Application of Brick as a Building Material for Low Cost Housing in Hot and Dry Climates.

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Abstract- Brick which is a by-product of clay soils can be found in the historical architecture of any civilization due to its affordability, accessibility, recyclability and social cultural connections especially in the hot-dry climates of the world. Its popularity as a construction material is still evident today with over a third of the global population currently living in earthen structures. Yet low cost housing provision, especially in developing countries is plagued by the ever increasing cost of building systems (technology, materials, transport, labour, etc.) and high demand for affordable housing for the low-income group. This paper examines sun dried and burnt brick production and construction technology through a study conducted in Kenya and Morocco in 2016 and 2017 respectively whose main objective was to examine the application of brick (sun-dried and burnt) in both the traditional and contemporary approaches in the hot and dry climates by using two case studies of Voi in Kenya and Tamnougalt town in Morocco. The study employed both qualitative and quantitative research methods (through case study method and structured questionnaire, discussions and observations) to collect information and data for analysis and presentation. The study findings show that in Voi, Kenya, the quality of burnt bricks produced is low which has led to high defects cases in buildings; while in Tamnought (Morocco), sun dried bricks are predominantly used with indication that more and more conventional imported materials (concrete, clay bricks, steel, etc) are being used.

Index Terms: Burnt brick/sun-dried bricks/building technology/ low cost housing.

I. INTRODUCTION

The 2005 report by the UN estimated that 100 million people are homeless worldwide and 1.6 billion lack adequate housing (Habitat, 2014). Housing as basic need outranks health and education and is a key developmental agenda for most successive governments. The housing crisis is evident across Africa as the continents growing population gets urbanized and is predicted to reach 25% of the worlds' urban population by 2050. This rapid urbanization and growth comes with its advantages such as a thriving work force, bustling commercial and economic sector. However the disadvantages are a rising demand on housing. A dire example is that of Nigeria with a population of 173 Million with a back log of 17 million units with 700, 000 additional units demanded each year. At present the housing sector is only providing 100 00 units (CAHF, July 2017). The latest statistics from the National Housing Corporation (NHC) in Kenya show that the country has a cumulative housing deficit of 2 million housing units, which grows by 200,000 units annually. Of the houses that are actually built 83% are for high and middle income earners, 15% for lower middle income and 2 % for low income segment (World Bank Group, 2017). The key constraints to affordable housing provision include high land values, high cost of materials and unaffordable mortgages. One of the key agendas for the Kenyan government has been affordable housing and the target sits as 1 million homes in 5 years. To do this the key component is embracing affordable, accessible and sustainable building technologies and materials in order to reduce the cost of construction and further reduce the price of the unit.

With this high demand for shelter the appropriate response to construction is to use locally available materials with simple construction techniques. Hence the use of appropriate building materials is a vital sustainable design strategy, especially in hot and dry climates where thermal comfort is key but hard to achieve. In these areas mud brick is the most affordable, available, climatically and contextually a suitable construction material. It is noteworthy that, the

cost of building materials is the largest single input in construction (accounting for 55%-65% of the total cost) yet in early days in Africa, traditional houses were built with materials sourced from the immediate environment and built with relatively inexpensive and simple technology. (G.Fa Y. A., 2012). The key constraints in embracing more affordable techniques in housing provision include a lack of government policy on their standardization and use, lack of confidence in the funding organizations due to minimal research in local building materials, social biases against the material, complicated machinery and technology not transferred to the local population, inertia in the building industry due to lack of information. Brick in hot-dry climates has been and still is a popular sustainable construction material choice due to its affordability, accessibility, recyclability and low embodied energy. Earth structures built over 100 years ago are still standing today proving the materials potential to be sustainable, durable, thermally comfortable and having little to no carbon footprint. (Ugochukwu, 2016). The key advantages of Brick are its: Availability - earth is a natural occurring source and if harvested properly and prepared well can be used for construction with little to no additional reinforcement. Affordability - the highest component of high cost of materials in construction is due to the high cost of importation. Energy efficiency - due to reduction in operation, importation, transport and inherent thermal comfort (Ugochukwu, 2016). The key Challenges facing adoption of brick are: Acceptability - due to its perception as a material for the 'poor' and substandard material. Durability and strength - brick performs best under compressive strength and requires external finish to protect it from natural elements. Building tall - the limitation in strength of brick counteract against very high structures unless with a timber floor system as was used traditionally in order to reduce the weight of the structure. Deforestation - this is in the case of burnt bricks which are produced in furnaces fueled by timber.

