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Earthen Architecture for Low-Cost Housing in Tropical Climates

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Abstract

Earthen architecture offers a sustainable, low-cost solution for housing in tropical climates, leveraging local soil to address affordability and environmental challenges. Core Problem Tropical regions face acute housing shortages due to high costs of conventional materials like cement and bricks, which are energy-intensive and unsuitable for hot, humid conditions. Rural populations often rely on basic earthen structures indicating poverty, while modern concrete designs with glass walls exacerbate heat gain and energy use for cooling. and Vernacular advantages. Traditional earthen techniques, such as rammed earth adobe blocks, evolved to optimize microclimates through thick walls that provide thermal mass, insulating against daytime heat and releasing it slowly at night. These methods use locally available clay mixed with sand, straw, or stabilizers like 5% cement, reducing transportation costs and enabling simple, labor-intensive construction. Applications. Modern Stabilized compressed earth blocks (CSEB) and interlocking designs enhance durability, strength, and aesthetics without compromising sustainability, as shown in Nigerian projects for low- to high-income housing. These achieve high thermal performance, fire resistance, and humidity regulation in swampy tropics, cutting costs by 20-30% compared to sand Crete blocks. Earthen architecture promotes eco-development by minimizing ecological impact, bridging housing deficits (e.g., Nigeria's 17 million units), and reviving cultural identities through passive bioclimatic design. It supports do-it-yourself builds and government-led models for scalable adoption in developing areas like Indonesia and West Africa.

Keywords: *Architecture, Sustainable environment, Earthen material, Low-cost housing*

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Background to the Study

Living in earth shelters has been a part of human history. The relationships between man and earth shelter dwellings began with the utilization of caves and overtime evolving technologies led to the construction of customized earth dwellings. Today earth shelter construction is a rare practice. The progress of earth as a modern building element was slowed down drastically by architects, engineers and the public who believe earth is unconventional, boring and unaesthetic. Technique of earth sheltering is still not popular as the society remains unaware of the process and benefits of earth building. This paper discusses the potentials of earth as a still relevant building material in development of low-income housing in developing nations. The paper recommends the use of earth either as adobe (mud bricks) pise (rammed earth) cob (compressed earth) as a major walling material in housing development. In all, the paper investigates earth popularity from Adam as building material and its still relevance in realizing affordable low-income housing in developing nations.

Earthen architecture offers a sustainable solution for low-cost housing in tropical climates, leveraging locally sourced soil to create durable, energy-efficient structures. These materials excel in regulating indoor temperature and humidity, addressing the challenges of high heat and moisture prevalent in such regions. Historically, earthen construction techniques, including rammed earth and unfired bricks, have endured for centuries, as seen in structures like traditional African huts and modern revivals in projects across Benin and Thailand. In tropical settings like Cotonou, Benin, these methods integrate bioclimatic design to minimize reliance on mechanical cooling.

Real (2007) observed that the ground we walk on and grow crops in also happens to be the most widely used building materials on the planet and that over half of the world's population, approximately 3 billion people on six continents lives or work in buildings constructed of earth. Earth is perhaps the oldest building material employed by man for shelter and Adam probably could have lived in a house built in earth, when he was ejected from the Garden of Eden, Cain founded a city, whose walling elements could have been earth and the early man stopped wandering when he evicted animals from caves made b termites from earth and ever then, man has employed earth in many forms in building his home. Man most certainly copied the termite, and the mud mixer cousin that built in earth. Termite built homes that rose very high compared to their size, heights which could have influenced man's knowledge of building the first skyscraper in life. "The tower of Babel", built in earth (Dethier 1981). Earth happens to be the most widely used building material on the planet. Civilizations in history made use of earth to create stable warm and low impact structures. The world's first sky scrapers in modern history were built in mud bricks, and world's renowned men such as Paul Revere, Chairman Moa, Ronald Regan and many others lived in earth buildings at various period in their lives (Real 2007). Early civilizations such as Egypt, Mesopotamia, the Greek and Romans, used earth as major materials in the development of their cities. Europe, Middle East, Africa and the Chinese all built in earth, therefore earth could be a veritable tool in housing development, especially in less privileged nations. To effectively employ earth as a building material in 21st century world, the architect as a chief builder, the only one according to (Fry 1956) who could bring man and his environment together must therefore revisit earth. This is supported by

