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POTENTIAL OF COMPRESSED EARTH BRICKS FOR AFFORDABLE LARGE SCALE HOUSING DEVELOPMENT IN NIGERIA

Juliet Azuka Obaje, Paul Bajere, Philip Ayuba

Abstract

The use of Compressed Earth Bricks for housing construction is at its infancy in Nigeria as compared to many developing and developed countries where it is utilised in several other components of the building such as foundation, cladding and roofing, resulting to reduced cost of housing production. The paper examines the challenges of affordable housing in Nigeria and the concept of large scale housing; it assessed the prospects of compressed earth bricks for housing production and established the parameters of compressed earth brick for affordable large scale housing development in Nigeria. Literatures on affordable and large scale housing were reviewed; stakeholders in the building industry with experience on the application of compressed earth bricks for housing development were interviewed. Local and international case studies of buildings were carried out confirming that compressed earth bricks is cost effective and applicable to every component of a building (such as roofing, walling and flooring), making it have great advantage over most contemporary building materials. The paper concludes that Compressed Earth Bricks (CEB), if appropriately applied, will significantly reduce the cost of housing production from inception to deconstruction and facilitate the development of environmentally friendly and sustainable housing that would help to ameliorate affordable housing production.

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vii) NIBRRI = Nigerian Building and Road Research Institute

viii) What is the meaning of CED on page 9?

ix) Missing references under REFERENCES include: Brian (2015), Higgins (2008), Carson (2012), Horner (2010), Neyer (1995), Wikipedia (2015), Dwell and Earth (2015), Rael (2014), Sun Shick and Mud (2014).

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POTENTIAL OF COMPRESSED EARTH BRICKS FOR AFFORDABLE LARGE SCALE HOUSING DEVELOPMENT IN NIGERIA

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ABSTRACT

The use of Compressed Earth Bricks for housing construction is at its infancy in Nigeria as compared to many developing and developed countries where it is utilised in several other components of the building such as foundation, cladding and roofing, resulting to reduced cost of housing production. The paper examines the challenges of affordable housing in Nigeria and the concept of large scale housing; it assessed the prospects of compressed earth bricks for housing production and established the parameters of compressed earth brick for affordable large scale housing development in Nigeria. Literatures on affordable and large scale housing were reviewed; stakeholders in the building industry with experience on the application of compressed earth bricks for housing development were interviewed. Local and international case studies of buildings were carried out confirming that compressed earth bricks is cost effective and applicable to every component of a building (such as roofing, walling and flooring), making it have great advantage over most contemporary building materials. The paper concludes that Compressed Earth Bricks (CEB), if appropriately applied, will significantly reduce the cost of housing production from inception to deconstruction and facilitate the development of environmentally friendly and sustainable housing that would help to ameliorate affordable housing production.

Keywords: Compressed Stabilised Earth; Affordable; Large Scale Housing; Housing Development.

INTRODUCTION

Housing related challenge is predominant in developing countries. Nigeria's housing deficit is put at above 16 million translating to about N80 trillion. This puts conservatively the cost of constructing a housing unit at approximately N3.5 million (Gemade, 2014; Star Connect Media, 2014). The housing deficit is traceable to the exponential population growth in the urban areas of developing countries. Adequate shelter is a basic human need for survival (Ayedun & Oluwatobi, 2011; Federal Government of Nigeria, 2012). Therefore for the housing deficits gap to be bridged there must be well thought out plans and implementation on housing provisions processes.

Building materials which have been identified as one of the major components of housing provision is associated with major challenges such as availability, quality, cost (affordability), effective application, aesthetics and material properties. The choice of building materials used in housing development can greatly influence the cost of production since about 60% of the ultimate cost is from building materials (Kerali, 2001). Morris and Booysen (2000), Adam and Agib (2001) and Rael (2014) averred that earth is a basic and universal building material, found on most of the surface of the world, which is cheap and extensively used in construction of living houses in various evolving technologies with the compressed earth bricks as the latest. Compressed earth bricks has the potential to make significant contribution towards reduction of carbon emissions, pollution and waste production impact on the environment when used for construction (Little & Morton, 2001; Zami & Lee, 2011; United Nations Environment Programme- Sustainable Buildings and Climate Initiative [UNEP-SBCI], 2012) and also, address the urban housing crisis in developing countries by enabling the provision of affordable housing (Rigassi & CRATerre-EAG, 1985; Guillaud *et al.*, 1995; Adam & Agib, 2001; Minke, 2006; Arumala & Gondal, 2007; Deboucha & Hashim, 2011; Riza *et al.*, 2011; Zami & Lee, 2011; Auroville Earth Institute [AEI], 2012; Brown, 2014; Openator, 2014).

This paper assessed the prospects of Compressed Earth Bricks as an economically viable building material and established its parameters for affordable large scale housing development in Nigeria.

AFFORDABLE HOUSING CHALLENGES IN NIGERIA

Fiscelli (2005), Onibokun (2014) and Litman (2017) averred that Affordable Housing is largely a function of income (ability to purchase) and defined it as households spending less than 30% of their budgets on rents, mortgages property taxes and insurance, maintenance and basic utilities that are safe, appropriate and accessible. According to Litman (2017), recently, experts recommends assessing affordable housing by combining housing and transportation budgets of a low-income household to be within the range of 45% of their income. This is based on the fact that a cheap house only becomes really affordable if there is low operating or transport expenses.

UN-HABITAT (2012) averred that one major challenge of housing development for the low income groups is the bias by stakeholders to address the issue in an essentially structured, sustainable and large scale approach. Survey carried out by Ibem *et al.* (2011) from fifteen public housing agencies in southern Nigeria, found that the challenges militating against public housing provision amongst others are scarcity of housing finance, lack of consistency and continuity in housing policy formulation and poor implementation of strategies. International Housing Collation (2007) described major constraints to providing housing and related infrastructure in Africa as lack of priority for housing urban infrastructure investments in national planning strategies; recognition of the public sector roles in the provision of housing; lack of human and institutional capacity; legal and regulatory framework; need for effective macroeconomic policies; shortage of land for housing; inability to provide infrastructure; high construction costs and housing finance constraints.

