled, and Gamil Abdullah. "Soil Properties for Earthen Building Construction in Najran City, Saudi Arabia." Computers, Materials & Continua 67, no. 1 (2021).*

[89] *Amede, Ermias A., Gebrella G. Aklilu, Helen W. Kidane, and Alemayehu D. Dalbiso. "Examining the viability and benefits of cement-stabilized rammed earth as an affordable and durable walling material in Addis Ababa, Ethiopia." Cogent Engineering 11, no. 1 (2024): 2318249.*

An approach such as this, made it possible to find potential site for raw material, which made *Qechenie* the perfect place to gather samples for the research. Accordingly this whole endeavor was to minimize the risk of studying the wrong material type for the laboratory testing.

4.2.2 PRIMARY TESTS IN SELECTING EARTH SAMPLES

Figure 29-Soil sedimentation (jar) test. Source: Lori Palmquist.

Figure 30-"The roll test". Source; Haseeb Jamal.

After pinning the location, the next step was roughly checking the samples for suitability. Particularly soil identification process of earthen sample considers different metrics so that sample is qualified for construction.

One technique to assess potential of soil is 'the jar test'. In a clear jar, soil and water are combined, and the mixture is left to settle for full day. Usually Sand and gravel sink to the bottom, followed by silt, and clay forming layer on top as the particles segregate according to size and mass.[90] In order to evaluate the soil's suitability, this test assists in determining the amounts of sand, silt, and clay.
Ideal soil should exhibit distinct layers of sand, silt, and clay otherwise the material could not have the tendency[91]which was exhibited in the research's sample. Next is evaluating the soil's plasticity using techniques such as the roll test. Wet the soil and roll it into a thin thread; if it forms a 3 mm thick thread without breaking, the clay content is sufficient.[92] Consequently the sample exhibited this characteristic as well.

[90] *Budhu, Muni. Soil Mechanics and Foundations. 3rd ed. Hoboken, NJ: John Wiley & Sons, 2010.*

[91] *Ibid.*

[92]*Terzaghi, Karl, Ralph B. Peck, and Gholamreza Mesri. Soil mechanics in engineering practice. John wiley & sons, 1996.*

PARAMETERS FOR THE IDEAL CLAY

When speaking about the ideal type of sample the following among many others are post characterization parameters, which are found after studying the material in the laboratory. But none the less they should be presented for context.

Clay-rich soil is often preferred for earthen construction due to its cohesive properties. Clay particles are very small and can bind together tightly, resulting in good strength and stability when dried[93]Particularly, when the material is intended to be compressed as in the case of rammed earth, clay ratio is important parameter. The other important trait of clay is its plasticity, and it is this reason that clay is preferred for poetry. When the degree of material's clay richness is high the engineering properties usually make it fat clay which can be enhanced using mechanisms to fit required standard.[94]

While clay is important for cohesion, a balanced mix of silt and sand can improve the workability[95] of the soil mixture. Silt adds smoothness and plasticity, while sand can increase drainage and reduce shrinkage upon drying.

Some amount of organic matter can be beneficial for enhancing soil structure and providing nutrients for potential vegetation on or around the structure. However, excessive organic matter can lead to instability and should be minimized.[96]Because it helps to bind the particles together, organic materials such as straw, fibers, or plant material can increase the tensile strength of the soil mix and decrease breaking.[97] Diverse range of particle sizes, including fine particles such as clay and silt as well as coarser particles like sand and gravel, can contribute to more stable and durable soil mixture.

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[93] *Bergaya, Faiza, Maguy Jaber, and Jean-François Lambert. "Clays and clay minerals." Rubber-Clay Nanocomposites: Science, Technology, and Applications (2011): 1-44.*

[94] *Terzaghi, Karl, Ralph B. Peck, and Gholamreza Mesri. Soil mechanics in engineering practice. John wiley & sons, 1996.*

[95]***Workability:*** *refer to how easily soil may be compacted, shaped, or worked for variety of uses, especially in agriculture and building.*

[96] *Brady, Nyle C., Ray R. Weil, and Ray R. Weil. The nature and properties of soils. Vol. 13. Upper Saddle River, NJ: Prentice Hall, 2008.*

[97] *Houben, Hugo, and Hubert Guillaud. "Earth construction: a comprehensive guide." (1994).*

Proper compaction during construction is essential for increasing soil density and reducing the likelihood of settlement or structural failure over time. Mechanical compaction methods or manual tamping can be used to achieve the desired density.

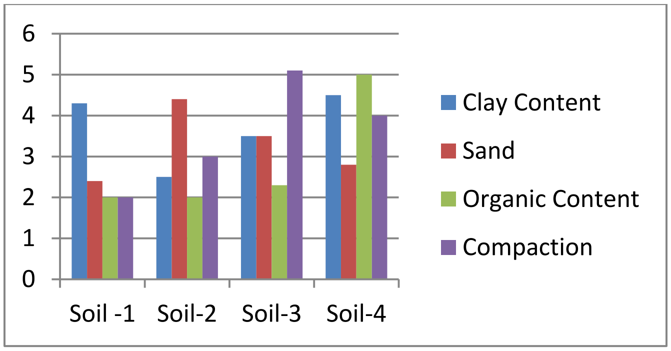

Table 2-Example of the ideal parameters of soil for construction.

The major components of soil affect the preference and degree of selection to the soil for construction purposes especially compressed earth blocks. According to ARSO the defining components of soil composition is recommended as followed:

clay content ought to be a minimum of 5% the overall composition, below that range is not recommended and it is preferable if the clay is the biggest proportion in the mix, if the clay percentage is maximized to the highest that is above 30%, 1.8 on the vertical scale (refer to *Table 2*) its performance should be tested and high clay ratio usage enhances the cohesion and compressive strength of the blocks.[98] That is why the paper went above line.

Moreover combined silt and sand concentration of about 1.5 (refer to *Table 2)* would be the ideal range for earthen construction. This translates to a silt content of roughly 15%–30%. Silt also reduces the plasticity index of the soil.

Additionally for clay construction, low organic matter level about 2%-4%, or a 0.5 on the scale (refer to *Table 2*) is usually ideal. This maintains the construction's overall strength and longevity while offering advantages of better binding and decreased cracking.

On top of that for earthen construction, high compaction around 5 on the scale (refer to *Table 2*) or 80%-90%[99] is usually ideal. This degree of compaction guarantees that the soil mixture is sufficiently workable throughout the building process while remaining dense and robust enough

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[98] *Reddy, BV Venkatarama, and BV Venkatarama Reddy. Compressed earth block & rammed earth structures. Springer Singapore Pte. Limited, 2022.*

[99] *The percentage indicates that the soil can attain high compressibility creating denser composition.*

to support the structure.[100] Even though it's impossible to discern the compaction result of clay, by visual inspection this metric is a decisive indicator in general.

Additionally studying the material on a granular level allows a contact between culture and scientific approaches. According to *Minke*, earthen houses are essential for maintaining cultural heritage and the materials should be given out most priority. Thus in order to maintain cultural continuity and pass on the knowledge of architectural legacy to future generations, these techniques must be preserved.[101]

4.2.3 LOCAL CONSTRUCTION PRACTICE

Understanding local construction methods can give insight on how to integrate earthen materials into existing practices. Up on the visual investigation the construction practice around *Qechenie Medhanialem*

Figure 31-Local earthen construction practice around Qechenie Medhanialem. Photo by author, [June, 2024].

area is comprised of old *kebele* houses in tandem with modern complexes. These *kebele* houses are usually made up of wood and earth. The area's urbanization trend seems to be evolving and utilizing conventional building materials. In parallel in the city in general the traditional construction technique is slightly different from the rural Ethiopia, as it is updated and conforming of some newly applied elements such as CIS roofs.[102] Additionally technique such as the holing method (*Figure **31***) was exhibited in the survey, which is traditional method of drilling small holes in the earthen wall for the applications including aesthetics, strengthening the finishing layers and allowing air to access the inner section of the wall.

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[100] *African Organization for Standardization (ARSO). Compressed Stabilized Earth Blocks: Requirements, Production and Construction (WD-ARS 1333:2018). ARSO, 2018.*

[101] *Minke, Gernot. Building with earth: design and technology of a sustainable architecture. De Gruyter, 2006.*

[102] *Cherenet, Zegeye, and Helawi Sewnet. "Building Ethiopia." (2012).*

Figure 32-Earthen construction highlights around Qechenie area. Photo by author, [July, 2024].

When examining accessibility and abundance of raw materials red clay in the areas is existent and is seen being utilized for application of walls and pottery. But from the expansion of the settlement and urbanization, these areas in the future could end up being covered by infrastructures, which makes it impossible to source raw materials.

4.2.4 COMMUNITY ENGAGEMENT AND INTEREST

For the growth and usage of earth as material in local construction, it is a conspicuous strategy when the community is interacting with the material. Additionally using earth encouraging self-sufficiency and community involvement in housing.[103] Based on the research's visual observation conducted in June, 2024, local community and the degree of intimacy with earthen construction trend in *Qechenie* area can be visible.

[103]Amede, Ermias A., Gebrella G. Aklilu, Helen W. Kidane, and Alemayehu D. Dalbiso. "Examining the viability and benefits of cement-stabilized rammed earth as an affordable and durable walling material in Addis Ababa, Ethiopia." Cogent Engineering 11, no. 1 (2024): 2318249.

4.2.5 URBAN TRENDS

Based on the investigation construction pattern in areas around the main street are comprised of conventional building materials and building complexes around inner section of the neighborhood are slums and *kebele* houses, most of which are predominantly earthen construction.

Figure 33-Construction style in the Qechenie Medhanialem area. Photo by author, [July, 2024].

Generally the urban construction practice shows the abundance of earth in larger proportion, which otherwise might not be true when observing the CBD[104] areas of the city, as they are overwhelmed by modern day construction materials.

Even though these buildings are reflective of urban construction dynamic, they are obsolete and built in a blend of traditional method with the modern materials such as, roofing system and gypsum finishing on top of the dried daub.

Figure 34-Construction trend in the Qechenie Medhanialem area. Photo by author, [June, 2024].

Moreover some exhibited character of these buildings is that walls are plastered using cement, gypsum and paints, making most of this construction appear modern like. Nevertheless in some cases earthen material is visibly exposed example (*Figure **33***). As claimed by local residents during the field visit this can sometimes be used as measure of economic status of households. If the building is cladded with cementing layer, the household is likely to attain more financial stature than the ones with the earth exposed.

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[104] ***CBD:*** *Central business district represents business areas in the city with high land value such as Bole and Lagare.*

4.3 EARTHEN CONSTRUCTION EXPERTIES

From a materials point of view earth is just another construction input the like of cement which is conventionally applied all over the world. However earth for Ethiopia is not just another material but a deeply rooted cultural construction supply. As a result there has been a development of construction tradition that is applied for execution. As an old-aged tradition it was not only the material but also construction expertise has been passed down across generations. These Skillman ship is existent in traditional earthen builders. However these experts along with the knowledge around it are currently fading away due to the spread of

Figure 35-Ato Angasso involving in the Abba Jifar palace conservation and reconstruction project. Photo by author, [July, 2024].

conventional building materials and variety of other factors. [105] This knowledge and dexterity resides in the hands of traditional experts who are undervalued and sidelined. As a result the research deems that conservation of this virtual knowledge must be given out most importance when thinking about conserving the construction as a tradition. Therefore they should be considered as one integral component of the culture.

The UNESCO initiative, 2007 states that involving traditional experts is an important stance, and underlines that integral interaction of different professionals is paramount to conserving traditional construction methods of different cultures.

[105] *Angasso, Urgessa.* Personal communication*, June 2, 2024.*

It mentions the need to develop regional and national capacities for site managers and technical

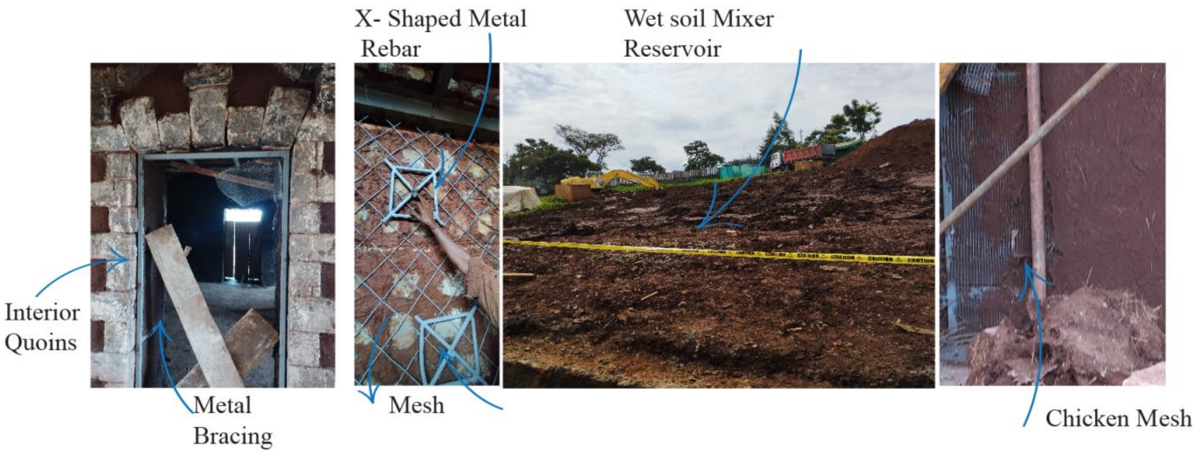

Figure 36-Abba Jifar place construction process and construction details. Photo by author, [July, 2024].

experts to enhance the conservation, presentation, and management of earthen architectural heritage in general. Furthermore, the document highlights significance of engaging artisans and heritage experts in specialized training on earthen architectural conservation. Traditional experts play important role in preserving the authenticity and cultural significance of earthen architectural sites, making their involvement essential in conservation efforts.[106]

Figure 37-Jimma Abba Jifar palace after completion of the projects. Source, Ethiopian broad casting corporate.

This acknowledgment emphasizes the role that traditional experts play in maintaining and disseminating the knowledge and abilities required for building with earth, guaranteeing the persistence of customary building methods and practices. But this research under lines it is not only in physical conservation of, an already built earthen construction, that we need these experts but also in the protection and transfer of the virtual knowledge. The best local case study that

[106] *UNESCO. World Heritage Programme on Earthen Architecture. WHC-07/31.COM/21C, 2007.*

corroborates this stance is the *Abba Jifar* palace renovation work. Although the issue of the focus and attention to the authenticity-aware and culturally informed intervention is for another discussion, Ato Angaso's substantial role was manifested in the outcome of the project. Thus experts like him are paramount in the likes of this project.

This is further supported by knowledge management model, where multi-directional skills and knowledge in the realm of conservation of earthen construction are structured and applied in the conservation process. [107] Hence traditional earthen construction expertise as virtual form of knowledge needs to be managed and preserved as part of earthen architecture culture. Moreover the research selected an individual, who is well versed in the domain of traditional earthen construction and practiced in the field for about twenty years in Addis Ababa. Subsequently he shared his knowledge and skills which he had acquired over the years.

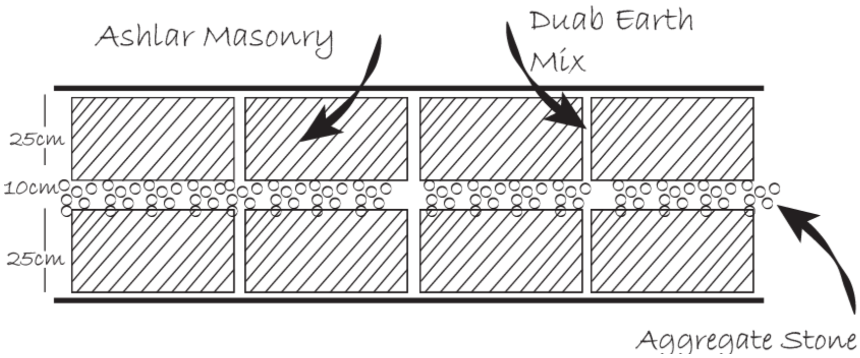

Figure 38-Generated wall plan of construction detail of earth and masonry Stone mixture wall according to Ato Angasso.

Figure 39-Common earthen architecture typologies in the city, two images taken for comparison; Source Mania Taher (left) and Philippe Jeanty (middle.) Bitwoded Hailegiorgis residence (right, photo by author).

