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ARCHITECTURAL FRAMEWORK FOR THE USE OF EARTHEN ARCHITECTURE IN DEVELOPMENT OF AFFORDABLE HOUSING, IBENO

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Abstract: Housing is a very critical basic need of man and constitutes the third necessity of life. The choice of material for housing construction determines the overall cost of a project. High cost of conventional building materials in Nigeria and its non–sustainability warrant the search for other sources of building materials locally in order to meet the housing needs of low income citizens. These lead to need to promote the utilization of earth as a material/construction technique for the designing and development of affordable and sustainable housing need of the local population. In this study, literature and case studies were carried out to find out the construction process employed. From the findings, affordable housing can be provided without compromising durability and strength through the use of modern earthen architecture technique. Therefore, a site was proposed; several analyses, architectural and structural designs of the components of the proposed building were presented using ArchiCAD 16. There is need for its implementation through government projects and housing to create a role model for people to see and adopt the method.
Keywords: Architectural Framework, Earth, Development, Sustainable Housing, Construction

INTRODUCTION

Nigerian population is estimated to be about 167 million with rural areas harbouring over 52.22% of her population. About 112 million Nigerians (representing 67.1%) of the population live below poverty level(NBS, 2016). The phenomenal rise in population over the past few years has manifested in the acsute shortage of housing in terms of both quantitative (short supply) in the urban areas and qualitative (low quality) in rural areas (Abimaje*et al.*,2014).The total housing needs of the country were put at 8 million units by the year 2000 by Federal Ministry of Works and Housing, and 12–14 million units in 2007 (Akeju, 2007). A more recent estimate puts the figure even higher at 16–17 million units, meaning that at an average cost of N2.5 million Naira per housing unit is envisaged. Nigeria will require N35 trillion Naira to fund the housing deficit of 17 million housing units (Onyike, 2007). Qualitative housing is particularly acute in the rural areas of Nigeria, resulting in the manifestation of such housing problems as habitability problem, substandard housing, durability problem and poor aesthetic houses. Traditional housing, which constitutes approximately 70% of rural dwellings in the north and 17% in the south of Nigeria, is constructed by individual households using locally available building materials. These traditional and makeshift housing in the areas are generally susceptible to damage, lack of durability and conditions for comfort as well as strength and stability (Amasuomo and Amasuomo, 2014). These buildings are constructed with thatch or zinc roofs, bamboo pole, mud or locally sawn and untreated timber walls; and mud floors that are usually damp especially during the rainy seasons. Because, the building materials are of organic origin (Parry, 1980), they are not durable, deteriorate quickly with an expected durability period of between 1 and 5 years (Osasona, 2007; Parry, 1980). Therefore, they require frequent replacement than modern building materials (Obande, 1990). According to Walker and McGregor (1996), earth is the most basic and the most ubiquitous building material known to man. In order to meet the supply gap of 23 million units by 2023, 2.6 million homes will have to be constructed annually. However, optimistic estimates suggest that only around 200,000 units a year are currently being built, hence earthen architecture perhaps offers the most likely practical prospect for bridging the housing deficit gap in that not only is earth available in abundance, cheap and eco–friendly; it also saves manufacturing cost, time and energy. Already, the environmental benefits of earthen architecture over the conventional buildings are a major advantage as the world is going green. The addition of minimal modern technology to the timeless wisdom of traditional building techniques with earth can create excellent hybrid structures that have greatly improved strength and durability (Joseph, 2017). Several literature searches and case studies have been made to affirm usability, durability and strength of earthen architecture (Morgan, 2008; Auroville Earth Institute, 2017; Filemio, 2009; Adam and Agib, 2001; Minke, 2006; Morris, 2012; Ahmmed, 2005).Hence, the major objective of this study was to create a design that would serve as model for affordable, durable, aesthetically pleasing and sustainable housing in Ibeno Local Government of Akwa Ibom State through the use of earth as the main construction material which has its ecological footprint within the study area.

MATERIALS AND METHODS

— Area of Study

Ibeno Local Government Area was chosen for the location of the proposed project. It is located at the southern part ofAkwa Ibom Stateon coordinates 4.568693°N, 7.976396°E, occupying a vast coastal area of over 1,200 sq. km. Ibeno town lies on the eastern side of the QuaIboe River about 3 kilometres (1.9 mi) from the river mouth, and is one of the largest fishing settlements on the Nigerian coast. It has an estimated population of 75,380 people. However, the project site is located along IwoachangAdorokuku Road, in Ibeno Local Government Area as shown in Figure 2.