Basorun and Fadairo (2013) examined the activities of Ekiti state government in housing the poor in Ado-Ekiti within the framework of the policies on housing reform in Nigeria and also averred that the major challenges of public housing includes administrative, institutional and management; financial and economic; physical and local participatory (adequate knowledge and application of the local building resources to minimize construction cost) challenge.

Akeju (2007) identified the problems faced with affordable housing provision as legislation (land use act); registering property; finance; acquisition of permits/licences; tax burden, high cost of building materials and lastly infrastructure provision. Finance is a part of housing problems but land and building materials are placed higher (Agbola, 1987; Onibokun, 1985 as cited by Akinluyi & Adeleye, 2013).

The impediments to rapid housing growth are macro-economic environment and absence of financing systems; Land Use Act restricting access to land that have no titles on them and limits development of housing units; high cost of building materials which are not necessarily of the appropriate type; high construction costs/dearth of good quality construction companies/poor quality of construction; high cost of land in urban areas and lack of physical infrastructure and social amenities (Adeleye, 2008).

The National Housing Policy listed priority areas which require specific intervention to ensure sustainable housing delivery in Nigeria and they are; land for housing, housing finance, building materials, no-income, low income, co-operative and rural housing, housing supply and demand planning, appropriate institutional framework, implementation, coordination, monitoring, evaluation and review, construction methods, sustainable construction workforce, maintenance, construction costs, infrastructural and estate development financing, data and statistics on housing (FGN, 2012).

Challenges of affordable housing can therefore be summarised to include lack of political will, finance/income (what people earn), consistency and continuity in housing policy formulation and poor implementation, high cost of construction and building materials. The onus is then on the housing provider stakeholders to seek solutions to the various problems of housing. One of these as recommended by the Federal Government of Nigeria in the National Housing Policy (2012), is to encourage the use of local building materials so as to ensure affordable housing. This study has identified Compressed Earth Bricks as an affordable and suitable locally sourced building material to be explored.

CONCEPT OF LARGE SCALE HOUSING

Large scale/mass housing is the combination of standardisation (standardised housing) with government involvement (social housing) in the production of housing in large scale for a selected group of people or the general public geared towards solving the problem of housing shortage (Urban, 2012; Adedayo, 2013), but these can vary from countries where public utility housing was built through indirect state subsidy of large developers to some where private or cooperatives build. The cost of construction is usually paid back with time by tenants.

The Federal Government of Nigeria (2012:3) in the National Housing Policy define Mass Housing as:

> *the process of simultaneous production (building) to target prices of large number of decent, safe, sanitary and affordable residential buildings with secured tenure; on a continuous and permanent basis with adequate physical infrastructure, amenities and social services in a planned, healthy and liveable environment to meet the basic and special needs of the population and reflecting their socio-economic status, cultural aspirations and preferences.*

The aim for Mass Housing Programme is to reduce the challenge of housing shortage by bridging the wide gap between the supply and demand of housing stock of a place. Ojo and Oloruntoba (2012) stated that the key functions of mass housing provision are to be used to redistribute income and correct imperfections of market situation.

The government of Nigeria have always put up several schemes to fashion diverse strategies in both State and Federal Housing Corporations on how to eliminate housing scarcity challenge and they include direct construction, establishment of the National Housing Fund, setting up mortgage organization to mobilise fund and having a Public Private Partnership initiation. Cities all over the world developed through both the efforts and programmes of government organisations and private individuals (Jibril & Garba, 2012). According to Benros and Duarte (2009), Adedayo (2013), Okpoechi (2014) and Team CALGRO M3 (2014) large scale/mass housing process or concept is to enable the provision of decent housing at a subsidised and affordable rate cutting off the heavy investment and rigour of acquiring land and building houses at prevailing market rates.

RESEARCH METHODOLOGY

The historical and case study designs were employed for this research, using both primary and secondary sources of data collection. Literature reviews and interviews were data instruments used for the study. Literatures were reviewed in order to understand the challenges of affordable housing and the concept of large scale housing. Interview was conducted across the study area of Jos Plateau and Kaduna States respectively amongst professionals/developers in the building industry who have had the experience in the use of compressed earth bricks either in design stages or construction. Eleven professionals in the building industry were sampled who comprised of architects, builders and civil engineers and one developer, the Centre for Earth Construction Technology (CECTech) Jos, Plateau state. Case study of buildings constructed with compressed earth bricks selected from over the global and narrowed down to the study area were sampled and pictures taken reflecting CEB application to the various components of the building and the cost savings made. All data collected at the course of the study were analysed using content analysis.

FINDINGS AND DISCUSSION

Prospects of Compressed Earth Bricks for Affordable Housing Development

Adedeji (2012) asserted that buildings are the largest energy consumers and greenhouse gases emitters therefore the choice of building materials should be such that has the capability of reducing energy used in buildings towards achieving materials efficiency and cost reduction. Adogbo and Kolo (2009) submitted that using Indigenous Building Materials (IBM) have a great influence on the total cost of any construction product and the potential to provide affordable housing while Alagbe (2005) established that Compressed Stabilized Laterite Bricks CSLBs is a sustainable and cheaper alternative to sandcrete blocks for housing production.

