The Role of Vernacular Construction Techniques and Materials in Developing Sustainable Building and Construction in Africa

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ABSTRACT

Vernacular architecture embraces a multitude of constraints from areas where it belongs, one of the key features being local techniques and materials. Vernacular materials have a reduced impact on the environment relative to industrial materials and are an alternative for constructing sustainable buildings. The increased use of modern manufacturing and standardized materials has contributed to the homogenization of various construction techniques and has created a globalized architecture, which in many cases is out of context and is highly reliant on energy and other resources.

A common issue in the building sector across African countries has been the reliance on knowledge of developed nations for their housing and construction needs. Applying this Knowledge in the use of materials and construction techniques directly with little regard for cultural, environmental and economic realities has led to a construction industry that is reliant on high consumption of energy and other resources on the continent. Studying the vernacular architecture where buildings were made traditionally with little technological advances is thus essential.

This study explores firstly the sustainable building and construction concept and identifies goals for achieving sustainability in buildings and construction. Secondly, the vernacular architecture of Africa is explored with a focus on its construction techniques and materials. Finally, four buildings located in four regions of Africa are chosen as case studies based on their location in different climatic regions of Africa and their application of vernacular construction techniques and materials. These four buildings are analyzed and evaluated to ascertain the contributory potential of these construction techniques and materials to achieve sustainable buildings and construction on the continent.

Keywords: Vernacular Architecture, Africa, Sustainable Building, Sustainable Construction, Construction Materials

ÖZ

Ait olduğu alanlardan gelen çok sayıda kısıtlamayı kucaklayan yerel mimarinin temel özelliklerden biri yerel teknikler ve malzemelerdir. Yerel malzemeler, endüstriyel malzemelere göre çevre üzerinde daha az etkiye sahiptir ve sürdürülebilir yapı inşa etmek için bir alternatiftir. Modern imalatın ve standartlaştırılmış malzemelerin artan kullanımı, çeşitli yapım tekniklerinin homojenleşmesine katkıda bulunmakta ve çoğu durumda bağlam dışı olan ve enerji ve diğer kaynaklara oldukça bağımlı olan küreselleşmiş bir mimari yaratmaktadır.

Afrika ülkelerinde inşaat sektöründeki ortak bir sorun, gelişmiş ülkelerin konut ve inşaat ihtiyaçları için bilgi birikimine güvenilmesidir. Bu bilginin, kültürel, çevresel ve ekonomik gerçeklere çok az önem vererek, malzeme ve inşaat tekniklerinin kullanımına doğrudan uygulanması, kıtadaki yüksek enerji ve diğer kaynak tüketimine bağımlı bir inşaat endüstrisine yol açmaktadır. Bu nedenle, binaların geleneksel olarak çok az teknolojik ilerlemeyle yapıldığı yerel mimariyi incelemek çok önemlidir.

Bu çalışma, öncelikle sürdürülebilir yapı ve yapım konseptini araştırmakta, yapılarda ve yapımda sürdürülebilirliği sağlamak için hedefleri belirlemektedir. İkinci olarak, Afrika'nın yerel mimarisi, yapım tekniklerine ve malzemelerine odaklanılarak araştırmaktadır. Son olarak, Afrika'nın dört bölgesinde bulunan dört yapı, Afrika'nın farklı iklim bölgelerindeki konumlarına ve yerel yapım teknikleri ve malzemelerini uygulamalarına göre örnek çalışmalar olarak seçilmiştir. Kıtada sürdürülebilir yapılar ve yapımlar elde etmek için bu dört yapının yapım teknikleri ve malzemeleri katkı potansiyelini belirlemek için analiz edilmekte ve değerlendirilmektedir.

Anahtar Kelimeler: Yerel Mimari, Afrika, Sürdürülebilir Yapı, Sürdürülebilir Yapım, Yapı Malzemeleri

To my Family

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All Thanks to God almighty who has enabled me, given me the strength and ability to learn and complete this thesis.

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Chapter 1

INTRODUCTION

In recent years sustainability and energy efficiency debate have dominated the world of architecture and construction. The increased negative impact of activities linked to construction has generated a need for sustainable buildings and construction. According to Agyekum et al. (2020) sustainable construction is not entirely pristine as it has traces in vernacular architecture where locally accessible construction materials and techniques have been used. Fernandes et al. (2015) implies that the use of materials that are available to a particular region for construction was common up until the industrial revolution which led to the use of contemporary standardized and industrially produced construction materials which has in turn created a homogenization of dissimilar construction techniques. Architecture of the modern world created with these standardized building materials has led to a globalized architecture that is reliant on use of energy (Fernandes et al., 2015). The world is now faced with several environmental and energy challenges. In a 2013 report by the Internal Energy Agency (I.E.A), fossil fuels reserve, which contributes to over 80 percent of the planets overall primary energy usage is declining and a demand for energy is on a steady increase (Alrashed et al., 2017).

Buildings and construction closely interact with global energy and environmental challenges. Buildings account for over 40 percent and about a third of the overall emissions of greenhouse gasses worldwide and energy consumption (Agyekum et al.,2020; Alrashed et al., 2017). As a building consumes energy in all through its lifecycle, the energy requirement in buildings is sometimes direct and other times indirect. This dilemma has ensured that efficient use of energy and comfort standards have been among the major issues of sustainable buildings in designing phase and decision-making (Agyekum et al., 2020). Mumovic and Santamouris (2009) reported that the introduction of energy efficiency and sustainable buildings has gained substantial interest worldwide, particularly the residential sector, as buildings are crucial to mitigation of energy and environmental problems. A 2014 report by the IEA showed that the residential sector accounted for 26% and 17% of global electricity demand as well as production of carbon dioxide respectively. According to Ozorhon & Ozorhon (2014) in halterpath of the twentieth century, resources which were available for mankind and expected to be inexhaustible are now facing exhaustion. With the wasteful use of resources, growing population and fossil fuels consumption, mankind is now facing a range of hazards, including air degradation, destruction of the ozone layers, global warming, and deforestation,(Ozorhon & Ozorhon 2014).

In attempt to mitigate these issues as they are concerned with buildings and building construction Fernandes et al. (2015) suggests there is a rather pressing demand to develop pristine ways of constructing buildings. In accordance with a number of researchers, reflecting on the past is crucial as traditional construction and buildings are instances of more sustainable construction and have a part to play in the future of building construction (Foruzanmehr & Vellinga 2011; Oliver, 2006; Machado et al., 2000). Agyekum (2020) notes that these traditional construction techniques also known as vernacular architecture and involves the utilization of vernacular construction materials, construction techniques and methods. He further notes that the sustainable features of constructing new buildings become a problem without making use of local or vernacular construction materials and techniques. According Fernandes et al. (2015) using alternative techniques and construction materials like that of the vernacular architecture can significantly lower the overall energy consumption of buildings.

Africa, a continent with a diverse people and culture possesses an also diverse and spectacular vernacular architecture peculiar to its regions. Construction materials and techniques are key features that distinguishes vernacular architecture around the globe and have thus differentiated that of Africa.

Studies have shown that the use of energy by vernacular architecture leaves minute environmental damage to attain decent indoor thermal comfort (Chiou et al., 2019).This form of architecture is seen as very beneficial for the modern and sustainable development of architecture, however for a building to be regarded as sustainable it needs to take into account not just environmental but also the economic and social aspects of sustainability (Fernandes et al., 2015), hence this thesis explores the sustainability concept as encompassing the environmental, economic and social attributes of sustainable buildings and construction. A variety of sustainable building projects have been implemented worldwide using vernacular construction materials and techniques (Alrashed et al 2017; Hamard 2017; Hashemi 2018, Tawayha et al 2019)In view of the number of research carried out on the utilization of locally available materials and technologies in constructing sustainable buildings, any suggestion made by these research would have been easier to address.

Nevertheless, this is not accurate in context, as it has many advantages to recognize vernacular construction techniques and materials typical of a certain location(Agyekum 2020). Therefore, it is important for the research to recognize vernacular construction techniques and materials that are specific to the African climate.

Literature on this subject has been widely published. For example, the performance of traditional architecture in the construction of sustainable buildings in a Mediterranean city of Palestine, was explored by Tawahya et al. (2019). The vernacular architectural design techniques used for sustainable urban buildings were rediscovered by Hamard (2017).The role of vernacular policies in constructing energy-saving residential buildings in Iran was also discussed by Hashemi(2018) In Turkey Kuyrukçu and Kuyrukçu (2015) have been investigating the possibility of local or vernacular materials for sustainable housing construction.

Despite numerous studies in vernacular materials in other regions, especially in Europe and Asia (Nguyen et al 2019),there are not enough empirical studies which identify the construction materials and techniques that are of vernacular importance for sustainable building and construction in Africa. The aim of this study was therefore to explore the African vernacular architecture and its importance to sustainable buildings and construction on the continent.

1.2 Problem Statement

In Africa, a critical issue plaguing construction activity in the various regions is that the construction systems have been modelled based on the experiences of that of the developed world (Taylor et al., 1994). This kind of thinking ignores national circumstances, climate, and cultural values. According to Adebayo (2002) this has proven inappropriate in cases where principles of the developed world were directly applied in Africa without any modifications. The copying of these construction techniques and materials without considering the African context socially, economically and environmentally has led to unsustainable practices, high cost of construction, maintenance of building and environmental degradation thus, there is a need to develop alternative ways of constructing buildings on the continent. Several studies have shown that vernacular construction techniques and materials are contributory to sustainable buildings and construction. Therefore, this thesis focuses on the construction techniques and materials of the African vernacular architecture seeking to answer the following questions:

1. Which construction materials have been used in the African vernacular architecture?
2. How are these materials used to construct buildings (construction techniques)?
3. How can these materials and construction techniques be utilized in a contemporary manner that is contributory to sustainable buildings and construction in Africa?

1.3 Aims and Objectives

The African continent comprises of different geographical regions with unique and often similar vernacular architecture. The African vernacular architecture has developed based on available materials and resources in the respective regions. The aim of this study is to ascertain the role of these materials and techniques used to build in developing sustainable buildings and construction in Africa. To do this the following objectives are developed:

1. Explore the sustainable building and construction concept.
2. Identify different methods and strategies for implementation of sustainable buildings and construction.
3. Identify and discuss materials and construction techniques of African's vernacular architecture in light of sustainability.
4. Explore, analyze and evaluate practical examples where materials and construction techniques of African's vernacular architecture have been utilized in Africa based on the strategies for implementation of sustainable buildings and construction.

1.4 Research Methodology

This study would adopt the use of literature review as a research method to explore, firstly, the sustainable building and construction concept focusing on strategies for achieving sustainability in buildings and construction. Secondly, explore vernacular architecture, and finally explore the African vernacular architecture with a focus on the construction techniques and materials used and the role they potentially play in developing sustainable building and construction. The study would go on to explore four Buildings in Africa chosen for their geographical location in the four major climatic regions on the continent and their resourceful use of vernacular construction techniques and materials. The buildings would be analyzed and evaluated on the basis of strategies identified by the literature as being crucial to implementing sustainability in buildings and construction with the aim of establishing vernacular construction techniques and materials of Africa, as playing a critical role in the future of sustainable buildings and construction on the continent.

1.5 Limitations of Study

A major limitation of the study would be in identifying the vernacular construction techniques of the African vernacular architecture as little has been documented about these construction techniques. Secondly, the financial cost and implications of the buildings chosen as case studies were not made available by the various sources. This makes it impossible to ascertain if costs are reduced or increased by the use of this vernacular construction techniques and materials. For this reason, evaluation of cost efficiency is removed from the analysis.

Chapter 2

OVERVIEWING OF SUSTAINABLE BUILDING AND CONSTRUCTION

2.1 Sustainable Building and Construction

The building industry is a crucial member of any economy yet momentously affects the environment. By merit of its size, building constructions are among the biggest consumer of water, material resource, energy, and a daunting polluter (Akadiri et al.,2012). Because of these effects, there is developing agreement among associations focused on environmental performance targets that suitable strategies and activities are essential to make building operations increasingly sustainable. The basis of sustainability includes bettering the quality of life hence allowing for individuals to live in healthy environments with better economic, social and environmental circumstances (Ortiz et al., 2009). The sustainability concept links together the attributes of environmental, social, and economic wellbeing. In this Study, sustainable building and construction is described as enveloping all attributes and not just as ecological or green buildings. Energy issues are one of the paramount considerations from the environmental point of view, and more recently are now considered at topmost of all agendas (Tessema et al., 2009). More so, energy consumption and utilizations of great significance in the sustainable building and construction field.

Sustainable buildings have several definitions, however some of them which are important to this study includes those developed in the course of the Marrakech task force on sustainable building and construction workshop in 2007 (Tessema et al., 2009) include:

Sustainable buildings and construction projects meet their efficiency criteria with minimal adverse environmental effects while promoting local, national and global changes in economic, social and cultural conditions.

Sustainable construction means responsible supply, service and maintenance, while promoting economic, social and cultural development, of the buildings which satisfy the needs of their owners and users during their lives with minimal environmental impacts.

Other possible ways of describing sustainable buildings and construction, one of them is as zero impact buildings, which is to say the buildings do not create an economic, social or environmental negative impacts to put this into perspective, a zero impact building will not contaminate water but go on to cleanse its own waste waters, produce all the energy it requires, would not produce waste but rather recycle all its waste, would not use up land than can be used to grow crops or conserve vegetation but use designated construction sites or renovate and repurpose older buildings (Attia & De Herde, 2010).

Sustainable buildings creates an effect on the economy, ecology and socio-cultural aspects of life such as comfort of users and health(Medineckiene et al 2011).The ecological , economic and social effects of the built environment on the human beings and on the natural world are taken into account in sustainable construction (Sobek et al. 2009)

But how then can a construction process or building be analyzed to ascertain if a construction or building is sustainable? According to Tessema, Taipale & Bethge (2009) using a life cycle perspective is beneficial as impacts of buildings usually happen over an extended period of time and involves various actors in the designing and construction, use and maintaining of a building. Furthermore, Abidin and Pasquire (2005) differentiated sustainable construction from sustainability, Parkin et al (2003) gave a reason for this differentiation by defining sustainable construction as the process of achieving sustainability over time. The time factor in this definition further strengthens the need to analyses sustainability of a construction over a period of time, thus the life cycle perspective. A number of tools and rating methods are available for life-cycle assessment, like LEEDs in the United States, GRIHA in India, BREAM in the United Kingdom, or the SB Tool and its local adaptations.

In the various phases of the construction process, the life cycle approach enables analysis of the position of different actors such as decision makers, developers, industry, consumers and individuals.

2.2 Life Cycle Perspective

The design, development, operation, maintenance and reuse process of a buildings is a procedure that consists of distinct phases which could be analyzed independently. Throughout each phase of the life cycle, a building impacts negative and positively, this can be analysed at each phase. The life cycle of a building could be distinguished in the following phases: predesign, involving project briefing, analysing the site and setting targets, designing phase, involving predesign, comprehensive design, the submission of a building permit, constructing phase, including tenders, building materials and construction process, usage phase and handing over, usage and repair, and lastly end of life phase involving recycle and reusing.

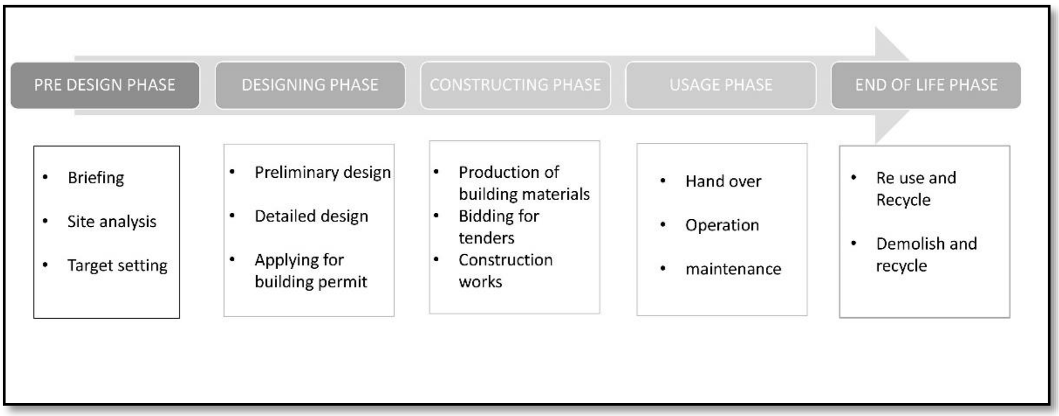


Figure 1: Life Cycle of a Building (Tessema et al., 2009)

Chen et al (2010), Yu& Kim (2011) and Jaillon and Poon (2008) indicate numerous advantages of sustainable construction and buildings to include: a shorter construction time, a reduced cost of construction, improved resilience of the structure, enhanced aesthetics, improved health, comfort and safety, reduced construction waste and an overall conserving of water and energy. However, not introducing certain strategies early in the predesign stages all through the lifecycle of the building (Figure 1) can compromise these advantages. According to Enhasis et al (2018) studies have confirmed the need to consider construction from the outset to the end of life to ensure that all the processes are carried out in a sustainable manner thereby achieving sustainability. The next section discusses strategies and methods to be applied during the life cycle of the building to achieve sustainability.

2.3 Implementing Sustainability in Buildings & Construction

Asif et al. (2007) propose the use of a multidisciplinary approach, covering various aspects some of which are: conservation of energy, better ways to use construction materials, reduction of material waste, controlling pollutants and emissions to attain a future which is sustainable for the building sector. many methods exist to control and better the current character of building activities, making them less harmful to the environment, unaccompanied by reducing the helpful performance of building activities. The continuous life-cycle of the buildings will then play the role of being the setting within which the activities are done to set up a strategic advantage through ecologically responsible construction practices. Akadiri et al., (2012) identified three basic goals that should form the basis for the introduction of sustainable design of buildings and construction when considering the sustainability aspects socially, environmentally and economically of sustainability. The goals are:

1. Conservation of resources
2. Cost efficiency
3. Design for human adaptation

In the subsequent sections these goals above would be discussed alongside strategies to be implemented all through the life cycle of the building for sustainable buildings and construction. These strategies and methods from literature would be then used to develop a framework with which case studies would be evaluated and analyzed in chapter 4.