Brick can be found in the historical architecture of any civilization and each society had their own version of brick production and construction technology. Earth has been used to create shelter since Neolithic times and the earliest evidence of it can be traced back to Egypt in the pre-dynastic civilization. Initially it was simple method of wattle and daub which in the 1st dynasty turned to brick construction (Shaw, 2000). Climate control was key in traditional brick architecture in hot dry climates, so buildings had high windows, dark rooms, and rooftop sleeping areas. Walls were white washed plastered for heat reflection. The soil composition used was a mixture of course sand for strength, and clay for binding. Rising from the Egyptian dynasties, the use of brick spread east ward with the Great Wall of China built entirely of burnt and sundried brick (in 210 BC) and northwards to the Roman Empire. It spread throughout Europe especially during the fires that ravaged medieval cities in the 15th century as it was more fire resistant than wood. Finally reaching the Americas through Coptic traveller in the 16th century with the Dutch west India Company being the first brick building, in Manhattan Island in 1633. Historically the brick production process involved kneading the mixture after which it was left overnight, then the bricks were formed with a timber mould and left to dry in the sun. Drying time varied from a couple of hours to a week and in some cases the bricks were left to dry when already on the structure. Brick making was a craft passed down through generation of skilled masons and moved from northern Africa to West Africa due to the popular trade routes through the Sahara Desert. One great example is the largest earth structure standing today; the great Mosque of Djenne in Mali completed in 1907. Historical research reveal that ancient Egyptians predominantly used sun dried bricks leaving burnt bricks to pavings in palaces and wealthy homes due to fear of fire and the high expense of fuel (Capaldi, 2011). In contemporary times the works of Hassan Fathy in Egypt demonstrate the far reaching benefits of earth as a building material for low cost housing and community projects. These benefits were demonstrated in his projects such as New Gourna in Luxor and New Baris Village in Kharga and documented in his ground breaking book, "Architecture for the poor" (1973), where he advocates for decent housing for the poor. Beyond that, Hassan Fathy favoured earth not only for its cost but also for its intrinsic human values and cultural connections (Fathy, 1986). Throughout time the brick production process consists of four stages namely soil selection, mixing process, brick formation and brick drying. The methods vary depending on location, climate, soil composition, economy and availability of resources and tools. The brickyards are usually set up along river banks to take advantage of the rich soil from river deposits and the easy access to water and transport. Each technique has its advantages and disadvantages, for example despite the low energy consumption of sun dried bricks, the drying area required is vast which is not practical in some projects.

A.Earth and brick construction technology

Earth is formed from erosion of rock and the chemical reactions of oxygen and plant material therefore the composition and properties of earth depends on where it is found. It is important to know the soil composition of an area before attempting construction because these properties determine the most appropriate method of construction. For example mountainous earth which has high gravel content is better for rammed earth construction as seen in the traditional building techniques of German brick houses. Soil used for construction should be relatively free from organic material with the exception of dry plant (straw) and animal waste (cow dung) to strengthen the brick. For

construction it is highly recommended that there is adequate clay as it acts as the internal binder. Brick construction technology changes by location, culture and climate and is often passed down through generations by craftsmen. Apart from walling, traditionally timber framed brick structure used rammed earth floor systems. This was the most affordable method for floor construction; however, this took a long time to dry. In palaces, public walkways and temples the vaulted earth floors were sometimes used. Brick bonding is the way the bricks are laid on a wall construction. This affects the walls structural strength, dimensions and appearance. Typical brick dimensions are 230mm x 110m x 76 mm but this varies with the mould used and where the brick will be used. The four main bonding types; the stretcher bond, header bond, flemish bond and english bond are used in the brick construction without exception. In hot-dry climates brick can be used to create pitched, flat and vaulted roofs. Vaults and domes are low cost because they do not rely on timber or concrete for structural support. Traditionally earth was used for roofing but faced challenges of water proofing and was replaced by brick roofing tiles which also made the roof more durable and strong for walking on if need arises (Gernot, 2006).