Taiwo and Adeboye (2013) established that the combination of stabilized earth blocks and composite building materials in construction will drastically reduce cost of housing and housing scarcity in Nigeria. The process having little environmental impact; little construction skills and suited to owner–building projects. Compressed earth blocks (from local soils) can be used for the construction of affordable residential buildings which is a better alternative to masonry blocks (Arumala & Gondal, 2007). According to Waitkare City Council [WCC] (2008), earth building material conserves Earth's resources by checking deforestation and pollution; achieves low energy costs throughout its lifetime and has high aesthetic qualities.

Didel *et al.* (2014) avowed that the cost of construction can be reduced by 20 percent using compressed earth blocks and compressed earth blocks is a more sustainable and cost-effective alternative building material to achieve affordable housing delivery. Nigerian Building Road Research Institute (NBRRI) interlocking block technology is locally sourced, viable, affordable environmental/user friendly, with better end-user thermal performance and about 20% construction cost advantage over sandcrete blocks (Maton *et al.*, 2014).

The summary of the literatures reviewed is that the challenge of high building cost and housing affordability can drastically be checked and reduced by the use of earth construction especially the most recent technology of compressed earth bricks and interlocking blocks.

Also the literatures reveals that compressed earth bricks have several advantages which cut down the cost of housing reasonably and making it a prospective building material for affordable housing development. The advantages on the application of compressed earth bricks is well articulated in Table 2.0 below.

Table 2.0: Advantages of Compressed Earth Bricks for Affordable Large Scale Housing

Advantages of CEB that makes it Affordable	
Availability- in large quantities in most regions; practically unlimited in supply.	Insect resistant: Insects are discouraged because the walls are solid and very dense, and have no food value
On-site materials can be used, which reduces cost, minimizes shipping costs for materials, and increases efficiency and sustainability.	Low energy input in processing and handling unstabilised soil, requiring only 1% of the energy needed to manufacture and process the same quantity of cement concrete.
Energy saving- without the need for heat, CEBs save large amounts of energy.	Fire resistant: earthen walls do not burn
Favourable climatic performance in most regions, due to high thermal capacity, low thermal conductivity and porosity, thus subduing extreme outdoor temperatures and maintaining a satisfactory moisture balance.	Easy to build- buildings can be rapidly built using unskilled labour/lower skill level; simple thin mud slurry; stabilisation with several materials (lime, cement, fly ash etc); encourages self-sufficiency, community involvement and speed.
Eco-friendly- The earth used in the production of the CEB is actually subsoil which leaves the nutrient rich topsoil. This healthy topsoil can then still be used for agriculture.	High brick production speed- The production rate is limited more by the ability to get material into the machine, than the machine itself.
The resulting hole/depth of soil extraction can become a basement, cellars, cister, and pond or smoothed out to blend in with the landscape.	Environmental appropriateness (use of an unlimited resource in its natural state, no pollution, negligible energy consumption, no wastage).
Recyclable/reusable- there is no wastage leftover bricks can be turned back into soil.	CEB can be pressed from damp earth. Because it is not wet, the drying time is much shorter.
Labour intensive and employability- employing people locally.	Some soil conditions permit the bricks to go straight from the press onto the wall.
Applicability and suitability as building material on all building components	Flexibility: can be manufactured to a predictable sizes, shapes and angles.
Time saving during production – easy to produce and cure	Non-toxic: materials are completely natural, non-toxic, synthetic chemical-free, and do not out-gas
Low cost- of materials energy and transportation; thermal mass for natural heating by the sun; low fire risk and non-combustible.	Presses allow bricks to be consistently made of uniform size, while also obtaining strengths that exceed the ASTM standard for concrete bricks (1900 psi).
Thermal comfort- gains/losses heat at a slower rate than the surrounding air; allowing buildings to store warmth in the cold weather and remain cool in hot weather.	Sound resistant: an important feature in high-density neighbourhoods, residential areas adjacent to industrial zones
The uniformity of the bricks simplifies construction, and minimizes or eliminates the need for mortar, thus reducing both the labour and materials costs.	Mold resistant: there is no cellulose material - such as in wood, Oriented Strand Board or drywall - that can host mold or rot.
Aesthetic- natural warm texture and colours; allows expression of personal creativity using traditional crafts and skills; can be shaped into attractively rounded forms and niches; variable light quality reflected from moulded and textured surfaces.	Strength: The bricks are strong, stable and long-lasting; greater strength than adobe; CEB brick can have a compressive strength as high as 2,000 pounds per square inch (psi) with the average compressive strength being around 1,200 psi.

Adapted from; Hadjri, Osmani, Baiche and Chifunda (2007), Waitkare City Council [WCC] (2008), Minke (2006) and Openator (2014).

Compressed Earth Technology has developed new innovations other than the regular original shape of a solid rectangle and fabrication processes that have considerably reduced the limitations on the application of CEB, making it more flexible, cheaper and enhancing housing development. These new innovations include; bricks with incorporated holes or grooves in the blocks to allow for the use of steel or bamboo to resist earthquakes, interlocking shapes (does not need to be laid in a bed of mortar), U-shapes or tapered bricks for use in reinforced lintels or arches and floor tiles and roof tiles (Minke, 2006; Rigassi & CRATerre-EAG, 1985).

Parameters of Compressed Earth Bricks for Affordable Large Scale Housing Development

From the interviews carried out, the study found out that the use of compressed earth brick in housing production would hugely ensure affordable housing provision through its lifetime (from selection and sourcing of materials, design, construction, operation, maintenance of new buildings, retrofitting of existing ones and the deconstruction of buildings).