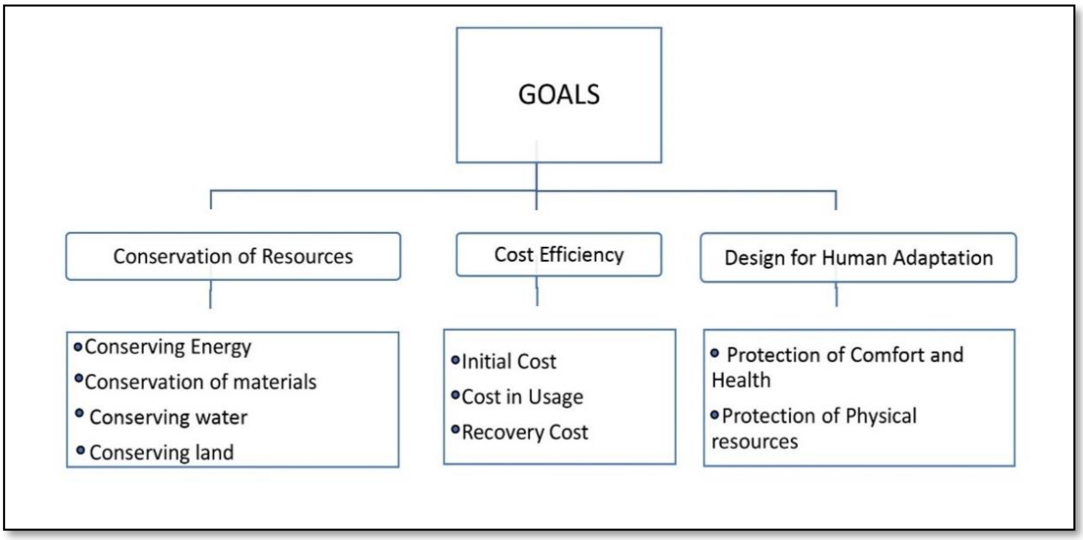


Figure 2: Goals for Achieving Sustainability in Buildings and Construction
(Amended from Akadiri et al., 2012)

2.3.1 Conservation of Resources

"Conservation of resources “means doing more for less. The management of human use of natural resources is structured to give current generations full benefits while maintaining their ability to provide the requirements of generations in the future (Wilson et al.,1998). Throughout discussions on sustainable growth, the definition has become a big issue. Halliday (2008) points out that some resources are turning out to be increasingly scarce and that the utilization of the still existing stocks ought to be carefully handled. He asked that rare materials to be substituted for more abiding or materials that are renewable. In political circles, bold declarations concerning the urgency for drastic changes associated with material usage and energy efficiency have been recognized (Akadiri et al., 2012). The claim is that increasing efficiency is important for minimizing the effect of waste material and energy assimilation as the industry is a major natural resource user, and many of the initiatives aimed at creating eco-friendly buildings focus on increasing resource efficiency. He noted that the methods of searching for such efficiencies are different. He cited instances from the concepts of solar passive design gear towards reduction the use of non-renewable energy, power utilization, life cycle design and construction design. The methods used to minimize waste material throughout the construction processes and to provide recycling and reuse opportunities for building material are also contributing to the improvement of resource consumption. Calls for resource conservation came out of concern for the growing depletion of natural resources which are not renewable. Because electricity, water, matter and land perform a crucial part in a building project, the preservation of the nonrenewable resource is significant to a sustainable tomorrow. Conservation of resource produces different designing methods and strategies as described in Figure 3.

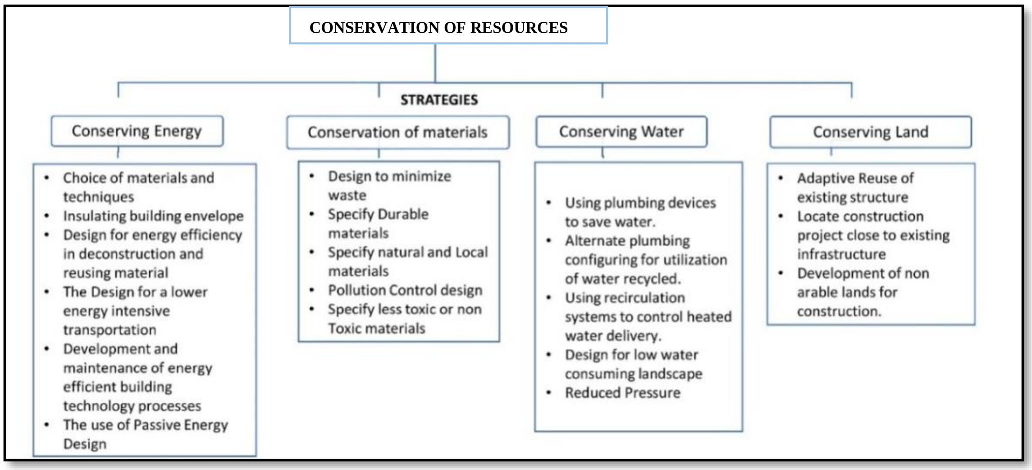


Figure 3: Strategies for Resource Conservation (Amended from Akadiri et al., 2012)

2.3.1.1 Conserving Energy

Energy usage is among the more significant environmental problems, every functioning civilization ultimately regulates its use. Construction is the dominant energy consumer. At each phase of building projects, buildings utilize energy and other resources, from the designing and constructing to operating and finally demolishing (Schimschar et al., 2011). Lenzen & Treloar (2002) indicate that the form and the amount of energy utilized throughout the life cycle of construction materials can affect the flow of greenhouse gases (GHG's) into the air from the producing processes to the treatment of construction materials after their end-of - life period. Their usage can be significantly minimized by increasing performance, an efficient way to minimize emittance of greenhouse gases and mitigate the loss of nonrenewable resource of energy (Lee & Chen, 2008).Considering this understanding, increased regard has been given to enhance energy conservation in the construction sector over the years, partially since this sector possesses significant possibility for primary energy savings and emission reduction, creating negative environmental impacts (Sasnauskaite et al, 2007). Consumption of energy in a life-cycle context requires energy demanded both for operational as well as for embodied energy. A building's operational energy needs can be seen as the energy it uses in order to maintain the interior atmosphere in the structure (Dimoudi & Tompa, 2008). A life cycle analysis by Thormark (2006)reveals that 85–95 percent of a building's overall carbon emissions and energy usage are results from activities meant to cool, heat, ventilate and heated water usage. This includes power, water, and fuel burning like oil or coal. When the energy used for operation reduces the energy usage for material processing, which is the embodied energy, needs to be more closely considered. The embodied energy represents the overall energy in which a building is created, including that of energy utilized the directly in the assembling and construction processes and the energy used indirectly to produce the construction materials and elements(Huberman & Pearlmutter, 2008). The indirectly used energy consist of energy utilized in extraction of raw materials, energy to process and manufacturing, all of the energy used in transportation all through the process of manufacturing. The energy life of a building can in this manner be regarded as being inclusive of various contributions of embodied and operational energy throughout the lifecycle of a structure.

Thus, the paramount conserving energy aim is to minimize fossil fuel usage and intensify the usage of renewable sources of energy. It can be done by the following approaches (Figure 3);

- **Choices of construction materials and techniques** are crucial to lessen a building's energy use by mitigating solar heat loss or gain, minimize air-conditioning loads. Choosing products and construction material with a reduced embodied energy can help reduce resources used to mine, refine, manufacture and transport construction materials. For instance, because of large quantity of electric power used to mine its raw material, aluminum has very high embodied energy. True low-energy building architecture must find this essential feature and take a wider method to energy evaluation.
- **Insulation of the building envelope** is one among the highly critical measures for conserving energy, as it possesses a major influence on energy spending. The heat expended by means of a building’s envelope will decrease significantly up to 50% by a properly designed and installed insulation (AL-Homoud, 2005). Air density technique would reduce draughts and thermal

loss, covering existing vents and fireplaces, isolating floors and ceilings and coating of improved plaster in the walls.

- **Design for energy efficiency in deconstructing and reusing material** Recycle of material decreases manufacturing energy usage and saves natural resources. The deconstruction buildings should require structures detachments and reduction in chemically incompatible glues, sticks or coating — or electrical, chemical or mechanical means of improved separation of constituent materials (Razaz, 2010). It will include a building plan and a deconstruction plan. These provide barcodes for goods in order that the deconstruction professionals have instructions for dealing with the materials or part at the time of removal. Such buildings have self-supporting and self-sturdy structures, functionality for components designed for staff and machinery, and incorporated into junctions and connections. The main feature is the use of non-toxic materials, biobased products, good quality and greatly re-useable materials, for buildings that promote recycling and reuse The designing for deconstruction presents opportunities for designing buildings that seal the loop in construction between materials and use supporting transitioning to a building sector with no or little resource consumption.
- **The design for a lower energy intensive transportation** lowers pollution-related emission by impacting the fuel consumed. Reducing energy usage in buildings has a minute effect on a nations overall energy usage in the case of continuous waste of energy in both rural and urban transit system. A community designed for efficiency that allows educational facilities, shops and other social amenities near home and businesses, which makes it easier to find places without using cars and offers pleasant walking and cycling

routes, can significantly reduce miles per household of vehicles (Carlisle et al., 2012). In addition, it would reduce the required energy for transport – whilst bettering living standards – even before expenses for cars are carried out. Designing of lower energy consuming buildings should thus be amalgamated with design of an urban environment which makes public transport and bicycles available. As cities increase public transit, bicycles are used and private cars are limited, the result will be lower energy and highway building costs, less traffic delays and less air pollution.

- **Development and maintenance of energy-efficient building technology processes**. For the purpose of accomplishing the target energy usage level, the project team will instigate at the beginning and continue with a genuinely inclusive view to efficient energy use in building process.
- **The use of passive energy design** such as vegetational landscape design, naturally ventilating, evaporative and cooling water pools, appropriate orientating of buildings , etc. can promote visual and thermal comfortability in the interiors of buildings so as to greatly minimize energy used by mechanical air-ventilating, and manmade lighting in buildings. Buildings can efficiently use energy by observing the site's macro and microclimate, using solar-passive and bio-climatic design function and benefitting from onsite natural resources.

2.3.1.2 Conserving of Materials

The misuse and usage of natural resource as construction materials or as raw materials for the manufacturing of building materials and structure components directly affects the natural biodiversity due to the degradation of natural areas and habitats induced by construction activities (Spence & Mulligan, 1995). An exceeding amount of minerals resource are utilized in construction and buildings, many of which are not renewable. However, this nonrenewable materials usage is essential. According to Abeysundara et al. (2009), this should be included into the project resourcefulness and design phases, where material choices are highly relevant, and the choice should be focused on environmental impacts of the materials. Throughout the building and deconstructing processes, different approaches may also be utilized to lessen the environmental impacts of material usage. The following sub-section addresses several strategies for achieving efficient use of material in building construction (Figure 2);

- **Designing to minimize waste**. The Building sector is among the chief waste generating industries, causing many natural, social and economic issues. Waste appears as utilized or disposed of materials from building and demolition process. Inhibiting waste and proper waste management in constructing buildings preserves a substantial quantity of nonrenewable resource. a body of scholarly research, especially that created by (Ortiz et al., 2009; Osmani et al., 2008; Baldwin et al., 2009;Coventry et al., 2001; Greenwood, 2003; Poon et al., 2004) has shown that a buildings designer plays a major part in reducing and eliminating waste produced in constructing the building. Minimizing waste will be discussed in the design process as a component of the project sustainability strategy by applying the three-key waste managing principles, namely: reduction and recovery of building wastes; recycling, reusability and storage and disposing of building waste;

- **Building waste reduction and recovery**: Esin and Cosgun (2007), indicate that the more successful approach to minimize the environmental effects of building waste is primarily to avoid and mitigate its production. It will raise demands for recycle, reusing and disposing, creating benefits economically. An experiment found that recovering decreases waste and greenhouse gas (GHG) emissions, saves electricity, and decreases raw material usage (Pimenteira et al, 2005). Recovering of usable energy and waste materials was additionally identified as among a major environmentally sustainable activity for conservation of energy to reduce crucial energy issues (Osmani et al., 2008; Marchettini et al., 2007).
- **Recycle and Reusing**: The recycle of products reduces the overall negative effects of production on the environment, especially in resource usage and waste generation. Literature has already addressed the value of options (such as recycle and reusing) to reintegrate construction materials and elements in the supply chain (Hill & Bowen, 1997; Peng et al., 1997). Reusing of a buildings material is an option for elimination of waste from constructing or demolition of structures while deconstruction activities are carried out, enhancing the recovery of some building pieces as usable components some of which are windows, bricks, tiles, as opposed to conventional demolitions where pieces are reverted to raw materials. Designers will decide if buildings that are existing can be renovated and repurposed

to new demands; perform a pre demolishing analysis of the building designated to be demolished to determine if some pieces or components could be reclaimed and reused accordingly.

  - **Construction waste disposing and storage**: in cases where constructional waste cannot be avoided and repurposed, it must be collected, properly treated and properly managed. (Esin & Cosgun, 2007). Non-dangerous building rubbles and construction rubbles are designated as special waste and disposed in special landfills designated for this kind of waste.

- **Specify durable materials.** Mora (2007) described durability as a measure of how long a material retains its original requirements. A building's longevity could be promoted by the resilience of individual materials (Malhotra, 2002) .A buildings material, part or device can be called durable when its functional service life (performance) is equivalent to the period needed to absorb relevant impacts on the environment (Mora, 2007). Components with longer-lasting lifespan compared to those with a shorter life span built for similar objective require less frequent replacement. It decreases the natural resources available for production and the finances expended on installing and labor increases. The longer the material longevity, the less time and money is required to preserve it (de Silva et al., 2004). Materials with high durability need to be less frequently replaced and thus would need less raw materials and in turn create less waste throughout the lifespan of the building.
- **Specify local and natural materials**. In embodied energy and toxicity, natural materials are usually lower than their artificial counterparts. This is because the natural material needs lesser energy to be processed and are a lot

less environmentally unfavorable. Others are potentially sustainable, including wood. By integrating natural materials into construction goods, the sustainability of the goods increases (John et al., 2005). Using locally sourced construction materials assist in minimizing environmental costs, shorten travel distance, limiting vehicle-generated pollution of air. Regional products are also ideally appropriate for climatic conditions, and these sales benefit local economies. For instance, decorative use of quarried marble worldwide isn’t a sustainable option. Steel is a fair utilization of generally imported materials some distances from the construction site as necessary for structural strength and reliability (Kim & Rigdon, 1998).

- **Pollution control design**. Pollution reduction steps taken during the process of production and construction will greatly contribute to environmental sustainability. Kibert (2016) suggests choosing products provided by a company with environmental consciousness promotes their effort to avoid pollution. While these materials may originally have advanced "off-the-shelf" quality, selecting materials that create higher pollution level is environmentally harmful (Kim & Rigdon, 1998). Air, water and soil type pollution. Nevertheless, soil emissions are rarely mentioned in any LCA literature, with very limited data available. In building, soil contamination is primarily a concern at the site of the building. It could also be an issue in mining many minerals when waste is stashed, particularly dangerous waste. Such wastewater is frequently deposited into waterways and can comprise of toxic constituents. Transportation is significant, too. Lane, air and rail emissions are a significant source of photochemical smog, with lower ambient organic compounds emitted by sunlight as a result of carbon monoxide, ozone, hydro-carbons and nitrogen oxide (Spence &Mulligan,1995). Due to the scale and huge volume, transportation of construction materials adds voluminously to the total emissions of transportation, contaminating the air. Building planners can encourage the use and promotion of recycled materials through recognizing and eliminating goods made through highly polluting processes by suppliers adopting eco-friendly manufacturing processes.

- **Specify Less Toxic or Non-Toxic.** De- or subtoxic components are less detrimental to building staff and residents. Some products have an effect on air quality indoors and subject inhabitants to safety risks. Most construction materials, like glues, paint, sealant, sanitizers and other standard goods, contains volatile organic compounds (VOCs) which emit harmful pollutants for a limited amount of time Throughout and after they have been installed. Certain building quality issues may occur (Kim & Rigdon, 1998). When making use of products with lesser or nonexistent hazardous contaminants, environmentally induced health issues can be eradicated and the demand for air scrubbing minimized.

2.3.1.3 Conserving Water

With global economy's exponential growth, water supply depletion becomes a major environmental concern. The UN Water Development Report (WWDR) reports that water is insufficient for all our requirements, resulting in a water crisis (World Water Assessment Programme, 2003). The environmental consequences of a business are no other place more evident than in the construction sector (McCormack et al., 2007). Structures and their operations are primarily focused on fresh energy. The rise in use of water by humans has contributed to a major drop in water levels, causing massive schemes to siphon away from irrigation (Roodman et al., 1995). Water for houses is an important aspect of regional water use. However, this is not the only source of water consumption in the life cycle of structures. Water is also utilized to extract, manufacture, manufacture and distribute materials and supplies for the site and in the on-site construction processes. McCormack et al., (2007) called water 'encarnated.' Ilha et al. (2009) found that the most frequently neglected elements of the planning plan were water management techniques and methods. Despite this, numerous water applications in a building are slowly being a prime concern, partially due to the growing awareness of water savings which can be achieved by water-saving initiatives. The literature shows a variety of techniques (Ilha et al., 2009; McCormack et al., 2007; Sev, 2009) that can be used to minimize water usage over buildings life-cycle. These methods generally include:

- **Using plumbing devices efficiently save water**. Ultralow flow toilet and urinal, waterless urinal baths, sensored and low flow showers, low flow sprinklers, efficient dishwasher, and less water cleaning machines to reduce water wastage.
- **Alternate plumbing configuring** for the utilization of Water recycled for toilets flushing or a site drainage gray water scheme. Gray water is generated by practices like washing hands and must not be handled as waste rigorously. It may be used for watering plants or toilet flush.
- **Collection of rainwater**. The use of treated water reduces substantially by combining rainwater from rainwater and gray water for irrigation purposes. For domestic usage, as water for drinking and for baths and chores, rainwater may be used. Historically, people of many regions of the world rely on the rainwater they collect to provide water.

- **Using recirculating systems to control heated water delivery**, this conserves water normally lost by consumers when waiting for hot water to flow from the hot water faucet.
- **Design for a low water consuming landscape**. using local plants often decreases on-site water use as the plants are adapted to local ecosystem relying on the rainfall, avoiding unnecessary watering (Mendler & Odell, 2000). Water quality can also be increased by underground drip irrigation systems, reducing water loss caused by surface waters evaporation.
- **Reduced pressure**. Owing to the pressure-related flow rate, the average, If water pressure is reduced it may decrease the flow from an outlet running on a fixed setting. For instance, the pressure at an outlet is reduced from 100 pounds per sq. inch to 50psi will result in a reduced water flow of up to three quarters (Brown, 1984).

2.3.1.4 Conserving Land

Land is a major construction industry resource. Human land use in both developed and developing countries has been recognized as a persistent issue. Although more land should be recovered from the sea, a massive land recovery is impractical, because it can clash significantly with biodiversity. Soil erosion, ground water floods, acid rain as well as other chemical pollutants damage the health of plant populations, exacerbating the crisis and the need to preserve ecosystems. Sustainable design will promote respect for the environment and allow further attempts to resolve the inter-relationships between land, water, plant organisms, habitats and wildlife and the impact of human use on them. The environmental impacts of the Construction industry and the expansion of urban areas prove that land is a vital development factor with a capacity to be an actual predictor of sustainable construction (Haberl et al., 2004). Land can be protected in urban areas by zero growth of already existing urban regions. It may be done by adapting buildings that are already built to minimize the need for new construction. furthermore, the convenient access to public transport, hospital services, recreational services and retail events to the sustainable development project will deter the growth of urban environment and occupancy in environmentally sensitive and agricultural areas. Both solutions would improve urban land use by increasing population density and enable greater usage of public amenities and transportation networks. An additional possible spin-off is developing of infertile land in for new building projects combined with an energy efficient public transport system.