B.Improving the performance of brick through stabilization

In order for bricks, especially sun-dried to perform well, they require stabilization for strength (compressive and tensile) and moisture control. Stabilizers can be added in the initial mixture or as surface protection in order to improve its performance in compressive and tensile strength, shrinking and swelling and its resistance to rain and wind erosion. The three main soil stabilisation techniques are soil compaction, fibre reinforcement and addition of cement, lime or bitumen (Guillard, 1994). The performance of the chosen stabiliser depends on the soil composition and should be tested through in-situ experimentation. The three main objectives for soil stabilisation are reducing porosity, filling the voids to reduce permeability and improving grain bonding. International Centre for Earth Construction (CRATerre) has three classifications namely mechanical stabilisation through compaction, physical stabilisation through texture and structure modification and chemical stabilisation through physio-chemical reaction (www.craterre.org). Soil stabilisation is unsustainable because it is an added cost, increases construction period and processes and not entirely necessary in low rise developments (1 to 3 floors). The main reason to use soil stabilisation is due to extreme site requirements (heavy rains and poor soils) and for increasing its strength in high rise developments. Fibres have played a key role in soil stabilisation for centuries. Ancient Egyptians weren't known for direct stabilisation of the earth mixture but instead whilst harvesting ensured that the stems of the stalk remained so that the soil already contained dried organic materials. The three main fibres used for construction include plant fibres (listed below), animal fibres such as fur and hair and synthetic fibres such as steel, cellophane, glass and wool fibres. Plant fibres constitute the larger portion and include straw (barley, rye, wheat and lavender), chaff off cereals, sawdust, shavings, hay, sisal, manila, grass, hemp, millet, cane, bagasse, bamboo and hibiscus. It is important to keep the fibres dry otherwise it will decompose. Fibre improves soil construction performance in four ways - by reducing cracking, by distributing the tension created by shrinkage and accelerating drying, by increasing internal drainage and thus reduce density therefore increasing insulation and by increasing tensile and compressive strength. Natural stabilisers are also popular and these cover all animal, vegetable and mineral products. Animal products used for stabilisation include manure, urine, blood, fur, hair, casein (milk), glues, oils and fats (water proofing). Vegetable products include ashes, oils and fats such as castor, coconut, linseed etc. Mineral products are mainly to improve the grain distribution of the soils like adding clay to sandy soil and vice versa.

II. THE STUDY APPROACH

A. Objectives

The main objective of the study was to examine the production and application processes of brick (both sun-dried and burnt) in both the traditional and contemporary approaches in the hot and dry climates by using two case studies of Voi in Kenya and Tamnougalt town in Morocco and come up with recommendations on . In order to meet this objective, the study examined how sun dried and burnt bricks production and construction technology is applied through a study conducted in Kenya and Morocco in 2016 and 2017 respectively.

B. The study area

Hot semi-arid climates (type "BSh- Koppen classification") where this study was conducted tend to be located in the 20^0 and 30^0 latitudes (i.e., in the tropics and subtropics), typically in close proximity to regions with a tropical savanna climate or a humid subtropical climate. These climates tend to have hot summers and warm to cool winters, with some minimal precipitation and are most commonly found around the fringes of subtropical deserts. The case study locations were decided using non-random purposive methods which means that they were selected on the

basis of what will provide the best data to achieve the stated research objective (Kumar, 2005). The two case study areas are Voi in Kenya and Tamnougalt in Morocco. These two case study locations were selected because they represent the hot-dry climate, in addition there is prevalence of brick production and use in the two areas and easy/quick accessibility to climatic and other data required for the study.

C. Research methodology

This study was an explanatory study aimed that used the case study research method to determine how and why brick architecture is sustainable. This was done through literature review and documentation of brick architecture in Kenya and Morocco located in East and North Africa respectively. Yin (2002) defines the case study research method as, "an empirical inquiry that investigates a contemporary phenomenon within its real-life context". This method is advocated when a "why" or "how" question is being asked. This research was a non-experimental cross-sectional study as it took a cross-section of the population at one time and studied the situation as it already is without trying to input new variables. Secondary data was collected and analysed from existing literature, the relevant internet sources, books, archival/other documents and journals. Primary data was collected through observations, interviews and climatic data collection. Observation was through structured and unstructured non participant observation of the phenomena in its natural environment and was recorded using narrative, photographs and sketching. Interviews were conducted by using structured and non-structured interviews and the respondents were artisans and construction workers focusing mainly on their methods of application, materials use and any other building components. Climatic data (both indoor and outdoor) was collected by taking daily measurements of temperature and relative humidity using digital data loggers for 5 days at half hour intervals. The findings and discussions in this paper are based on variables that were identified and studied that include brick production, brick architecture and construction technology, transformation of settlements and thermal performance of traditional and contemporary brick architecture.