The result of interview conducted with professionals and developers in the building industry is summarised in Table 3.0

Table 3.0: Interview Summary on the Parameters of CEB for Affordable Housing

Parameters that showcases Compressed Earth Bricks as Building Material for Affordable Housing		
Elements	**Features**	**Details**
Design	a. Flexibility in Design	CEB is flexible in its design process, because the bricks can be produced to different shapes and sizes to suit requirement and does not need cutting during application.
	b. Simple and Detailed Design	CEB design usually is not complex, it is made as simple as possible and so no time is wasted in trying to read and understand.
Materials selection and sourcing	a. Natural Materials use	Laterite used for CEB production can be referred to as natural material since it occurs in an unaltered state, low in embodied energy and toxicity; requiring less processing and are less damaging to the environment but more sustainable and cheap.
	b. Local Materials use	Laterite is locally sourced therefore shortens or reduces transportation burden and is better suited to climatic conditions. Equipments/tools/machines and stabilisers (lime) are locally manufactured/sourced.
	c. Non-Toxic or Less-Toxic Materials.	Laterite is a non-toxic material and non emitter of gas , therefore has no health effect on users that would warrant wastage of resources. Low or no energy required for drying/firing.
Product manufacturing	a. Pollution Prevention	Non toxic therefore has no impact to the environmental through noise pollution, toxic substance and transportation.
	b. Waste Reduction/Resource Efficiency	Waste is reduced drastically because there are limited scraps or crumps coming from moulding, trimming, finishing process, or from the damaged products since CEB can be recycled.
	c. Low Embodied Energy Requirement	CEB has low embodied energy including energy required in the collection and transportation of the raw materials; energy (power/fuel) for production; transportation of finished product and tools and equipments used, which means CEB has low/non impact on the environment.
Construction	a. Reduced Construction Waste	Waste is reduced or completely eliminated during construction since most of the brick size, shape and types to be used at every point are determined before production at design stage.
	b. Simple skills	Simple skill is required in the application of CEB (through production to construction) and so also employs females.
	c. Labour intensive	Construction with CEB is labour intensive so is an avenue for job creation and wealth generation.
	d. Flexible and Self help application	CEB construction provides the opportunity for self- help of building process making it flexible.
Operation	a. Renewable Energy Systems/ Thermal comfort	Renewable energy systems are used to supplement or eliminate traditional heating, cooling, and electrical systems through the utilization of natural energy. Building sites are

		surrounded by natural energy in the forms of wind, solar radiation, and geothermal heat. CEB has good thermal regulator ability and so saves cost of energy generation.
	b. Energy efficient	The amount of energy required to be generated in the running of CEB building is minimal since it has the ability to regulate the temperature (heating or cooling) of the building.
Maintenance/Retrofitting	a. Longer Life-Durability	CEB is durable and cost effective since it does not require being replaced often; it produces less landfill waste over the buildings lifetime and has a longer lifespan.
	b. Longer Life- Less Maintenance	CEB require less maintenance which usually consumes a significant portion of a building's operating budget over the building's lifetime,
	c. Reusability	This is a function of the age and durability of a material; involving the salvaging of old/used materials for renovation or new construction. CEB may be easily extracted and reinstalled.
	d. Recyclability	This measures the capacity of a material to be used as a resource in the creation of new products. The embodied energy contained in CEB is preserved while recycling since the energy used in the recycling process is far less than the energy used in the original manufacturing. The brick is blended and used as aggregate for new masonry at recycling.
Deconstruction	Biodegradability	This is the potential of the material to naturally decompose when discarded. CEB integrates to the environment when demolished/deconstructed without causing any hazards either alone or with other substances.

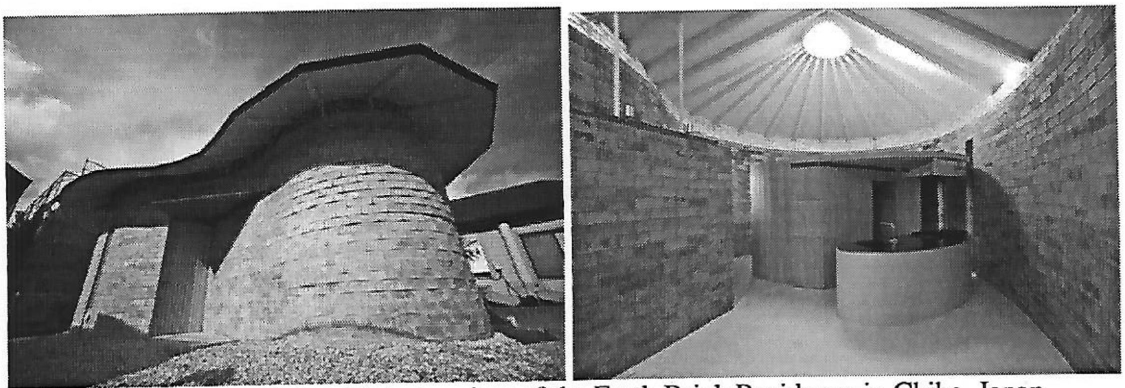
Case Studies on the Application of Compressed Earth Bricks for Housing Development

Compressed Stabilised Earth has built a bridge between traditional and contemporary architecture of various building elements as established by several authors such as; Rigassi and CRATerre-EAG (1985), Houben and Guillaud (1994), Guillaud *et al.* (1995) and Minke (2006) and these components include; roof, renders, embellishment and decoration. The cases below indicate that compressed earth bricks can conveniently be applied to every component of a building from the foundation to the roof.

Case Study One: Atelier Tekuto's Earth Brick House Chiba, Japan

Atelier Tekuto's earth brick house utilised all environmentally friendly building material. It was constructed using compressed earth bricks on walling that was stabilised with magnesium oxide (produced almost everywhere in the world, non-toxic, used as a food additive and resourceful). The project which commenced in 2008 had the collaboration of Universities, corporate bodies, and specialist.

This chemical reaction of magnesium oxide with the soil gives unification to soil grains and builds more strength to the construction that makes it application advantageous to Japan which is prone to earthquakes. Both materials are locally and naturally obtained, therefore, it will check cost of production and ensure affordability.