[107] *Masera, M., Mecca, S., & Stracuzzi, A. (2003). Knowledge Management approach for conservation of earthen architecture heritage.*

According to Ato Angasso, earthen construction technique has been underestimated by the construction sector and struggled to strive as an industry.[108] In his experience over the years Ato Angasso was able to witness a shift in construction industry from utilizing earth to utilizing HCB blocks as a primary construction material. But none the less earthen construction edifices and methods survived among the lowest financial echelon and less fortunate section of the community. This is mainly because earth as a material is very affordable to find and easy to construct. In his early days of earthen construction practice Ato Angasso served as daily laborer in the local earthen construction of private houses trying to make ends meet.

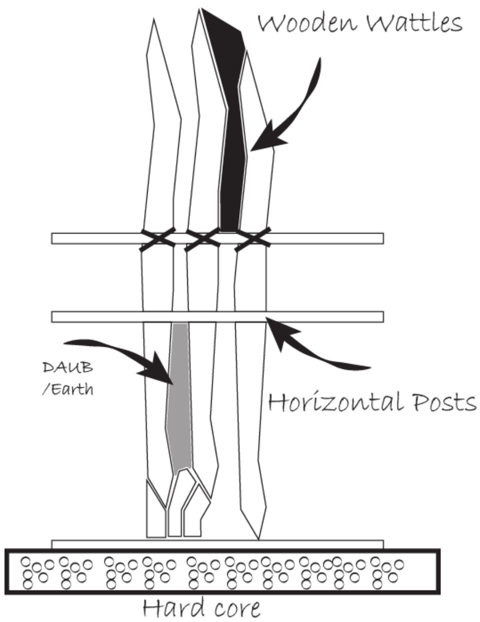

Figure 40- Representation of wattle and daub method according to Ato Angasso. Source; Author.

After years of being in the traditional construction practice, he was able to acquire substantial understanding of the skill, that he is now fully committed to the practice.

This has enabled him to get involved in much bigger earthen construction and conservation projects in and outside of the city.

Among all other projects, one notable work, he has participated on, was the Abba *Jifar* palace reconstruction and conservation project, which he is the head expert of earthen construction specialists. The project is government backed aiming to conserve the falling earth, stone and wooden construction palace of *Abba Jifar* II. Ato Angasso's task in this project was focused in the earth based techniques and their application, But due to the magnitude of the project volume it was imperative for him to collaborate with structural engineers, electricians, welding and finishing experts, allowing him to interact with other professionals and adapt to circumstances. In his experience with earth as a building material, he was able to adapt certain techniques, which eased the construction technique.

[108] *Angasso, Urgessa.* Personal communication*, June 2, 2024.*

For instance he was also able to apply detailed techniques such as the *x-rebar*[109](refer to **Error! Reference source not found.**) and combine them with the traditional knowledge in the *Abba Jifar* conservation project.

Although this detail was mainly coerced by the engineers, the fact that he was able to follow along and merge his expertise is versatile. In Addition he was also able to execute multi story building projects in *Kazanchis* area where the structure of it was built using conventional method and the partition walls were executed using the wattle and daub method. [110]

Furthermore, over the years he participated in different projects and variety earthen construction typologies. Particularly his experience in the application of earth and ashlar masonry, which is a particular trait of the vernacular Addis Ababa Style architecture[111], makes him rare among few earthen construction experts.

These construction styles were also existent in the *Axumite* period (100 AD-900 AD)[112] more so in a newer and grand fashion they were being applied in the Addis Ababa architecture of royal complexes that were erected during the flourishment of the city. The fact that Ato Angasso was able to acquire such skills and got involved in such projects indicates that, the dexterity is rare and can get passed down across generation.

Additionally Ato Angasso stated that his experience in wood and mud traditional (wattle and daub) constructions has helped him to explore more ways to construct and identify materials suitable for earthen construction.

However according to him due to urbanization, legislative coercion, advancement and exposure to modern buildings the trend seems to be disappearing. Supported by the inverse relationship between development levels and the use of earthen construction, these experts are in imminent threat of extinction.

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[109] ***X-rebar:*** *Is the application of reinforced steel bars (rebar) arranged in a cross (X) pattern inside the structure to increase its stability and tensile strength.*

[110] *Angasso, Urgessa.* Personal communication*, June 2, 2024.*

[111] *Levin, Ayala. "Haile Selassie's imperial modernity: Expatriate architects and the shaping of Addis Ababa." Journal of the Society of Architectural Historians 75, no. 4 (2016): 447-468.*

[112] *Jetie, Samuel Bekele. "Appraisal of vernacular stone housing typology of Tigrai, Ethiopia." International Journal of Architecture, Arts and Applications 11, no. 2 (2019): 1-9.*

4.4 MATERIAL ANALYSIS AND CHARACTERIZATION

In an integrated study of earth as a construction material, it is essential not only to recognize its cultural value but also to conduct detailed material-based research to fully understand its characteristics and behavior which helps focus on the material more closely. As a result this section is dedicated to the attempt that sheds light on the behavior and over all properties of the designated soil. It is the analysis framework for the material's behavior, which involves investigation of its substantial characteristics.

4.4.1 PRODEDURE

Around 26 kilograms of sub-soil section[113] was collected as a sample from the area. Also it was collected in two sections, which were around 13 kilograms each. The main reason for the selection of soil that is found under the top soil section was to avoid impurities that could impact the testing process.[114] For earthen construction, sub-soil is typically chosen over the top soil. In addition the following are some of the other reasons why sub-soil in general is preferable strata when selecting sample for construction;

Sub-soil is more stable and durable due to its higher proportions of silt, clay and lower organic content. By using as little organic material as possible, structures are kept stable by lowering the chance of breakdown over time especially stabilized blocks. Because of the cohesive strength provided by the clay and silt content, the subsoil is perfect for compacting and molding into sturdy, long-lasting buildings.[115]Compared to topsoil, the composition of subsurface is more constant. While subsurface stays more consistent, topsoil fluctuates as a result of vegetation, erosion, and surface activity.

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*[113] **Lower soil section:** the lower layer (sub-soil) of that exists 50-100cm below the surface.*

[114] *Maïni, Satprem. "Earthen architecture for sustainable habitat and compressed stabilised earth block technology." The Auroville Earth Institute, Auroville Building Center-India 14, no. 4 (2005): 112-128.*

[115] Terzaghi, Karl, Ralph B. Peck, and Gholamreza Mesri. Soil mechanics in engineering practice. John wiley & sons, 1996.

PREPARATION OF THE SAMPLE

After selecting the appropriate site, soil strata and identifying soil type, the first sample was collected from the site. The research extracted approximately 26 kilograms of particular clay sample for laboratory analysis.

After the sample was brought to the laboratory the next step was quartering[116] the whole soil unit in four divisions. This procedure is used to obtain the ultimate uniform soil composition. Clods also need to be pulverized[117] to finer soil so that it is suited for the quartering.

Figure 41-The primary stage of soil testing (quartering). Photo by author, [July, 2024].

Figure 42-Compartmentalizing the sample and readying it for different tests. Photo by author, [July, 2024].

[116] ***Quartering:*** *refers to mixing and dividing the sample into four equal sections to have the mix contain the ideal combination of the composition, then use the one quarter.*

[117] ***Pulverization:*** *is the process of crushing clods (stacked clay) into finer particles.*

After one fourth of the whole sample was taken, then it is extracted for the sampling of particle size distribution. Particle size distribution (PSD) in soil testing is the division of the soil into its constituent particles according to size. Understanding a soil's behavior requires the use of the PSD[118] and index property[119] test. This phase sets the amount of sample ready for studying the earthen sample.

Henceforth the next step was preparing three compartments for the three different tests from the final quartering output. These tests are the hydrometer test, Atterberg limit test and specific gravity test. Hence they are imperative to determine the soil character and mandatory instruments for engineering construction.[120] The compartmentalization used sieves[121] to identify smaller soil samples from the bigger one. For example a No. 200(0.075mm) was used to filter out the samples for specific gravity test. And the other samples are for hydrometer and Atterberg limit test. The filtered out residue from the three sieves is put for the moisture content. The sieving is used for the three samples and the last one is the residue that is extracted from the three sieves. The only difference between the sieves is the difference in diameter which discerns the grain size of the clay by filtering out the finer ingredients. The smaller the diameter the finer the filtered out soil is. After the necessary samples were taken the next step was extraction of sieve samples. This took place in the workshop of the testing center *Figure* ***43***. From sieving the final residue using a No. 200 sieve under water, the final filtered out

Figure 43-The final residue left from the sample sieved using a No. 200. Photo by author, [July, 2024].

Figure 44-The three different types of sieves applied. Photo by author, [July, 2024].

[118] ***PSD (particle size distribution):*** *describes the proportion particles of different sizes with in the material.*

[119] ***Index properties****: are physical properties that indicate the behavior of the soil under certain conditions.*

[120] ASTM International. ASTM D4318-17e1: Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. ASTM International. https://doi.org/10.1520/D4318-17E01.

[121] ***Sieves****: are tools that filter and retain out different radius soil grains accordingly, they are expressed in opening diameters or number of openings, for instance No 200 refers to a sieve with its opening size 0.075mm and 200 square openings.*

sample that was obtained was used for the sieve analysis test. Therefore through this step the samples were ready for the necessary tests.

4.4.2 LABORATORY TESTING

Afterwards the research went to measure the granular composition and properties of the selected soil type, in the laboratory, where the room temperature is assumed constant.

In the next phase the soils Atterberg limits, hydrometer test, specific gravity, sieve analysis, and compaction tests were conducted. Thus it is the first phase where the raw material that has been extracted from the quarry is directly tested without any addition of ingredients and stabilizers. The first test from these set of tests is the Atterberg limit.

ATTEBERG LIMIT

The behavior of fine-grained soils under various moisture conditions can be understood and predicted with the help of the Atterberg limits. They offer vital data for construction quality control, soil categorization, and the evaluation of the stability and workability of the soil.

In this process the three Atterburg limit tests are carried out to understand the soil characteristics. The first test is liquid limit test the intention of which is to get the water content where soil changes from a plastic to a liquid state and begins to flow.

1-LIQUID LIMIT TEST

The test is conducted using a liquid limit apparatus known as the *Casagrande* cup.[122] In order to perform the test, a soil sample is wetted down to the moisture content at which the dirt folows a predetermined distance when force (blow) is applied.

[122] ***Casagrande Cup:*** *is a device used in soil mechanics to determine the* ***liquid limit*** *of a soil sample.*

Figure 45-Liquid test limit. Photo by author, [July, 2024].

After extracting a handful of fined soil from the sieved Atterberg limit sample, the soaking[123] of the clay followed. The sample is soaked for a day and then scoped out to be mixed on a glass plate with a limited amount of water.

The soaked sample is well mixed with spatula[124] to have the water reach the different parts of it. Later, the *Casagrande* cup is filled properly for the test, then a slit in the middle of the cup is grooved separating the sample in to half which are called clay pats. A standard of three ranges of blows follow to find the liquid limit of the sample. And if errors occur the process is done over and over again. The first blow range[125] is from 25 to 35, the second is 20 to 30 and the third blow is 15 to 25. Following the procedure shown in first phase the test iterated the procedure ten times before it was an accurate blow.

Figure 46- Liquid test blowing process using the Atterberg limit device. Photo by author, [July, 2024].

[123] ***Soaking:*** *Refers to the process of saturating a soil sample with water to ensure uniform moisture distribution before performing specific tests.*

[124] ***Spatula:*** *a handy metal plate that is used to flatten and mix the soil with water.*

[125] ***Blow range:*** *is used to describe how many blows are necessary to transform a soil sample from a liquid to a plastic condition.*

So the numbers where the blows accurately produced closure point[126] for the three trials were 33, 26 and 18 respectively. Refer to appendices.

After the correct blow, the opened groove[127] intersected at a point and that section of the sample was taken out of the cup to be measured. The sample that is extracted from the *Casagrande* cup is 13mm covering the closure points. The first, second and third samples were placed in a can and the weight of it was measured in a wet state and afterwards it was placed in an oven to have the water dried and then the mass was measured in a dry state.

Figure 47- The Extraction of the liquid test sample and weight measurement. Photo by author, [July, 2024].

And according to the extracted data (refer to appendices); the liquid limit (LL) of the soil was found to be 83[128], the plastic limit (PL) is found to be 36 and the Plasticity index (PI) became 47.

2-SHRINKAGE LIMIT TEST

The simplest test, in the Atterberg limits, is the shrinkage limit test. Determining the shrinkage limit and measuring soil shrinkage are done to find the volumetric stability of the soil during drying. This data is essential for classifying and managing soil, guaranteeing the stability of structures, and anticipating and averting possible issues associated with changes in soil volume. The apparatus used, is called shrinkage dish which is made of brass or bronze, it is used to hold

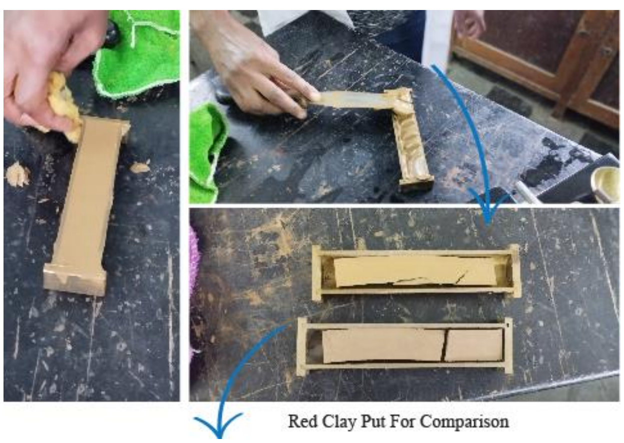

Figure 48-Shirinkage limit test and result. Photo by author, [July, 2024].

[126] ***Contact points:*** *point along a predetermined length (usually 12.5 mm) where the groove made by the Casagrande device closes or makes contact after being struck several times.*

[127] ***Groove:*** *is a slit opening that is cut using a grooving tool to separate the clay pats in the disk.*

[128] ***High liquid limit:*** *a liquid limit that is generally above 50 is considered high, which means it requires large amount of water to transform from plastic to liquid state.*

the soil sample. The sample is taken from the soaked clay of the Atterberg limit test, then filled with spatula. Later it was labeled and put into an oven so that it loses its water content. The red clay in the picture (*Figure **48***) is a sample that has been used by the paper discussed in the literature, while the yellow clay is the test sample for this research. The results of the shrinkage test shows a bigger shrinkage length after it dried in the oven for two days, when compared to the red clay sample. The average length of the mold is 13.96 cm, and the average length of the sample after it was brought out of the oven was 11.705 cm, showing a 2.25 cm shrinkage. A shrinkage limit 16.3% indicates that the clay has already undergone significant shrinkage with certain amount of water loss. This means that the clay is highly prone to shrinking and cracking when it dries out. Additionally the liquid limit and plastic limit tests showed that the raw clay exhibited fat clay characteristics. Hence the plasticity index (PI), the plastic limit and liquid limit were 47, 36 and 83 respectively.

SIEVE ANALYSIS

Figure 49-Sieve analysis test. Photo by author, [July, 2024].

The particle size distribution of a granular substance is ascertained via a sieve analysis test, sometimes referred to as a gradation test. It is often used in soil science and construction to evaluate materials. And the procedure that was used here was sieving the soil for different particle size later the residues of each sieve were collected in a can. The wider sieve size is placed on the top and the smaller one in the bottom. A mass of 3239.3 gram was sieved through six sieves aligned together and the percentage passing for each sieve number turned out to be 99.76%, 99.64%, 99.376%, 98.377%, 96.777%, and 94.765% .This depicts that the soil contains a considerable amount of silt and clay-sized particles, the high percentage passing through the finer sieves, particularly the No. 200 sieve, indicating that the soil has significant clay content (for more refer to the appendices).

SPECIFIC GRAVITY

A specific gravity test measures the density of a substance compared to the density of water, which offers information for comprehending the properties of soil, creating safe and efficient structures, and guaranteeing the stability and durability of building projects.[129]This test is conducted for particles less than 4.75mm of radius.[130] By measuring the specific gravity of a soil sample, we can infer the minerals present based on how closely the measured value matches the known specific gravities of various minerals. For the test two *pycnometer*s were calibrated each with a volume of 240 cubic meters, and soil that is primarily composed of distilled water is filled in to the *pycnometer* until the level reaches the meniscus. Then a 35.5grams and 36.6 of an oven dried soil is poured in to the two *pycnometer*s, thereafter shaken manually. From then on the air is sucked using an apparatus called de-aeration device (vacuum apparatus). This step is re iterated again and again until the air is sucked out of the apparatus. Afterward the result of the average specific gravity became 2.66(refer to appendices).