Figure 1: Ibeno on the map of Akwa Ibom State
Source:www.akwaibomstategov.com(2017)

Figure 2: Google imagery
Source: Google Earth (2017)

— Design Criteria

The location is expected to be:

- convenient for health facility, shops, bank or ATM boot, park, public transport, leisure and sport facilities,
- integrated with surrounding area with close proximity to existing facilities and infrastructures,
- aesthetically compatible,
- clear delineation of public, communal and private spaces,
- free from excessive noise / industrial pollution,
- vehicular access essential,
- well secured with essential surveillance and adequately drainage system due to high rainfall.

— Materials / Equipment

Materials / equipment used in this study included surveying kits with its equipment, Architectural design software application (ArchiCAD 16), etc.

— Methodology

Both environmental and infrastructural analyses were conducted for the proposed building construction. Environmental analysis was carried out using the data collected from GIS Department, University of Calabar, Calabar (Table 1).Besides, a trial pit soil test and building orientation were conducted to ascertain its soil bearing capacity and direction that would be subjected to sunlight, respectively. Infrastructural analysis included accessibility to proposed site location, large–scale public systems services e.g. power and water supplies, public transportation, telecommunications, roads and schools.

Table 1: Summary of environmental data collected from GIS Department, University of Calabar,

S/N	Parameters	Mean	Range / Description
1.	Relative humidity	80%	65% – 96%
2.	Air Temperature	29^{0}C	Day: 28 – 30^{0}C daily
		20^{0}C	Night: 18 – 22^{0}C daily
3.	Sunshine	1450 hours/ year	1400 – 1500 hours /year
4.	Rainfall		Very high between May – October (2000 – 3000 mm)
5.	Wind		South –west wind prevalent between April – October.
			North east trade wind prevalent between December – January
6.	Vegetation		Swamp forest that allows the growth of trees, shrubs and vast greeneries.
7.	Topography		Slight slope towards thewest

Source: GIS, University of Calabar (2017).

Besides, comparative analysis of different blocks worksin terms of cost of production such as compressed stabilized interlocking earth block (CSIEB) masonry (5% cement stabilization), sun–dried mud block, burned clay brick, stabilized soil block and concrete masonry unit was also carried out. The site was surveyed and marked out for low, middle and high income earners apartments. The architectural design software application was used to generate ground, first and second floors, roof plan, sectional views and elevations for low, middle and high income earners apartments. Details for floor plan, channel design, sections, staircase design and exterior views of three different apartments were also generated.

RESULTS AND DISCUSSION

— Site Analysis

The result of site analysis is shown in Figure 3. The site is easily accessible. It is a part of the landscape of the main Airport layout; hence it is well positioned to allow for easy drainage of rainwater. It slopes towards the west. This would be harnessed during construction. The soil type is loamy clay which makes it good for water to drain off easily and also a material for construction. Existing services are electricity, pipe borne water and telecommunication network. However, the design for orientation is a fundamental step to ensure that buildings work with the passage of the sun across the sky.

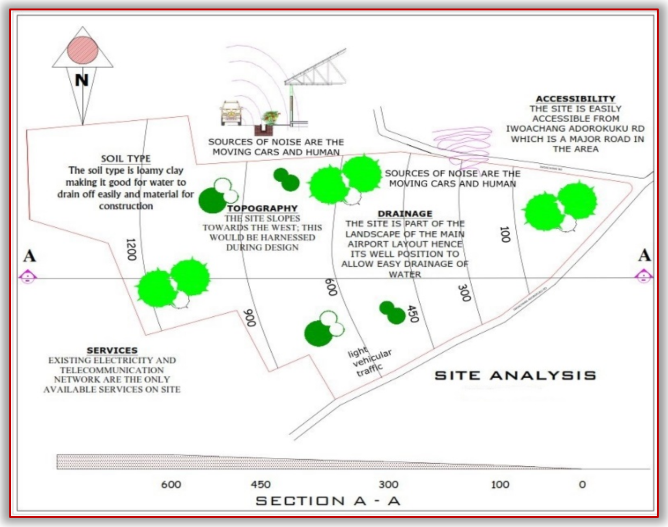

Figure 3: Site analysis

The proposed project should be oriented along or close to the East–West axis such that the shorter facades are subjected to the sun for the greater part of the day as shown in Figure 4.