2.3.2 Cost Efficiency

Building customers expect long-lasting economic output and building costs. In turn, the construction supply networks of manufacturers, vendors, distributors, architects and development teams is facing increasing market demand to lower the total expense of the construction and to pay attention to how much the building can expend all through the life cycle and how easily it will afford to satisfy the needs of the occupant. Buildings entail significant and long-term investments in financial and other services (Oberg, 2005). Therefore, improving the economic efficiency of a building is of common relevance to owners, customers and the community. The philosophy of sustainability applied to building construction aims at encouraging optimum efficiency and rising financial costs. Substantial proof exists that most companies, in the public and private sectors as well, make judgment on building spending relying on estimates of initial construction costs with minimal to no concern for operating to repair expenditures over the life of the structure (Woodward, 1997). Project decisions include the option of construction materials, structural systems and building services, frequently followed by investment errors by poor economic decision-making (Giudice et al., 2005). The drastically increasing energy costs highlights the potential for total building life savings that can be accomplished by making an investment in better energy conserving solutions at the outset. Even cutting cost on other operational and cost of maintenance can be seen, for example utilizing building finishing that does not require regular renovation. Consideration has to be paid to a buildings economic functioning during the construction process, as well as its preservation and conservation during its functional life. In order to guarantee these goals are accomplished, the Life-Cycle Costing Analysis (LCCA) concept will perform a major role the economics of a buildings project. 'Life-cycle cost analysis' (LCCA) is an economical evaluation method that can estimate a building's cost of service, repair and reconstruction before the end of its lifespan (Lombera & Rojo, 2010). Successful life-cycle costing implementation includes using careful, detailed designs as well as building activities with specified environmental consideration. Therefore, 'life-cycle cost' (LCC) is a crucial method in attaining cost-effiency in a building construction project. This study describes three key life cycles to remember at the start of a construction project. Original or initial cost, consumption or usage cost and recovery cost (Figure 4).

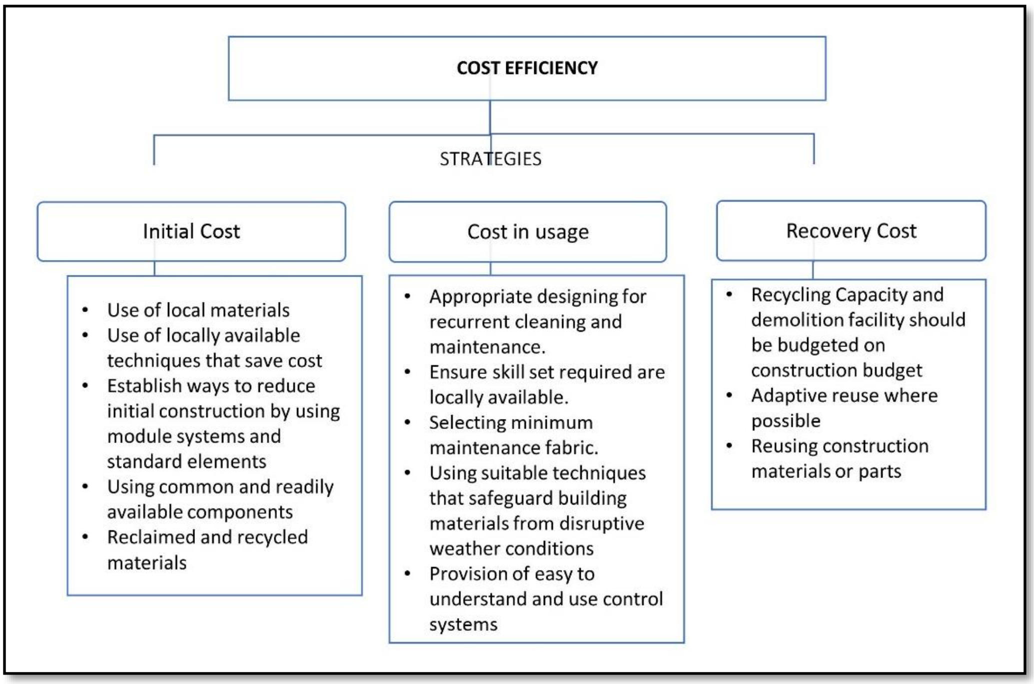


Figure 4: Strategies for Cost Efficiency

2.3.2.1 Initial Cost

Often known as the procurement expenditure or the construction expenditure, this includes the overall cost of constructing or remodeling a structure (Emmitt & Yeomans, 2008), like the cost of purchasing buildings / land, the fee for qualified contractors, the cost of the materials that damage the finished structure, and the cost of piecing it together. While preparing a large asset purchase, Emmitt and Yeomans (2008) found that companies expend significant time and energy in making an initial cost economic assessment. For a number customers, this is their basic concern. Cost savings can be achieved by choosing less costly construction materials and lessening the period taken to manufacture them on the site, but this in meaning that these costs will be found. Many approaches relating with initial cost reduction include:

- The design would make use of local materials. For majority of the time, goods produced in a locality are less expensive as compared to those produced abroad because shipping/transportation expenses are not usually as high and do not come with importation taxes. In Africa that would mean using materials such as mud bricks, stone, thatch and timber.

- Using building techniques that save Cost. an instance is using masonry stone to create foundations rather than reinforced concrete keeps costs down. This approach only suits low-rise buildings like bungalows. Careful structural design should be used for high-rise buildings to have the best base form to guarantee little excavation of soil.
- Establish ways to reduce initial construction costs by using module systems and standard elements with a high compatibility in relation to their context, high-quality, distinctive architecture. For instance, a standard program of similar office spaces provides an organizational structure which can be recomposed if appropriate, including company modifications. Additionally, architecture should endorse technological change (Kohn et al., 2002).
- Using common, readily available-to-use components to reduce replacement costs and custom component storage where necessary. Project parts that cannot be quickly fixed or replaced will be long enough to avoid costly maintenance and retrofitting.
- Reclaimed and recycled materials. Reuse and reprocess construction, demolition, and recovery materials on-site Instead of more costly new material reclaimed and recycled materials would noticeably lessen the total project costs. For instance, using high-recycling materials such as recycled asphalt or cement replacement in concrete products decreases the expense of the project by a minimum of three percent (Innes 2004) excluding a substantial investment expenditure.

2.3.2.2 Cost in Usage

Also referred to as running costs or operating costs, the costs in usage are defined by the briefing decision and later decisions taken throughout the designing and assembling phases (Emmitt & Yeomans, 2008). It further requires frequently planned modifications and checks to secure buildings in order to maintain the similar comfort and appliances resource and maintenance costs for parts (Arkpe & Strong, 2006). These also included lighting, construction materials (i.e., roofing, outside walls), services (i.e. ventilation and heating). Throughout several years, operating costs have only been given shallow consideration at the design level, but this is changing with the advent of lifecycle costing methods that aid explaining the relation between design choices and costs in operation. Long-lasting materials and component are more expensive than others anticipated not to last as long, and planning to reduce both management and operational costs will lead to higher initial costs (Emmitt & Yeomans, 2008). In the long run, for instance 20 years, it can cost the structures proprietor lesser than the procurement cost solutions. Given the following, cost savings in building usage can be accomplished;

- Take appropriate steps in the designing of fundamental building elements for provision of designated and generous spaces for recurrent, maintenance cleaning and repair of the HVAC system 's core or major elements and ensure entry spots are not hardly recognized and located.
- Ensure the skill set required are amongst the expertise of available labor supply. Lack of experience with buildings facility maintenance skills will lead to increasing cost in maintenance. Where skills are available within a locality, such as masons, buildings should be built to optimize these skills. In lieu of

precast concrete, a project should define brick manholes to leverage available skills.

- Selecting minimum-maintenance fabrics. When appropriate, pick products requiring minimal maintaining (repainting, retreatment,, etc.). For instance, low-maintenance Wood plastic composite benefits over wood still encourage advancement in applications of replacing wood replacement (Markarian, 2005).
- Using a suitable procedure and techniques throughout the design phase to safeguard materials from disruptive conditions like heat, temperature fluctuations, heavy rains or strong winds, and isolating critical parts of buildings or structures from damage that may result from floods or storms.
- When completely fulfilling the building's operating specifications, provide tenants and building management with easily understandable and simple-to-use building control systems to establish use of energy saving and ecofriendly equipment and products. If a simple building system is able to accomplish the target, avoid a complex one.

2.3.2.3 Recovery Cost

Another factor that is often not recognized— demolition factor and recovery of material cost (Emmitt & Yeomans, 2008). It is partially for the reason that the owner of the structure could have sold it before it gets to the time of recycling, and partially for the reason that it is generally correlated with the initial expense of potential growth. additionally, this could be of minimal interest to the present customer seeking short-term benefit with limited outlay. If environmental issues are to be taken significantly, the following approaches will be introduced to limit or eradicate recovery costs.

- During the design phases, recycling capacity and demolition facility should be considered and spent on construction budget. This improves construction industry 's sustainability. Waste means new building capital. When manufacturing goods by recycling demolition waste, a reduced amount of harmful air emissions and water contaminants are produced as compared producing all new goods. Recycling, more times than not generates jobs and saves finances, whilst saving nature.
- A current project's adaptive reuse greatly eliminates waste and saves the resources needed to produce and install products. Unless the available resource is not efficiently used, the energy invested in building a structure and manufacturing materials would be lost. This method may also protect cultural heritage by preserving and restoring a historic structure.
- Reusing construction materials or parts minimizes waste output if an obsolete structure is not completely eligible for reuse. In these cases, renovating and reusing singular components like windows, interior fixtures and doors may be preferred.

Consideration to building project's life-cycle expense concerned with of both designs and material choices would reduce total expenses for owners and consumers. It is necessary to decide how much time the structure will remain and if its functional specifications will alter over time. However, if re-sale value is most likely to be improve by the capacity to be adaptable to new functions, effective design will significantly lessen the cost of adapting to new functions. Improving a structure's cost-effectiveness is a vital technique for sustainable construction.

2.3.3 Design for Human Adaptation

A sustainable building aims at creating comfortable and healthier spaces for human activities. Building's must fit and offer floor space, room length, shelter, light and facilities for work, living, studying, healing, processing, etc. In addition, the building should provide people with a comfortable and healthy indoor environment. While providing to the essential needs, buildings also does not induce harm to the environment or its occupiers and must be tectonically sound and provide safety from fires. A Sustainable development implies that buildings should not create avoidable environmental load or harm, such as energy usage. To encourage and improve human adaptation, 2 design methods should be recognized (Figure 5).

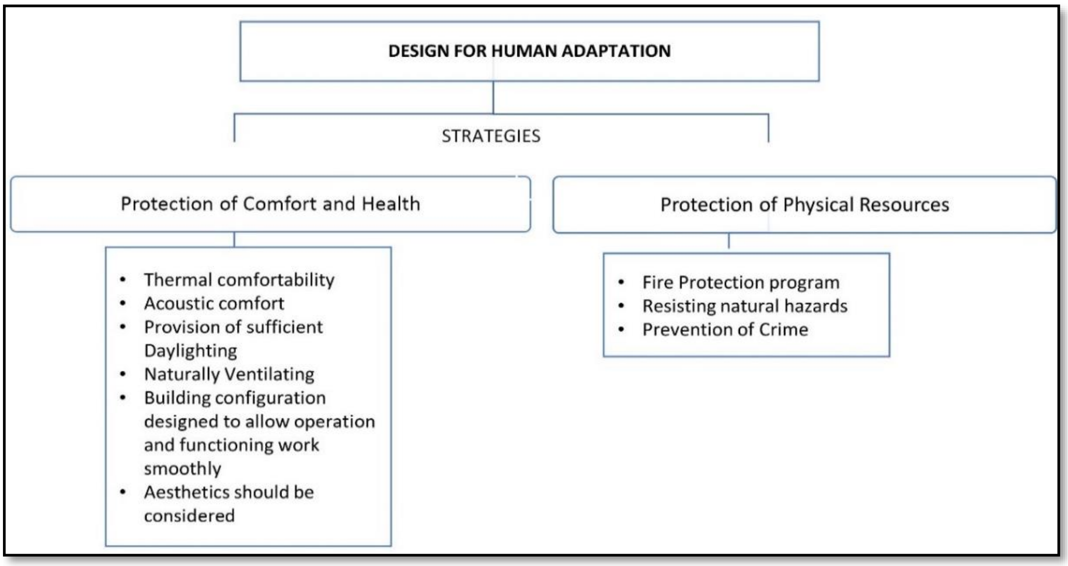


Figure 5: Strategies for The Design of Human Adaptation

2.3.3.1 Protection of Comfort and Health

Well-being (comfort and health) is a critical aspect of a building occupant's quality of living. In the society today where persons spend more than 90 percent of their time indoors — and more than 70 percent of their time indoors at home (Sev, 2009;

Adgate et al.,2002), Architecture performs a significant role in maintaining safety, physiological security, fitness, efficiency and physiological comfort. The definition of health is important in describing "sustainable buildings" in terms of building efficiency (i.e. thermal comfort, indoor air quality, acoustics and lighting quality). Sustainable building must balance human interests with cultural and natural ecosystems. A safe building is rid of dangerous contaminants (e.g. asbestos and lead) and have the capacity of supporting residents' health and wellbeing throughout their life span, improving productivity and fulfilling social needs. healthy buildings consider human comfort and health as priorities. Most building designers were concerned with decoration and form-making, ignoring human satisfaction and environmental quality inside and outside the built environment. Sev (2009), indicates that a product can perform well and be energy efficient; however, unless it positively affects the comfort of the occupants and improves productivity, it is not sustainable. A literature review identified the methods discussed below as a requirement to improve coexistence between buildings, their occupants and the environment (Figure 5). The method includes but are not limited to the following:

- Thermal comfort is crucial to a building occupants' productivity and their satisfaction. achieving thermal comfort for any other enclosures or buildings occupants should be an essential goal for any building designer. The thermal environment's variables are temperature (radiant, surfaces, air), air velocity, humidity and individual variables are activity level and their clothing. considerations of the Building envelope like, window tinting, , low-E windows, solar shading and reflective roofing are among the tools designs can utilize to optimize thermal comfort and improve energy efficiency. Considering factors like the seasonal heat gain and sitting buildings accordingly is also advantageous to thermal comfortability, and so is the landscape.

- A workspace 's acoustic environment usually receives little to no consideration during planning stage and designing phase. Acoustical comfort has to be obtained by monitoring noise origins from electrical and mechanical devices to building from external origins. Appropriate choice of materials, windows, wall framing and insulation, are important to reduce external noise. Some materials that are sound insulating, like the straw-bale construction and acoustical ceiling tiles can provide the benefits of recycling and the use of natural materials (Sev 2009; Oral et al. 2004). absorbent versus Hard surfaces also influence the noise level of spaces. HVAC equipment noise reduction, monitoring or isolation can also be tackled by acoustic regulation, equipment selection, installation and necessary electrical, pipe sand duct. There could be ways to achieve a project’s sustainability targets in tandem with better acoustic design if recognized earlier in the planning stage.
- Daylighting entails constructing buildings for efficient use of sunlight, offering several advantages over use of artificial lighting. In general, health and well-being benefits are known. making Maximum use of daylight in housing is thus necessary. Healthy daylight means daylight levels adequate to adequately see with no glaring or unnecessary contrast. Excessive direct sun can create discomfort and lead to ill health, especially when it comes to surfaces with high reflectivity.
- Natural ventilating is the method by which air is replaced in a space in order to enhance indoor air quality without using mechanical devices. conditions

of Ventilation in a room directly affect occupants' well-being, health, and comfort. Natural ventilation has now become an important architecture technique. this can be utilized to supply air from outside, minimize smell and toxic substances, eliminate heat from rooms, mass and people. Natural ventilating designs also possess the ability to minimize constructing and maintaining costs related to the procurement and usage of air-conditioning devices. Additionally, building occupants' productive nature and efficiency is improved or declines due to changes in the interior climate and exterior connections (Akadiri et al.,2012) stipulating another benefit of natural ventilation. window orientation, Weather suitability, and operational windows are main factors in ventilating naturally. Models include cross-ventilation with the utilization of wind vents to cause stack ventilation and the use of water evaporative system in humid, dry conditions to cause movements of air. The ability to unshut windows, relax in the sun or shadow and interact with the natural environs looks to be essential aspects in sustainable architecture (Edwards, 2006).

- Building configuration should be designed to allow the operation and functioning of a building to work smoothly. At the event of the extension, the ability of the building to support its future operations will be measured at the beginning and the extra supplies and waste management costs minimized. Considering low-maintenance and robust construction elements is crucial, but it might not be incredibly necessary in the long run.
- The aesthetics of a building is another attribute to consider, in order to contribute to the living and the working environments psychological comfort. This psychological comfort aspect will involve may mean pleasant

architecture, visually appealing structures, wall artworks, or natural elements like trees and flowers, water bodies or aquarium. Beauty 's influence may be difficult to quantify, but it stresses aesthetic necessity as a sustainable factor

2.3.3.2 Protection of Physical Resources

Protection of physical resources is also among the core concepts of designing for sustainability in buildings. It is necessary to pay Attention to designs that provide building resistance to natural and hazards such as earthquakes, tsunamis, flooding, fire accidents and crime assault. Damage mitigation plan is the strategizing of what methods to use minimize or stop loss of human life's and property harm, and the approaches are discussed below;

- Fire-protection program. The most important element of building protection is a system design that allows the builder to evaluate all the structures components as a full building fire safety system kit. When structures grow increasingly intricate and architects advance the design skin further and further, it is necessary to recognize the fire protection consequences at design level of new buildings or other construction or reconstruction programs. Another significant criterion is that the fire safety facilities allow the inhabitants of the building to provide independent, effective fire response. In terms of the protection and dignity of a building or construction with a fire (Mousaviet al., 2008) fire stoppage and passive fire prevention steps are important. A fire strategy can only gain optimum efficacy if passive fire defense actions such as fire-resistant insulation panels, cavity walls, professional fire-stop structural openings and approved fire-efficiency properties are incorporated into a building structure. Not only does passive fire safety preserve the integrity of a building during burning, it also provides insulation and breaks the system into areas of controlled risk (also called emergency services). These are built to provide secure escape routes and assist in insulating and controlling flames, heat and smoke, allowing firefighters and residents to evacuate safely. This protection is provided or created by the structures that the buildings have been designed to preserve or maintain fire safety.

- Resisting natural hazards. Notable natural and manmade incidents have demonstrated the vulnerabilities of buildings to hazards. The remainder of the residents are left to paying for losses, including the repair of destroyed houses and infrastructure from storm attacks, flooding, wildfires, blizzards, tornadoes and other natural disasters. Approaches to danger avoidance should be a crucial criteria for project preparation, since quality requirements are also the main components of project management. For example, strategies for flood mitigation involve elevation of structures above the ground level in regions disposed to flooding; making water-tight structures to avoid water intrusion, integrating floodwall and levee into the designing of sites to keep water away from buildings. Including retrofitting technologies like ferro-cement coating, vertical corners reinforcing incorporated in mortar and incorporating tie beams and introducing structural buttresses to mud-walls and brick masonry can also help to defend against natural hazards.
- Prevention of crime through design and architecture has emerged globally as a promising and effective approach for reducing crime opportunities. The fundamental theory of crime prevention by building design is that good planning and efficient utilization of the built environment will minimize crime fear and occurrence, thus enhancing general quality of living.