HYDROMETER TEST

The next test was the hydrometer test which is used to analyze the particle size distribution of fine grained soils, such as silts and clays. The purpose of the test is to determine the proportions of different-sized particles in the sample, which helps understand the soil's physical properties and behavior. The test measures the relative density of a soil suspension over time, related to the particle size distribution. Finer particles take longer to settle,

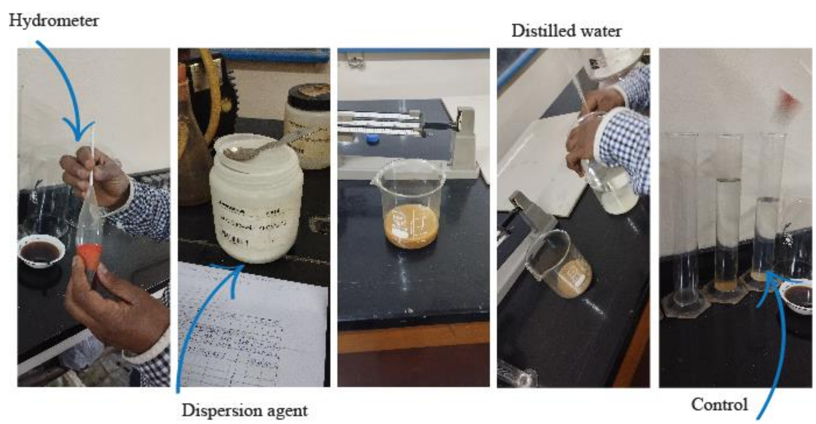

Figure 50-Hydrometer analysis test. Photo by author,   [August, 2024].

[129] *Craig, Robert F. Soil mechanics. Springer, 2013.*

[130] *Millspaugh, Andrew M., James M. Tinjum, and Timothy A. Boecher. "Specific gravity of expansive chromium ore processing residue with complex microstructure." Geotechnical Testing Journal 33, no. 4 (2010): 322-328.*

and the hydrometer readings at specific intervals help determine the distribution of these particles within the sample. [131]For this test a 1000 ml sedimentation jar, control jar, an ASTM 152-H hydrometer apparatus, 5.4g of a soil dispersion de-flocculent[132] (sodium hexa-meta phosphate) a squirt bottle (100 ml of distilled water) and a thermometer were used. A mechanically pulverized soil of 50g was mixed with a dispersion agent shaken inside the sedimentation jar. The result from the hydrometer test reads a percentage passing of 84.3 from the first one to 58.514, the last one. For more information refer to appendices.

COMPACTION TEST

This test will specifically tell us the ideal moisture level at which the soil will reach its maximum dry density and the optimum water content. Prior to this test, there was a first compaction test using the same clay with varying water content, but the test was disqualified owing to a procedural failure, and another test was required to be performed.

Figure 51-Soaking sample for compaction test preparation process. Photo by author, [August, 2024].

Figure 52-Compaction test using standard proctor apparatus. Photo by author, [August, 2024].

Therefore for the re-do test trial, the rest of the quartering residue soil, was collected and crushed together and sieved with a No. 40 sieve. And the filtered out sample is then compartmentalized in to five samples of each 2000g. And a moisturizing water of 8 percent

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[131]*Das, Braja M., and Khaled Sobhan. "Principles of geotechnical engineering." (1990).*

[132] ***De-flocculant:*** *is a substance that is added to the soil-water suspension to break up or reduce the flocculation (clumping or agglomeration) of fine particles, especially clay particles.*

increment from a reference of 8 was added to the samples. The reason increment of water is added to the samples, is to find the exact water content that yields the maximum dry density.[133] Following a day of soil soaking[134] using a regular rammer[135] and the 4 inch mold, the compaction was carried out. The soaked sample is later applied in to the compaction mold with each sample approximately one third of the whole compaction mold volume. Then the collected final samples are taken to the oven to dry so that the moisture content is measured. Finally the result showed a dry density of 1.24, 1.26, 1.29, 1.33, 1.34 and 1.073. Thus the maximum dry density is found at the final trail at 1.34 (for more information refer to appendices).

4.4.3 RAW MATERIAL SUMMARY

All of the above tests are carried using the raw clay that is extracted, without any mixture. The reason is that, the characteristic of the soil has to be understood at first before any kind of intervention is executed.[136]This phase of the research is called material characterization, where the properties of the material are understood.

Figure 53- Air drying wet Dembaqie sample in the laboratory. Photo by Author, [August, 2024].

There the intervention was tested on the soil sample with different proportion of stabilizing agents in order obtain the ultimate performance of the soil. Stabilizers are elements that are added to soil intentionally to enhance a certain character or yield the performance of it to with stand different challenges. The first proposed agent to test out was cement, because according to ARSO cement is an ideal stabilizing agent and a plasticity index reducing element that helps in strengthening the soil composition.

[133] ***Maximum dry density (MDD):*** *represents the highest achievable dry density for a soil at a given compaction energy and corresponds to the point where the soil particles are most densely packed.*

[134] ***Soaking****: refers to the procedure of immersing a compacted soil sample in water for a specific length of time in order to fully saturate it.*

[135] *R**ammer:** is a tool used to apply force to the soil in a mold during the compaction process.*

[136] ***Intervention:*** *in the research's context, refers to the act of mitigating the materials characteristics by stabilizing it.*

The Second element is locally extractable material that exhibits silt like property, called *Dembaqie.*

The material is sourced from *Debre-libanos* area; which is located 100 km away from Addis Ababa. More over the pottery workers were applying it alongside the clay in the making of these traditional pots. The proportion they used was half the size of the clay. The reason they were utilizing the *Dembaqie* was due to its strengthening character.[137] It also helps in the composition by reducing the plasticity of the soil. According to ARSO the maximum cement usage as stabilizing agent in earthen blocks is 10%. However given the research's imperative and economic reasons the utilization of cement is kept bare minimum. As a result different experimentation at 3%, 6% and 9% were executed below that standard range. These numbers are chosen to even out the range scale and experimenting with in the allowed threshold. Thus according to ARSO the silt in CSEB is recommended from 15%-30% and using this along with the ratio provided by the pottery workshop, the research tried to use the *Dembaqie* at the 30%. While further scientific analysis of the material is necessary, preliminary visual inspection has led the research to consider two potential assumptions regarding the type of element Dembaqie might be. The first one is Pumice.

Pumice – In the non-pulverized state the material resembles white pumice, which is a volcanic ash that is found on a mountainous confinement. The material (Dambaqie) exhibits somewhat similar physical properties as Pumice. During violent volcanic eruptions, pumice—a light, porous volcanic rock is created. Its foamy, sponge-like texture is the result of gas bubbles being trapped inside. [138]

Figure 54-White tuff formation, Source; Richard Roscoe.

Figure 55- Uncrushed white pumice. Source; Katsumi Murouchi.

Pumice's composition mostly consists of silica

[137] *Qechenie Women's Pottery Association, personal communication, June 27, 2024.*

[138] *Best, M. G. (2013). Igneous and metamorphic petrology. John Wiley & Sons.*

(SiO_2) with minor amounts of alumina (Al_2O_3) and other minerals. Its high porosity renders it incredibly lightweight. Pumice is widely utilized in horticulture (such as soil aeration), abrasives, and building (such as lightweight concrete).[139] And the second is Tuff.

Figure 56-The dry ball test method, Dembaqie. Photo by author, [June, 2024].

Tuff –is a type of volcanic rock (Igneous) formed after consolidation of volcanic ash that is spewed during explosive volcanic action, it mostly includes finer volcanic particles, quartz (silt), feldspar and others.[140]

In order to discern whether the material exhibited a pozzolanic behavior it was checked using the ball (pozzolanic activity) test[141], where by the *Dembaqie* is molded in to a ball and left to dry, afterwards it was crushed using bare hand. If it exhibited silt like characters then it would simply fall apart, thus if it possessed pozzolanic characters it would be hard to crush the ball with bare hand. And the test showed that the material possesses no pozzolanic properties and has more proclivities to be silt.

But none the less these two materials contain silt in them, which gives the research the incentive to utilize the material as one of the stabilizing agents. Subsequently fixing the *Dembaqie* sample at 30% (ARSO maximum requirement for silt) the research tried 3%, 6% and 9% cement application with an Atterberg limit test to understand how the sample behaved under wet circumstance. And studied how the clay responded from the perspective of the plasticity index and limit. The intention is to reduce the plasticity and elastic limit of the material and enhance the materials potential for a strong mix in the application of construction.

According to ARSO the plasticity index must fall in between 2 and 30 but the raw sample showed 47 this is one of the indicators that ought to get in line with the standard and this is one of the drawbacks the research found in the material characterization.And the following are tests

[139] *Klein, Cornelis, and Anthony R. Philpotts. Earth materials: introduction to mineralogy and petrology. Cambridge University Press, 2013.*

[140] *Ibid.*

[141] ***The ball (pozzolanic activity) test :*** *is a quick field test to assess the pozzolanic nature of clay or other materials, by making a small ball and when it dries using bare hand to crush it.*

that were run for the mixed combination of the clay, *Dembaqie* and the cement at different ranges.

The reason the research did not recommend sand is due to the reason; first cost wise it is expensive material and second *montmorillonite* clay has a high swelling capacity due to its propensity to absorb substantial amounts of water. Sand, being a non-cohesive substance, cannot sufficiently reduce this swelling, thus in construction applications, the expansion of *montmorillonite* resulting from water absorption can cause instability when combined with sand.[142] Because of the poor binding between sand and the small particles of *montmorillonite*, the mixture is nevertheless prone to splitting, shrinking during drying, and expanding upon wetness.[143]

TEST-1 (3% CEMENT)

For this first test the *Dembaqie* is fixed at 30% and one of the stabilizing agents (cement) was applied at 3%. Just like in the raw clay test, the Atterber limits test is important to carry out to understand whether desired parameters are achieved. And when mixing it, the combination became slightly whiter than that of the raw clay mix there by reflecting a color change.

ATTERBER LIMIT TEST

After many attempts this test was achieved at 31, 27 and 19 blows. And the result showed that

Figure 57-Atterberg limit tests for the first mix. Photo by author, [August, 2024].

the Liquid limit, Plasticity indexes and plastic limit are 67, 34 and 33.56, reducing the plasticity index by 13, and all the limits. For more information refer to appendices

[142] *Holtz, Rd, Wd Kovacs, And Tc Sheahan. "An Introduction to Geotechnical Engineering, Pearson Education." Inc., Upper Saddle River, NJ (2011).*

[143] *Uddin, Faheem. Montmorillonite: An introduction to properties and utilization. Vol. 817. London, UK: IntechOpen, 2018.*

Therefor the results for the liquid limit (LL) are found to be 67, the plastic limit (PL) is 34 and the Plasticity index (PI) is 34.

SHRINKAGE

For the above tests the clay (3% cement) was put in to an oven, and shrinkage limit test showed, length of the mold is 13.9, Shrinkage average; 11.95 and the difference in shrinkage is 2.01 and the shrinkage percentage is 14%.

Figure 58-Shrinkage Test 3% cement. Photo by author, [July, 2024].

TEST-2(6% CEMENT)

For this test the *Dembaqie* was fixed at 30%, with the stabilizing agents (cement) applied at 6%. Just like the raw clay test, the Atterberg limits test is carried out. While in this case visually inspecting it, the color of the mix became whiter, and the influence of the cement was clearly visible.

Figure 59- 6% Cement mix-up process for Atterberg limit test. Photo by author, [August, 2024].

ATTERBER LIMIT TEST

This test was also achieved after many attempts at 30, 24 and 17 blows. And the result showed that the Liquid limit, plastic limit and Plasticity indexes are 62, 40 and 22 respectively, reducing the plasticity index of the 3% mix by 12, along with the other limits**.** For more information refer to appendices.

TEST-3 (9% CEMENT)

The Atterberg limit test (liquid limit) was achieved at 30, 25 and 17 blows. And the result showed that the Liquid limit, plastic limit and Plasticity indexes are 61, 49 and 12, reducing the plasticity index of the 6% mix by 10, lowering the plastic limit. The goal is to use as much clay and *Dembaqie* as possible while using the least amount of cement. And according to the above result the mixture of *Dembaqie* along with cement was able to substantially reduce the plastic limit and plastic index of the clay, making it the ideal mix for construction of compressed earth block. The middle percentage (6%) was a preferable for the prototype production as it did lower the plasticity index and plastic limit according to ARSO. With this data, the next phase was conduction of the compaction test which lets us determine the bulk and dry density of the mix with 6% cement and 30% *Dembaqie*.

COMPACTION TEST (6% CEMENT)

The compaction test for this selected mix used water content increment[144] of 4 using 14 as a reference, resulted in dry density of 1.16, 1.18, 1.14, 1.18 and 1.17 dropping the density at the third trial where the maximum dry density is found to be 1.14. And taking the point where the density fall, the ideal density MDD was known from the test. Thus in order to correct plausible errors and taking the previously done compaction test results has approximated the value from 1.34 to 1.14. Refer to appendices for more.

4.5 INNOVATIVE FORMULATION

Inferring from the results of the three mix test results along with the first raw sample test results the addition of the stabilizing agents (*Dembaqie* and cement) was able to substantially lower the plasticity index, plastic and liquid limit, Which was the desired intention of adding the stabilizing agents following ARSO.

The raw clay test has a Liquid limit of 83, plastic limit of 36 and plasticity index of 47 with 16.03 % shrinkage.

[144] ***Water content increment:*** *refers to the range used to add the water from the starting reference point.*

And the second phase of tests which involved the three different cement inputs produced the following Atterberg limits; the first test (3% cement, 30 % *Dembaqie* and 67 % clay) produced a liquid Limit of 67, a plastic limit of 34 and a plasticity index of 34. And the second test with (6% cement, 30% *Dembaqie* and 64 % clay) produced a liquid limit of 62, plasticity index of 22 and a plastic limit of 40.

Figure 60- Raw clay Atterberg limits.

Finally the third combination (9% cement, 30% *Dembaqie* and 61% clay) produced a liquid limit of 61, a plastic limit of 49 and a plasticity index of 12. Therefore in accordance with ARSO plasticity index of (2-30) is recommended, thus the middle range (6%) is preferred for the ideal prototype preparation process, which has PI of 22.

This reflected that the increment process lowered both the plasticity index and the liquid limit but the plastic limit kept varying from test to test. The innovative formulation is approved here, as the experiment provided us with clear insight of the material and the ideal preference to stick with. And the 3% mix lowered the shrinkage by 2% from the raw clay.

The final step after the experiment is the production of the prototypes, which is the ideal mix of the three combinations that results the ultimate material addressing the demerits. Thus for the production process two types are prepared; one is the ideal mixture which is the 6% cement and the second is the raw clay which is used as a control sample.

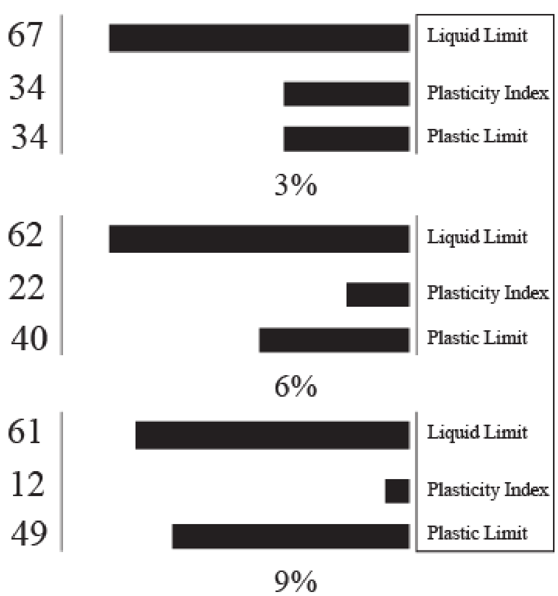

Figure 61-Atterberg limit results of the three mixtures.