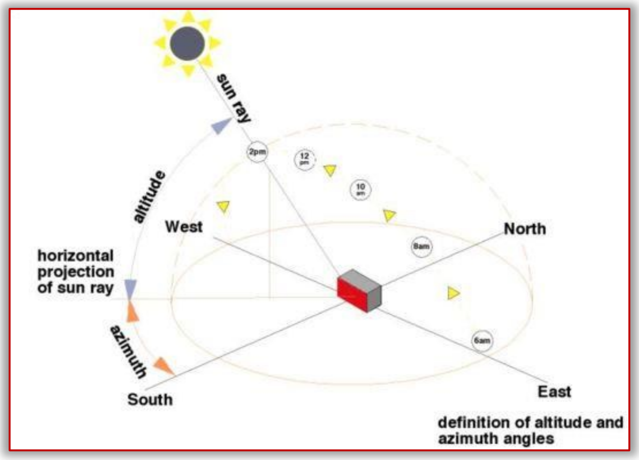

Figure 4: Building orientation

— Comparative Analysis of Different Block Works

The results of comparative analysis of different block works are presented in Appendices 1– 3. Based on block and wall appearances, dimensions, weight, texture, number of blocks needed to make up a square meter; wet compression strength, thermal conductivity and density, stabilized soil block and interlocking stabilized soil block were suggested for use. Though, no performance test was conducted, they were selected based on texture (smooth and flat). However, it takes total of N 3,120.00 andN2, 463.63 for the production of 150 mm sand–crete block and compressed stabilized block, respectively, in making a square meter wall. The compressed stabilized block seems to be a better option in this regards.

— Site Layout

The site layout is presented in Figure 5. The blue, yellow, purple and light green legends represent public facility, high, middle and low income earners, respectively. Different facilities are indicated with alphabets A to L.

Figure 5: Site layout

— Architectural Drawings for Low, Middle and High Income Earners Apartment Buildings – Low, Middle and High Income Earners' Apartment Buildings

Figure 6 to 21 are the ground, 1st and 2nd floor plans, roof plan and sectional views for low, middle and high income earners' apartment buildings.