Designing for safety comprises of incorporating measures that counter, prevent, track, respond and delay human aggressor attacks. This also calls for hazard-limiting steps to avoid major harm and provide protection if an attack happens. Crime reduction strategies emphasize three design strategies: access control; natural monitoring; and territorial actions (Marzbali et al., 2011). Access control involves using doors, fences, shrubs, gates and other physical design features to prevent all but intended users from entering an area. vigilance is accomplished by installing windows in places that intended users can be looked at and look at whilst ensuring intruders are detected. Surveillance is improved by providing appropriate landscape and sufficient for unhindered views. Lastly, a territory is characterized by, landscaping, pavements, patios, and other elements setting the boundary between private and public areas. All of these strategies collaborate to produce an atmosphere where building occupants feel secure to stay, work and visit.

2.4 Evaluation, Criteria and Rating of Sustainable Building and Construction

It is important to be able to quantify and check their efficiency to evaluate the sustainability of buildings and construction processes. Various standards and ranking systems have been developed to provide an indicator of building efficiency and sustainability activities. According to Tessema et al. (2009) the ranking schemes have two key goals: (1) advocate for the construction of sustainable buildings and (2) determine the quality of buildings. This can be argued that no one measurement device can offer a total and undisputed evaluation of any component of a building's sustainability. This does not, nevertheless, preclude efforts to generate at least meaningful evaluations by gathering data and analyzing indicators. The topic of sustainability in the built environments is so critical that ongoing attempts are needed to fully understand the question given the difficulty of the challenge.

Early certification systems such as LEED and BREEAM originated as simple checklists of what to do and not do. Rating systems have evolved quickly into systems that award points for certain successes, strengthening comparison between specific structures and increasing weighting of certain parameters.

The idea of sustainability incorporates natural, social and economic elements, often difficult to integrate. The social aspect requirements range from housing safety to workplace well-being and maintenance of social and cultural values. The environmental aspect requires standards for the use of carbon, resources, water and waste management. Economic parameters apply to elements of sustainability, life cycle costs and externalities of local markets for residential and retail rates. Historically, several ranking schemes have been advanced primarily to evaluate environmental concerns rather than the total spectrum of sustainability problems. Such structures underline social and economic aspects as well.

Akadiri et al., (2012) indicates that rating systems and ranking methods like BREAM, BEEs and LEED etc., are continuously developing and upgraded to work with present practices in creation of sustainable buildings. However much the vary, the recurrent goal is to ensure structures are designed to lesser their entire impact on the natural environment and health of Humans.

In this study the sustainability of buildings chosen as case studies would be analyzed based on the strategies discussed in the previous section. The analysis main objective is to evaluate if the materials and construction techniques utilized can adequately (1) Conserve resources and (2) Improve Design for human adaptation. The next chapter discusses vernacular Architecture, Vernacular architecture of Africa with a focus on materials and construction techniques and their importance to sustainability.

Chapter 3

VERNACULAR ARCHITECTURE

The word “VERNACULUS” in Latin is translated to mean ‘native’. An architecture that displays its characteristics as been associated with the native context is vernacular in the sense that it is only recognized and accepted within a specific social group by the application of some specific construction technics, building materials, social rules and social structures(Rapoport, 1990). Vernacular architecture is a human construct that results from the interrelations between ecological, economic, material, political and social factors (Asquith & Vellinga 2006;Rapoport, 1990).The Architecture and Landscape Dictionary (2000) describes vernacular architecture as "unpretentious, basic, natural, traditional constructs created of local materials and pursuing well-tried shapes and forms."

According to Singh(2009), whenever people build their houses in a community using materials available in a locality with traditional construction techniques, that is vernacular architecture .The architecture and construction of vernacular structures was the result of ideas gained overtime by way of trials and errors. Its form of architecture aims to provide solutions to climate problems and allows optimum adaptability and versatility. Such characteristics make architecture distinctive, thereby establishing a cultural identity related to its tradition (Plemenka, 1982). Through a step-by - step method, locals can micro climatically modify their architecture to attain human thermally comfortable conditions by bioclimatic incorporation (Gaitani, 2007). Bioclimatic considerations have proved to be an important feature of vernacular construction (Ancell, 2008). Richard (2012) introduces the reader to a world of vernacular, which represents living practices and ethical approaches to creativity; an original type of architecture that represents rural way of life and demonstrates incorporation of construction into the life of the whole society while regarding local circumstances in its novel, "Vernacular accommodations: terms in contemporary architecture theory."

Throughout the world, various vernacular techniques and materials have been used in the local culture influenced by the environment and geographical location(Aziz & Shakwet 2011; Boadach, Lang, & Wahamber 2014; Egnin et al 2007).Moreover, much of these methods and materials are used in numerous areas with diverse climatic environments and cultural contexts. For instance, earth construction (mud or clay) was utilized as a primary building material for millenniums for the constructing of houses in predominantly living areas of the world (Boadach et al., 2011; Priya et al., 2012; Yorulmaz, 1981; Smith &Austin, 1989). In many countries with various climates, there are instances of modern structures built from earth construction. A variety of vernacular techniques, such as courtyards and wind towers (catchers) have been applied in contemporary buildings as passive design strategies. The choice of these materials and techniques for buildings is typically based on desirable advantages and the local available construction materials and professional work (Alrashed et al., 2017).

Vernacular architecture embodies natural, climatic, environmental economic and cultural characteristics of a place for instance, Desert Vernacular architecture, along with the combined economic, social, religious and cultural background elements, embodies a distinctive quality and character that emerges through a combination of factors like natural desert topography , climate and geography (Correa, 2009). All these aspects make a major difference to their way of life and to the quality of their structures. The compatibility of buildings with nature is outstanding as it is possible to use natural resources and local construction materials (Dabaieh, 2011). The historical custodians and historians practically classified architecture as historic and esteemed. Such structures were designed in general for members of the highest class of society and for certain uses, such as docks, religious structures, palaces, tombs and government offices. Moreover, the buildings of the time were generally thoroughly planned and designed by the designers and builders (Islam, 2003).

There are several descriptions of modern and classical buildings provided by numerous designers and theorist. The houses of common citizens of all cultures were usually neglected or not considered an expression of architecture (Oliver, 1997). According to Valipour (2014), by studying the terms "architect" and "architecture," the features and locations of these structures will help one obtain a clear understanding of architecture.

Vernacular architecture scholars were seeking to expand the concept of vernacular in various ways. Many people tried to provide a description to differentiate vernacular architecture from other architectural forms. There are also other concepts that generally expand on the characteristics of vernacular architecture. The following texts state some of these conservative descriptions of vernacular architecture:

The vernacular architecture includes the residences and all other structures. In terms of their environmental conditions and resources available, they are typically created by a society using traditional methods. All manner of vernacular architecture is designed to meet the particular needs and entertain values and finances of the cultures which produce them (Oliver, 2003).

Vernacular architecture are practical activities which seek to promote environmental adequacy rather than knowledge; it is a manner of acting in the conditions of life, meeting the environmental demands of a given community of people (Turan 1990).

The explanations of the basic elements or the purposes of vernacular architecture may be referred to for the most part. With the aid of these definitions and in conjunction with the critical features, a concept of vernacular architecture can be defined as built forms of local materials that are designed using available technologies to suit ordinary people's needs in their place and time (Richardson, 2001).

In his book "*House Form and Culture*" Rapoport (1990) notes that it is impossible to characterize vernacular architecture satisfactorily and at present the only way to explain it adequately is in terms of the processes under which it is built.

In identifying attributes of vernacular architecture. The appraisal typically involves assessing its essence as more or less vernacular. Therefore, a working concept is the one that compares one condition to other to see if it is more or less 'vernacular' and not just the optimal forms. Additionally, the form of vernacular architecture may tend to vary from place to place and location, actually, because the climate varies over time within the same area vernacular architecture may also change. For instance, vernacular architecture identified with industrialization, as in western and European countries, and is often referred to as post-industrial or pre-industrial architecture. whilst it is usually defined in plain terms in Asia instead of related to post- or pre-industrial revolutions (Denel 1990).

"It is a functional feature of vernacular architecture that each practice is closely linked to cultural - financial considerations; it has evolved to address unique needs of each cultural context" (Oliver, 2003). Strategies or styles can be identical from place to area, but their unique approaches of surviving are assisted. There is no single collection of vernacular architecture but often some different words are used to describe the features and settings of vernacular architecture. Vernacular architecture is often defined as "rural" and "industrial" in the description of rural and urban environments where places are regarded as the key guiding force of the distinction.

Burnskill (1998) listed vernacular architecture based on their uses in the book, “Illustrated Handbook of Vernacular Architecture”;

- Domestic vernacular architecture includes structures for living, as they are commonly used as cooking, seating, sleeping, storage, etc., as well as supplementary dwellings, such as the braw home, the baking-room, kitchen, hobbies, washhouses etc.
- Vernacular of Agriculture includes all the houses Except the farmhouse and its domestic auxiliaries, farm structures. The barn, goathouse, barn, farmstead , wagon shed etc. are instances of agricultural vernacular architecture.

- Industrial vernacular architecture includes the structures that typically house the agricultural operations related to the countryside – wind and water mills, maize and limestone, smithies and pottery, among others. This urban vernacular architecture often includes the buildings in which such production operations are more domestic than economic including, for example, a workshop that is connected to or embedded in a house.

In this group, Burnskill (1998) tries to distinguish the agricultural and industrial practices connected to houses and mentions them as different kinds of vernacular architecture.

3.1 Vernacular Architecture and Sustainability

In the last three decades , the world has become increasingly aware of environmental challenges like global warming, scarcity of land, electricity, pollution of air and water, waste, human population rise and globalization (Salman 2018).According to Salman Such problems are the burden of sustainability claims that suggest the need for environmental inclusion of our way of thinking, behaving, utilizing energy and building. Sustainable architecture is the interrelation of environmental, political, social and economic tools in order to establish optimum connections between humans and their habitats in order to satisfy human needs (Salman et al., 2016).

When talking about sustainability, we have to go beyond concepts to look for the root meaning. Sustainability is not just about and enhancing the quality of life and incorporating environmental, social and economic challenges (Senosian & Aguilar, 2003). The aim of sustainability is to ensure that our present policies and activities do not harm future generations in order to satisfy their own requirements. Re-evaluation and study of vernacular architecture reinforce the interrelationship between policy and culture (Hinrichs, 1987). One must ensure that human activities do not undermine our environmental structures. Sustainable design entails accountability which ensures that ecological environments, natural resources, respect for human beings and a life cycle are highly valued (McLennan, 2004).

Vernacular architecture is the result of resource availability constraints. Historically and with no modern machinery, extraordinary associations of people have often created the most distinctive architecture and identity, with limited means available (Thomas, 2007).Vernacular architecture was built on principles inherently sustainable, for example the resource limitation of economic or natural factors, but has been able to offer rational solutions to harsh environments and human life (Salman, 2018).Reza & Dincyurek (2016) indicate that Vernacular architecture is an organic form of architecture, which is characterized by response to economic cultural and environmental factors. Sustainable design elements are central to all well-established forms of vernacular architecture, these are tested and practiced approaches which have developed through long trials and failures using local natural and cultural resources and technologies.

3.2 Vernacular Architecture in Africa

Traditional African architecture is inherently ecological and culturally suited to the inhabitants. Stone, timber, grass, earth/adobe/mud and thatch were typically developed in combination with the easiest methods and processes for constructing practical and comfortable houses. While globalization has dismissed them "primitive," recent sustainability definitions have given them a new position as possible inventions for the modern world. Along with the others redeveloped, earth was late accepted as an appropriate infrastructure for modern buildings.

As a tropical continent amid the Atlantic Ocean to its West and the Indian ocean to its east, Africa possesses a long history of more than 5000 years that includes buildings and temples built from various natural materials abounding in its geographical landscape. Her indigenous architecture practice was influenced by environmental philosophies, although it was carried out in ignorance. These have been made from natural material and cyclical regenerative possibilities to control the wise use of capital in the creation of their communities and settlements, towns and markets, churches, houses, monuments and religious buildings. In fact, the decision to choose a location, the use and reuse of materials and sites has all been taken by a community of uncomplication and simplicity, loving the environment and recognizing that the world needs to be handled kindly as it is fragile as well as precious (Dayaratne, 2000). Unsurprisingly, earth / mud / clay was one of the main and principal construction materials along with timber (bamboo, eucalyptus and trunks of palm) grass/ coconut/palm thatch and straw bales, all available in the villages. Stones were utilized where necessary and suitable for building for public and religious buildings in particular that needed enduring longevity. According to Ejiga, et al., (2012) the traditional African architecture has thoroughly maintained that it will not limit its supply and has not negatively affected the ecological equilibrium it relies on as an agrarian society.

3.2.1 African Geography and Climate

Vernacular architecture of Africa, like that of many regions across the world has been greatly influenced by its geographical location. According to Beswick (2010) vernacular architecture of Africa is not grouped by national boundaries but by climatic regions. He suggests that native vegetation is an expression of climate and grouping architecture by region directly links it to construction techniques.

Building forms and construction techniques have thus evolved as a result of availability of materials and a response to local climates.

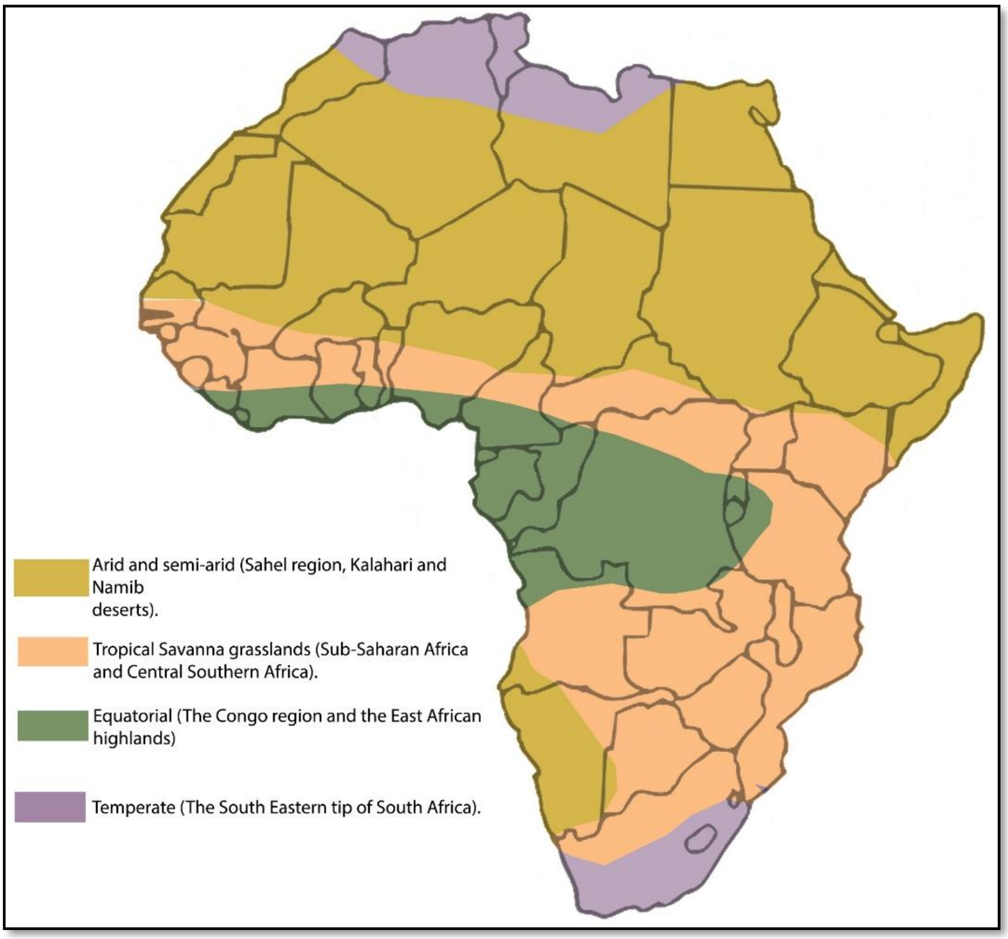


Figure 6: Africa's 4 Major Climatic Regions (Nagira, 2007)

Africa can broadly be divided into four (Figure 6) climatic zones based on a combination of temperature, evapotranspiration and rainfall (Ngaira, 2007).The zones are: i) Arid and semi-arid (Sahel region, Kalahari and Namib deserts). ii) Tropical Savanna grasslands (Sub-Saharan Africa and Central Southern Africa). iii) Equatorial and rainforest regions v) warm Temperate/Mediterranean (The bottom South Eastern of South Africa and top most part of north Africa).The African vernacular architecture construction techniques showcase each region of Africa. The arid and semi-arid regions having little and insufficient rainfall is very dry with a relatively high temperature possesses less vegetation and trees thus the prominent building material in this region is earth/ mud. The tropical savanna grassland has a sufficient amount of rainfall and possesses an enormous amount of grass and sparsely planted trees hence the use of thatch, sticks and earth is prominent in these regions. The equatorial region is by far the wettest region of the continent with a lot of rainfall and dense vegetations and forests. This accounts for prominent the use of timber and thatch in this region.

3.2.2 Vernacular Construction Materials of Africa

The four prominent materials that that have been utilized in the vernacular buildings of the Africa are timber, thatch, earth and stone (Ejiga et al.,2012; Beswick, 2011, Adekunle & Odeyale 2008; Agyekum, 2020) These materials have been skillfully and ingenuously used individually or collaboratively. In the actual context of its construction, different places have primarily used materials that are unique to them on the basis of their quality and specialized technologies (Ejiga et al., 2012). Notably, irrespective of the materials used, their inventions, backed by remains of ancient cities and other archeological records, have developed and appreciated with such creativity. The relatively few structures that have endured across centuries of human dwellings, the existing repair and demolition fails indicate that they would have lasted more decades if better managed and preserved; therefore, a major consistency of sustainable construction practice.

3.2.2.1 Stone

The original process of the usage of stone for housing had started with the inhabitation of the naturally existing caves in which walls and roofing in mud or thatch, brick and straw were built turning them to livable places. As ethical norm, when natural rock caves, stones or boulders were transformed into houses, little alteration of the rock itself was made, but other structures ended up with the same enclosure. In addition, the area surrounding the village was built using identical stone views, methodically arranged and designed to form the splendor of the natural landscape. The emergence of these favorable factors inevitably enhanced its production in the physical world. Because of its natural endowments, stones / rocks / boulders have been used to describe piety, seclusion and respect in its natural and human nature (Dayaratne 2010).

undoubtedly, the stone architecture of Africa has traditionally created many unique pieces. Rock building craftsmen of Africa are exceedingly competent in usage of stone for construction with a distinguishing awareness of the rock types, their materials, and refining, including extraction from the earth and cuts and remodeling them in an architecturally stable way. The accomplishment of this ability is apparent and can be seen in the great pyramids in Egypt, the old world's only living wonder (Ejiga, et al.,2012).

Stone, a natural product of earth is an ultimately durable material(Klemm, & Wiggins, 2016). It can be easily recycled repurposed and reused. According to Vierra (2019) stone contains no harmful chemicals or toxins ensuring that interior environs are inherently health when used as walls. In Africa, especially in the semi-arid and arid areas stone is available regionally and locally, this regional availability, according to Vierra (2019) ensures the greenhouse emissions from extraction and transportation is cut out increasing the materials sustainability.