(Dethier 1981) who believes that the progress of earth as a major walling material in our contemporary houses has been played down by architects, engineers and the public. According to Nigeria Demographic and Health Survey NDHS (2003), the population of Nigeria a typical case of developing nation has increased to an alarming 150 million people; without a corresponding growth in the housing sector to cushion the stress that will result from the population explosion surge. NDHS (2003) puts the occupancy ratio of Nigerians to 5 persons to one room, far above the acceptable ratio of 1.5-2 persons per room, indicating that Nigerians live in an overcrowded situation, and may need more than half a million housing Units before 2035 to bridge the gap between housing demand and supply (NPC 2024). Earth may be the material to achieve this.

Buildings in Earth

Earth ensures optimal "thermal comfort", providing natural regulations between indoor and outdoor temperatures; and overheating characteristics of other materials, and particularly concrete. Unbaked earth has been used for thousands of years not only in rural housing, but also for the vast, prestigious monuments, that reflect the material and spiritual development of communities, warehouses and aqueducts, ziggurats and pyramids, monasteries, churches and mosques. In these, mankind's creative drive seemed to reach its full expression. Among world architectural exponent in earth is the tower of Babel, which stood at 90 meters, mankind first skyscraper. The Great Walls of China of which large parts are of unbaked earth as a building material (Dethier, 1981). Cities of the past appear to have a deep knowledge of the enduring character of earth, as it was extensively used in fortification of the cities. Cities like Jericho, Tiznit in Morocco and Babylon were all built and fortified in earth with their walls rising high. Earth was also used by the military during the Second World War in erecting dams, building camps and airstrips (Real 2007). Earth in the afore stated circumstances were either used as mud bricks (Adobe) compressed earth or rammed earth (pise), each of these forms exhibit an inert strength and longevity that history has revealed through remnants of Great walls of China, Pyramids in Egypt and many others (Real 2007).

Forms of Earth used in Building

According to Doat (1991)**,** Adobe is sun dried-earthen brick, and are of the earliest materials, dating back 6000 years B.C. In the making of adobe, earth (composed of sand, silt and clay) is mixed with enough water to make a stiff mu, which is placed in form of mold bricks. Once removed from their mold, are allowed to dry slowly and bake in the sun over several weeks. Being turned and stacked to expose the different surfaces to the air and sun for complete drying and curing. Factors such as temperature and humidity affect the requisite drying time of sand, clay and silt is necessary for good adobe soil, and the sand grains and silt act as aggregate and filter while clay is the binder (Doat 1995**)** the following table classifies adobe particle size.

Table 1: Particle Size Classification

Gravel	> 4mm	>16m
Fire Gravel	2mm-4mm	0.6m-16m
Coarse sand	250microns - 500 microns	0.1-0.2m
Fines	< 2005 microns	< 0.01

Darley, (1980) observes that traditional adobe marker adds chipped straw to their mix for several reasons: first, straw adds tensile strength; second the addition of straw retains moisture to slow drying time for a more uniform curing period, thereby reducing shrinkage cracks as the material dries, this system is analogous to adding synthetic fibers to concrete for same reasons. Adobe blocks range from 75mm-100mm in thickness from 200mm-350mm in width and 400mm-450mm in length. In modern times, adobe have been produced industrially using Portland cement as stabilizers. Stabilized adobe is resistant to erosion and do not require protective plaster coating (Real 2007).

Adobe has the following advantages

i. Thermal mass
ii. High compressive strength
iii. Abundance of raw material (Earth)
iv. Low embodied energy in production.