Plates VI & VII: Exterior and Interior view of the Earth Brick Residence in Chiba, Japan.
Source: Rael (2014). Earth Architecture

Case Study Two: Auroville Earth Institute

a. Vikas Community

Vikas Community utilised environmentally sound materials and appropriate building technologies such as stabilised earth from foundations to roof, renewable energies (solar and wind) and ecological water management (watershed harvesting and biological waste water treatment). Vikas community located in Tamil Nadu, India, was built in stages from 1992 to 1998 starting with the kitchen to the block of four apartments, then, a block of five and thirteen apartments respectively. The block of thirteen apartments was built four floors with a basement see Plate X. The basement floor was where the soil used for construction was retrieved from (1.2m depth) and stabilised with 5% cement. The Vikas community won the World Habitat Award 2000.

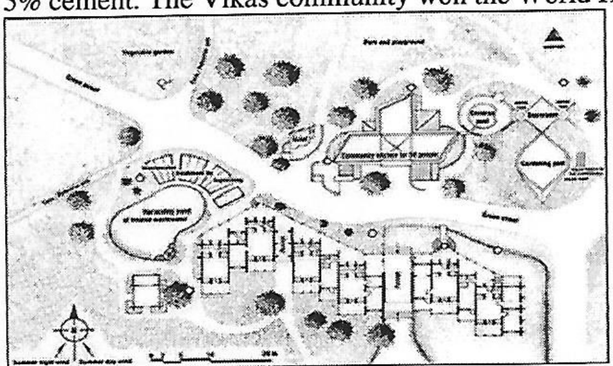


Figure 1.0: Vikas community layout 1448m2 carpet area with 23 apartments and a kitchen

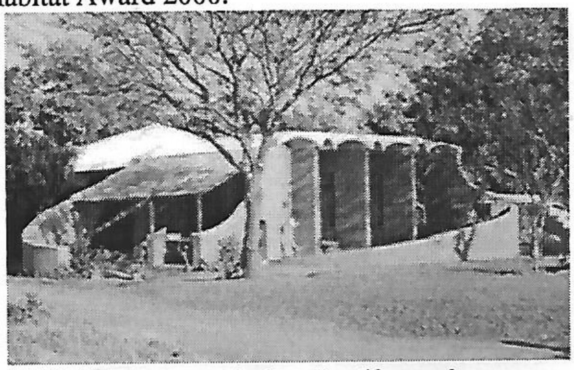


Plate VIII: Vikas Kitchen for 50 people

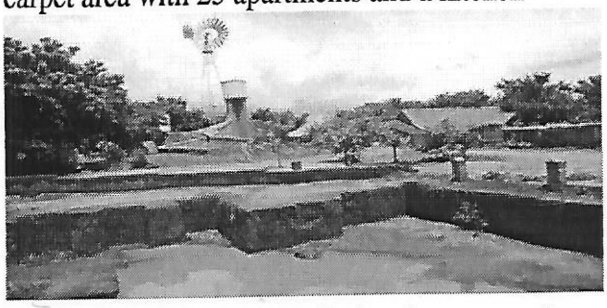


Plate IX: Excavation of the basement floor (laterite used for construction)

Plate X: Block of 13 apartments on four floors including a basement floor.

Source: Auroville Earth Institute.

b. Visitors centre Auroville's International Zone, India

Auroville Visitors Centre (VC) is a complex of buildings located in Auroville's International Zone between Bharat Nivas and Edayanchavadi village and specially designed to attend to interested visitors on energy saving construction materials (alternative sustainable technology and building techniques, renewable energy, and integrated waste water management). It was constructed in 1988 with grants from HUDCO and the Foundation for World Education to display the possibility of running an energy saving construction with low cost, low or no environmental impact and pollution. The centre welcomes large numbers of visitors every day.

Plate XI: Aerial view of Visitors Centre

Plate XII: Entrance to Visitors Centre

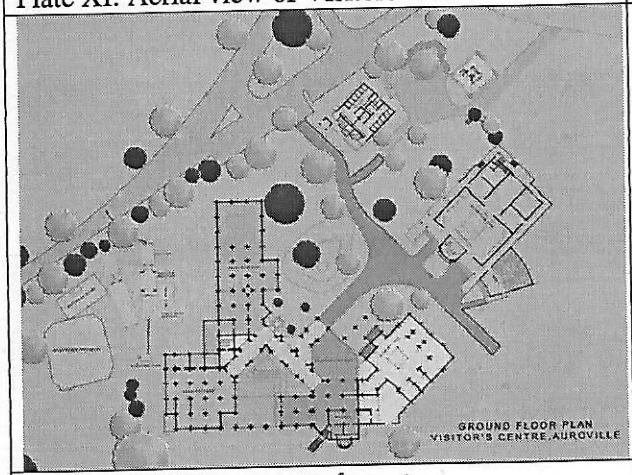


Figure 2.0: Visitors centre layout

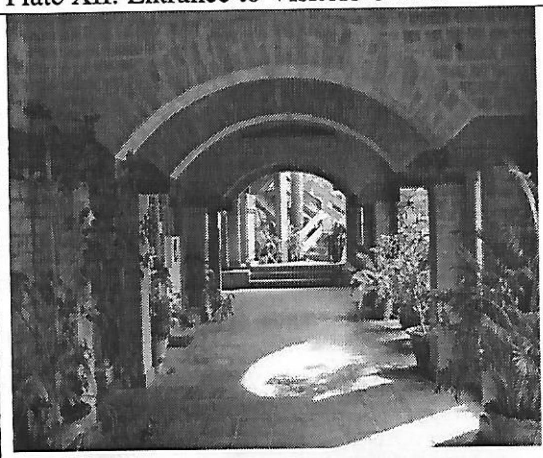


Plate XIII: Hallway Visitors Centre

Source: Rabie (nd). Auroville Earth Institute

c. Others at the Auroville Earth Institute

The Auroville Earth Institute tried sampling Compressed Earth Bricks by utilising them at different components (of flooring, walling and roofing); shapes and appearances. Plates XIV to XXI illustrate various CEB applications of Auroville Earth Institute.