4.5.1 CONTROL PROTOTYPE PRODUCTION

The length, the width and the height of the compression mold available at the laboratory is 22.843cm, 10.805cm and 8.788cm respectively. Thus the volume of the mold is 2168.95 cm^3. Where in the compaction test it is found the dry density of the soil as 1.34 g/cm^3.Therefore in order to prepare a prototype for the single mold about 2326.3 g of the sample is needed. Hence for the control including the production waste consideration 11.63 kg was needed to produce five blocks, but for the probable loss of material in the process, around 2kg was added.

Figure 62-Preparation and mix up of the clay sample. Photo by author, [September, 2024].

Figure 63- The ball test method. photo by author, [September, 2024].

Afterwards a clear and flat surface was prepared for the mixing process, later by using the OMC 4.089 (0.6 liters improvisation) of water was added to the spread clay, slowly so that the moisture were distributed. The reference of the water content range was the OMC and later tuned by visual inspection of how the clay responded under moisture.

About six times, as shown in (*Figure 64*) the water is distributed equally, afterwards mixed with hand for more than twenty minutes. Later to discern whether it has attained the right amount of water, a ball from the sample the size of a human fist molded and dropped from the height of a human waist to check if the sample cracks. If so it can be possible to prepare the prototype. And after the pouring of water the sample was ready for the prototype preparation.

For the preparation of the blocks manual compression mold[145] was used, which uses a liver to execute the compaction process.

Then by limiting the input with the scoop[146] the sample was added in to the mold, and then manually compressed to create the prototypes. ,

Figure 64-Prototype production using the raw sample. Photo by Author, [September, 2024].

As shown in image (*Figure **64***) the compression is hand driven. When the maximum human power is applied the prototype is produced. The need for the control prototype is merely for comparison data to put into perspective how the difference in the mix (6%) is when compared to the raw sample. As a result total of five blocks were prepared.

4.5.2 6% CEMENT MIX PROTOTYPE PRODUCTION

With the exception of the sample content, the production process for the mix prototype is identical with the raw clay (Control) procedure. So in this mix up the 6% of the combination is Cement, 30% is *Dembaqie* and the 64% is pure clay. Since the mold has a volume of 2168.95 cm^3 and the compaction test revealed that the soil's dry density is 1.17 g/cm3, roughly 2537.67 g of the mix is needed to create a prototype and 12.66kg for the five blocks was needed. And in accordance with this, 3.8 kg of *Dembaqie*, 0.761kg of cement, and 8.1 kg of pure clay was added to make up the remaining 64%. The sample was added in alignment in order to potentially adjust for the weight loss that occurred during the experiment. But in the mixing process the *Dembaqie* and the clay were first mixed to prevent the cement from being lost in the mixing process, as it is

[145] ***Manual compression mold:*** *a manual machine that uses lever to compact the sample to produce the mold.*

[146] ***Scoop:*** *a handy tool used to pick soil samples.*

light weight and small in amount. Then around 5.5 liter was added, assuming 2.43 l for the clay and 1.14 l for the *Dembaqie* and 2.02 l improvisations.

Figure 65- Process of prototype preparation for the 6% cement mix. Photo by author, [September, 2024].

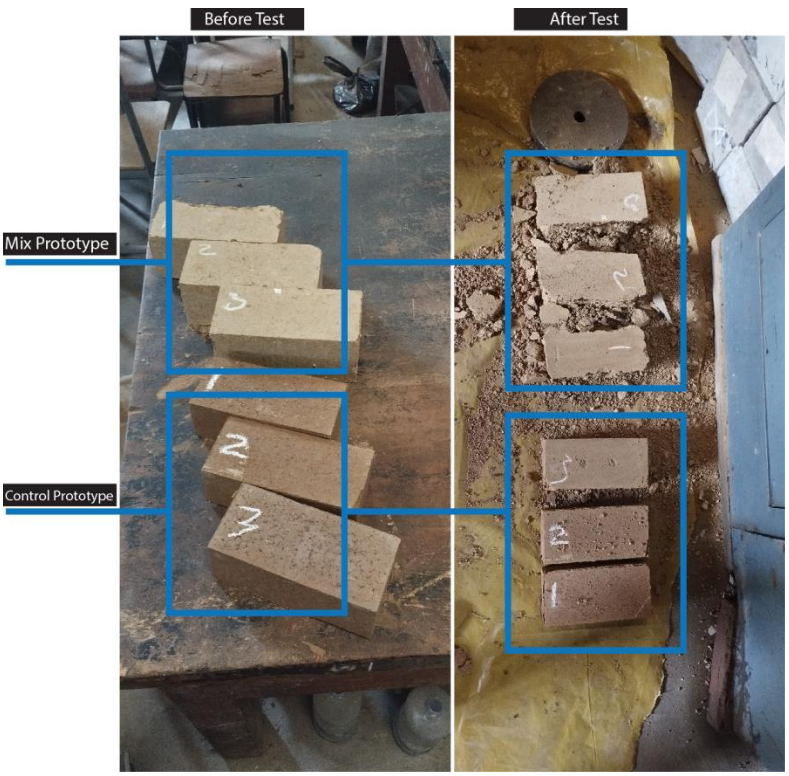

Figure 66- Compressive strength test and visual analysis. Photo by author, [September, 2024].

Due to the shortage of time and unavailable human resources the production step of the raw sample had exceeded the 6% prototype production by one day, resulting a one day shift in the strength testing day. According to ARSO the recommended drying period of the cement stabilized earthen blocks is about 28 days. And during the span of that time no drying agent or crack protection water was added but rather the sample is air dried. And after the blocks were casted all the dimensions were measured and recorded, this is to understand the shrinkage that could occur during the drying time. This measurement is once recorded on the 28th day. It has to be noted that during the casting process some constants were impossible to maintain equal, like the magnitude of the load as the machine is manually operated thus the load applied is not measured. And secondly the sample input in to the mold is estimated with a scoop, which may not inform us the exact amount applied. For instance, if more samples were applied to the mold, height would have increased when compared

Figure 67-Comparative physical visual analysis of the two prototypes. Photo by author, [September, 2024].

to that of the small sample amount. And the same is true for the manual guy, if the load applied varies each time is different or not comparable the compression of the block ends up being lose.

Control Prototype	length	width	height	Size of the Mold
1	22.5	10.6	7.4	22.84 X 10.805 X 8.788
2	22.5	10.7	7.7	
3	22.6	10.6	7.5	
4	22.5	10.5	7.5	
5	22.5	10.6	8.2	

Table 3-Measurement of the blocks for the control sample.

Mix Prototype	length	width	height	Size of the Mold
1	23	10.9	9.3	22.84 X 10.805 X 8.788
2	23	10.9	10	
3	23	10.9	7.5	
4	23	10.9	7.5	
5	23	10.9	8.2	

Table 4-Measurement of the blocks for the 6% cement and 30% Dembaqie sample.

4.5.3 DRY COMPRESSIVE STRENGTH TEST AND RESULTS

After the 27^{th} and 28^{th} day of the casting, the strength test[147] was conducted, and the benefit of this test is that it provides vital information about the soil's strength and behavior under stress, which is essential for safe and efficient design and construction in structure.

[147] ***Dry compressive strength:*** *the ability of a material, such as soil, concrete, or any other building material, to withstand compressive forces while it is dry is known as dry compressive strength.*

Sample No.	Marking	Date Poured	Date	Age (D)	`Dimension (cm)			Volume (dm^3)	Weight (Kg/dm^3)	Unit Weight (Kg/dm)	Press Area (cm^2)	Total Load	Compressive Strength (Mpa)	
					l	w	h							
1	Control	08/28/24	26/09/24	28	20.7	9.9	6.8	1.43	2739.5	1.92	204.95	143.2	6.9877	7.14
2					20.8	9.9	6.9	1.42	2754.4	1.93	205.92	142.8	6.9347	
3					20.7	9.9	7.6	1.55	3107	2.00	204.93	150	7.5	
1	Mix (6%)	08/29/24	26/09/24	27	22.3	10.1	9.5	2.14	3217.1	1.50	225.23	34	1.51	1.55
2					22.4	10.5	9.5	2.23	3280.7	1.47	235.2	39.4	1.6751	
3					22.4	10.6	9.9	2.35	3377.2	1.43	237.44	35.4	1.4909	
1Mpa equals 100KN/cm^2														

Table 5-Compressive dry strength test results.

It has to be noted that the prototype casting date of the two samples differed by one day (the raw clay prototype was prepared one day before the mix) and the testing was done in the same day. There by diminishing the test date for the mix by one day.

For raw soil materials, the clay reflected a very high dry compressive strength, by surpassing the average range (for rammed earth is between 1 and 2Mpa)[148]. This corroborates the results indicated in the Atterberg limit test result of 83 liquid limits, suggesting it to fall under the category of fat clay. And for the 6 % cement and 30% *Dembaqie* mixture, the dry strength result became incomparably lower showing a dry strength difference of 5.5828 Mpa. In the assumption the cement and *Dembaqie* were expected to enhance the material's dry strength, even though their addition was intentioned toward minimizing the plasticity index of the clay. The dimensions of the raw clay prototype also shrunk the highest and the mix in return indicated the lowest shrinkage.

[148] *Walker, P., Keable, R., Martin, J., & Maniatidis, V. (2005). Rammed earth: design and construction guidelines.*

4.5.4 COST ANALYSIS

Material	Type	Measurement Per unit	Dimension (cm) (l x w x h)	Content	Consideration	Total Cost In ETB
Prototype-1	Control	Block	20.7 x9.9x 6.8	Clay water		15
Prototype-2	Mix	Block	20.7 x9.9x 6.8	Dembaqie Cement Clay water	Cement is included	20
HCB	B	Block	40x 20x 15	Cement Sand Water gravel		40
HCB	C	Block	40x 20x 15	Cement Sand Water gravel		38
Cement	Portland	Quintal	Invalid	Lime Clay Iron ore gypsum	Quality Cement	1800

Table 6-Comparative cost analysis of conventional building materials against earth-based prototype.

The pricing for the research prototype materials was based on the standard market rate, but significant overpricing occurred due to two primary factors. First, since the samples were procured for research purposes, suppliers charged higher "research sample" prices rather than the usual market rate. Second, the materials were sourced through third parties who mined them from quarries, incurring costs that forced them to apply a markup. However, the estimations for the study reflect real-time market prices where quarry owners directly supply the materials.

CHAPTER-FIVE

5.1 MAJOR FINDINGS

This study systematically explored various aspects of reviving earth as a construction material while preserving traditional building techniques through a scientific approach. By employing a convergent parallel design, this section provides a critical analysis and synthesis of the findings discussed in the previous chapter, reinforcing the argument for the practical and sustainable application of enhanced earthen construction methods.

5.2 ANALYSIS AND IMPLICATION

Earth has been a fundamental construction material in Ethiopian culture for centuries, playing a significant role in shaping the architectural identity of Addis Ababa. Despite being a traditional building resource, it presents both advantages and challenges from a construction perspective. This research focuses on earth as a primary material due to its deep-rooted connection to Ethiopia's heritage, particularly in the architectural fabric of Addis Ababa.

Thus one of the topics of the research was 'why is there a visible decline in the utilization of earth in the city of Addis Ababa and the country in general?' As a traditionally preferred construction material the paper highlighted some driving factors in the city. Specifically reasons such as; community perception and construction code, which have subtle but substantial impact on the tradition, both negatively and positively.

Even though there is a default collective public opinion that is held regarding the value of earth as a construction material, a questionnaire to overview the existing opinion of the community towards earthen construction had been used to further understand the social dynamics. Thereafter through the subjects the survey showed the general public disregard for the material. Also the survey indicated public opinion to be among the major degrading factor for traditional earthen construction.

Additionally construction codes are listed among the factors influencing earth-based construction in the city and the country as well. More so the recorded responses indicated that the legal landscape is one of the many reasons subtly hindering earth from being utilized.

In tandem the research also studied some of the existing construction code of the country and pinpointed the inexistence of specific codes dedicated to earth as a construction material, and absence of clear empirical standard on the legal sphere.

Ethiopia's as well as Addis Ababa's historical enticement and connection to earthen construction is brought to discussion to portray the cultural value of the material. Furthermore, through literatures the research indicated that earth in not just a locally utilizable material in different parts of the country, but also a historic legacy. Thus the need to studying the material stems from this very reason.

Even though earth is abundant everywhere, the research indicated that there are particular types of the material, with in the spectrum that are suited for construction. Hence in selecting them specifically in urban area like Addis Ababa, it becomes challenging. As a result the paper show cased different replicable approaches and indicators to select locations and make sure the material is ideal for construction, especially for CSEB.

Additionally one of the challenges of traditional earthen construction is the selection of a suitable material. In order to select earthen samples in the traditional context, it would require skilled traditional expert in discerning whether the sample is fit or not. But the rout the research took was, using different proven selection criteria as a metrics to discern the sample. This helped point the potential location where the material could possibly exist, which can be applied and replicated to locate a potential site in other instances. Following these steps narrowed the chance of falling in to the wrong type of soil like black cotton soil, with weak characteristics that is not suited for the desired requirement.

Furthermore, in an effort to preserve the tradition of earthen construction, the research highlights that, despite being largely overlooked, skilled specialists in this craft remain central to the cultural fabric. These artisans possess invaluable generational knowledge, techniques, and a deep understanding of earthen construction. However, the study reveals that both the tradition and its practitioners are gradually disappearing. If this trend continues, earthen construction may soon become obsolete. To address this concern, the research engaged an expert with over twenty years of experience in the field. Through this collaboration, the expert shared his insights and demonstrated traditional construction techniques, including a method for building stone and earth composite walls, approximately 60 cm thick. The stones utilized are masonry stones where each is around 25 cm thick, and they are placed on top of one another, in opposite end of a small space in the middle which is filled with aggregate and coarser soil and the stones are conjoined with daub. This is one of the techniques applied in the royal Addis Ababa architecture, making it one of the strongest traditional wall construction utilizing primarily earth and stone.

The study also acknowledges that earthen construction has both strengths and limitations. However, the primary focus is on maximizing the material's potential while addressing its shortcomings. One of earth's most distinctive advantages is its hygrothermal properties, which set it apart from conventional construction materials such as hollow concrete blocks (HCB) and reinforced concrete (RC). Unlike these materials, which often require mechanical air conditioning systems to regulate indoor climate, earth naturally provides thermal stability and moisture regulation, making it a more sustainable and energy-efficient alternative.

The research compared the environmental impact of conventional materials like cement and HCB with earth, highlighting issues such as resource depletion, pollution, and carbon emissions. It also showed that earth-based materials, like CSEB, have lower embodied energy and life cycle impact. From both ecological and cultural perspectives, earth is a more sustainable alternative.

The study on earthen construction enhancement followed a step-by-step procedure, beginning with selecting a site with ideal soil typology. The research used indicators to identify a suitable location within Addis Ababa's 527 km² area, narrowing it down to a specific site for sample extraction and related visual data collection.

Following that enough amount of the sample from the sub-soil section is brought in to the test laboratory. Consequently using laboratory equipment the tests were carried out. The primary test is focused in studying the material characteristics (index properties) of the raw sample. This study is the base line reference which the research draws the prototype preparation from. Even though this is a process itself, it should be marked as part of the phase to study the material. This endeavor was incorporated as a means to indicate that it should not only be our priority to focus on the virtual aspects, but also material wise efforts should focus on enhancing the qualities for it to be usable.

Afterwards a standard soil testing process recommended by ASTM is executed in the study. The Atterberg limit, specific gravity, hydrometer test and compaction test are all carried out using the apparatus available at the laboratory. These tests simly portray; what the material is like, what setbacks or merits it possesses and what are the general index properties.