III. FINDINGS AND DISCUSSION

A.Case study 1- Voi, Kenya

Voi is the largest town in Taita Taveta county, located in the south east corner of Kenya. It lies at the western edge of the Taru Desert, South West of the Tsavo East National park and North East of the Tsavo West National Park. Voi town is an important nodal point in the county as it lies along the Nairobi –Mombasa highway, the new Standard Gauge Railway (SGR) line as well as the Voi – Taveta road which connects Kenya to Tanzania. Its position as the gate of the world famous Tsavo national park is also key in making it a gateway city for the region. The national parks as well as privately owned sisal estates in the region have restricted growth of the town.

Climate and terrain

Voi is 590 meters above sea level and has a hot-dry climate with about 300 mm of rainfall each year. The BSH Koppen climate classification is typical of pre-desert regions with hills that protect it from harsh and dry desert winds. Temperatures in Voi range between 20°C and 30°C with annual highs of 40°C and lows of 10°C. Relative humidity readings are low levels of 40-55% and the region typically experiences south westerly winds at 1500hrs and at 09hrs south easterly with seasonal and even daily variations. The hottest and coldest months are March and July respectively. There are distinct dry and wet seasons with short rains from March to May and long rains between October and January. In terms of terrain, to the West there is the Taru desert, to the South lies the sagala Hills and to the North east and South West the Tsavo East and West National Parks. The hot-dry climate and the high cost of irrigation explains the sparsely vegetated Voi landscape with hard dusty grounds. The seasonal Voi River which is a very important source clay, runs through the town leaving rich clay deposits in its river bed and banks that is used as a raw material for making bricks.

Brick construction technology

Brick is the main construction material found in Voi. It can be seen in low cost construction as well as high end apartments. It is also the main walling material that is used in the construction of government projects including schools, hospitals and offices. The primary source of brick used in construction in Voi is from the Sofia Brick yard which is located about 4 Km from Voi town alongside the Voi river. The brick-making techniques were passed onto the local community by brick makers from Tanzanian who were harvesting soil by the river in 2000. This site is used for mass commercial production with over 300 brick makers able to produce 1500 bricks a day. Before this commercial production of bricks was started, there were uncoordinated brick makers who could not be relied on to

supply good quality bricks to big projects. Sofia brick yard is approximately 4 km from Voi town centre. This brick yard consists of individually claimed plots of land alongside Voi River. The makers find an ideal location for minor excavation (3-5 M deep) along the river. After preparing the soil, bricks are formed manually and sun dried. Thereafter a kiln using the same bricks to be burned is built within the same location with holes through which wood is fed into the furnace for the bricks to burn for 6-36 hours depending on the size of the furnace and the quantity of the bricks. On average, it was calculated that one person can produce 500 bricks a day. Bricks in Voi have a standard dimension of 210 x 110 x 110mm (9 x 4.5 x4.5 inch) and one good quality brick costs Ksh.8.00 (1U$=100 Kshs). A tanuri (furnace) that burns 10,000 bricks will require fuel wood of about Kshs. 9,000.0 as illustrated in Figure 3. It is estimated that a house of 10m x 12m can take approximately 1,000 bricks and developers will factor in other costs including loading and off-loading and transportation cost. It was noted that not all the bricks kilned will be suitable for construction. At least 2%-5% depending on the brick makers expertise will be defective.

1. Dry soil mixture is prepared. A variety of soil is dug out and mixed together. Some from top, middle and bottom layers to get a sandy-Clayey mixture which is good for building.	**2. Soil mixture mixed with water left to dry for 1 day to loosen up clay particles.**	**3. Mixture moulded by hand into formwork. Dimensions are 4.5 inch x 4.5 inch x 9.0 inch. Dimensions can be modified if specified.**	**4. The formed bricks are laid out to dry in the sun for 7-10 days and turned every 2 days to get cons istency in drying.**
			
5. A Tanuri (furnace) of bricks is made.	**6.** Bricks burnt for 12-24 hours depending on no. of bricks in the tanuri)	**7.** 3 days cooling time before selling the bricks.	**8.** Quick field test for buyer to check brick quality by submerging in water for 10minutes.
			