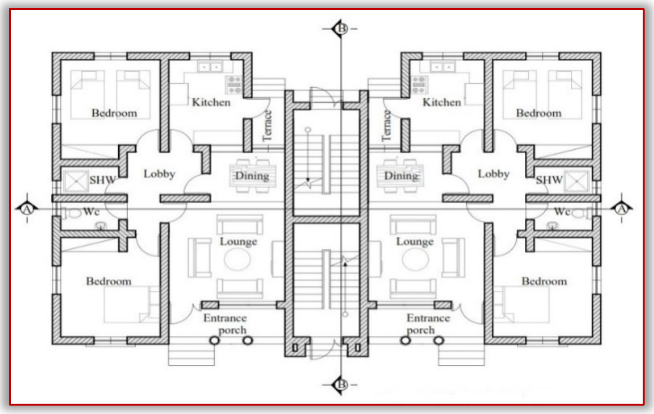

Figure 6: Ground floor plan for low income earners' apartment building

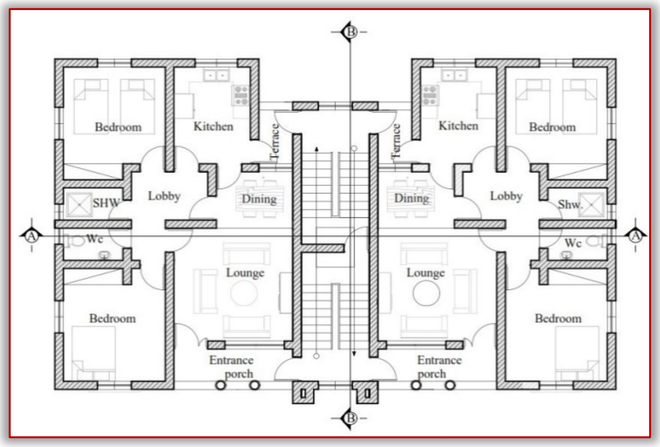

Figure 7: 1st and 2nd floor plans for low income earners' apartment building

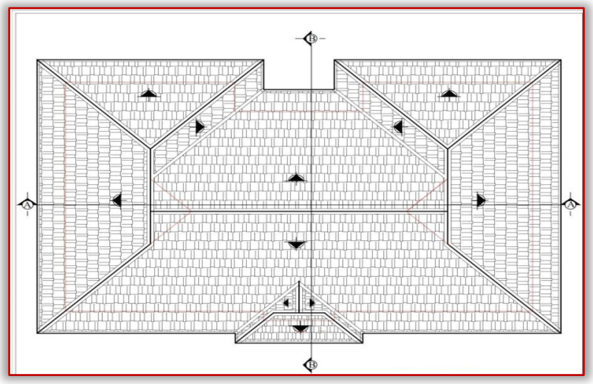

Figure 8: Roof plan for low income earners' apartment building

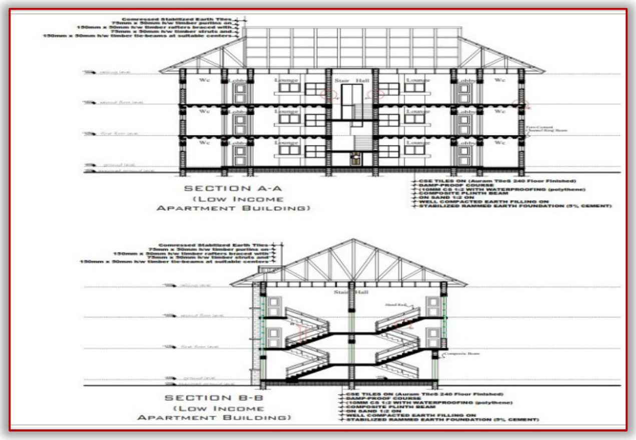

Figure 9: Sectional views for low income earners' apartment building

Figure 10: Front and right elevations of low income earners' apartment building

Figure 11: Rear and left elevations of low income earners' apartment building

Figure 12: Ground and 1st floor plan for middle income earners' apartment building

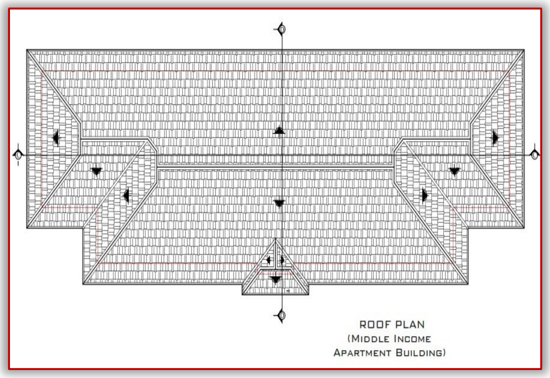

Figure 13:Roof plan for middle income earners' apartment building

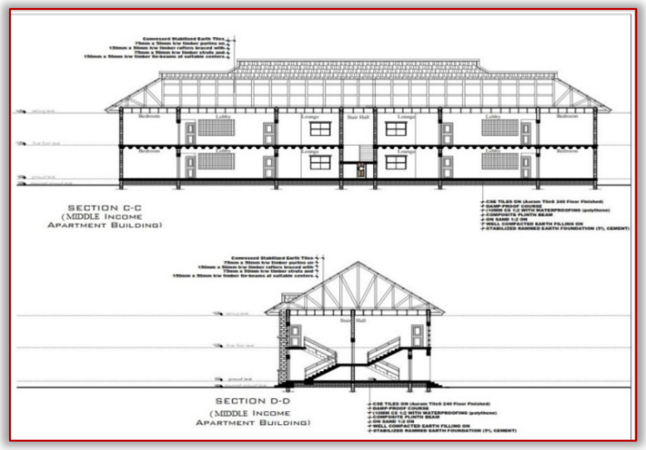

Figure 14: Sectional views of middle income earners' apartment building

Figure 15: Front and right elevations of middle income earners' apartment building