Results of the Atterberg limit indicated that the sample had an LL value of 83, PL of 36 and PI of 47. These results can merely tell substantial information about the type of earth. For example the liquid limit alone falls under the category of *montmorillonite* (*bentonite*) clays, which have a large capacity to absorb water; their LL is usually very high, for clays rich in *montmorillonite*. The majority of these clays have common LL values above 50.[149] This broad range is subjected to the mineral content and the clay's water-retention capacity.[150] These materials usually exhibit high shrinkage traits with expansive behaviors. The shrinkage percentage is 16.3% is more than the recommendation by ARSO, which sets it as less than 0.05 %. Additionally this recommendation is impossible to attain as the clay typology is hard to minimize its shrink percentage, as a result the material is prone to shrinkage and swelling. And due to this shrinkage percentage, it will entirely dry out from its liquid or plastic form, which leads to a 16% decrease in volume. This occurs as a result of the soil's decreased water content, which pushes the particles closer together and lowers the volume overall, which it is an expected behavior of fat clay.[151] Thus in order to utilize it as a construction material for non-load bearing structures, which could have exposure to wet conditions, it is crucial to lower its shrink percentage. According to the shrinkage test, addition of the stabilizers; 30% *Dembaqie* and 3% cement resulted a reduction of the shrinkage by 2%, which conveyed that further addition of the stabilize would lower it further. Unfortunately due to the shortage of the sample for the 6 and 9 percent, shrinkage tests were not conducted.

Likewise the specific gravity test result shows information regarding the soil's mineral mix, soil strength, and soil classification for example. Minerals such as calcite, dolomite, and limestone are frequently found in soils with a specific gravity of 2.66, which adds to their strength and resilience.[152] By increasing the soil's compressive strength, these minerals help make it ideal for buildings. With a specific gravity of about 2.71, calcite is especially significant since it is non-expansive, which lowers the possibility of warping or breaking. Additionally, it improves workability and facilitates soil compaction by decreasing plasticity.[153]

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[149] *Busscher, Warren. "Fundamentals of soil behavior." Soil Science 158, no. 1 (1994): 74.*

[150] *Ibid.*

[151] *Ibid.*

[152] *Craig, Robert F. Soil mechanics. Springer, 2013.*

[153] *Ibid.*

Moreover the sieve analysis portrays the sample contains mostly finer particles with more than 90% of the sample on the No. 200 sieve 94.76% passed while 5.235% was coarser particles.

The hydrometer test indicated the soil contains finer ingredients, possibly including silt soil and clayey silt. This portrayed that the soil could be highly plastic, corroborating the evidence found in the liquid limit results. The higher percentage of finer particles indicates that drainage may be hard for this material, meaning the material could hold water for long and this could pose challenges in construction.[154] The smallest particle size is also found according to the Hydrometer test, which is 0.00035 mm at the 1440 minute. This shows that the significant portion of the soil is clay.

Material characterization and understanding the index property[155] of the soil helps the research devise a solution that addresses the flaws, such as extreme properties. For example high liquid limit can be a trait of fat clay[156], which was challenging as these typologies exhibit high shrinkage.

Furthermore, the compaction effort test indicated information about the soils maximum density that can be attained at the optimum water content. This helped in preparing prototypes and is useful at a mass production level. Hence for the raw sample the highest attained density was 1.34 g/cm^3 found at the sixth trial with the OMC (optimum moisture content) 30%. This gives the amount of water that can be added when casting blocks.

The research also experimented on finding ways to address the material's drawbacks. The first setback was the materials high liquid limit and shrinkage properties which were not the recommended ideal expectations. For that the researcher wanted to try the addition of other stabilizing agents, cement being the primary one. The reason the research chose cement, even though it is not a cultural material that poses environmental threat to the surrounding, was due to ARSO's recommendation. Although, the standard allows the use of about 10% cement, the volume was kept as low as possible. The other additive was *Dembaqie,* which is a volcanic ash comprised of silt. The research went to experiment different cement amount inputs while fixing the *Dembaqie* at 30%. This fixation and its application were based on the data from ARSO, for

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[154] *Das, Braja M., and Khaled Sobhan. "Principles of geotechnical engineering." (1990).*

[155] ***Index properties:*** *are fundamental characteristics providing information about the behavior of the soil.*

[156] ***Fat clay****: is a soil that is plastic, cohesive and expansive.*

the percentage of silt in a compressed earth blocks and the information from the pottery workshop. At the pottery work the crafts people were utilizing the *Dambaqie* almost as equally as the clay itself.

Moreover, it was due to the shortage of raw materials and time, that the experiment did not test the different percentage of *Dembaqie*. It has to be noted that with different testing a more proficient and competent prototypes can be produced. But for this project the *Dembaqie* was fixed at 30%.

Having that in mind the next phase was testing different cement mixes to see how it can impact the raw sample. The research executed three experiments where the *Dembaqie* is fixed at 30% and the cement proportion varied at 3%, 6% and 9% and clay resorted according to the percentage.

The 3% mix lowered the three properties slightly, the 6% mix lowered these two properties moderately and the 9% mix dropped the two properties too low and increased the plastic limit thereby creating an anomaly and fluctuation in plastic limit result, disrupting the decrement. This fluctuation in plastic limit when increasing cement content could be likely due to the combination of inconsistent cement bonding, changes in microstructure, and the complex interplay between clay, *Dembaqie*, and the cement. More so it could be due to the procedural inconsistency.

The method, which the research used to choose the ideal mix, was using ARSO as a standard. Technically the plasticity index of upper two mixes fall in line with ARSO's recommended value, but sustainability and eco-friendliness considerations led the preference of the 6% mix.

The mix includes two materials that can locally be obtained along with cement. From a cultural point of view putting the proportion in terms of ratio, the bigger proportion of the input which dictates the appearance of the output is clay, covering around 64%.

Moreover from the preservation of the construction tradition, the raw material usage is more advocated over the mix but it comes at a risk of moisture vulnerability and more clay content requirement. Thus in order to enhance the material intervention was mandatory. That is why there was a need to stabilize the material with agents.

Even though *Dembaqie* has not been used in traditional construction technique, it has been used by the pottery field. In the due course this research has highlighted a point of contact between the two traditional realms of culture, migrating one of the materials applied in the traditional pottery in to earthen construction. Therefore cross-discipline endeavors especially in the untapped cultures like pottery could help create findings and newer research thematic areas.

Thereafter by selecting the ideal mix the next step was preparation of the prototypes. For the preparation process the research utilized the compression mold available at the laboratory which used manual press lever. But for endeavors such as this, the mechanical compression can be locally constructed to function similarly. Additionally for this production step, five prototypes were needed to be prepared from both the ideal mix and the raw material which served as a control for comparison.

The afterwards the first prototype casted was the control, followed by the ideal mix. But due to the time and labor unavailability the casting process for the mix was pushed to go one day after. This decreases the testing day by one day, which according to ARSO is 28 days.

Later on the prototypes, each with five samples were casted and left in a closed room to air dry until the testing dates. After 28 days (for the control prototype) and 27 days (for the mix prototype) the dry strength test was conducted with three samples from each compartment. Also the result indicated that the mixed prototype (6% cement) portrayed lower dry compressive strength (1.55 MPa) than the control prototype (7.14MPa)[157] with an average dry compressive strength difference of 5.582 MPa. As a result, on the dry strength test the mix prototypes were deformed and disfigured *Figure **66*** when compared to the control prototype which somehow preserved its appearance. This may be due to the usage of *Dembeqie* at the applied percentage. While this means that the *Dembaqie* while lowering other index properties it might have had impacted the mechanical properties of the prototype to be weak. Thus as a new experiment this phenomenon could happen and is expected. This as mentioned above can be fine-tuned by doing iterated experiments on the different amounts of *Dembaqie* and the cement.

While the final result of what this experiment had put forward is compatible for traditional constructions that can serve as a replica for wattle and daub, it can also compete with grade-C HCB block as it was only 0.45 MPa less than the dry compressive strength accepted by the country's standard.

On top of that as shown in *Figure **67*** the physical over look and the mechanical behavior of the edges of the 6% mix appeared to be weaker when compared to the raw prototype. While this was not expected, the edges of the mixed prototype also turned out to be fragile and were easily

[157] *A dry compressive strength for a raw clay such as this is extremely high.*

crumbled up on contact with hand, while the control prototype has very sharp and strong edges. As a final point these prototypes in construction can address one of the demerits of traditional earthen construction, which is lack of sharp surfaces.

Additionally it has to be noted that these traits are recorded under dry circumstances. In wet environment and due to an exposure to rain these two prototypes are expected to behave differently. However, inferring from experiment results of the Atterberg limit, the 6% mix prototype is expected to perform better than the raw clay (control) prototype in wet conditions. But none the less to understand the behavior in wet circumstances a test called drip test can be carried out.

Moreover the price value of HCB grade B and C in the city of Addis Ababa varies between the range of 38 and 40 ETB, and the cost required to produce the earth based prototype is between 15 and 20 ETB, which is incomparable in terms of price value, almost half less the price of one HCB block. This is only the comparative price value, but when the environmental factors and degradation to culture are considered as a parameter the earth based prototype becomes incomparably preferable over the HCB, which is cement based.

Also the minimum compressive strength of hollow concrete block (HCB) grade C, B and A, according to the Ethiopian Standard ESC D3.301, is specified as 2 MPa, 4MPa and 5.5MPa respectively at 28 days from an average of 6 samples.[158] Likewise the dry strength for the raw prototype produced by the research is recorded to be 7.14 MPa which is way higher in terms of strength value, using three samples, exceeding three of the HCB grades. However this high dry compressive strength does not mean in a wet environment which all grades of the HCB are capable of standing. As the data from the liquid limit and the prototype dimension record showed, the raw clay can exhibit higher level of shrinkage as a result it is expected to lower in strength.

Thus the 6% cement mix prototype yielded a dry compressive strength of 1.558 MPa per three samples, which is 0.45MPa less than the minimum requirement for HCB grade-C. And the Atterberg limit test showed a 21% decrease in Liquid limit and 25% decrease in plasticity index.

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[158] *Abera, Mikiyas Alemeshet. "Investigating the acceptable quantity of fine aggregate to be replaced with sawdust to obtain strong, light weight, and economical result for HCB production." International journal of Advance Research, Ideas and Innovations in Technology 5, no. 5 (2019): 391-395.*

This prototype has produced the ideal earth based construction material for the given raw clay. Given the information above when compared to the control (raw clay) prototype, it can perform more under wet circumstances. Yet further experimentation and investigations need to be carried to enhance it farther before real life experiences. Moreover when comparing these to the traditional earthen construction especially to the wattle and daub technique (one of the most widely utilized traditional method), the two prototypes surpass it in many areas that were mentioned as the demerits in the discussion section of the research.

Additionally unlike conventional building material such as HCB of all grades and cement, production process of the two prototypes was completely sustainable and eco-friendly with no; gas emissions, deforestation and mineral depletion, material importation, involved. While cement usage on the mixed prototype is minute in quantity 0.761kg per 5 blocks of each 2537.67g with minimal environmental impact reducing its utilization to lower percentage when compared to conventional construction methods like HCB and RC walls which use cement above 10%.

More so the raw prototype can be bio-degradable and recyclable unlike HCB and cement. However the mix prototype is partially bio-degradable as it possesses cement in its composition.

One of the demerits of traditional earthen construction as discussed is lack of proper documentation and archiving. Thus these skills are orally thought and challenging to obtain availably in an archived form. According this research indicated the proper way of documenting the processes and the steps of preparing and experimenting earth based prototypes for future use.

Furthermore the research not only indicated the stages and documentation of the process, but also put forward the template for the production of different prototypes for varied typologies of soil. Additionally it addressed generic problems associated with traditional earthen construction and the shortcomings of the sample.

By the same token the other shortcomings of earth is inconsistency of the wall thickness, which the research addressed by proposing modular prototype that can construct walls with consistent thickness. The modular approach to production of units also prevents further loss of the clay in construction, which used to be the case in most of traditional constructions (wattle and daub). The research also addressed there issue cultural relevance, cost efficiency, energy efficiency, surface inconsistency and none modularity of the traditional construction.

Finally as a novel aspect of this study, the paper explored the use of a new material, Dembaqie, which has not been previously researched upon. This makes the study unique in its experimentation with a material that was traditionally used only in pottery. Additionally, the research stands out by integrating a material from the pottery discipline into a new context, thereby bridging two fields of study.

Similarly, the research aimed to integrate a range of topics to ensure that crucial aspects of earth as a construction material were thoroughly explored and highlighted. These discussions were then applied to the broader goal of conserving traditional construction methods, ensuring their relevance and adaptation in a modern context.

CONCLUSION

This research aimed to reinvigorate traditional earthen architecture practices in Addis Ababa by integrating the invaluable cultural heritage of the city with scientific advancements, with a particular focus on the enhancement of earthen materials for contemporary and traditional construction needs. By approaching the study from multiple directions, including laboratory testing, field observations, and extensive cultural data collection, the research sought not only to preserve and conserve but also to innovate upon traditional construction techniques.

According to the study, earthen architecture has enormous promise as a cultural and sustainable building material because it is a practice that is firmly ingrained in Addis Ababa's and Ethiopia's cultural history. However, a number of issues have caused it to lose favor. These include the absence of policies that encourage its usage in urban development, misunderstandings regarding its structural soundness, and a lack of technical expertise on material augmentation. Despite these obstacles, this study shows that earthen architecture can be revived to satisfy contemporary building codes while retaining its cultural relevance provided the right technological developments are made.

A significant breakthrough in this study was the experimental use of Dembaqie (tuff volcanic ash) as a stabilizer for clay in earthen construction. This novel approach was found to dramatically improve the material's durability, compressive strength, and resistance to water absorption. These findings are particularly crucial for urban areas like Addis Ababa, where modern building standards demand materials that are resilient and long-lasting. The successful application of these stabilized earth mixtures opens the door for the widespread use of earthen construction in the city’s future development, making it both a viable, cultural and sustainable alternative to conventional construction methods.

Additionally, the research highlighted the crucial role of local artisans and traditional builders in preserving the knowledge and techniques that have been passed down through generations. These artisans are not only the stewards of traditional construction methods but also integral to the integration of cultural values into modern construction practices. The study emphasizes the importance of their involvement in any future efforts to revive earthen architecture in Addis Ababa. Their expertise ensures that the knowledge is kept alive and adapted to contemporary needs, combining the old with the new.

Additionally, stronger legislative and regulatory backing is also recommended by the study in order to promote the resurgence of earthen building techniques. As of right now, there aren't many legislative frameworks that legally acknowledge earthen materials as legitimate building materials. The material is marginalized in the construction and urban planning sectors as a result of this lack of support. According to the findings, integrating earthen architecture into Addis Ababa's urban fabric requires the establishment of a favorable legislative environment as well as incentives for the use of sustainable materials. Such changes would promote the use of clay materials in both larger-scale urban projects and home construction.

Furthermore, this research emphasizes that the revival of earthen architecture in Addis Ababa could offer significant environmental benefits. As a locally sourced material, earth requires far less energy to produce than conventional construction materials such as concrete or steel. This makes earthen construction a more environmentally friendly alternative, aligning with the global push toward sustainable building practices. By reintroducing earthen architecture in the context of modern urban development, Addis Ababa can become a model for other cities in Africa and beyond, demonstrating how traditional materials can be used to address modern challenges in a sustainable and culturally meaningful way.

In conclusion, this research highlights that the conservation of earthen architecture goes beyond the physical preservation of existing buildings. By incorporating a range of vital subject matters, this study emphasizes the importance of focusing not only on tangible structures but also on the virtual aspects of cultural heritage. It advocates for bringing underrated components of traditional wisdom to light, such as cultural practices, materials, and construction techniques that are often overlooked in conventional conservation efforts. The research ultimately underscores the need for an integrated approach that blends different disciplines to ensure the survival and relevance of traditional practices in the modern urban context.

RECOMMENDATION

This section synthesizes the analyzed data from the research to advocate for compatible and broader application of earth as a traditional construction material in Addis Ababa. Beyond the discussed factors, a key advantage of studying earth is the versatility of test results, which can be applied to similar soil types for various construction techniques, including rammed earth.

- For instance by determining the optimum moisture content (OMC), an enhanced ideal earthen wall of 4m high, 35cm thick, and 3m long can be constructed by any stakeholders using the studied sample. The ideal maximum dry density (MDD) at OMC, found through standard compaction, is 1.34 g/cm^3. However, for exterior applications in high-rainfall areas, additional water-repellent treatments are necessary to prevent material degradation and ensure longevity. While treatments such as epoxy coating, bitumen emulsion, and silicone-based water repellents can enhance the wall's water resistance, further research is needed to determine the most suitable option for the prototype.
- Additionally, as per the study it is recommended that the samples be used in modular construction, where standardized rammed earth units are prefabricated for on-site assembly.
- Moreover, the defined water range also allows the mixes use in 3D modeling of buildings and construction. Furthermore, the mixture can aid in the repair of traditional earthen buildings by filling cracks with a stabilized blend, restoring structural integrity.
- The dry strength test revealed that the raw clay outperformed the mix by 5.8 MPa more, indicating its viability as a construction material. This strength is notably high for a clay and, when compared to the dry compressive strength of HCB Grade-A (5.0 MPa for an average of six units), suggests its potential as a walling component, offering a viable alternative to HCB and stone in construction.