Cost

Earth, the raw material of adobe has the lowest possible embodied energy content of known building materials. That is the least energy required for its production. Adobe is a recyclable material as it can be dissolved back into earth. True adobes are naturally sun dried, another source of unlimited and free energy, therefore the largest cost of adobe manufacturing and construction is human labour. According to Real (2009**)** Adobe has found extensive use and application in the building industry in Yemen and Iran where it has been used for multi storey buildings, in the U.S where building codes have limited the use of adobe to one storey. Real express the thermal mass of adobe as slowly absorbing and releasing heat energy, in arid border lands. Summer days are hot while nights are cool, the dryness of climate permitting the earth to radiate the days heat into the dark night sky. The night's coolness is stored in the massive adobe walls and moderates the interior temperatures of building during the day; thus, keeping the occupants thermally comfortable. In the cooler months the ability of the adobe will be to store heat from sun during the day and release it to the interior during the night is a measure of its thermal quality, and Real opined that a minimum of 16mm wall thickness is recommended, since the thermal mass strategy works only in regions with significant dismal temperature swing like desert areas where humidity is low. The 16mm thickness is recommended since the greater the mass, the greater the stabilizing effect of interior temperature. Adobe is strong in compression making it adequate to resist gravity loads; Real observes that at 300psi minimum strength, a 214mm square adobe pillar is able to support 43,200 pounds of downward load, however because adobe has no tensile strength it cannot resist bending, making it vulnerable to lateral forces (i.e. earthquakes).

Rammed Earth

Rammed earth is an earth-based wall system made of compact gravel, sand and clay, which are extremely strong and durable. Rammed earth is among the oldest building materials, and was used in ancient Egypt over 6000 years ago in filling the great pyramids. The Great Wall of China is largely in rammed earth. Rammed earth is classified as industrialized adobe, and involves the compacting of moist soil between rigid forms to create monolithic earth walls with similar properties as that of adobe walls. The soil for rammed earth construction must have about 30% clay and 70% sand and small gravel. Cement is sometimes added as a stabilizer. It is critical to ensure that the moisture content of the wall is just right as if the mixture is too dry then it will lead to a weak and crumbly wall (Alozie, 2017).

Too wet a mixture, on the other hand, will result in a mixture that will take long to dry and harden. When combined carefully with concrete structures rammed earth building could produce a very appealing architectural aesthetics. (Onyegiri and Okonkwo 2008). Like all earth buildings, rammed earth buildings must also be placed on firm foundations made of concrete or stone. The process of erecting the wall includes raising the form and pouring the earth into the forms, and then, compacting it either by tampers or pneumatically. The process results in a strong monolithic wall. Rammed earth is highly associated with thermal comfort. Rammed earth structures possess all the qualities and shortcomings of other types of earth construction. They too need surface protection against moisture; the rammed earth walls have a compressive strength of about 1000 psi and are therefore fairly strong.

Compressed Earth Brick

Compressed earth blocks (CEBs) are a relatively recently technology. They combine the best characteristics of traditional earthen technology and modern brick making process. The concept is akin to a miniature rammed earth wall. Earth is poured into molds and compressed either manually or mechanically. The constituents of the earth mix are similar to those of adobe; clay sand and additives or stabilizers such as cement, fly ash, rice husk, lime etc. have been found to be a lot stronger and more weather resistant than traditional adobe structures.

Earth Potentials as Element of Sustainability in Building

For the developing country such as Nigeria to attain meaningful development in its housing sector, architects, engineers and the people must change their outlook towards earth as a major walling material in buildings, this is so because despite other many fine attributes of earth in building, it still remains the most economical (Onyegiri and Okonkwo 2008). Earth come in many different compositions that could be processed in many ways is available everywhere, thus possess the quality of being the most efficient and most economical means of housing a population of more than 150 million people. The fact that advanced nations are involving earth more in their building industry must be underscored. This is due to the economic advantage associated with earth materials, such advantages range from cost to thermal comfort quality, its environmental friendliness and health (Onyegiri and Okonkwo 2008). According to Guilland, Ogunsusi and Joffor (1995), earth despite its sustainable quality have other inert qualities which marks it significantly out as a low-cost building material, such qualities include the strength, embodied energy in earth, its porosity and thermal mass.