3.2.2.2 Thatch/ Straw

Many locals of Africa took to straw / thatch as a construction material in a comparable way preferring to considerable degree the suitable material for the more appropriate application (Ejiga, et al., 2012). In comparison to the stone not easily renewable thatch / straw is a vegetation byproduct therefore a cultivated material it is highly renewable. Even if significant quantities of this material could be gathered from the immediate vicinity and the forest, the locals in their farms grew most of the straw as food crops and this in effect gave them building material. In most instances, straw is used for or singularly for adobe bricks or masonry walls. This method of construction is still used by nomadic tribes some of these areas today. According to Danja et al. (2017) Many tribes in Africa have lived in dwellings built of thatch all through the year in different seasons. Thatch building utilizes baled or matted straw of wheat, oats, corn, grass, rye, and other materials as walls or stucco covered with lime or rye. Straws bale is a waste material traditionally; it is the dried plant or stalk left on the ground after the plant ripens and is harvested for grain and is dead.

Thatch/ straw is a very popular vernacular material in Africa that is utilized in constructing roofs. According to Ralshida and Ara (2015), there are a number of roofs which can be constructed using thatch, the include and are not restricted to gable roof, hipped or conical, double pitched and hemispherical roofs. Thatch is a material usually available within a locality and possesses a high insulation value (Agyekum 2020) thatch has being used to take advantage of solar radiation and reduce heat loss in cold winters (Fernandes et al., 2015).

3.2.2.3 Earth

Earth is another important vernacular material. The definition of earth includes soils uncemented mineral grains, usually created by rock disintegration, involving water and organic matter. Earthen building materials are among the more highly advanced technology in today 's exploration for environmentally and economically sound housing. According to Oyelami & Van Rooy (2016), when used and managed in a correct manner, earthen materials do not lead to increased pollution, resource depletion or bio diversity degradation when comparing them to industrialized construction materials. Some examples of earthen based construction materials comprise of laterite, mud bricks, adobe, clay earth, and rammed earth (Adegun & Adedeji, 2017; Oyelami & Van Rooy, 2016).

Ejiga, et al., (2012) indicates that although examples have not yet been represented, adobe / earth / mud brick architecture persists, other than some of the churches, temples and mosques, as seen today. He further notes that regardless, the lasting cultural tradition of rural people shows that earth has certainly been one among the more popular and commonly accessible materials which shaped and sustained rural villages as part of an ecological surrounding which responsibly and carefully linked them to the cyclical and fragile eco-system, whilst making use of their resources and inhabiting the areas that have been developed and that Africa's local earth technologies have extended to refined earth bricks from the use raw earth.

Wattle-and-daub earthen techniques was generally employed; in some situations, the method utilized solid timber post frames, firstly laid out and then stuffed with mud balls to make a wall. In most cases African constructors use mud bricks and a slurry mixture of soil as a mortar to construct the concrete walls of their sheet of construction

(Dmochowski 1990; Osasona 2008,). When wall has dried and joined to a singular frame, a densa mud-mix plastic plaster is been spread on by the hands to smooth the façade with different additives based on the nature of humans (cow dung, goat dung, beaten wool, animal fur, fat) In constructing farmsteads and even the grain storing buildings (Dmochowski 1990, Fathy, 2010), this method was used. The environmentally friendly materials and the community's workforce made them a highly sustainable practice that used little energy and didn't create any greenhouse gas or harmful waste. As soon as the earth buildings were plastered and properly covered with overhanging ceilings, they were structurally solid, environmentally friendly and are long lasting.

3.2.2.4 Timber

Timber here refers to any form of wood prepared for use ranging from sticks, to eucalyptus trees and bamboo. Bamboo is an eco-friendly and broadly available renewable building material in most parts of the globe. (Van, 2018;Van Der Lugt et al., 2015)It is very abundant as a vernacular construction material in the tropical and subtropical parts of the globe. Van der Lugt et al. (2015) also indicated that bamboo being a flexible is tough and light weight. He further notes that test for tensile strength of bamboo shows that it unbelievably exceeds a lot of other building materials including steel. The hollow tubular form further strengthens the material. Due to its fast growth, harvesting and transportation rates, it has been categorized as a highly economical construction material. (Van, 2018; Van Der Lugt, 2015). This is considered to be vulnerable to buckling, given its various advantages over its properties. Research demonstrate, however, that it is easy to remedy this deficiency. This according to Van (2018) has made bamboo the world's fastest growing natural and renewable construction material.

Timbers used in Africa can be classified as part of the structure(structural) or not part of the structure (nonstructural). Structural timber is utilized in the creation of frames, load bearing wall, etc. On the other hand, nonstructural timber is typically used for nonstructural works such as partition walls, ceilings and floors. Research has demonstrated that current timber houses in some parts of Africa have more durable in contrast to those built with other conventional materials (Baiden et al.,2005).As a flexible material with attractive properties. The timber is durable, and able to endure fire attacks, has a decent thermal expansion and conductivity and aesthetically pleasing (Baiden, et al., 2005).

3.2.3 Vernacular Construction Techniques of Africa

Over the years, African vernacular architecture has been built through trials and errors to provide adequate defense against the various environmental conditions, resulting in the creation of specific architectural types depending on the local circumstances. The key goals of sustainable growth are to limit the use of non-renewable energy and to eliminate waste, e.g. using goods that have a low environmental cost and that have a local source to control the transport's carbon footprint. Such ideas are widespread in African indigenous construction technology as they are focused on the use of materials readily available in nature and that do not have a detrimental environmental effect (Mellone, 2018).

Richard Hull, African Cities and Towns before the European Conquest (1976) identified and classified many indigenous African designs as domical or beehive shaped, cylinder with cones, pyramid-shaped square box, pyramidal cones, pole cone and clay pyramid, rectangular with gable roof, rectangular or quadrangular with roofs sloping at the ends; or flat roof or square with dome and quadrangular surrounding an open courtyard (Figure7).

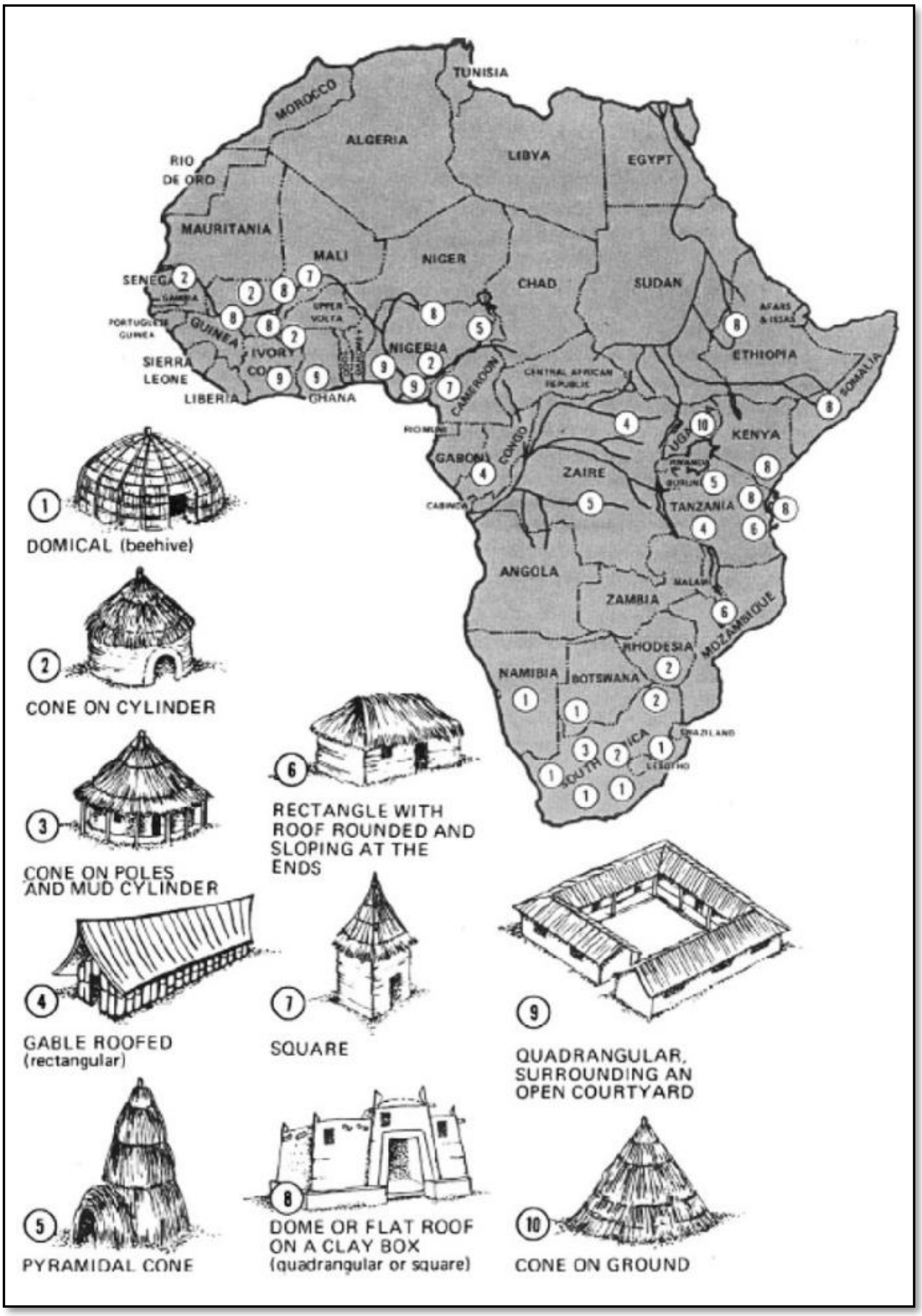


Figure 7: Richard Hulls Classification of African Architecture (Hull, 1976)

These structural forms were often in response to their local conditions and availability of materials. According to Adekunle & Odeyale (2008) people of Africa have looked inward where they have found building materials used to construct their buildings, the buildings may be oval, rectangular or semicircular based on ingenuity and indigenous technical know-how using existing resources, capital and manpower.

In this study the vernacular architecture is identified classified and grouped according to the construction techniques. The study identified five main construction techniques of the African vernacular architecture, the rammed earth technique, wattle and daub, and the timber frame construction technique, mud brick masonry and Thatching. The first four of the above-mentioned techniques are mainly concerned with construction of walls while the last mentioned is mainly concerned with constructing the roofs of these vernacular buildings.

3.2.3.1 Rammed Earth

Rammed earth construction is an ancient practice where a combination of moist soil and a stabilizing agent are compressed into forms (Kim, 2011). The blend is put in layers and compacted up to the desired wall height (Figure 8). According to Kim (2011), the rammed earth construction can be labor-intensive, but the technique saves on material cost because the ground is mostly a subsoil from the building site. Apart from the reduction in cost, it has other benefits such as thermal comfort, Eco friendliness, close-to-nature appearance (Kamaladasa 2005). In addition, the low effect of its life cycle evaluation on the atmosphere makes the rammed earth construction technique valuable for the developing a more sustainable construction sector (Fernandes et al., 2019; Serrano et al., 2013).

Rammed earth walls are not affected by rain, fire or pests, when properly planned and built. The walls are load-bearing and require no additional finish. The structures serve as ventilation walls that allow air to be shared without substantial heat loss. The rammed earth material also functions naturally as a thermal mass, store warmth in winter and refuse in summer. (Easton & Easton 2012; Kamaladasa, 2005; kim 2011). The passive method provides a stable, controlled temperature and humidity that will reduce air-conditioning requirements.

Figure 8: Rammed Earth Construction Walls

This technique for creating walls is often utilized in regions where wood supply is low. Rammed earth's walls are moist soil compacted temporary forms (Kamaladasa, 2005). The typical coating involves two shutters typically made of 19 mm thick soft wooden planks (Figure 9). According to the Australian Standards (2002) most earth-ramming systems around the world have been using only minor variants of formwork for decades.

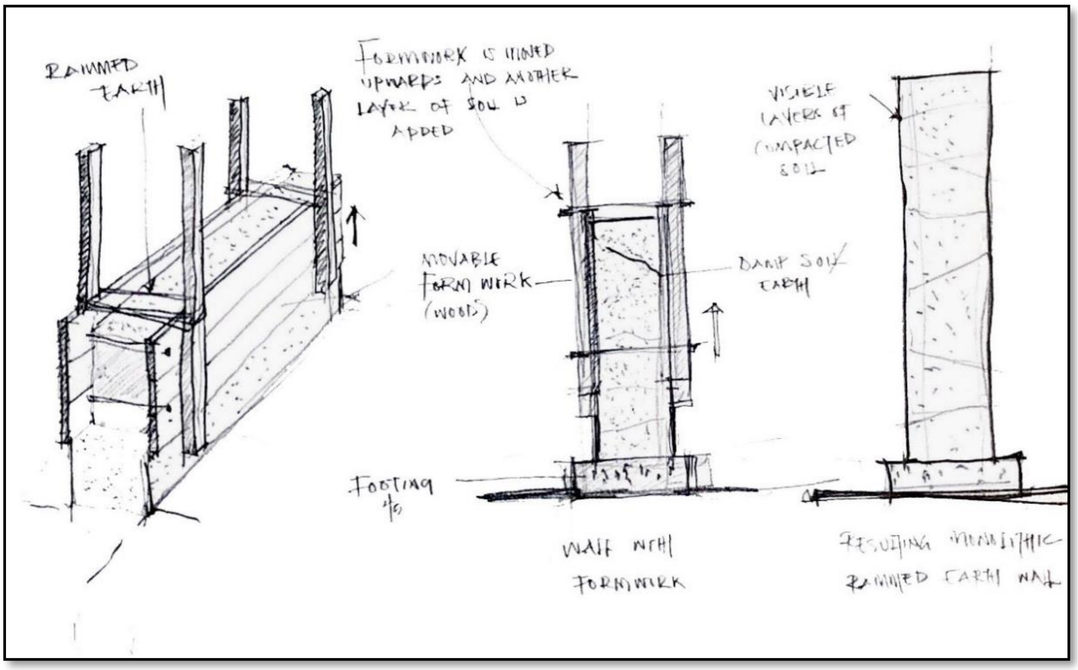


Figure 9: Rammed Earth Construction Formwork & Removal Process

Walls are usually 300 millimeters thick with footings measuring 45 centimeters and heights of 2,5 meters. For the Ewe ethnic group in west Africa, Builders start by outlining desired wall forms (either rectangular or circular) with pegs and string and then digging a pit nearby to prepare the laterite /earth needed for construction (Cultural Encyclopedia, 2017). Builders shape 200-millimeter diameter laterite/earth balls by kneading using water, forming layers of about 600 millimeters in height each utilizing leaves palm trees. Before adding a further layer, the individual layers are leveled and dried; openings for doors and windows are also marked as lintels with fan palm pieces. After the last soil, builders produce holes in the top at an interval of 600 mm using wooden posts to support the rooftops. For flat roofs, mud is used by the builders (Figure 10), but for the pitched roofs builders make use palm fronds and thatch constructed by tying smaller pieces of sticks to the primary timber rafter with twines (Figure11).

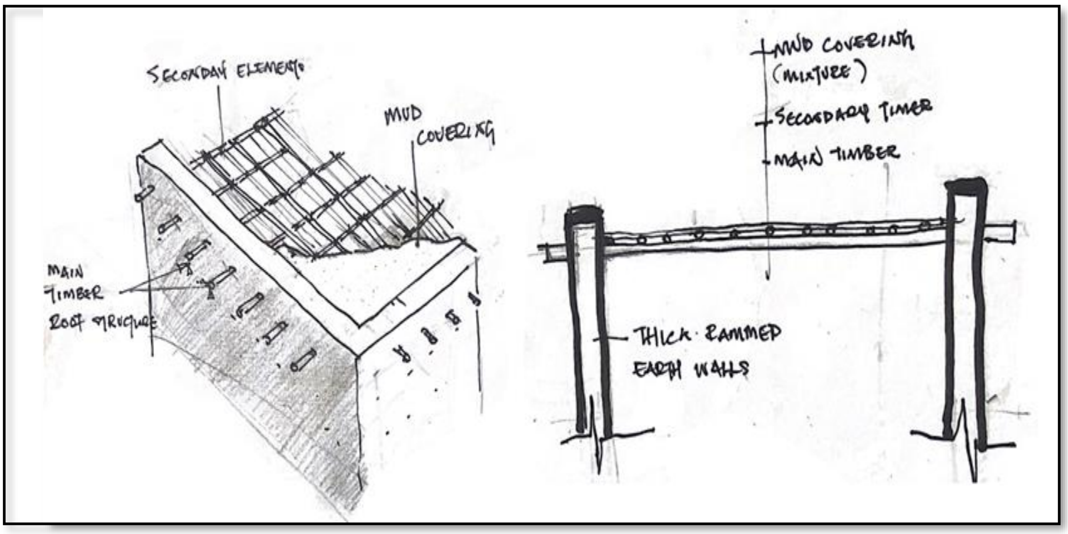


Figure 10: Flat Roof Construction

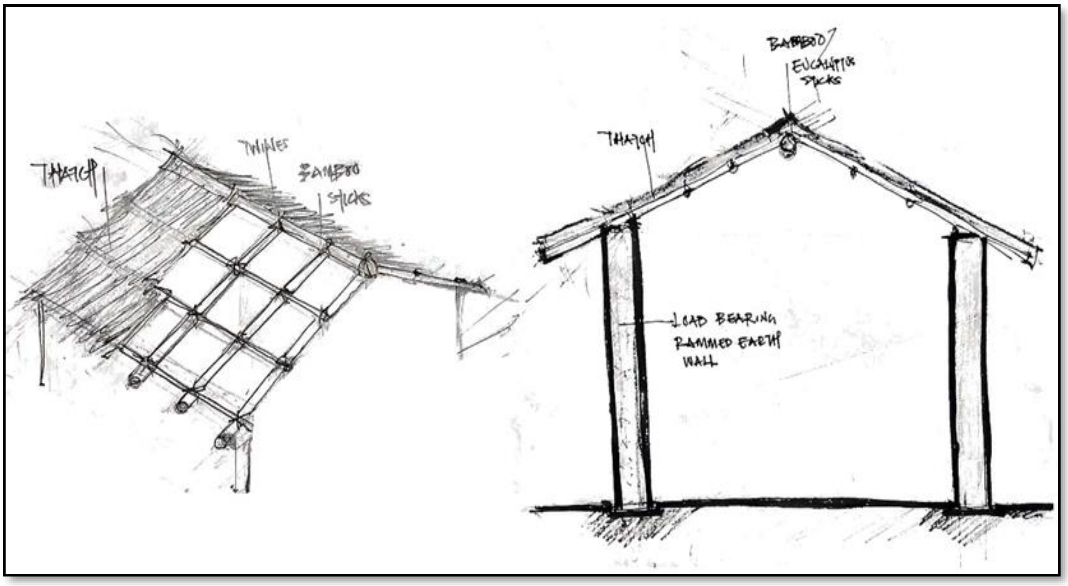


Figure 11: Pitched Roof Construction

3.2.3.2 Wattle and Daub

Wattle and daub (Figure 12) epitomize vernacular construction, its use has been continuous for at least 6000 years owing much to its inexpensiveness and availability of its raw materials (Graham, 2004).