Figure 1: Brick production in Sofia brick yard – Voi (Source: Field Survey 2016)

To fire the bricks a Tanuri (furnace) is constructed of the bricks with vertical and horizontal ventilation channels that moves the heat through to all the bricks as shown in Figure 1. The last layer on the outer most part of the Tanuri is made of old discarded bricks that help keep the heat in. The bricks are burnt continuously for 6-36 hours depending on the size of the Tanuri which ranges in size from 4,000 bricks to 10,000 bricks. However, it was observed that during rainy periods, bricks are covered with a plastic polythene sheet to keep away water until the rains stop. It was, noted that Voi experiences sudden and heavy rain fall which completely destroys unfired bricks and paralyses production during this period of time which results in heavy loses to the brick makers. In the whole process of brick

production and use, there are two main causes for concern that need to be addressed. One is the degradation of Voi river bank because of the unsustainable soil harvesting methods and the burning of bricks using fuel wood which causes deforestation and releases harmful gases into the environment as shown in Figure 3. It was observed that the quality of some of the bricks produced is very poor as a result of the high demand for the bricks. This has brought in a new thinking from investors who now increasingly prefer to use conventional materials (masonry, concrete, etc.) for walling instead of the burnt bricks which are found to be inconsistent in quality.

Figure 2: Wood fuel and Soil harvesting site (Source: Field survey, 2016)

	01	02	03	04
No. of Bricks	900	1,500	4,000	10,000
Cost of Timber (Kshs)	2,500 (1 pick-up)	2,000 (1 pick-up)	4,500 (1 Lorry)	9,000 ((2 Lorries)
Hours of Burning	6	18	24	36
Dimensions-LxHxW (M)	2.4x1.3x1.6	2.5x1.8 x1.75	3.7 x 1.7 x 2.9	3.7 x 3.4 x 4

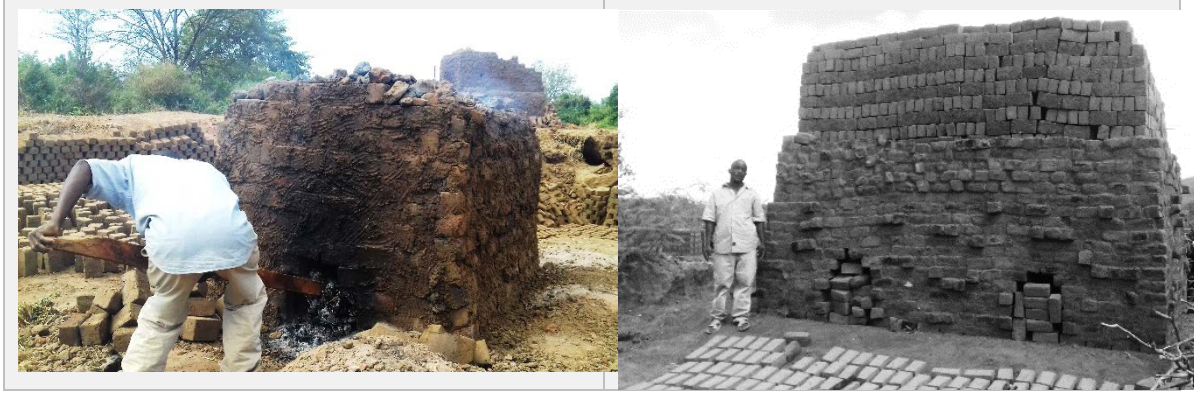


Figure 3: Sofia brick furnaces (Field survey, 2016)

Brick construction technology(Voi)

The main brick laying technology used in Voi is the stretcher bond, because is the most understood by the local artisans than the other bonds as shown figure 4. Concrete is not easily accessible and is costly so the walls are typically load bearing for low-rise structures. In modern times high property prices and rural to urban migration have necessitated multi-storey construction in order to meet the demand for living space. For high-rise brick apartments, reinforced concrete is used for structural stability and brick as an infill. Higher cost of living and construction led to the reduction in wall thickness from the traditional 300mm to 200mm and now to 150mm which

in effect has reduced the structural stability, resilience against wind, wall erosion and thermal performance of the buildings.