- Also the *Dembaqie* proportion taken at 30% has its impact in reducing the extreme properties to the desired standard; on the other hand it has resulted in physical fragility and weakness of the blocks. According to the results it is recommended to lower the percentage of the *Dembaqie* and experiment further in different proportions to fine tune the end result.

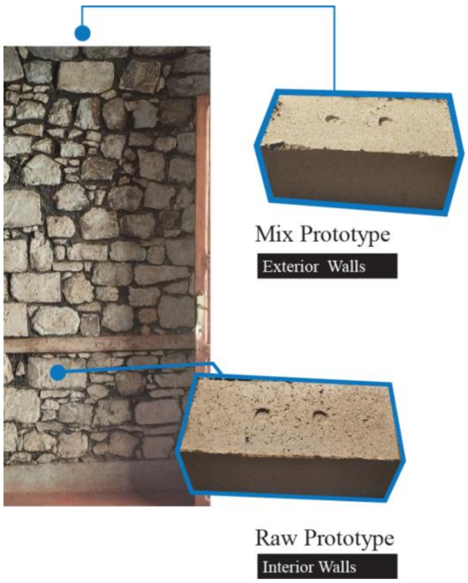

Figure 68-Proposed CSEB in place of stone masonry. Source, Author (May, 2024)

- Another area where the produced prototypes are recommended to be applied is in a stone and daub technique. In the traditional sense the fermented earth is used as a conjoining agent between two masonry stones but having the expensiveness and unavailability of the stone in

Figure 69- Negadras Bitwoded Haile-giorgis residence. Source, Author (May, 2024)

Addis Ababa under consideration, it is ideal to replace them with the produced prototype. And according to the shrinkage of the two prototypes and the Atterberg limit result, the raw clay responds poorly to water than the stabilized one for that matter, the research proposes the raw prototype to be used in interiors and the stabilized mix on exterior walls. But as mentioned earlier further enhancement and water resistant coating is necessary.

- Additionally structural applications including vaulting[159] are also a tested out strategies that can further grow and advance utilization the prototypes as a structural material, thereby facilitating the usage by enhancing the exposure of the material to different stakeholders.

Figure 70- Earthen masonry vaulting. Source Building Ethiopia.

- Further experimentation in the area of enhancing the material using locally available products such as *Enset* and *Teff* straws is another way of addressing the setbacks of the material particularly to reinforce the blocks.
- More so the application of the amended earth sample is recommended to be applied in pottery. This involves the usage of enhanced clay to produce tiles for flooring at pottery sites. And through continued testing, particularly in improving the adhesive properties and water resistance of earthen mixtures, the studied material has potential to become an excellent finishing material for earthen walls.
- The preservation of traditional earthen construction relies on knowledge transfer from experts to future generations. This research recommends structured mentorship programs, apprenticeships, and community engagement initiatives. Raising awareness through campaigns, panels, and seminars will enhance exposure and integrate traditional expertise with modern practices, ensuring the tradition's continuity and relevance.
- Additionally the end user of the product (stakeholders) which are one vital component of the equation, should be integrated. Thus the endeavor in protecting legacy of earthen construction without the involvement of community is futile. Hence the research proposes an inclusive frame work where by, the community is incorporated in the effort of protecting

[159] ***Vaulting:*** *refers to the construction of an arch-like structure used to support a roof or ceiling, typically made from materials such as stone, brick, or concrete.*

earthen construction tradition. This can be achieved by organizing training sessions and workshops on earthen building materials and techniques.

In summary the pursuit of recognizing and conserving earth as construction material and the culture around it would be futile if the focus is a single parameter. But rather it should be of a multi-directional endeavor cognizant of integral aspect where by different elements, that are substantial to the tradition, come together to render the bigger picture. Henceforth the research proposes the following overarching operational domain to help recognize the culture, revive its utilization as construction material and enhance the culture of traditional construction by incorporating constituent components.

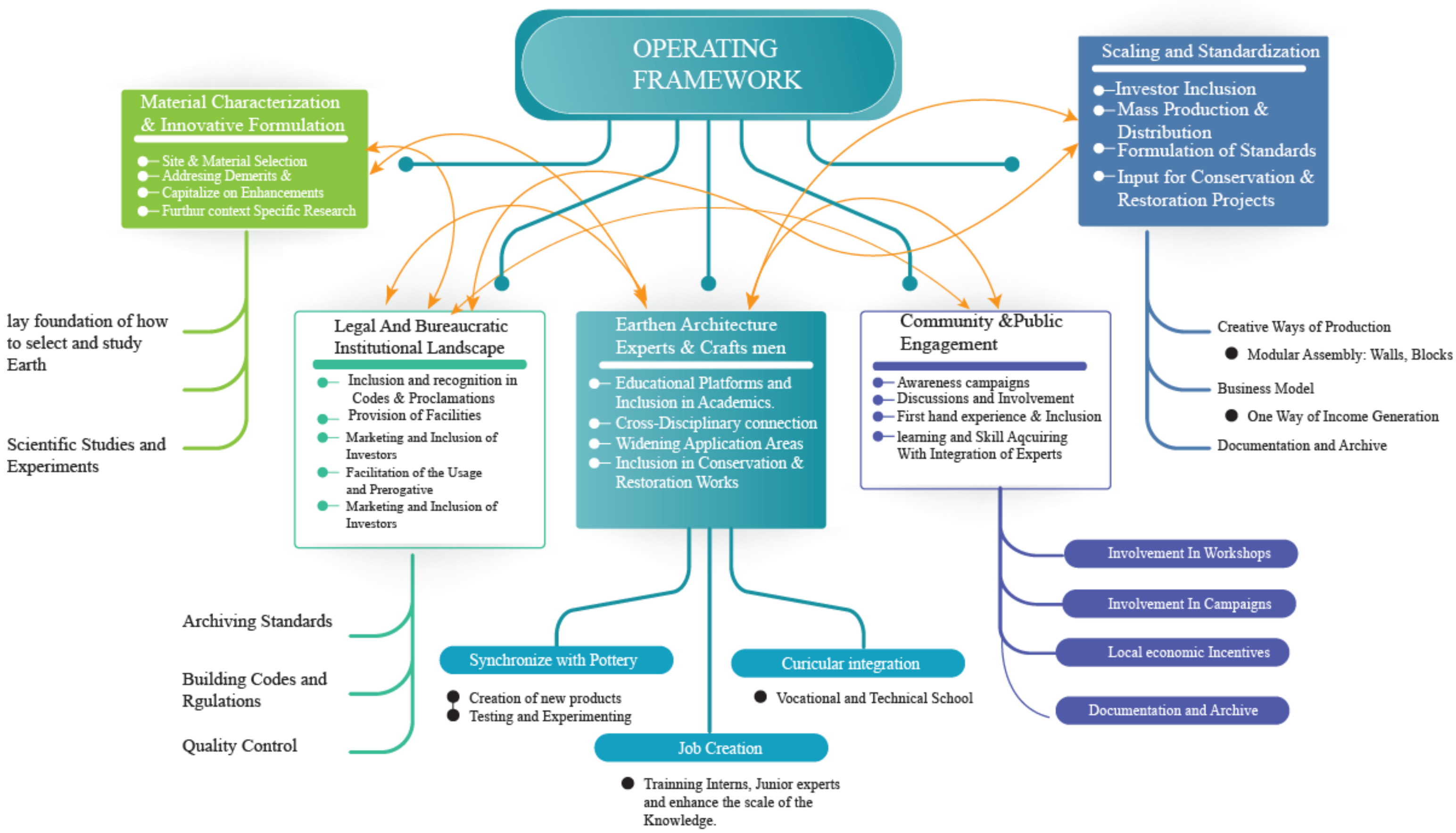

Figure 71- Proposed framework.

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APPENDIX 1:

QUESTIONAIRE FOR POLICY AND REGULATION REGARDING EARTHEN CONSTRUCTION (CONSTRUCTION AUTHORITY)

Name of The Official: ____Position: _______________________________________Phone: +2519_______________________email:______________________________Institution: ____

1-Are there specific codes or regulations in the city regarding the use of earthen construction in construction projects?

A) Yes B) No C) Not sure D) Not applicable

Codes-

2-If Prohibited what are the specific reasons behind the prohibition of earthen construction in the city's construction codes or regulations?

A) Concerns about structural integrity B) Zoning regulations or aesthetic concerns C) Lack of familiarity with earthen construction techniques D) Other (please specify

3-Has there been any consideration or discussion within the city administration regarding revisiting or amending the regulations related to earthen construction?

A) Yes B) No C) Not sure D) Not applicable

Note__

5-How does the city address the preservation of cultural heritage in the context of urban development, particularly concerning traditional building materials and architectural styles?

A) Significant consideration B) Moderate consideration C) Limited consideration D) Not a consideration

6-If earthen construction materials are upgraded to construction standards, meaning scientifically enhanced to compare with conventional building materials, would it be a plausible scenario for the policy to consider it as part of the construction materials that are allowed to be used.

7-If earthen construction is allowed, what do you think are the specific requirements or guidelines for its use?

A) Minimum structural standards B) Preservation of cultural heritage C) Environmental impact considerations D) Other (please specify)

8-Regarding the removal of obsolete and outdated buildings in the city, of which earthen buildings account for the bigger part. What do you think is the reason for the abolishment of these structures?

9-Regarding the application of enhanced earthen material, if older obsolete buildings that are made of earth as primary materials are repaired and maintained to an extent that is fit for the modern day building standards, would it be acceptable by the policy sector.

10-How does the city administration value the knowledge and expertise of earthen specialists and experts in the context of urban development, particularly concerning traditional building materials and architectural styles?

A) Significant consideration B) Moderate consideration C) Limited consideration D) Not a consideration

11-"How does your institution perceive the potential cultural loss associated with the diminishing presence of earthen construction, considering its historical significance in Addis Ababa and Ethiopia, where it is deeply intertwined with the community's identity and culture? In light of the current trend favoring conventional buildings, if this continues for the next 20-30 years, what measures does your institution propose to safeguard and promote the preservation of earthen construction as an essential aspect of Ethiopia's heritage?"

For Earth Architecture	Existent	None Existent	In The Process Of Discussion	Degree Of Importance Of The Topic	In Number	
Existing Regulations						
Policy Enforcement						
Specialist Consultation On Earth Architecture						
Cultural Significance Priority Study						
Preservation						

Initiatives						
Sustainable Practices Incentives						
Public Awareness Campaigns						
Policy Revision						
Documentation And Archiving						
Current Preservation Works						

QUESTIONNAIRE FOR EXPERTS (LOCAL SKILLED MEN)

Name ____________________________________age_____________________________Current Occupation

Phone Number +2519____________________________

1- How long have you been involved in traditional earthen construction practices?

For ________

2- What motivated you to learn and practice these techniques?

____
____

3- Have you observed any changes in the popularity or use of traditional earthen construction methods over the years? If yes what is the change? If No what is the current traditional trend like?

Yes___ No___

4-Have you maintained and repaired traditionally built earthen building? And if so what role do you have?

5- In your experience, have you noticed any shifts in construction trends away from traditional earthen methods towards modern alternatives?

____

6- What factors do you believe contribute to these potential shifts in construction preferences?

7- What role do you think community education and outreach could play in preserving these practices?

8- How is traditional earthen construction skills passed down from one generation to the next in your community? How did you learn it yourself?

9- Have there been efforts to document or archive the knowledge and techniques associated with traditional practices?

10-What steps do you believe should be taken to ensure the continued practice and preservation of these techniques?

11-Beyond practical construction purposes, what cultural or heritage value do traditional earthen construction methods hold for your community?

12- Looking ahead, what do you envision for the future of traditional earthen construction in your region? Are there opportunities for collaboration between traditional practitioners and modern construction experts to integrate earthen methods into contemporary projects ?

13- Looking ahead, what do you envision for the future of traditional earthen construction in your region? Are there opportunities for collaboration between traditional practitioners and modern construction experts to integrate earthen methods into contemporary projects?

14- Can you walk me through the step-by-step process of preparing for an earthen construction project from start to finish?

15-What are the key phases or stages involved in the preparation of earthen construction?

How do you typically plan and organize the construction process to ensure efficiency and effectiveness?

What are the primary ingredients used in traditional earthen construction in your Area (Addis Ababa)?

Mateial-1 ____

Use and Application-

Which Type of Material one is best suitable for earthen Construction?

Material-2

Use and Application

Other Typologies

16-Could you describe the properties and characteristics of each ingredient and how they contribute to the overall strength and stability of the structure?

17-Are there any specific proportions or mixtures of ingredients that are commonly used, and how are they determined?

APPLICATION TECHNIQUES

18-What techniques are employed for mixing the earthen materials together?

19- How the mixture is applied during construction, and is there any specialized tools or methods used for this purpose?

20-Can you explain the importance of proper layering and compacting during the application process?

21- Have you had the opportunity to get involved in a conservation project locally? ______If so Where ________________________________

22-What are the techniques that you use to apply when conserving (maintaining and repairing) earthen buildings?

STRUCTURAL INTEGRITY AND DURABILITY

23-How do traditional earthen construction methods ensure the structural integrity and durability of the resulting structures?

24-What measures are taken to protect earthen buildings from water, weathering, erosion, and other forms of damage over time?

25-Are there any specific design features or reinforcement techniques used to enhance the longevity of earthen structures?

26-What are some common types of damage or deterioration that earthen structures may experience?

27-How do you approach the maintenance and repair of earthen buildings when they are damaged?

28-Are there traditional methods or materials used for repairing cracks, holes, or other forms of damage in earthen construction?

29-In your Opinion what are the flaws of earthen construction that make it less desirable for construction when compared to other conventional building materials?

30- Seeing the current construction trend in the city, which is highly influenced by conventional building materials, do you think that there is hope for the revival of earthen construction?

31- If the existing earthen construction wisdom is merged with scientifically available information thereby upgrading the material, do you think it would be possible to produce a high end construction material for conservation practice (maintenance and repair) and general building material Production?

LESSONS FROM TRADITION

32-In your experience, what lessons or insights can be drawn from traditional earthen construction practices regarding sustainable building techniques and materials?

33-How do traditional approaches to maintenance and repair compare with modern methods in terms of effectiveness and environmental impact?

	Tools	**Application**	**Used Phase**	**Importance /10**
Earthen Architecture				

COMMUNITY PERCEPTION

Name________________________________age_________Occuation__________

Phone_________________________________

Address ___________________________No_________

1-Why does the community perceive earthen construction as something bad and primitive?

☐ The aesthetics ☐ Strength and Durability ☐ negative community perception

☐ Existence of other Advanced building materials that perform better

2-what do you know about the History and linkage of the material to Ethiopian Culture and History?

☐ No Idea ☐ Yea I can guess as its very Prevalent

3- Do you think earthen construction is part of Ethiopia's Cultural Identity?

☐ Yes ☐ No ☐ don't have any Idea

4- Do you think this building material and the trend of construction associated with it being lost?

☐ Yes ☐ No

5-What do you think about the local crafts men (Experts) who are skilled at earthen construction in relation to the trend of earthen construction?

6-If an Existing earth constructed Building is damaged to a reversible extent, should it be demolished or maintained? If yes/ no why?

7-How do you think can we protect this traditional method of earthen construction?

Approval level for earthen construction out of 3________________

1- This material should not be used by our construction sector that it is generally unfit for any sort of construction.
2- The material can be used or may be not until proven and studied to function properly.
3- The material is highly recommendable to be used especially if enhanced.