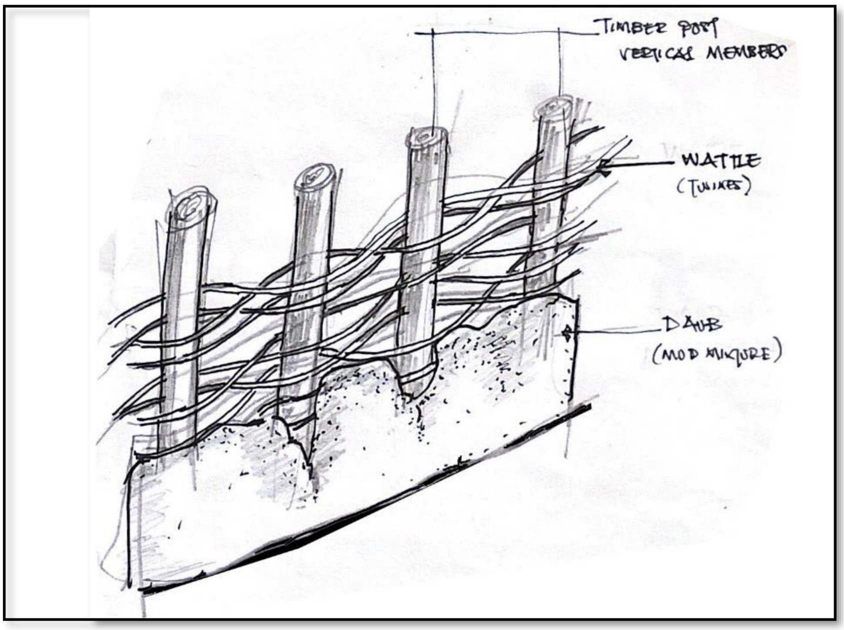


Figure 12: Wattle and Daub

This constructing technique is mostly utilized in the equatorial regions with little differentiations shaped by shifts in precipitation, humid levels and termite existence. Builders start by outlining the anticipated building forms (whether it be circular or rectangular) with strings and wooden pegs on the ground surface before formation, in similar intervals, of circular holes (footings).The builders then insert timber posts into individual bases and attach stones that have been broken to enhance stability. The builders build a woven grid of vertical and horizontal branches or wooden posts in this structure. From there, builders add a palm-thatch roof and finish with a wet mud mix and plaster the mixture over the surface of the grid at a thickness of between 6 and 9 inches (Cultural Encyclopedia, 2017).

The Maasai is one of the most renowned groups in the region that have maintained their identity over the centuries (Mellone, 2018). Maasai huts (Figure13) – known as

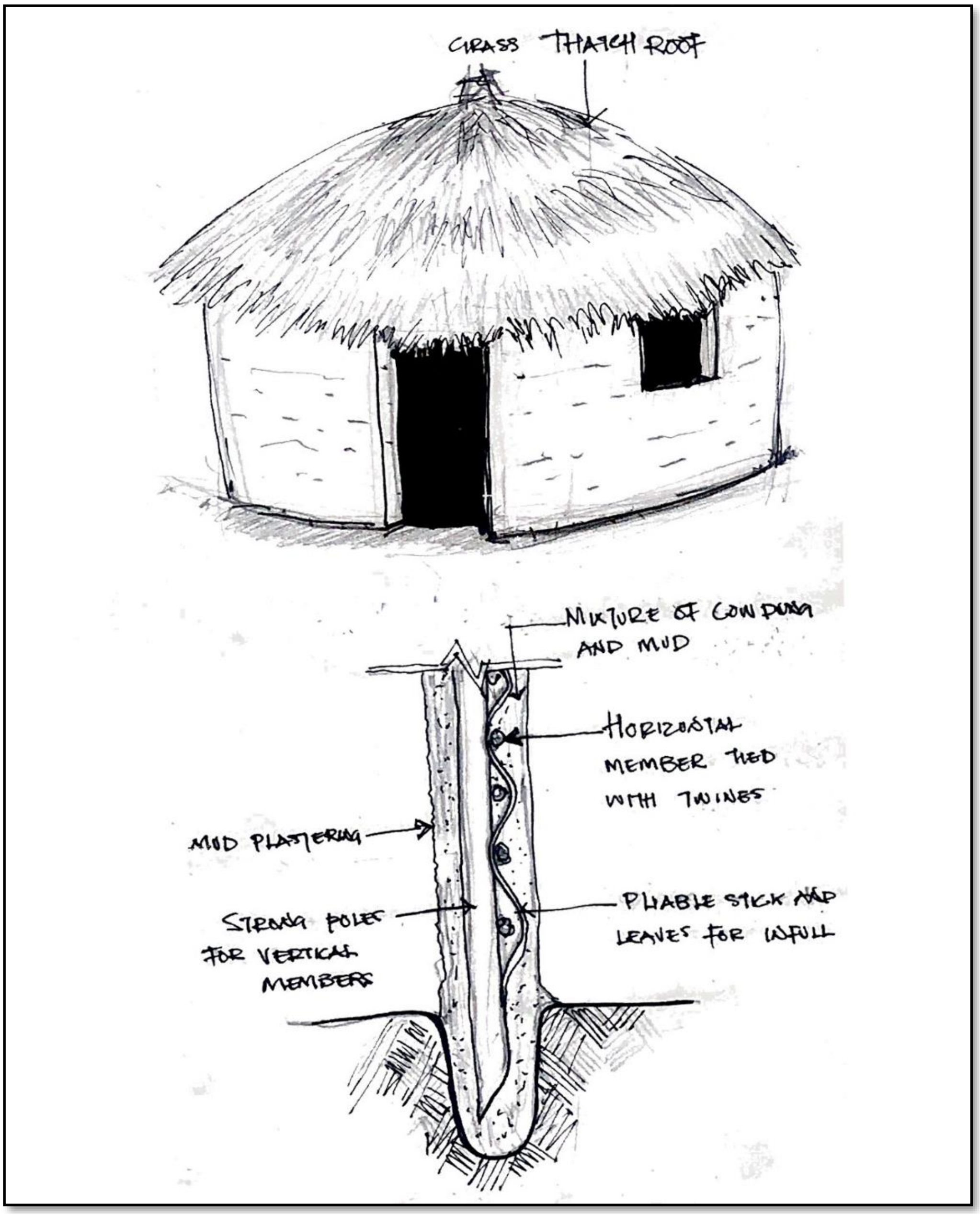


Figure 13: Section of Maasai Hut

Manyattas – are made by their women. The walls are constructed with horizontal sticks, which instead are connected to sturdy vertical wooden posts, with leafy branches and intertwined flexible sticks. The structure is then plastered. as a bonding agent, a mixture of mud and cow dung. In addition to the materials all over the construction, the relatively thick walls also beneficial in providing thermal insulation (Figure 13).The Maasai ingeniously improve the aesthetics of these wattle walls by leaving some areas exposed shoeing the timber lattice structure (Figure 14).

Figure 14: Maasai Huts Aesthetic Quality

3.3.3.3 Timber Frame Construction

This technique is utilized mainly in both coastal and rainforest regions and implements a method similar to the wattle and daub. here the vertical timber posts have wider based and bifurcated ends; smaller beams are then mounted on the ends and tied with ropes gotten from the bark of trees or raffia. In this sense, constructors then construct a bamboo gridded structure in advance of the infill wall treatment of palm mats, rubble stone, or mud daubs depending on the position and purpose and location of the construction. Palm matts are common in coastal communities, built from the fronds of palm or coconut trees, woven into the patterns of a herringbone, utilizing twines and ribbed portions of the mats.

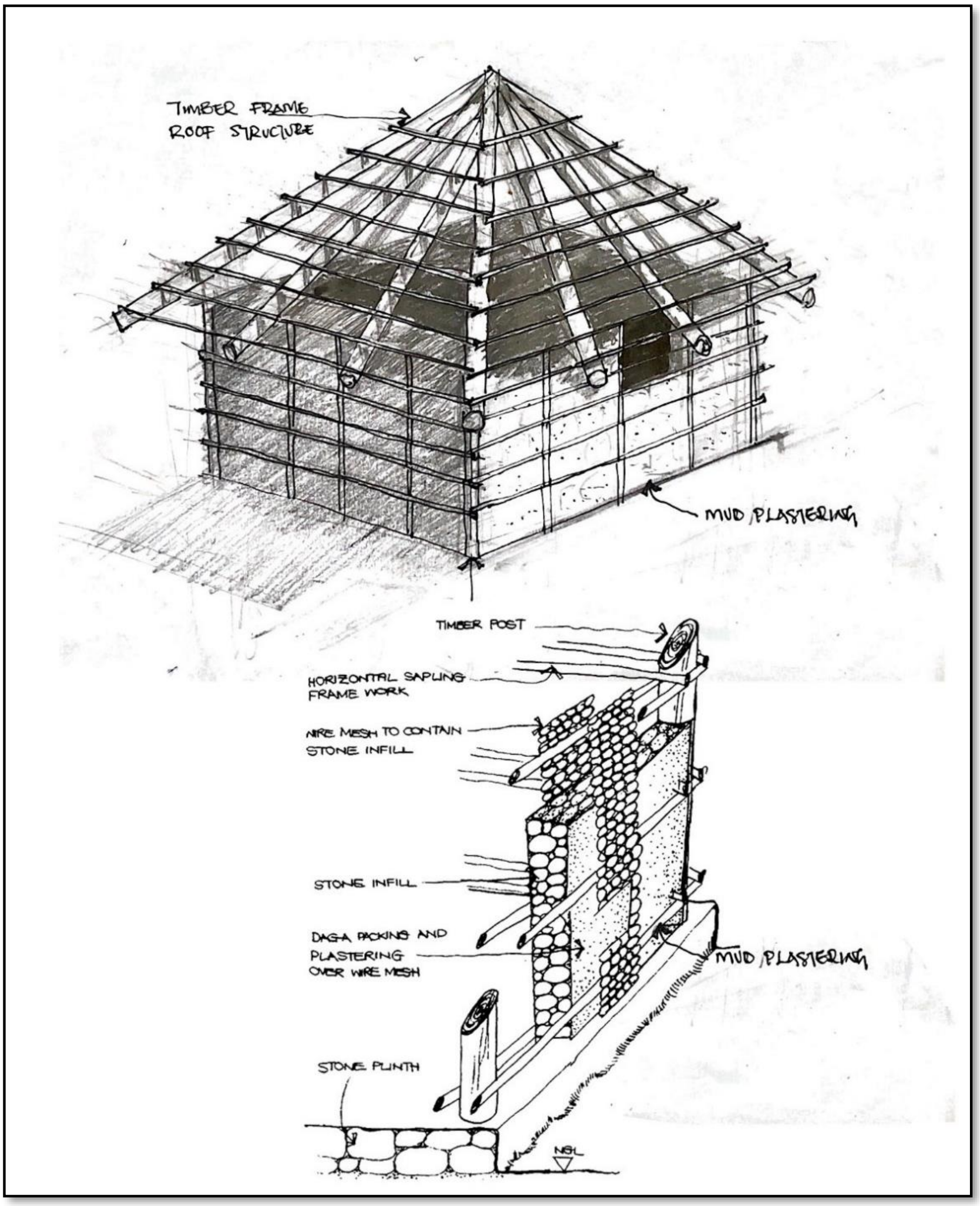


Figure 15: Timber Framed Structure with Stone Infills

In the Umasizahke region of south Africa due to their availability of rubble stone, timber columns are placed at intervals of about 500mm to 1000mm(Figure11). Rubble stones are used as infill. a wire mesh is used to restrain the stones. the walls are then plastered with a mixture of mud (Steenkamp 2012).

3.3.3.4 Mud Brick Construction

Mud brick building technology represents some of the oldest and most enduring building styles, and it is commonly used in buildings all over the world. Evidences have been found in the Middle East for the dried riverbeds with 10,000 years old pieces made of clay(Oliver, 2016). The systems of clay bricks were found in Egypt about 3,800 years ago. Arg-e Bam is the most prominent example of a fortified medieval town based on Adobe technique in South-eastern Iran, based between the 6th and 4th centuries BC (BrickArchitecture.com, 2017). Sections of the Chinese Great Wall and remnants of Roman ruins made of mud brick remain till this day. Presumed to have emerged in the Middle East, the mud brick tradition was introduced through North Africa where it spread west to Spain and south to sub-Saharan Africa (Oliver, 2016).

Despite some slight variations in techniques and blends, Adobe is remarkably universal worldwide, consisting of three key components. First, bricks must have a binder to hold and make them solid. For this cause, the main ingredient is a subsoil of at least 15% clay. Secondly, a fiber is added to the mix, to further boost the resilience of the bricks and to give them tensile strength. Usually straw or a sturdy grass is used, though more natural fibers may also be used. Finally, the mixture is molded by pouring it into a formwork to give the brick its dimension. Many of the oldest bricks were placed in small cavities in the ground, but all bricks are shaped in wooden or metal frame, aside from older examples (Oliver, 2016).

The bricks are left to dry in the sun when the formwork have been removed. When the bricks have been fully dried, they are usually moved and stored under cover until they are needed so that more bricks are made. When the bricks are ready to be used, the same mix for the mortar is made which binds the bricks together and lines are established to ensure that the bricks are all straight and level. string lines and levels are widely used for ensuring plumbing and level of the walls.

Through the usage of their knowledge of construction with mud the citizens of Dogon in Mali who leave on cliffs and cultivate grains on a plateau build their dwellings with mud bricks. Influenced by geographical location, available materials, financial abilities, cultural factors. They constructed their villages on the steep sides of the cliffs (Figure 16).

Figure 16: Dogon Structures Built on Cliffs

Their buildings are rectangular in its form and constructed of sun-dried mud brick for the walls and stone for the foundations. The roofs are constructed using the thatching roof construction technique, and the dwellings rest on hedges along the cliffs. In

Timbuktu, Mali the use of mud bricks is also profound. Their houses are mostly rectangle but unlike the people of Dogon their roofs are flat created with short timber sticks plastered with mud.

Figure 17: Mud Brick Construction in Da Zarraba Morocco

Da Zarraba (Figure 17), Morocco located in the warm temperate climatic region of Africa houses fine examples of vernacular architecture of the Moroccan people. The use of earth/adobe is prominent in this region. Their walls are constructed of mudbricks and their flat roofs constructed of timber and earth mixture. Due to the availability of stone their foundations are made of stone.

Another ingenious application of mudbricks is the Nubian vault technique of the Sahelian region (semi-arid climatic zone). this region as discussed earlier have minimal timber supply hence rather than use timber for roofs construct the entire building with earth. Here the roofs are vaulted (Figure 18) and can be buttressed to create flat roof s or terraces. load bearing walls are usually 60 centimer thick. These bricks are laid alternately width size and length size and are bound with a mortar made from mud. As protection against rainy season, plastic sheeting is integrated into roof mortar. It is also possible to render mud bricks with stones.

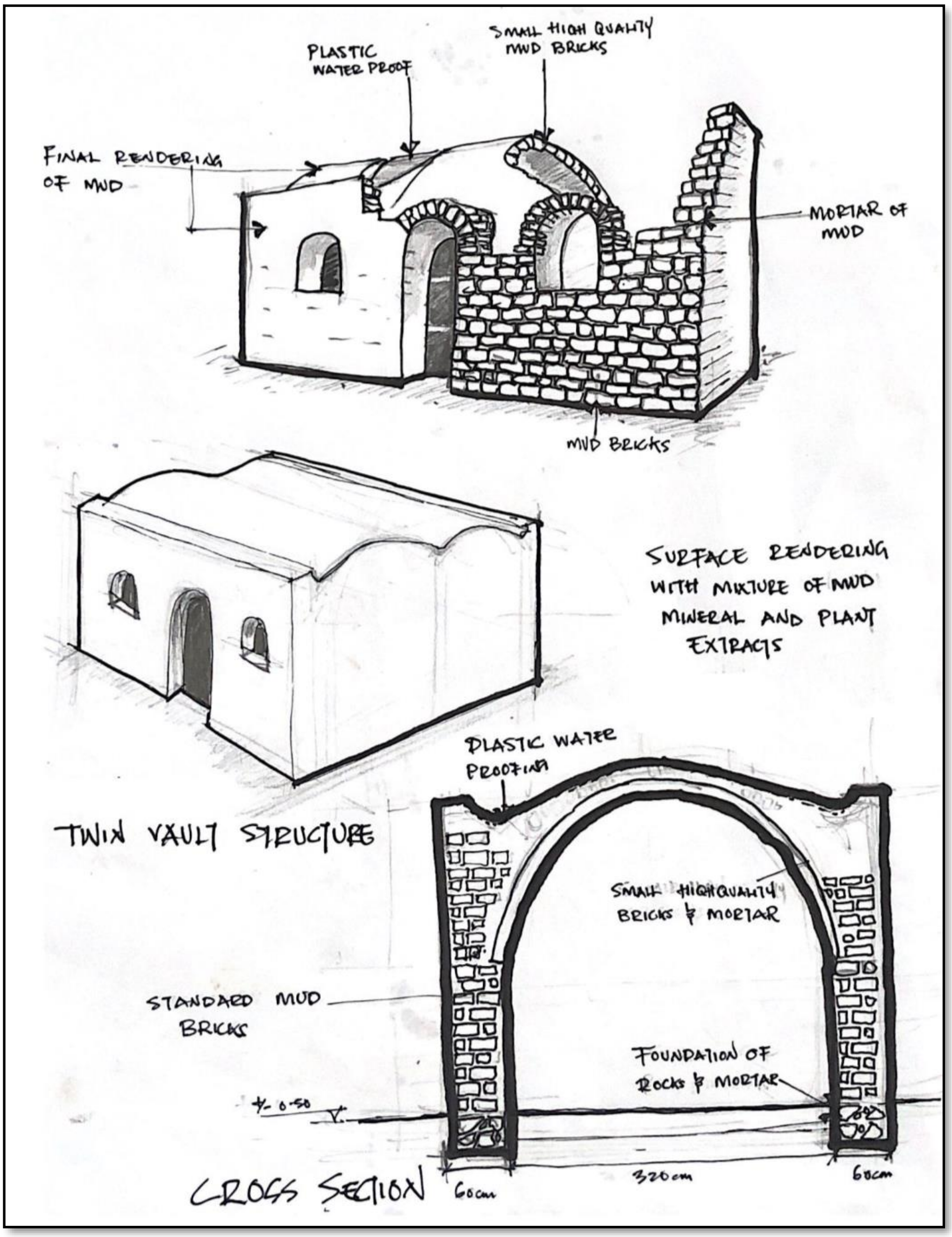


Figure 17: Nubian Vault Technique

3.3.3.4 Thatching

Thatching as defined by the Cambridge dictionary (n.d.), is to create a roof of a building using straw and reed. It is a traditional roofing technique that involves the making use of dry vegetation such as straw to create roof coverings ("Thatch roofing," n.d.). This roofing technique has been used and is still being used widely across Africa. And has been identified as the main roofing technique of the African vernacular.