Figure 04: Voi Brick Construction Technology (Source: Field survey, 2016)

B. Case study 2- Tamnougalt, Morocco

Tamnougal is a Kasbah (Berber for fortified village) located in the date palm oasis of the Draa valley in the south east of Morocco. It is located within the Zagora province which is in the Souss masaa, Draa administrative region. Ouarazate is the nearest city located 95 km away and Agdz, the nearest town is 5 km away. The name Tamnouaglt in Berber means meeting point. True to its name Tamnougalt was a crucial node for nomadic Berber clans who were passing to and from the popular Saharan desert trade routes. Tamnougalt is 930 meters above sea level and has a hot and dry climate with about 300 mm of rainfall each year. The BSH Koppen climate classification is described as warm–semi arid climate typical of pre-desert regions with hills that protect it from harsh and dry desert winds. These areas are also found in close proximity to a seasonal river to alleviate the water table and keep the sparse vegetation alive. The temperatures are highest on average in July, at around 31.7 °C and lowest in January with temperatures averaging 10.4 °C and the annual temperature average is 20.5 °C. In terms of rainfall he annual average is 106 mm with June being the driest and November the wettest..Tamnouaglt is found at the foot of the Atlas Mountains in Draa valley (Date palm oasis) and at the bank of the Draa river which leaves clayey soil deposits which are suitable for making long lasting brick. The mountains shield the town from harsh desert winds. The ground is hard and dusty as grass and farming activities are unsustainable due to high cost of irrigation.

Brick Production

Brick is the main construction material found in Tamnouaglt. It can be found in 1000 year old fortified houses as well as in modern construction. Brick production is through specialised artisans who are hired for each project. This is an unsustainable production model as it is slow and unpredictable in terms of availability of the artisans. It is also not viable for large scale projects. The artisans make on average 500 brick a day which dry for 10 days before use. For efficiency once bricks are ready for use the workers then alternate between making bricks and constructing with the ready bricks. However in high traffic areas and socially important spaces such the mosque and palaces; the use of burnt brick is preferred for durability. Brick is no longer the preferred construction material in the area and hence the qualified artisans who take up the trade are few which has caused a decline in the quality and hence a reduction in the demand for the material. In this set up, the sun dried brick is a much more sustainable production method than the burnt brick because it does not burn wood which in the first place is not available and of course as noted in the case of Voi release dangerous gases in the environment and cause deforestation. However, the sun dried bricks are not strong enough to withstand heavy loads thus stabilisation of the brick is done to strengthen it by addition of straw and other additives to the mixture.

The process described in Figure 5 involves preparing the mixture of soil, water and large amounts of dry straw which is an organic additive that strengthens the brick. The mixture is left for 3-4 hours for the mixture to settle before being placed in a timber formwork which the dimensions are determined by the owner depending on where the brick is to be used. For upper floors smaller dimensions (100x150x100) are advised to reduce on loading and for the lower floors larger dimensions (200x300x150) are used for structural stability. Once the bricks are moulded, they left on the floor to dry for a minimum of one (1) day and up to six (6) days in the sun then ready for use or stored.

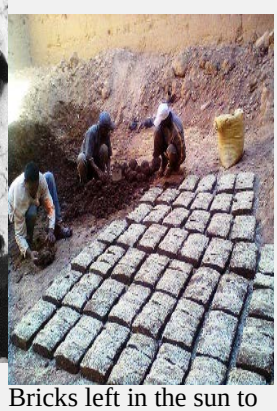
1. A mixture of soil, water and large amounts of dry straw. The straw is an organic additive that strengthens the brick. The mixture is left for 3-4 hours before being placed in timber formwork.	2. The formwork dimensions are determined by the owner depending on where the brick is to be used.	3. Formed bricks are laid out to dry in the sun for 10 days with continuous turning.	4. Bricks stored until they will be used for construction.
 Soil, water and straw mixture	Bric 	 Bricks left in the sun to dry	 Brick in Storage

Figure 5: Brick production process in Tamnougalt (Source: Field Survey, 2016)