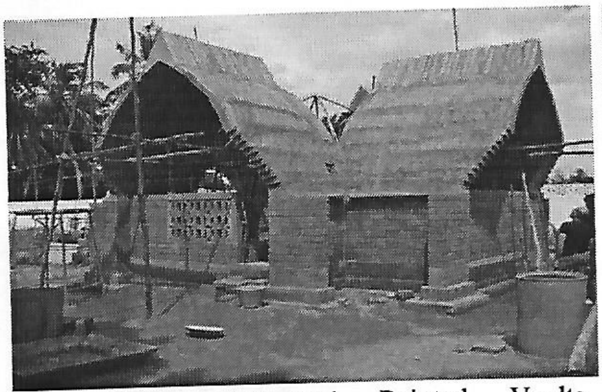


Plate XIV: Optimized Pointed Vaults construction.

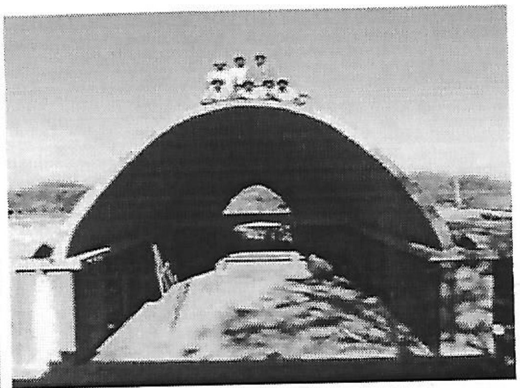


Plate XV: Egyptian Vault

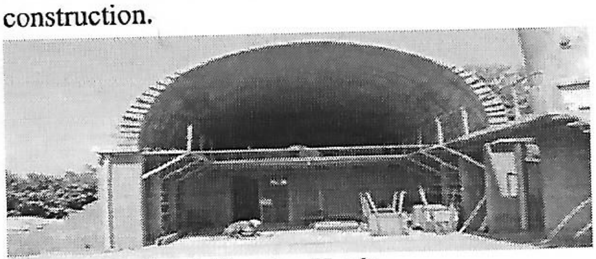


Plate XVI: Semi Circular Vault

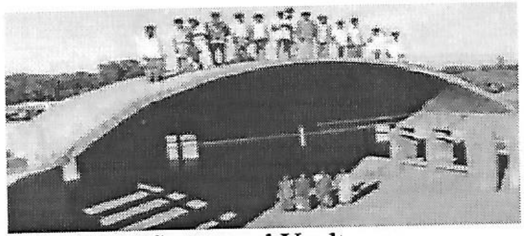


Plate XVII: Segmental Vault

Plate XVIII: Free Standing Vault

Plate XIX: Catenary Vault

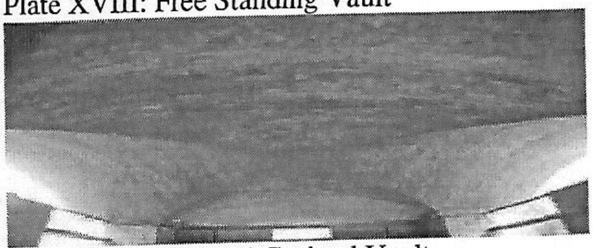


Plate XX: Segmental Groined Vault

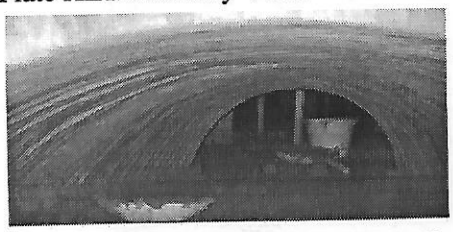
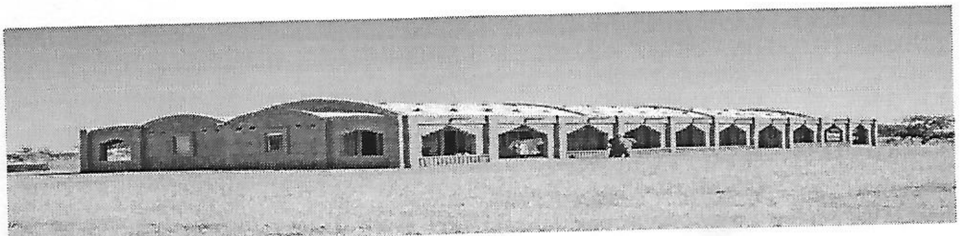


Plate XXI: Vault connecting between a segmental arch and a semicircular arch.

Source: Rabie (nd). Auroville Earth Institute

Case Study Three: Primary school in the village of Tanouan Ibi, Dogon Plateau, Mali

The school is a barrel-vaulted structure constructed with compressed earth bricks from local clay mines by Dutch firm Levs Architecten with the aid of a nearby University and members of the local community in the construction. The whole building structure of walls, floors and roofing was constructed of compressed earth bricks. Plates XXII to XXIV is the Tanouan Ibi primary school Mali.