The roof framing normally consists of eucalyptus sticks and in some case bamboo sticks. The poles can be spread up to 900 millimeters apart and the timbers of the roof must be securely connected, spiked, tied or bolted. The African hut (rondavel) is the most prevalent structure of which this roof form is constructed, and the roof structure can be constructed up to 10 meters in diameter. The rafter will extend beyond the peripheral walls by at least 600 millimeters' in this type of roof (Mogey, 1940).

Because local materials always integrate with the countryside surrounding their place of origin, thatch will always blend well with a rural setting as a natural fiber. Following one season of release, thatch loses its fresh straw color and assumes a rusty and not unattractive grey look. The ecological benefit of using thatch is provided by natural processes which do not use finite and costly energy resources. The method of stinging is labour intensive and thus of realistic economic benefit where unemployment is widespread among the lower income classes. Thatch has a high insulation value During the summer a thatch roof guarantees a house is cooler and in winter warmer (Mogey, 1940)

The Zulu’s in the South of Africa, who heavily cultivate grains and rear animals, use their indigenous traditional techniques to build dwellings with spherical shapes like beehives (Figure 19) using the thatching technique for entire structure. They build their houses in the middle of the house in a square, fenced enclosure. The roofs of the Zulu house are made of a thatch which is tied with a rope and which covers a frame of wooden strips

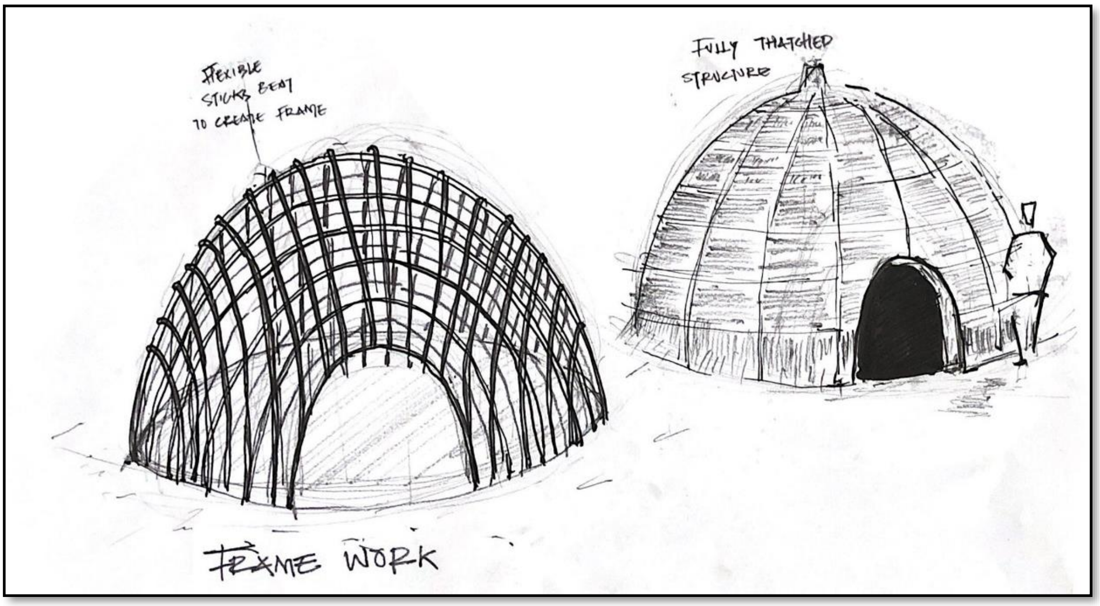


Figure 18: Zulu Thatch Houses

Chapter 4

SUSTAINABLE BUILDING AND CONSTRUCTION BY MEANS OF VERNACULAR CONSTRUCTION TECHNIQUES AND MATERIALS

In a quest for sustainability and energy efficiency architects have started to look inward to the very regional distinctive vernacular practices. This section presents some examples of buildings where the designers innovatively combined vernacular construction techniques and materials to achieve a degree of sustainable construction and sustainable buildings in Africa. based on the use of materials and adaptation of the local vernacular construction techniques. Four buildings located in the four major climatic zones in Africa (Figure 20) are chosen as case studies and analyzed.

Figure 19: Locations of Case Studies in Africa

Case study 1, located in Mali- semi arid and Arid climatic zone. Case study 2, located in Burundi- Equatorial climatic zone. Case Study 3 located in Senegal- the Tropical savanna Grasslands. Case Study 4 located in morocco- the temperate and Mediterranean climate.

4.1 Case study 1:Primary School Tanouan Ibi, Mali

Figure 20: Primary School Tanouan Ibi, Mali (Valenzuela, 2014)

The project is located in the village of Balagiuana, in the Dogon Province of Mali, western Africa. Designed by Joop van Stig and Jurrian van Stiert, the Netherlands architects. Tanouan Ibi Primary School is a modern building located on the outskirts of a village in the large Dogon Land plain in Mali (Figure 21). The building comprises of three classrooms measuring 7 x 9 meters, with a total measuring 180 students, an administration, a warehouse and a sanitary building.

Constructed with earth as the main construction material. The vaulted structure (figure 22) follows principles of the Nubian vault eradicating the need for timber which is less available in the region. The walls are not as thick as that of the Nubian vault technique as the requirement to carry the vault has been placed on the brick made columns reinforced with steel rods. The clay bricks have been stabilized and strengthened by addition of 6 percent of cement to the earth mixture. To protect the vaulted structure. from rains, a mixture of earth and cement is used to coat the vault providing water proofing.

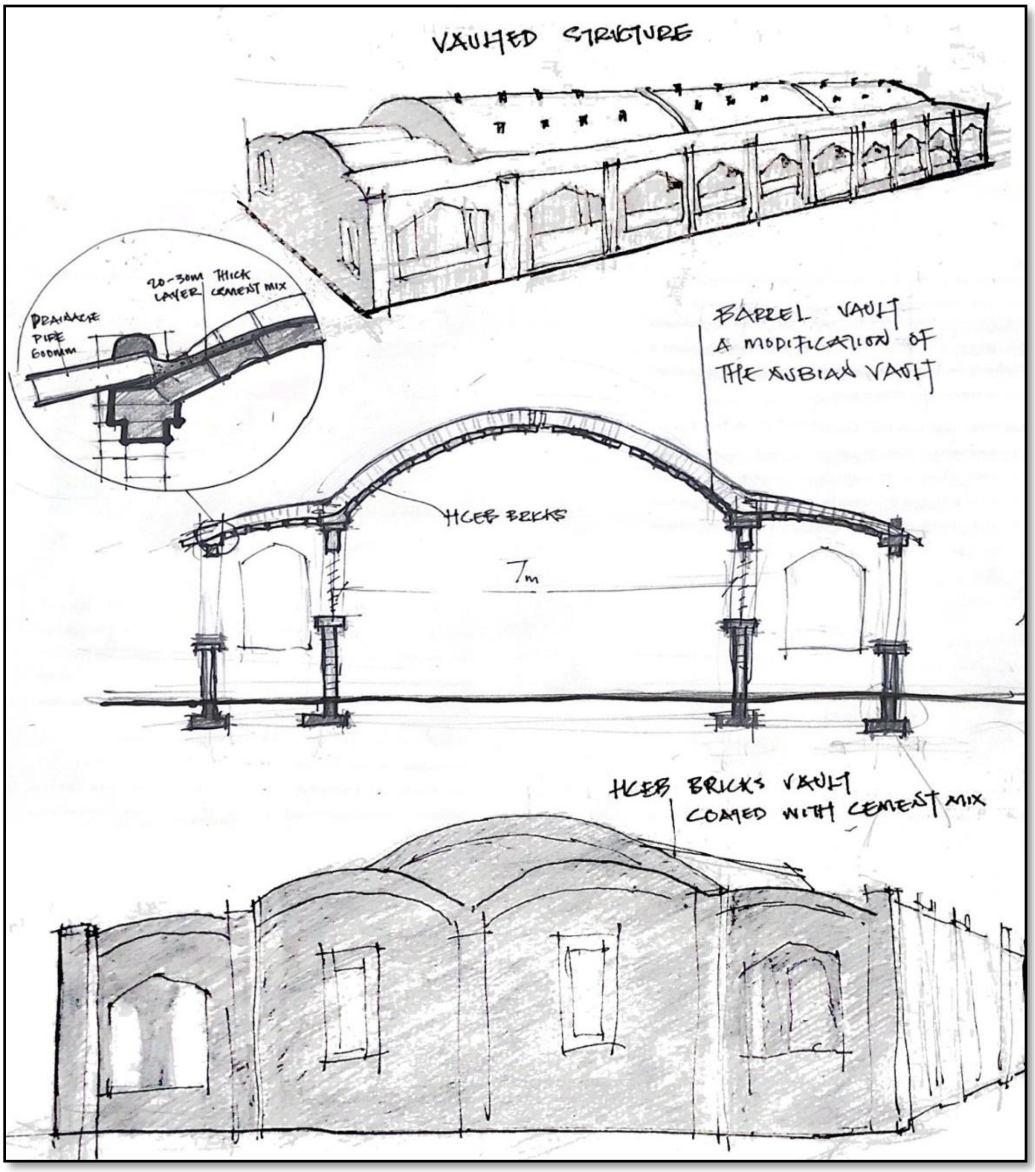


Figure 21:Primary School Tanouan Ibi, Mali Section and Sketches

Evaluating Resource Conservation

The building is made mainly of Hydraulic Compressed Earth Blocks (HCEB). The bricks are non-fired and produced from earth sourced from the site. in the previous chapters earth (clay) has been discussed as having a low embodied energy. As this material has been sourced from the very site where it is being built, Energy consumed through mining, transportation and manufacturing are greatly reduced.

The HCEB are used for the floors and roof, with the insulating properties of earth bricks the building envelope is insulated. This According to (Valenzuela, 2014)have significantly cooled the interiors. Reducing the need for mechanical cooling devices. The building makes use of gargoyles on the roof (Figure23), ceramic tubes locally produced with clay, passively cool the interior and allow for natural light to light up the interior. This again reduces the need for electricity to cool and light up interiors.

Figure 22: Gargoyles on the vault(Valenzuela, 2014)

The clay used to produce the HCEB is sourced on site meaning it was locally sourced hence it is relatively cheap as compared to if it was not sourced locally. The building was constructed by local craftsmen whom were involved in all the process of construction and by so doing learnt to improve and refine their traditional construction techniques of mud brick masonry (Figure 23), this ensures the availability of skills required and labor supply and creates job for the local economy. The exposed brick material of the building's façade would require little cleaning and maintenance because of its earth color reducing the need for regular paint jobs.

Figure 23: Local Builders Involved in the Construction (Valenzuela, 2014)

Evaluating Human Adaptation

The windows on both sides of the spaces, the gargoyles on the roof all allow for an enhanced ventilation and daylighting. Moreover, the buildings naturally insulating envelope cool the interior in warm climate making the spaces thermally comfortable.

Continuous use of the HCEB-bricks for floor, roof and walls and the color of these bricks leads to the building being integrated into the environment. The earth color of the Dogon dwellings is how their villages fit into the landscape.

Figure 24: Library of Muyinga ("Library of Muyinga / BC Architects," 2020)

4.2 Case Study 2: Library of Muyinga, Burundi

The building is located in Muyinga, Burundi. And designed by the BC architects Muyinga's initial library, part of a proposed comprehensive school for children with disabilities. The building (Figure 25) is made of compressed earth blocks, built with a participatory approach.

By a thorough investigation of the vernacular architecture of Burundi("Library of Muyinga/BC architects," 2020), BC Architects designed a structure constructed of compressed earth bricks, baked earth roof tiles, and timber. located in the equatorial region, Burundi possesses an adequate amount of timber, thus the roof structure is constructed of eucalyptus wood. Knowledge gained from the study of vernacular architecture were updated, reinterpreted applied, and the techniques used improved. For instance, the bricks were formed by compacting soil in a formwork like the rammed earth techniques but other than creates monolithic walls, the designers opted for bricks instead. Additionally, the structure is organized along a long narrow and covered circulation space, a tradition common to the people of Burundi to protect from harsh sun and heavy rains common to the region (Figure 26).

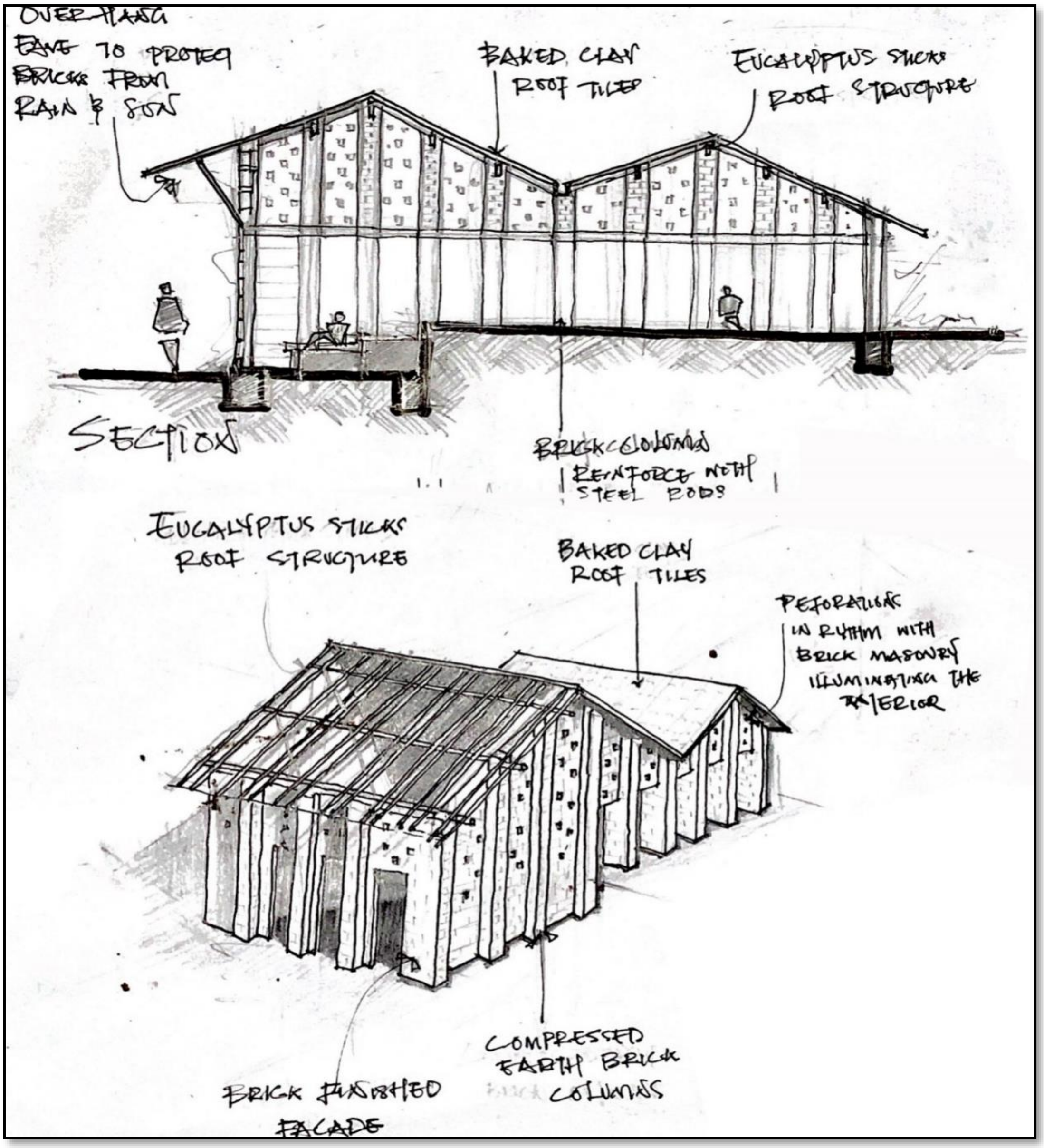


Figure 25: Muyinga Library in Sketches

Evaluating Resource Conservation

The building is made of compressed earth bricks (CEB) and baked clay roof tiles. The clay used for the Bricks and roof were excavated on site and then compressed in a process similar to the rammed earth technique. The production of these bricks manually cut energy consumption in manufacturing, transportation and processing.

The volume and façade were inspired by climatic considerations: a high interior with constant cross-ventilation helps direct humid and hot air clear. The façade is perforated as per the Compressed Earth Blocks (CEB) masonry rhythm, flooding the library's interior with natural light("Library of Muyinga / BC architects," 2020).These are passive design strategies to cool and make use of natural light. The construction waste would be mostly clay which would easily decay and return to earth. Moreover, the earth material can easily recycle.

Construction materials used here are sourced locally. The compressed earth bricks (CEB) are made of earth dug on site (Figure 27). The eucalyptus timber wood structure (Figure 26) is gotten from a nearby wild and the baked roof tiles are also made of earth from the site. The buildings are constructed by the locals whom in the process also gained an improved knowledge of utilizing their local construction techniques and materials in a modern way.

The unfinished CEB façade would require less cleaning and maintenance. The baked earth roof with its overhang protects the brick walls from rain and other harsh weather conditions.

Figure 26: Earth Bricks on Site ("Library of Muyinga / BC Architects," 2020)

Evaluating design for Human Adaptation

The building large openings and perforations on the brick wall (Figure 26) allow for cross ventilation and adequate natural lighting.

The tactile nature of the building exposed material from the unfinished brick walls to the earth floor tiles stimulate the senses giving a pleasing sensation therefore improving the aesthetics of the building. Additionally, the harmony of the building with the natural environment is another quality that improve the structures aesthetics.

4.3 Case study 3: New Artist Residency, Sinthian, Senegal

Figure 27: New art Residency in Senegal ("New artist residency in Senegal/ Toshiko Mori," 2020)

The building is Located in the south east of Senegal village of Sinthian and designed by the architect Toshiko Mori. The building (Figure 28) delivers artist residences alongside a variety of programs to allow citizens of the village and the surrounding area to explore new ways of creativity and improve their skills ("New artist residency in Senegal / Toshiko Mori," 2020). The center is a forum for the local community and a location where the resident artists will have a more positive view of Sinthian culture. The Structure is built with local materials and advanced knowledge of bamboo, brick and straw has been shared by local architects. These vernacular approaches are combined with Mori 's architecture developments. The normal pitched roof is inverted and can capture about 40% of the domestic water use of the villagers from rain (Figure 29) ("New artist residency in Senegal / Toshiko Mori," 2020).