Construction technology

The construction technology evolved from mud and wattle single storey dwelling to multi-storey brick structures. This combination of rammed earth and sun-dried brick was used for wall construction. In multi-storey buildings rammed earth was used in the lower floors because it was structurally more stable and brick for the higher floors because it was lighter hence reducing the structural load. The walls were typically 350mm to 600mm wide hence were load bearing and were combined with timber beams and brick columns as structural support. Small windows (800x400mm) were used to have small spans and in some cases for security although this created poor internal lighting and ventilation. In contemporary brick architecture timber is replaced with concrete for beams and columns and brick or clay blocks used as wall in-fills. Traditional floor deck designs had timber supports from the date palm followed by thin timber strips from the saf saf plant. The saf saf plant was known for keeping away termites. In palaces and important rooms the timber strips were painted and arranged elaborately and decorated as shown in figure 6. Contemporary floor decks are made from concrete with plastered finish; traditional water proofing used bamboo flutes and palm leaves and while modern times waterproofing use plastic sheeting or damp proof membranes. Decorative column designs with niches for lighting and ornaments are used in the main halls of the house.

Figure 06: (Left) Ceiling with strips of saf saf wood for decoration and termite protection. (Right) Roof deck section with bamboo strips and palm leaves for water proofing (Source: Field survey, 2016).

VI. CONCLUSION

Fieldwork studies in Voi (Kenya) revealed that the soil harvesting along Voi river bank is compromising its flood plain and the burning of bricks causes air pollution and deforestation. The high number of brick artisans has increased competition and hence reduced brick quality over time which has increased the defect rate of bricks in the market. This reduces bricks' viability as a preferred sustainable material choice for construction and contributes to its low perception in the community which increases the preference of imported materials such as concrete, steel and stone. Climatic data from the traditional Brick house in Voi were more thermally comfortable than the contemporary case. This can be attributed to the use of 300mm thick walls and timber ceiling with a thatch roofing system, inward facing courtyard designs and compact urban layouts. Compared to the current construction trends that use a 150mm-200mm thick single layer wall system, corrugated iron sheets for roofing, isolated housing units with wide roads in between; all of which increases internal heat gain and reduces occupant thermal comfort.

Fieldwork studies in Tamnougalt (Morocco) reveal that Brick production has and still is predominately sun-dried with addition of straw stabilisation for strength as the scarcity and high expense of timber used in burning brick method. Trends indicate increased use of imported materials such as concrete, clay blocks and steel, hence the valuable tradition of brick construction is not being passed down through the generation which means that the quality and reliability of the bricks in the market is dropping and may lead to the total lose of this valuable construction technology unless there is increased documentation and awareness.

Traditionally Moroccan earth construction technology uses rammed earth in the lower floors for strength and Brick for the higher floors Additionally 500mm thick walls are used and courtyards to create thermally comfortable internal spaces during the high daytime temperatures. Traditional design had small windows (800x400mm) which prevented appropriate ventilation through the spaces. Buildings typically have flat roofs and multiple verandas to use as sleeping areas on hot nights. Contemporary brick design uses larger openings (1500x1000mm) which increased ventilation and natural lighting in the spaces but the urban layout has moved from compact layouts with winding streets to isolated units. In contemporary design concrete is used for the structural member instead of timber as it is scarce and is vulnerable to termite attacks.

Fieldwork findings conclude that there are various advantages and disadvantages to brick construction technology. These include unregulated soil harvesting, use of imported labour and techniques, use of imported materials, high energy brick production techniques, loss of knowledge transfer and thermally uncomfortable architectural design strategies. This is despite the great lessons traditional brick construction techniques found in each region. In Voi trends in brick construction show depleted river banks quarries, use of imported materials, un-finished and thermally uncomfortable brick buildings. In Morocco trends in brick construction show the loss of knowledge transfer of construction techniques usually passed down from generation to generation, contemporary lower quality brick architecture and a move away from compact to sprawling urban layouts.

This study recommends appropriate soil harvesting, use of local labour, simple construction technology, use of locally available resources, incorporation of government and community regulation of soil harvesting sites to ensure rehabilitation of the quarries, use of local labour and low energy construction and production techniques, documentation and training of appropriate traditional and contemporary techniques.

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