MATERIAL TEST RESULTS

SPECIFIC GRAVITY OF SOIL SOLIDS (RAW SAMPLE)

Testing Standard:	ASTM D854	Method:	Method A (Oven Dried Specimen)

Test No.	**1**	**2**
Pycnometre No.	A6-2	A-1
Mass of Pycnometer, M_p (g)	100.2	68.2
Mass of Soil Sample, M_s (g)	35.6	36.6
Calibrated Volume of Pycnometer, V_p (ml)	249.649	249.825
Testing Temprature, T (^{0}C)	20.3	19.8
Density of Water at Testing Temprature, ρ_w (g/cm^3)	0.99814	0.99825
Calibrated Mass of Pycnometer + Water, M_{pw} (g)	349.4	317.6
Mass of Pycnometer + Water + Soil, M_{pws} (g)	371.9	340.1
G (at Testing Temprature)	2.721	2.598
Correction Factor	0.99994	1.00004
G (at 20 ^{0}C)	2.721	2.598
G_{avg} (at 20 ^{0}C)	2.66	

HAYDROMETER TEST (RAW SAMPLE)

Mass Used= 50.2 g			Specific Gravity Gs=2.66					
Time	Hydro Meter reading (Rh)	Correction Cylinder Reading (Rc)	Test Temperature (c^0)	Distance from Surface to density measure	Corrected Hydrometer Reading(R)	K	Particle Size (D)	Percentage Passing (N) %
2	48	5.4	19.8	8.4	42.174	0.1345	0.028	84.3
4	46.2	5.4	19.8	8.8	40.392	0.1345	0.020	80.77
8	45	5.4	19.8	8.9	39.2	0.1345	0.013	78.4
15	43	5.4	19.8	9.2	37.224	0.1345	0.0105	74.1
30	40.1	5.4	19.8	9.7	34.353	0.1345	0.076	68.4
60	39	5.4	19.8	9.9	33.264	0.1345	0.005	66.26
120	38	5.4	19.8	10.1	32.264	0.1345	0.004	64.27
1440	35	5.4	19.8	10.6	29.264	0.1345	0.00035	58.29

$D = k \sqrt{L/t}$ $N = \frac{(Rh - RCorrection)a}{W} \times 100$ ((NaPO3)6=5.4 g	R= Rh-Rc

ATTERBERG LIMIT TEST (RAW CLAY SAMPLE)

LIQUID LIMIT TEST

Test Number	1	2	3	
Number of Blows	33	26	18	
Container Number	181	196	140	
Mass of Empty Container, M_c	33.3	33.4	33.7	
Mass of Container + Wet Soil, M_{csw} (g)	47.1	49.9	45.7	
Mass of Container + Dry Soil, M_{cs} (g)	40.9	42.4	40.1	
Mass of Dry Soil, M_s (g)	7.6	9	6.4	0
Mass of Water, M_w (g)	6.2	7.5	5.6	0
Water Content, *w* (%)	*81.58*	*83.33*	*87.5*	*#DIV/0!*

PLASTIC LIMIT TEST

Test Number	1	2
Container Number	137	112
Mass of Empty Container, M_c	33.4	33.2
Mass of Container + Wet Soil, M_{csw} (g)	40	42.2
Mass of Container + Dry Soil, M_{cs} (g)	39.7	39.8
Mass of Dry Soil, M_s (g)	6.3	6.6
Mass of Water, M_w (g)	0.3	2.4
Water Content, *w* (%)	*4.76*	*36.36*

SIEVE ANALYSIS (RAW CLAY SAMPLE)

Adjusted = 2961.4g	Initial 3239.3g				
Sieve Size (mm)	ASTM Designation (Inch)	Mass Retained	Cumulative Mass Retained(g)	Cumulative Mass Passing (g)	Percentage Passing (%)
75	3	0	0	2961.4g	100
37	1 1/4	0	0	2961.4g	100
25	1 1/2	0	0	2961.4g	100
19	5/8	0	0	2961.4g	100
9.5	7/6	0	0	2961.4g	100
4.75	5/16	0	0	2961.4g	100
2	No.10	0.7	0.7	2960.7	99.976
0.85	No. 20	0.1	0.118	49.892	99.764
0.425	No.40	0.2	0.3118	49.69682	99.376
0.250	No.60	0.5	0.8118	49.1982	98.377
0.150	No.100	0.8	1.6118	48.3982	96.777
0.075	No.200	1.00	2.6118	47.3982	94.765
Pan		0.2			
Sum		Total=3.5			

The data for the sieve size less than 2mm

(No.200) is

Computed in relative to 50g

COMPACTION (RAW CLAY SAMPLE)

standard compaction effort						
Test Run No.	1A	AB	2A	2B	3A	3B
Can No.	155	170	138	117	140	163
Mass of Can (g)	33.1	32.6	33.3	33.2	33.6	33.7
Mass of Can + Wet Soil, Mcms (g)	182.6	161.7	167.6	168.3	160.2	167.3
Mass of Can +Dry soil ,Mcs (g)	159.9	142.3	144.1	144.4	134.6	139
Mass of Water,Mw (g)	22.7	19.4	23.5	23.9	25.6	28.3
Mass of Dry Soil, Ms (g)	126.5	109.7	110.8	112.2	101	105.3
Water Content, W (%)	17.94	17.68	21.21	21.49	25.34	26.87
Average Water Content,W (%)	17.81		21.35		26.105	
Test Run No.	4A	4B	5A	5B	6A	6B
Can No.	76	109	87	82	77	102
Mass of Can (g)	33.6	33.5	33.5	32.9	33.2	33.4
Mass of Can + Wet Soil, Mcms (g)	167.6	170.4	132.7	138.7	189.5	191.2
Mass of Can +Dry soil ,Mcs (g)	137.1	139.5	108.4	113.3	136.5	137.2
Mass of Water,Mw (g)	30.5	30.9	24.3	25.4	53	54
Mass of Dry Soil, Ms (g)	103.5	106	74.9	80.4	103.3	103.8
Water Content, W (%)	29.46	29.15	32.44	31.59	51.30	52.42
Average Water Content,W (%)	29.31		32.01		51.86	
Density Measurement						
Test Run No.	1	2	3	4	5	6
Assumed Water Content	8	14	18	22	26	30
Actual Water Content						
Mass of Compacted Mould, Mmmb (g)	5948.2	6005.5	6103	6182.6	6239.6	6096.9
Mass of Mould, Mmb (g)	4555.9	4554.8	4554.9	4556.3	4558.4	4554
Mass of Soil In Mould, Ms (g)	1392.3	1450.7	1548.1	1626.3	1681.2	1542.9
Bulk Density, ρ (g/cm^3)	1.47	1.53	1.63	1.72	1.78	1.63
Dry Density, ρ_d (g/cm^3)	1.24	1.26	1.29	1.33	1.34	1.073

ATTERBERG LIMIT (3% CEMENT)

LIQUID LIMIT TEST

Test Number	1	2	3	
Number of Blows	31	27	19	
Container Number	112	197	137	
Mass of Empty Container, M_c	33.2	33.2	33.4	
Mass of Container + Wet Soil, M_{csw} (g)	50	51.6	51.5	
Mass of Container + Dry Soil, M_{cs} (g)	43.4	44.2	44.2	
Mass of Dry Soil, M_s (g)	10.2	11	10.8	0
Mass of Water, M_w (g)	6.6	7.4	7.3	0
Water Content, *w* (%)	64.71	67.27	67.59	#DIV/0!

PLASTIC LIMIT TEST

Test Number	1	2
Container Number	102	77
Mass of Empty Container, M_c	33.4	33.2
Mass of Container + Wet Soil, M_{csw} (g)	43.2	42.5
Mass of Container + Dry Soil, M_{cs} (g)	40.7	40.2
Mass of Dry Soil, M_s (g)	7.3	7.0
Mass of Water, M_w (g)	2.5	2.3
Water Content, *w* (%)	34.25	32.86

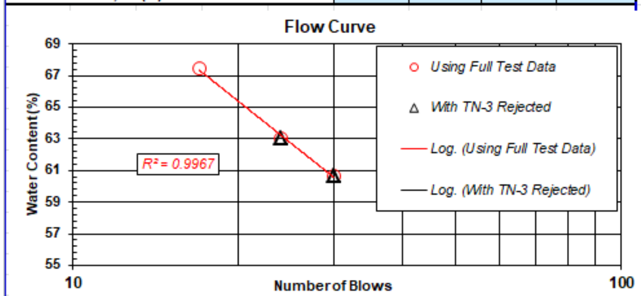
ATTERBERG LIMIT (6% CEMENT)

LIQUID LIMIT TEST

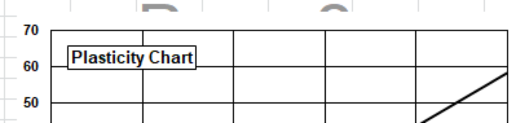
Test Number	1	2	3	
Number of Blows	30	24	17	
Container Number	132	153	149	
Mass of Empty Container, M_c	33.4	32.8	33.1	
Mass of Container + Wet Soil, M_{csw} (g)	52.2	53.5	54.7	
Mass of Container + Dry Soil, M_{cs} (g)	45.1	45.5	46	
Mass of Dry Soil, M_s (g)	11.7	12.7	12.9	0
Mass of Water, M_w (g)	7.1	8	8.7	0
Water Content, *w* (%)	60.68	62.99	67.44	#DIV/0!

PLASTIC LIMIT TEST

Test Number	1	2
Container Number	111	156
Mass of Empty Container, M_c	33.4	33.3
Mass of Container + Wet Soil, M_{csw} (g)	40.5	40.2
Mass of Container + Dry Soil, M_{cs} (g)	38.4	38.3
Mass of Dry Soil, M_s (g)	5.0	5.0
Mass of Water, M_w (g)	2.1	1.9
Water Content, *w* (%)	42.00	38



Results	
Avg. W, (%)	40.00
Plastic Limit, PL	40



COMPACTION TEST (6% CEMENT)

Compaction Effort standard						
Test Run No.	1A	AB	2A	2B	3A	3B
Can No.	172	112	132	153	154	149
Mass of Can (g)	32.7	33.2	33.3	32.6	33.2	32.9
Mass of Can + Wet Soil, Mcms (g)	156.5	154.8	148.2	151.9	147.9	144.8
Mass of Can +Dry soil ,Mcs (g)	135.4	134	126.9	129.6	122.3	120
Mass of Water,Mw (g)	21.1	20.8	21.3	22.3	25.6	24.8
Mass of Dry Soil, Ms (g)	102.7	100	93.6	97	89.1	87.1
Water Content, W (%)	20.54	20.80	22.75	22.98	28.73	28.47
Average Water Content,W (%)	20.67		22.85		28.6	
Test Run No.	4A	4B	5A	5B	6A	6B
Can No.	137	197	150	152		
Mass of Can (g)	33.4	33.1	33.6	33.1		
Mass of Can + Wet Soil, Mcms (g)	152.3	151.2	151.8	149.4		
Mass of Can +Dry soil ,Mcs (g)	123.2	122.6	119.8	118.2		
Mass of Water,Mw (g)	29.1	28.6	32	31.2		
Mass of Dry Soil, Ms (g)	89.8	89.5	86.2	85.1		
Water Content, W (%)	32.41	31.95	37.12	36.66		
Average Water Content,W (%)	32.18		36.89			
Density Measurement						
Test Run No.	1	2	3	4	5	
Assumed Water Content	14	18	22	26	30	
Actual Water Content						
Mass of Mould, Mmb (g)	4553.6	4553.6	4554.4	4554.3	4553.6	
Mass of Compacted Mould, Mmmb (g)	5882.5	5931.7	5947.7	6032.9	6071	
Mass of Soil In Mould, Ms (g)	1328.9	1378.1	1393.3	1478.6	1517.4	
Bulk Density, ρ (g/cm^3)	1.41	1.45	1.47	1.56	1.61	
Dry Density, ρ_d (g/cm^3)	1.16	1.18	1.14	1.18	1.17	

HAYDROMETER TEST (6% CEMENT SAMPLE)

50g							
Time	Hydro Meter reading (Rh)	Correction Cylinder Reading (Rc)	Test Temperature	Corrected Hydrometer Reading(R)	Distance from surface to density measure(L)cm	Particle Size (D)	Percentage Passing (N) %
2	35	6.1	16.8	28.9	10.5	0.0320	57.8
4	32	6.1	16.8	25.9	11.1	0.0236	51.8
8	30	6.1	16.8	23.9	11.4	0.0169	47.8
15	28	6.1	16.8	21.9	11.7	0.0125	43.8
30	27	6.1	16.8	20.9	11.9	0.0089	41.8
60	25	6.1	16.8	18.9	12.2	0.00639	37.8
120	23	6.1	16.8	16.9	12.5	0.00457	33.8
1440	18	6.1	16.8	11.9	13.3	0.00134	23.8

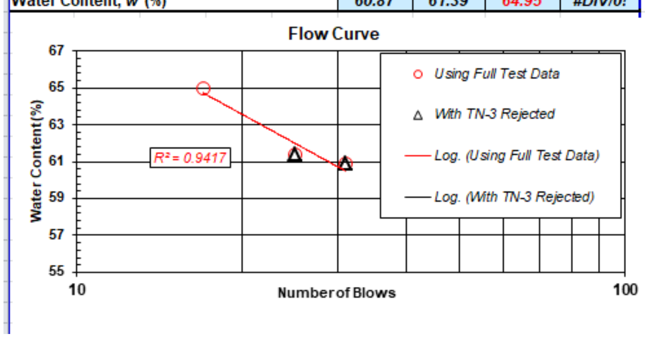
Specific Gravity 6% Mix= 2.64

Using Weighted Average Formula

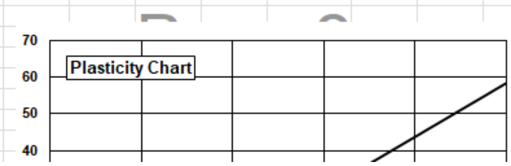
ATTERBERG LIMIT (9% CEMENT)

Number of Blows	31	25	17	
Container Number	112	154	150	
Mass of Empty Container, M_c	32.8	33.2	33.7	
Mass of Container + Wet Soil, M_{csw} (g)	47.6	49.5	49.7	
Mass of Container + Dry Soil, M_{cs} (g)	42	43.3	43.4	
Mass of Dry Soil, M_s (g)	9.2	10.1	9.7	0
Mass of Water, M_w (g)	5.6	6.2	6.3	0
Water Content, *w* (%)	*60.87*	*61.39*	*64.95*	*#DIV/0!*

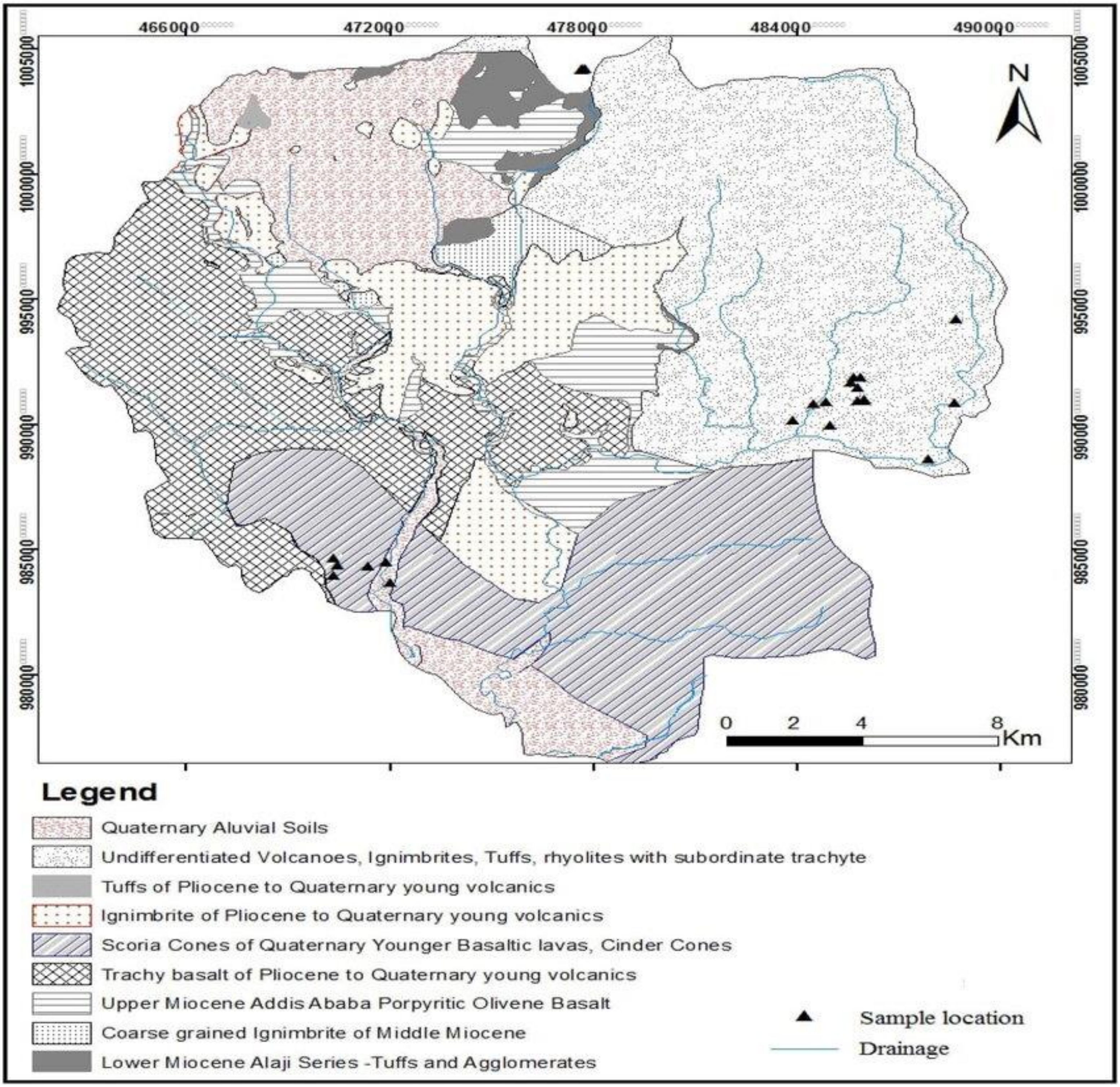
Container Number	111	156
Mass of Empty Container, M_c	33.4	33.3
Mass of Container + Wet Soil, M_{csw} (g)	40.5	40.2
Mass of Container + Dry Soil, M_{cs} (g)	38.4	38.3
Mass of Dry Soil, M_s (g)	5.0	5.0
Mass of Water, M_w (g)	2.1	1.9
Water Content, *w* (%)	*42.00*	*38*