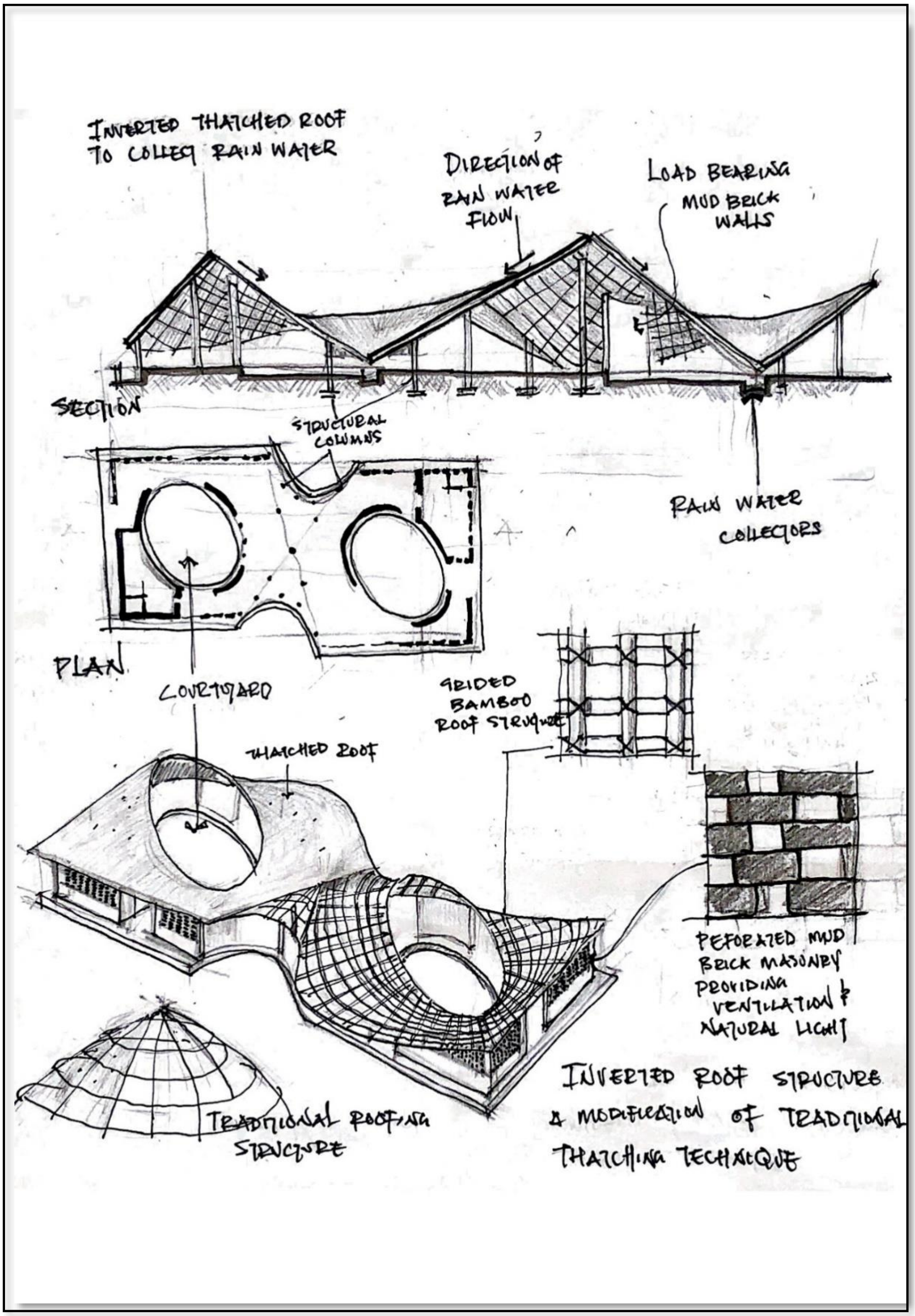


Figure 28: Sketches of the Structure Plan and Section Showing Roof Structure

Evaluating Resource Conservation

The choice of materials here are more bricks for the walls and thatch and bamboo sticks for the roof("New artist residency in Senegal / Toshiko Mori," 2020). These materials are low embodied as little processing is needed to manufacture the materials and energy usage is very minimal because the thatch is scoured from the immediate surrounding and the bricks made from earth excavated on site. The technique employed in this site building the walls (masonry) and the roof (thatching) do not involve the use of heavy machinery thus efficiently conserving energy.

The insulation value of thatch is high as discussed earlier ensuring the structures envelope to be naturally insulated in its entirety. The walls are perforated using the rhythm of the mud brick masonry. This enhances natural ventilation and passively lights the interiors. The courtyard also contributes to passively cooling the spaces.

The iconic roof of this structure (Figure 29) is creatively designed to collect rain water this goes a long way in contributing to the conservation of water.

The use of locally sourced materials is key in reducing cost of construction of buildings. Most of the materials used in the structure are locally sourced. the laborers and builders are of the locality meaning that operation and maintenance of the building will be managed locally. The materials and labor are less expensive as compared to if it was imported. This also creates jobs for the locals improving their economic capabilities. The overhangs provided by the roof protects the building from hash climatic conditions contributing to the longevity of the structure.

Evaluating Human Adaptation

Again, the insulating qualities of the roofing and walling materials encourage thermal comfortability of the building's occupants. The perforated brick walls enhance natural ventilation and provide adequate and healthy natural lighting. The building materials with less processing emits little to know volatile organic compounds enhancing comfort and the overall human health.

The contrasting effect of the white walls of the building to the dark brownish color of the roof improves the aesthetic quality of the structure in harmony with the natural landscape of trees and grasses.

4.4. Case Study 4: Bioclimatic Primary School in Morocco

Figure 29: Bioclimatic Primary School in Morocco ("Bio-climatic Preschool / BC Architects," 2018)

The building (Figure 30) is located in the Mezourg region of Morocco and was designed by the BC architects. The structure of 172 meters square was completed in 2017. Inspired by the vernacular architecture of the region, the building is put together using vernacular material (earth and stone) and techniques (mudbrick and stone masonry) to achieve a bioclimatic and earthquake proof structure("Bio-climatic preschool / BC architects," 2018).

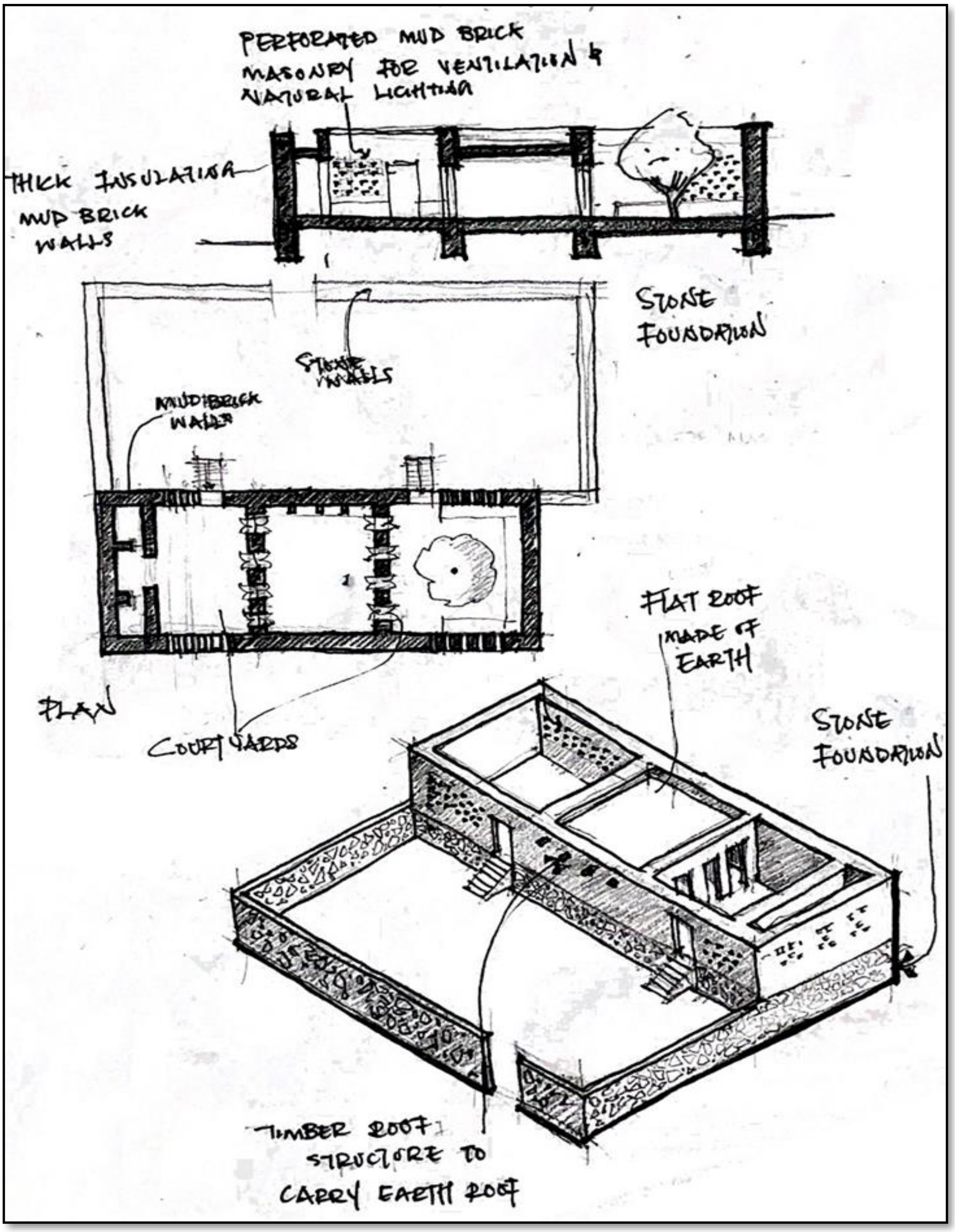


Figure 30: Bioclimatic Primary School in Morocco

Evaluating Resource Conservation

The material choice here were stone and earth for the walls and timber and earth for the roofs. The stone was sourced from the mediate environment cutting energy utilization in transporting the material. The wall construction is thick (Figure 31) presenting a thermal mass which cools the temperature of the interiors by day and keeps a worm temperature by night limiting need for mechanical cooling and heating devices. The stone and earth bricks are bio based and do not emit any VOCs into the interiors.

The building also possesses perforated brick walls and courtyard with trees, these serve as devices that passively cools and lights the building. Stone is a highly durable material as discussed earlier. The choice of stone as a foundation material adds further strength and resilience to the structure.

All major materials and skills utilized in the construction of the buildings are locally sourced and readily available. The building is finished with earth plastering consisting of a mixture of earth and straw. This finishing requires very little maintenance as it will only look better as with ages thus, the building's façade would require little cleaning and maintenance because of its earth color reducing the need for regular paint jobs.

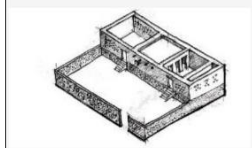
Evaluating Human Adaptation

The building designed to be bioclimatic in its nature pays attention to the utilization of the passive design techniques as courtyard and vegetation to enhance thermal comfort therefore improving occupant's health and comfort. The bio-based materials utilized here emits less harmful toxins and real VOCs into the atmosphere. Designed to be earthquake proof, the stones, adobe walls and earth flat roof adds to the structure's resiliency safe guarding human life and property.

Table 1 Summaries analysis of case studies showing vernacular construction materials and techniques applied in all 4 case studies and also the sustainability goals and strategies achieved by the use of these materials and techniques.

Table 1: Analysis of 4 Case Studies

Project Name	Climatic Region	APPLIED		SUSTAINABILITY GOALS					
		Construction Materials	Construction Techniques	Conservation of Resources				Design for Human Adaptation	
				Conserving energy	Conserving materials	Conserving Water	Conserving land	Protection of Comfort and Health	Protection of Physical Resources
Case study 1: Primary School Tanouan Ibi, Mali 	• Semi-arid region	• Earth (Hydraulic compressed Earth Bricks)	• Mud brick construction	• Use of low embodied construction materials and local techniques • building envelope is insulated by means of earthen walls • The use passive design strategies to naturally light up and ventilate spaces	• Use of Earth which is a durable material • Use of local and natural materials • Use of Less toxic materials	• No apparent water conserving strategy	• Building site was selected by locals strategically to enable ease of access of surrounding communities	• Thermal comfortability enhanced by earthen walls • Provision of sufficient Daylighting and natural ventilating by means of gargoyles on roof and window openings • Building configuration designed to allow operation and functioning work smoothly • Harmony of the building with the natural environment is another quality that improves the structures aesthetics.	• Use of cement as a binder to increase structures resilience
Case Study 2: Library of Muyinga, Burundi 	• Equatorial region	• Earth (compressed earth Bricks) • Timber	• Rammed earth construction • Timber frame (roof)	• Use of low embodied construction materials and local techniques • Building envelope is insulated by means of earthen walls • Use of perorations on wall and large openings as passive design strategies.	• Use of durable materials • Use of earth bricks , earthen roof tiles and eucalyptus sticks which are local to this region • Materials used are Less Toxic	• No apparent water conserving strategy	• Building is Located strategically for easy access and use by locals	• Thermal comfortability provided by earthen walls • Provision of sufficient Daylighting and natural ventilating by perforations on walls in rhythm with earth bricks • Building configuration designed to allow operation and functioning work smoothly • Tactility of unfinished brick façade and harmony with the natural environment enhance aesthetics of the structure	• Overhangs of roof protect building from harsh weather conditions

Project Name	Climatic Region	APPLIED		SUSTAINABILITY GOALS					
		Construction Materials	Construction Techniques	Conservation of Resources				Design for Human Adaptation	
				Conserving Energy	Conserving Materials	Conserving Water	Conserving Land	Protection of Comfort and Health	Protection of Physical Resources
Case study 3: New Artist Residency, Sinthian, Senegal 	• Tropical savanna grasslands	• Earth (mud Bricks) • Timber • Thatch	• Mud brick construction • Timber roof frame • Thatching	• Use of low embodied construction materials and local techniques • building envelope is insulated by means of earthen walls • The use of courtyards as passive energy design	• Use of durable materials (Earth) • Use of local and natural materials • Use of Less Toxic materials	• The iconic roof of this structure is creatively designed to collect rain water thus, conserving water	• Building is located in close proximity to existing infrastructure	• Thermal comfortability provided by earthen walls • Provision of sufficient Daylighting and natural ventilating by means of perforations on walls and courtyards • The contrasting effect of the white walls of the building to the dark brownish color of the roof improves the aesthetic quality of the structure in harmony with the natural landscape of trees and grasses.	• Overhangs of roof to protect buildings skin from harsh weather conditions
Case Study 4: Bioclimatic Primary School in Morocco 	• Mediterranean/ warm temperate region	• Earth • Stones • Timber	• Mud brick construction	• Use of low embodied construction materials and local techniques • Building envelope is insulated by means of earthen walls • The use of courtyards and vegetation as passive cooling strategies	• Use of stone and earth which are highly durable materials • Materials used are local and natural materials • Use of Less Toxic or Non-Toxic materials	• No apparent water conserving strategy	• Building is an extension of an already existing school on a rocky and hard to cultivate land.	• Thermal comfortability enhanced by thick by earthen walls • Provision of Daylighting and natural ventilating by means of perforations on walls in rhythm with earth bricks • Building configuration designed to allow operation and functioning work smoothly • Tactility of finishing earth plastered façade and harmony with the natural environment enhance aesthetics of the structure	• Designed to be earthquake proof, the stones, adobe walls and earth flat roof adds to the structure's resiliency safe guarding human life and property.

Chapter 5

CONCLUSION

As a highly functional and Practical way to meet human needs, vernacular architecture has thrived on sustainable principles. In the age of rapid technological advancements and a massive construction activities, vernacular architecture presents a vast source of knowledge. This knowledge is characterized by the construction techniques and materials used with a high regard for local conditions.

This study has been carried out to research construction techniques and materials utilized in the vernacular architecture of Africa and explore their contributory potential in creating sustainable buildings and construction. The continent relies on knowledge gained from the developed world to cater for their construction and housing needs. Applying this Knowledge in the use of materials and construction techniques directly has led to a building and construction sector with unsustainable practices. This is not to say learning from the developed world is bad but ignoring local conditions and regional differences does not always achieve results befitting to regional and national differences. Studying how buildings were made traditionally with little technological advances is thus essential. The low-tech techniques utilized by vernacular architecture can be used to create buildings that are well suited to not just climatic or environmental conditions but also the culture and economic realities of Africa in contrast to modern buildings which pay little considerations to the afore mentioned factors.

Sustainable building and construction is viewed as a way for buildings and the building industry to shift towards environmental conservation. Promoting sustainable building practice is intended to strike a balance between environmental, social and economic performance in construction projects. If this is accepted, it is clear that there is a relation between construction and sustainable; construction has high economic importance and strong social and environmental impacts. With an increasing understanding of environmental protection, building experts worldwide have paid more attention to this issue. The introduction of sustainable construction practices was encouraged as a way to encourage economic growth in the building industry while reducing environmental impacts. There are three principles that emerge to minimize the damaging environmental effects of buildings and construction and in the process accomplish sustainability in the building industry: conservation of resources, cost efficiency and human adaptation design. They create a basis for integrating the principles of sustainability in construction projects from the pre-design phase. The primary aim of this study is to explore the role of African vernacular architecture in (1) Conservation of Resources (2) promote design for human adaptation.

Stone, earth, timber and thatch are the main construction materials utilized in the African vernacular architecture of Africa. A common advantage of these materials is the are readily available and require little energy to extract and process them. Materials like thatch are by products of crops such as rice and wheat indicating the use of waste productively. the Timber is mostly sourced from local trees as bamboo and eucalyptus trees. These materials were creatively and ingeniously used most of the times jointly or independently to create buildings. The vernacular construction techniques identified consisted of the rammed earth technique, wattle and daub, timber fame construction and thatching. All the other construction techniques but thatching is associated with constructing walls whilst thatching is seldomly used for walls but for roof construction. In fact, a larger part of the buildings of the African vernacular architecture are roofed using the thatching technique. Other form of roofing involves the use of earth in a form of wattle and daub technique or vault systems. The walls created mainly of earth presented numerous advantages one of which was its thermal mass.

In analyzing the case studies, one starts to understand not only the practical application of sustainability in buildings and construction but also the application of vernacular construction techniques and materials in a contemporary manner.

In conserving resource, Energy is saved the by the use of locally available and locally sourced construction materials. These construction materials have a low embodied energy as compared to their standardized counterparts. The energy cut in the transportation, extraction and manufacturing makes this possible. The thermal mass of the mostly earth walls also conserves energy in cooling the buildings. While case studies 1, 2 and 4 show no apparent water conserving strategy case study 4 shows an ingenious modification of the vernacular construction technique of thatching in a contemporary manner to collect rainwater thus, conserving water.

The skills needed for construction are also available locally, furthermore the vernacular materials are relatively cheaper as discussed earlier. In case studies 1 and 2 the buildings skin is left unfinished while in case study 4, the building is finished with a plaster made of earth and straw. This creates a lesser need to repaint and renovate as the materials would only look better as they age saving cost all through the life cycle of the building.

In designing for human adaptation, the vernacular construction materials do not emit Volatile organic compounds or toxins because of the little technological process involved in processing and manufacturing as compared to the standardized building materials creating a healthier interior environment. In case study 1, cement, a construction material widely used in modern buildings is used as a binder for the earthen bricks rather than straws used in typical vernacular mud bricks. In case studies 1 and 2 steel rods are used to reinforce buildings structure.

The insulation qualities of construction materials combined with the techniques used promotes thermal comfort. Aesthetics is subjective however the tactility of these unfinished construction materials and harmony with the environment are notions that are widely known enrich sensory experiences of buildings.

To conclude, the role of vernacular construction techniques and materials in Africa is an essential one as it does create buildings and a construction industry that will conserve energy and resources, save cost creating cheaper ways to maintain and construct buildings, and finally create thermally comfortable and aesthetically pleasing buildings.

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