Plates XXII: Primary school Exterior

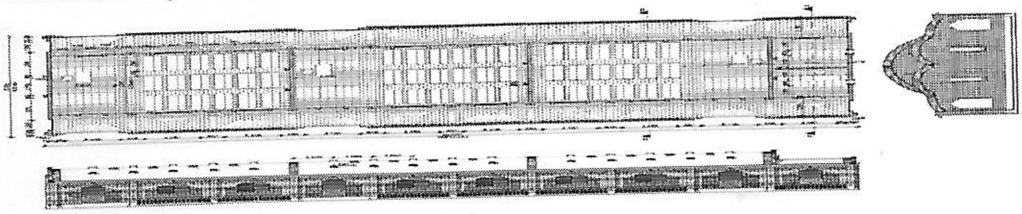


Figure 3.0: Primary School Floor Plan, Section And Elevation

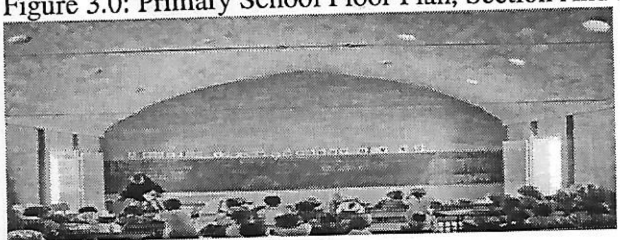


Plate XXIII: Interior of a classroom

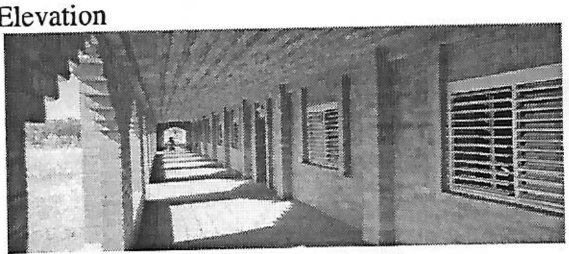


Plate XXIV: The Entrance Corridor

Source: Rael (2014)

Case Study Four: The El Haj Yousif School Sudan.

The El Haj Yousif experimental prototype school is located Khartoum Sudan, constructed with compressed stabilised earth bricks and found to be very cost effective, making a total savings of approximately 40% square metre as compared to conventional brick and sandcrete block construction in Plate XXV.

Plate XXV: El Haj Yousif School under construction with CSEB.
Source: Adam and Agib (2001)

Case Study Five: Entrepreneur Village Kumasi Polytechnic Ghana

The Entrepreneur Village Kumasi Polytechnic is located in Piase near Kuntenase built of compressed earth interlocking bricks. The building frame is made of sandcrete block while the floor lintels and beams of concrete.

Plate XXVI: Entrance and approach view of the training centre.

Plate XXVII: Rear view of the Centre.

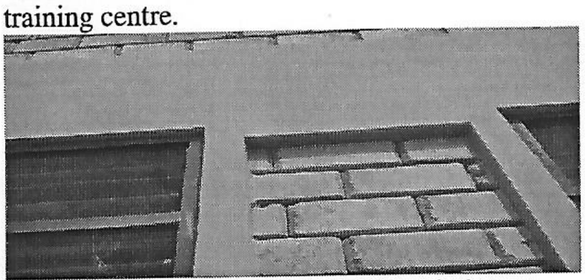


Plate XVIII: Lintel and window level views

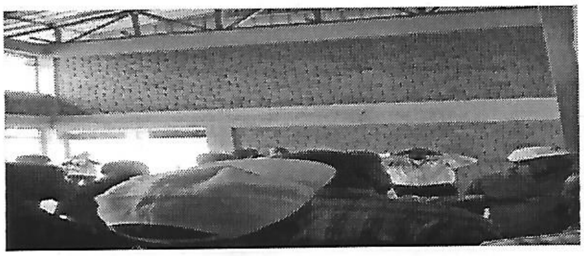


Plate XXIX: Interior of the training centre

Case Study Six: Nigerian Building Road Research Institute (NBRRI) Skill Acquisition Centre Ota, Ogun State

The NBRRI Skill Acquisition Centre in Ota is constructed using compressed earth bricks for the walls while concrete were used for the frame structures and flooring. The building which was completed in the year 2015 is for the purpose of training and teaching techniques and skills in the application of compressed earth bricks and demonstration of the cost effectiveness of CEB.

Plate XXX: Approach view NBRRI Skill Acquisition Centre

Plate XXXI: Both side views of the centre

Plate XXXII: Side view of centre

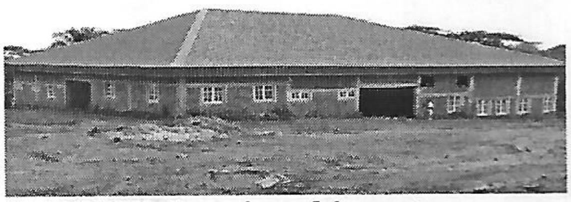


Plate XXXIII: Rear view of the centre

Case Study Seven: National Museum Kaduna, Nigeria

The compressed earth construction in the National Museum Kaduna is for shops and exhibition halls under construction. The plans are both rectangular and curvilinear; the bricks are stabilised with cement and built up with cement mortar.

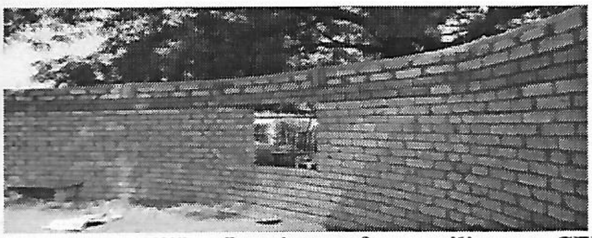


Plate XXXIV: Interior of curvilinear CEB construction for an art exhibition hall

Plate XXXV: Construction of a restaurant and kitchen within the museum

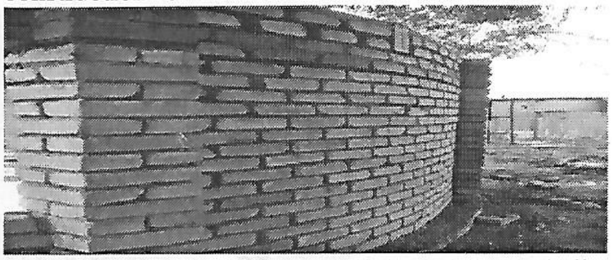


Plate XXXVI: Exterior view of the exhibition hall

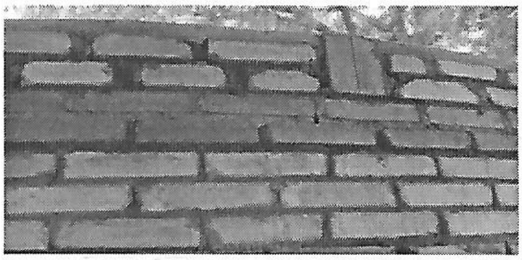


Plate XXXVII: Special (frog) bricks for window lintel, tie beam and roof anchorage.