Results	
Avg. W, (%)	*40.00*
Plastic Limit, PL	*40*



MODIFIED GEOLOGICAL MAP OF ADDIS ABABA



APPENDIX 2:PUBLISHABLE MANUESCRIPT

REINVIGORATING TRADITIONAL WISDOM: CONSERVING EARTHEN CONSTRUCTION FOR THE REVIVAL OF THE TRADITION IN ADDIS ABABA

Ethiopian Institute of Architecture, Building Construction and City Development

Addis Ababa University,

ABSTRACT

This study examines the potential of earthen construction in Addis Ababa, stresses on the recognition of the material culture and seeks to protect and promote it by focusing on material innovation, regulatory research, and cross-disciplinary conservation approaches.

Despite its historical and cultural significance, earthen architecture has received little attention in contemporary urban planning due to concerns over durability, structural integrity, public prejudice and legal restrictions. This research introduces a novel approach of studying a model sample to indicate replicable ways of showing a cross-disciplinary conservation strategy. And it does this by studying the material and coming up with problem-driven solution the likes of stabilization of the main material, for instance by utilizing Dembaqie (volcanic ash) as a natural stabilizer to enhance the performance. Through comprehensive laboratory testing and experimental prototypes, the study evaluates optimal mix proportions that effectively reduce shrinkage, decrease permeability, and improve compressive strength which is a key factors influencing the durability and applicability of earthen construction in modern contexts.

Key word: *Dembaqie*, cross-disciplinary, problem-driven, stabilizer.

INTRODUCTION

For numerous years, Ethiopia's architectural identity has been influenced by earthen construction, which combines cultural heritage specific to a given confinement. This legacy is especially important in Addis Ababa, where the city's traditional architecture demonstrates a strong bond with the local way of life and environment. However, modern growth patterns are posing a growing threat to Addis Ababa's earthen architecture, endangering not only the actual structures but also the intangible knowledge systems that are linked to it. This study investigates the potential benefits of empirical material studies of earthen sample for public awareness and legislative reform, particularly in the setting of Addis Ababa. Providing a replicable approach to restoring earthen construction in the city as a respected and practical building method is the aim, maintaining its legacy while adjusting to current day requirements.

CHALLENGES TO EARTHEN CONSTRUCTION

One of the main concerns of earth as a construction materials, especially as mortaring is its vulnerability to environmental factors, contributing to their decline in Addis Ababa's construction landscape. Traditional earthen structures, primarily clay-based, are prone to water erosion, cracking, and gradual degradation. During Ethiopia's wet seasons, moisture absorption weakens structural integrity, while dry seasons cause contraction and surface cracks. Without proper stabilization, these issues make earthen buildings less viable in urban settings.

Temperature fluctuations and occasional seismic activity further exacerbate these vulnerabilities. Seasonal shifts create cyclical stress, weakening structures over time. Traditional earthen buildings, unless reinforced, may lack the tensile strength to withstand even moderate tremors, discouraging their use in contemporary construction.

Because they think that clay buildings are not as durable as steel and concrete, engineers, architects, and legislators are skeptical. Cement-based building has become the norm as developers give preference to materials that are low maintenance and resilient to high-density urban situations. Earthen building is still disregarded despite improvements in stabilization techniques because of a lack of policy backing and a restricted dissemination of research.

Scientific innovations, such as using local stabilizers and fiber reinforcements, have been seen improving earthen construction's strength and durability. However, without greater awareness among decision-makers and urban planners, these advancements have yet to influence large-scale construction practices. Increased recognition of stabilized earthen materials could position them as a sustainable alternative in Ethiopia's evolving built environment.

MTHODOLOGIES

The methods applied in the research systematically analyze and enhance the properties of earthen construction materials. Material characterization is applied to evaluate the sample scientifically; ensuring stabilization processes are based on empirical data. The study assesses soil suitability, optimizes composition, and identifies stabilizing agents such as *Dembaqie* (volcanic ash) and cement to improve structural performance. Afterwards raw materials included 95 kg of selected clay, around 13 kg of *Dembaqie*, and 5 kg of cement, chosen for their availability and historical relevance. The soil was air-dried, pulverized, and sieved before undergoing laboratory tests to evaluate its properties under different stabilization conditions.

A range of tests analyzed soil behavior and stabilization potential. The Atterberg Limits Test measured plasticity and liquidity, revealing how stabilizers impact consistency. Hydrometer Analysis assessed particle size distribution, confirming the predominance of fine clay and its susceptibility to shrinkage. Specific Gravity Tests identified minerals such as calcite and dolomite, indicating structural potential. Compaction Tests determined an optimum moisture content of 30%, producing the highest dry density of 1.34 g/cm^3. Sieve Analysis classified soil particles, showing over 90% passed through a No. 200 sieve, verifying its fine-grained composition. Pozzolanic Behavior Assessment of *Dembaqie* established its effectiveness in reducing plasticity and shrinkage, making it a promising stabilizer in reducing certain traits while reducing some other parameters.

Thereafter findings from these tests guided the stabilization phase and the innovative formulation. *Dembaqie* was fixed at 30%, while cement varied at 3%, 6%, and 9% to identify the optimal mix for strength and durability.

Material characterization provided critical insights into the physical and mechanical properties of the soil. Evaluating composition, density, moisture behavior, and stabilizer interactions established a scientific framework for optimizing earthen construction. These findings contribute to developing durable, sustainable, and culturally relevant earthen materials in Addis Ababa, supporting efforts to revive traditional construction techniques with enhanced engineering performance.

LABORATORY ANALYSIS AND MATERIAL OPTIMIZATION

The study focused on selecting a suitable soil type for earthen construction. A total of 26 kg of sub-soil was collected, as sub-soil tends to be more stable and durable compared to topsoil. It contains a higher proportion of silt and clay, which contribute to the strength and plasticity required for construction applications. To determine its suitability, the soil underwent a series of tests, including the Atterberg limit test, specific gravity test, hydrometer test, and compaction effort test. Results indicated that the selected clay exhibited high dry compressive strength, classifying it as fat clay with significant plasticity and shrinkage characteristics. These properties make it a suitable candidate for earthen construction, though they also necessitate stabilization to enhance durability and water resistance.

Atterberg Limits Test- This test evaluated the raw clay's plasticity and workability before stabilization. The results showed that the raw clay had a liquid limit (LL) of 83, a plastic limit (PL) of 36, and a plasticity index (PI) of 47. These values indicate that the raw clay was highly plastic and capable of retaining significant amounts of water. While this property made it easy to mold, it also meant that the material was prone to excessive shrinkage and cracking upon drying. Additionally, the shrinkage test recorded a shrinkage percentage of 16.03%, reinforcing the challenges of using raw clay in construction without modification.

Hydrometer and Specific Gravity Analysis- These tests were conducted to determine the raw clay's particle size distribution and density, essential for load-bearing applications. The specific gravity of the raw soil was measured at 2.66, which falls within the standard range for clay-rich soils. The hydrometer test revealed that 58.29 % of the soil particles were smaller than 0.00035 mm, confirming its classification as fine-grained clay with a high proportion of colloidal material. Compaction and Moisture Content Analysis- Testing various moisture levels revealed the most effective compaction strategies to increase the density and cohesion of raw earthen materials. The optimum moisture content (OMC) was found to be 26%, indicating the best water-to-soil ratio for achieving maximum dry density. The maximum dry density was recorded at 1.34 g/cm^3, suggesting moderate compaction potential. However, the high plasticity also meant that excess moisture could lead to significant swelling and shrinkage cycles.

INNOVATIVE FORMULATION

To address the limitations of raw earth in construction, the study experimented with different material formulations. The goal was to improve strength, reduce shrinkage, and enhance durability. Various compositions were tested, including a 6% cement and 30% *Dembaqie* mix. However, this combination resulted in a comparatively lower-than-expected dry compressive strength, prompting further exploration of other mix ratios.

Three variations of soil stabilization were examined, incorporating cement in proportions of 3%, 6%, and 9%. Among these, the 6% cement mix was determined to be the optimal proportion, offering a balance between structural integrity and sustainability. The final prototypes were cast and cured over a 27 and 28-day period, allowing for proper material stabilization before undergoing compressive strength testing.

DRY COMPRESSIVE STRENGTH FINDINGS

The strength of the materials was a crucial factor in evaluating their feasibility for construction. The study found that the control prototype (pure clay) had a dry compressive strength of 7.14 MPa, which was significantly higher than that of the 6% cement-stabilized prototype, which only achieved 1.55 MPa. This unexpected reduction suggests that the cement addition altered the soil's inherent bonding properties, emphasizing the need for alternative stabilizers or modifications in the mixing process.

Additionally, the shrinkage test demonstrated that the introduction of stabilizers, such as *Dembaqie* and cement, reduced shrinkage by approximately 2%. While this was a positive outcome, the reduction was not as significant as initially anticipated, highlighting the necessity for further experimentation with other natural or synthetic stabilizers.

KEY RESEARCH FINDINGS AND PERFORMANCE OUTCOMES

The study investigated the effects of *Dembaqie* at a fixed 30% proportion on the physical and mechanical properties of earthen materials. The findings revealed that while *Dembaqie* effectively reduced extreme plasticity values, it also contributed to an unexpected decrease in mechanical strength, necessitating a reassessment of its role in stabilization.

One of the most notable improvements was the reduction in plasticity. The Plasticity Index (PI) of the raw clay was 47, a value indicative of highly plastic and shrink-prone material. After adding 30% *Dembaqie* and varying cement proportions of 3%, 6%, and 9%, the PI dropped to 34, 22, and 12, respectively. This significant decrease made the material easier to work with and less prone to excessive shrinkage and cracking. The 6% cement mix was deemed optimal, balancing workability and sustainability while keeping the PI within the ARSO standard range of 2-30.

However, compressive strength tests yielded unexpected results. The raw clay prototype (control) exhibited an impressive dry compressive strength of 7.14 MPa, a value exceptionally high for untreated clay. Surprisingly, the *Dembaqie*-stabilized 6% cement mix prototype recorded only 1.55 MPa, a drastic 5.58 MPa reduction from the raw clay. This decline suggested that the interaction between cement and *Dembaqie* might have weakened the material's internal structure rather than reinforcing it. The weakening effect was further evident in the prototype's structural integrity, as the edges of the mixed sample crumbled upon hand contact, unlike the raw prototype, which retained its strength and sharp edges.

SHRINKAGE AND STRUCTURAL BEHAVIOR

Shrinkage behavior was another crucial factor in evaluating *Dembaqie*'s impact on earthen materials. The raw clay displayed a shrinkage percentage of 16.03%, confirming its classification as fat clay with a high tendency for volumetric changes. With the addition of 30% *Dembaqie* and 3% cement, shrinkage reduced by 2%, though expectations were for a more significant reduction. While the reduction was a positive step toward improving stability, further refinements in mix proportions are needed to minimize shrinkage effects further.

From a comparative standpoint, despite the lower strength recorded, the 6% cement-stabilized prototype was only 0.45 MPa weaker than a Grade-C Hollow Concrete Block (HCB), making it potentially competitive for non-load-bearing applications. This finding suggests that with optimized formulations, earthen materials stabilized with *Dembaqie* could become a viable alternative to conventional masonry materials.

ECONOMIC VIABILITY AND PRACTICAL APPLICATION

Cost analysis provided valuable insights into the affordability of *Dembaqie*-stabilized earthen materials. The research found that the cost of producing the earth-based prototype ranged from 15-20 ETB per block, nearly half the price of a conventional Hollow Concrete Block (HCB), which costs 38-40 ETB. This economic advantage highlights the potential of earth-based materials in providing affordable construction solutions, especially in low-income and rural communities.

Despite its economic feasibility, the study identified limitations in material performance. Due to high shrinkage and moisture vulnerability, the raw and stabilized earthen materials were recommended primarily for interior walls, where exposure to environmental conditions is minimized. For exterior applications, additional water-resistant coatings or alternative stabilizers would be necessary to enhance durability and weather resistance.

APPEARANCE AND PHYSICAL MAKE-UP

There are noticeable variations in strength, durability, and structural integrity between the control and mixed prototypes based on their physical performance. Significant shrinkage was seen in the pure clay prototype, resulting in uneven surfaces and fragile, breakable edges that collapsed readily under pressure. Its vulnerability to erosion and distortion was brought to light by its incapacity to maintain sharp edges. With sharper, more defined edges that resisted chipping and held their shape over time, the *Dembaqie*-stabilized prototype, on the other hand, showed superior stability. By reducing excessive shrinkage, the stabilizer ensured a more compact and Cohesive structure and prevented fissures. Furthermore, the mixed prototype demonstrated improved resistance to outside forces, while the control sample continued to be brittle and prone to shattering.

CONCLUSION

The findings of this study highlight the dual impact of *Dembaqie* as a stabilizer it significantly improved plasticity control and workability while unexpectedly reducing compressive strength. These results underscore the need for further research into optimizing mix proportions, particularly by reducing *Dembaqie* content below 30% and exploring alternative stabilizers that complement rather than compromise strength.

While challenges remain, the research demonstrated the potential of earthen materials as cost-effective and culturally relevant alternatives to conventional building materials. The affordability of these materials presents a significant advantage in Ethiopia's housing sector, where cost-effective and sustainable solutions are in high demand. Additionally, the study underscores the importance of developing context-specific building codes and policies that encourage the use of traditional materials in modern construction while maintaining safety and durability standards.

Moving forward, future research should explore ways to enhance the mechanical strength of *Dembaqie*-stabilized materials while retaining their workability. Investigating natural additives, improved curing techniques, and hybrid stabilization approaches could contribute to the widespread adoption of earthen construction in both urban and rural settings. With continued advancements, stabilized earthen materials have the potential to play a crucial role in Ethiopia's sustainable architectural landscape, blending tradition with innovation for a more resilient future.

This research highlights material analysis as a key strategy for improving earthen construction, ensuring its durability and relevance in modern architecture. By studying structural behavior and integrating stabilizers like *Dembaqie*, it enhances resistance to shrinkage, moisture, and load-bearing challenges, making traditional methods more viable. Additionally, material research bridges traditional knowledge with modern engineering, demonstrating earthen construction's potential for sustainable development. Empirical studies provide evidence-based improvements, supporting its inclusion in building regulations and wider urban applications. Without scientific validation, earthen methods risk becoming obsolete. By refining materials through rigorous testing, this study advocates for their revival, ensuring future generations inherit both the structures and the craftsmanship behind them.