Strength:
The strength of earth as a building element is variable, depending on its composition and method of processing, the quality the type of clay and the grain distribution of silt, sand, and larger aggregates affect the basic strength. Compressive strength of processed earth can vary from 300 to 700 psii and for comparison typical concrete varies from 200 to 600 psi**i** (Onyegiri and Okonkwo, 2008).

Embodied Energy:
According to Nelson (2005) although earth construction methods are more labour intensive, than other methods of construction, earth walls are significantly lower in embodied energy than other structural materials as energy cost related to the transportation of building materials, can be cut short with the use of materials found close to site.

Porosity:
Nelson (2005**)** opines that humidity is a major factor that determines thermal comfort conditions, Nelson observes that earth possess a high thermal quality second to none: by the ability of earth walls to balance indoor thermal condition, which it does by absorbing and releasing humidity, thereby creating a healthy interior. Onyegiri and Okonkwo, (2008), reveals that recent studies have confirmed that 1.50m thick layer of unfired earth brick wall can absorb air pollutants.

Thermal Benefits
Earthen walls provide high thermal mass, reducing indoor temperature fluctuations by up to 70% compared to conventional materials, while moisture buffering prevents condensation and enhances comfort without HVAC systems. Simulations in hot-humid climates confirm comfort bands of 18-26°C are maintained for 70-89% of hours annually. (Alozie, 2017) Thermal mass refers to materials that have the capacity to store thermal energy for extended periods. Thermal mass can be used effectively to absorb daytime heat gains (reducing cooling load) and release the heat during night (reducing heat load) the use of thermal mass in shelter dates back the dawn of humans and until recently has been the prevailing strategy for building climate control in hot regions. Although today passive techniques such as thermal mass are termed “alternative” methods to mechanical heating and cooling, still the right use of thermal mass offers an efficient integration of structures and thermal services. Onyegiri and Okonkwo (2008) observes the advantages of earth in building is due to its potentials as building materials for actualization of low-income mass housing are numerous and include most importantly, its use as locally available materials on site which is striking and come from:

1) Blocks being produced on site
2) The use of semi-skilled labour
3) Self-help possibility
4) Easily transferable technology
5) Simple technology
6) Requires no major financial mobilization
7) High adaptability
8) Creation of jobs and skill acquisition
9) Reduction of importation of building materials

Onyegiri and Okonkwo (2008) compared the cost of compressed stabilized bricks with other materials and concluded that compressed stabilized Earth Brick (CSEB) showed the lowest cost per square meter of wall constructed. Onyegiri and Okonkwo (2008) opines the fact that the bricks are produced on site and attracts no cost from transportation and that its finished form does not make plastering compulsory help in cost reduction, a big plus for its adoption to mass production of low-income houses in Nigeria and other developing nations.

Conclusion

Earth from humble has sheltered man. Early man became settled when he occupies caves, made in earth. Most prominent men lived all their lives in earth buildings and most outstanding edifies, dating back to zero in history, the Pyramids, the Great walls of China were all building in earth. Most palaces were built in earth; and the qualities of earth as a building material places it well above others as a choice in housing the low income in a developing nation like Nigeria. Earth building is an eco-friendly and low-cost technology, whose future relevance is still unfolding. Economically, projects using earthen materials cut construction costs by 30-60% through local sourcing, do-it-yourself labor, and minimal processing, making it ideal for social housing in developing tropical areas. Rammed earth further lowers embodied energy and transportation expenses versus concrete. This paper strongly believes that if emphasized, earth could be employed as a sustainable low-cost housing material to change housing narrative in Nigeria and other developing nations by 2035.

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