Case Study Eight: Centre for Earth Construction Technology (CECTech) Jos, Plateau State.

The Museum of Nigeria Traditional Architecture (MOTNA) has the Centre for Earth Construction Technology (CECTech) situated in it. The CECTech is involved in CEB research and construction technology through the production of buildings for individuals and corporate bodies. The buildings are used for residential, commercial and industrial purposed. The soil used for most of their construction is sourced within the construction sites.

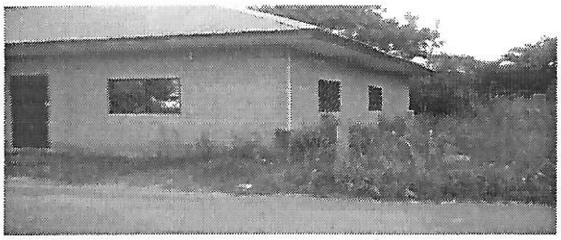


Plate XXXVIII: Residential building within the CECTech production yard

Plate XXXIX: Tie and Dye shop within the CECTech production yard.

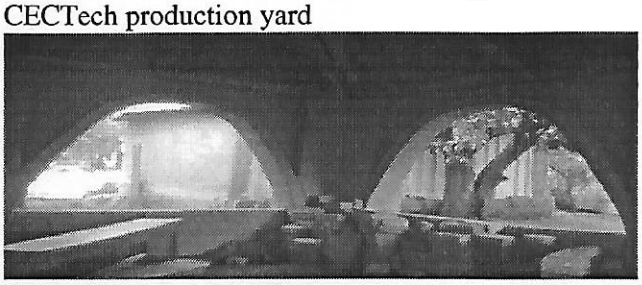


Plate XL: Interior of CECTech Production hall. Eternal view of CECTech Production hall.

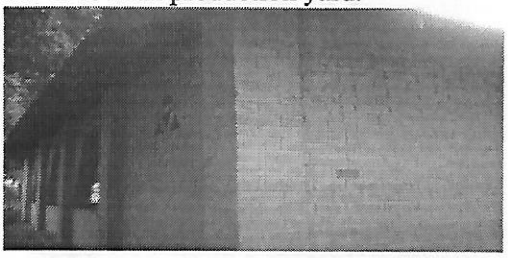


Plate XLI: Compressed earth bricks (CECTech) production yard MOTNA Jos.

Case Study Nine: Nigerian Building Road Research Institute (NBRRI) Skill Acquisition Centre Bokkos, Plateau State.

NBRRI has another Skill Acquisition Centre located in Bokkos, Plateau State, constructed for same purpose as that in Ota.

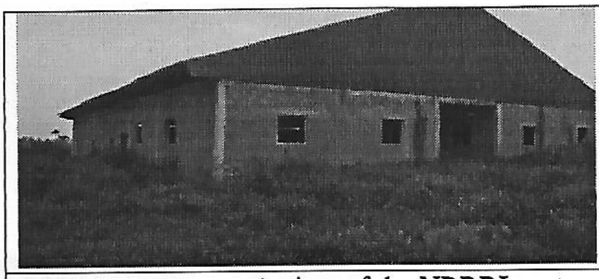


Plate XLII: Approach view of the NBRRI centre

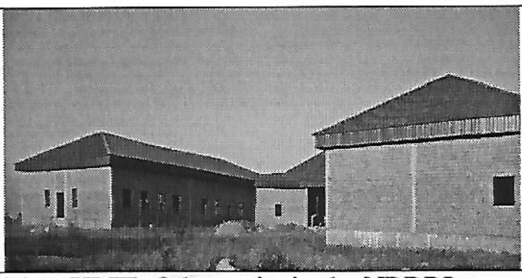


Plate XLIII: Other units in the NBRRI centre

CONCLUSION

In proffering solution to the looming challenge of housing shortage, Compressed Earth Bricks (CEB) has been identified as a viable and affordable building material for large scale housing development because of its availability, flexibility and ease of use. Soil for CEB can be enhanced/upgraded/strengthen through stabilisation to be durable for vast application. CEB is regarded affordable since its raw materials are available, locally sourced and has low cost and energy of production; it has design flexibility; its construction can be done through self help, low labour, little skill and low energy; the operation is environmentally friendly (thermally comfort and energy efficiency) and lastly its deconstruction ensures reusability, recyclability and biodegradability. Compressed Earth Bricks (CEB) can be applied to any component/element of the building. Compressed Earth Bricks (CEB) if appropriately applied, significantly reduces the cost of construction; facilitate the development of environmentally friendly, sustainable and affordable housing.

RECOMMENDATIONS

The Nigerian Government should ensure the implementation of the policy on the use of local building materials as declared in the Nigeria Housing Policy of (2012) by utilising materials such as Compressed Earth Bricks (CEB) for their various projects thereby making housing affordable for the masses. The Nigeria Government in collaboration with private developers should invest and promote additional research on Compressed Earth Bricks (CEB) application for different components of the building (aside walling) to improve the durability and affordability so as to further reduce cost of housing production. Developers and/or Marketers should purchase/manufacture machines for easy access and reduced cost to intended clients/builders.

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