Figure 16: Rear and left elevations of middle income earners' apartment building

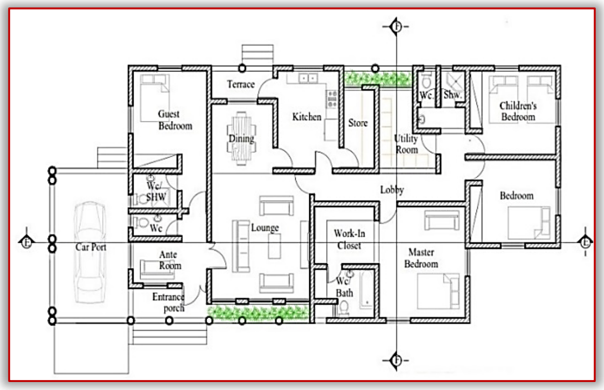

Figure 17: Floor plan for high income earners' apartment building

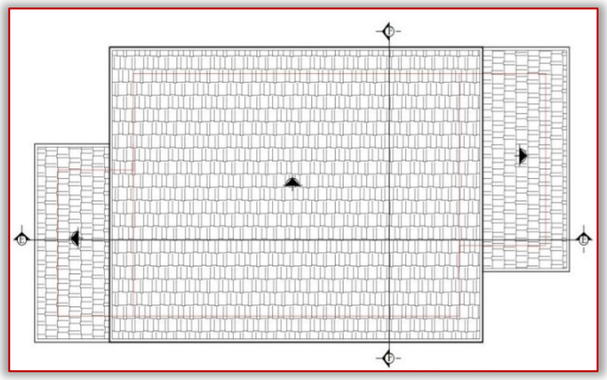

Figure 18: Roof plan for high income earners' apartment building

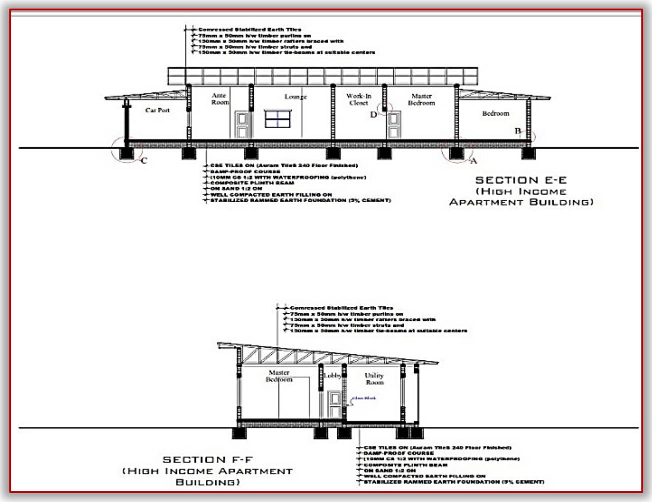

Figure 19: Sectional views of high income earners' apartment building

Figure 20: Front and right elevations of high income earners' apartment building

Figure 21: Rear and left elevations of high income earners' apartment building

Typically, the ground floor, 1st and 2nd floor plans of the proposed building structure for low income earners' apartment has 2–bedroom flat on each arm (Figures 6 and 7). The ground and 1st floor plans for middle income earners' apartment has a 3–bedroom flat on each arm (Figure 12), while the floor plan for high income earners' apartment is a 4–bedroom flat (i.e., consisting of children, extra, guest and master bedroom) with a car port (Figure 17). The roof plan for all categories of income earners is designed to allow for easy running down of rainwater (Figures 8, 13 and 18). The sectional views of the proposed building for low income earners' apartment represent a 2–storey building (Figure 9); that of middle income earners' apartment represents1–storey building (Figure 14) while that ofhigh income earners' apartment is to be a bungalow (Figure 19).The sections (A–A and B–B; CC and DD; and E–E and F–F) are meant to give the details of the interior components and how they are to be built. The elevations of all categories of income earners apartments (front and right, and rear and left elevations) depict the aesthetic views of the proposed building.

— Proposed Building Components, Materials and Construction Techniques

The proposed building components, materials and construction techniques are tabulated in Table 2.

Table 2: Building components, materials and construction techniques

Building Components	Materials and Construction Techniques
Foundations	Stabilized rammed earth foundations (5% cement stabilization).
Plinth Units	Composite plinth – step plinth with CSEB, plinth beam with reinforced concrete cast in U shaped CSEB.
Walls	Compressed stabilized interlocking earth block (CSIEB), masonry (5% cement stabilization).
Floor Slab	Ground floor: Stabilized rammed earth finished with AURAM tiles 240. Upper floors: Floor with hourdi blocks placed on ferrocement channels.
Columns	Composite columns with AURAM round hollow blocks 240 and RCC
Beams	Composite lintel, single height, with AURAM U blocks 240 and RCC
Roof	Energy serving clay tiles.
Doors	Wooden doors and frames made from trees cut on site
Windows	Glass
Finishing	Lime stabilized earth plasters for mortar and plastering.
Internal finish	Smooth cement finish or stone for bathrooms will be preferred to energy intensive ceramic tiles.
Ceiling	Bamboo mat
Water Proofing	Wallswith bitumen paint on a stabilized earth plaster. Floor with a layer of pebbles.

— Space Analysis

Thus, the following functional spaces are required for the proposed building (Table 3).

Table 3: Space and floor area requirement for a single unit

Living room	19.8 m^2
Visitors WC	1.82 m^2
Dining	14.0m^2
Kitchen	9.0m^2
Store	4.0m^2
Master bedroom	20.0m^2
Twin bedroom (children)	14.0 m^2
Toilets	3.0 m^2
Verandahs	6.0m^2
TOTAL	140.62m^2
Add 20% circulation space for lobby and walls	28.20m^2
GROSS TOTAL	136.82 m^2

— Detail of Structural Design of the Building Components – Ferro Cement Channels

Figures 22 and 23 show the layout of ferro cement channels and its floor details, respectively.

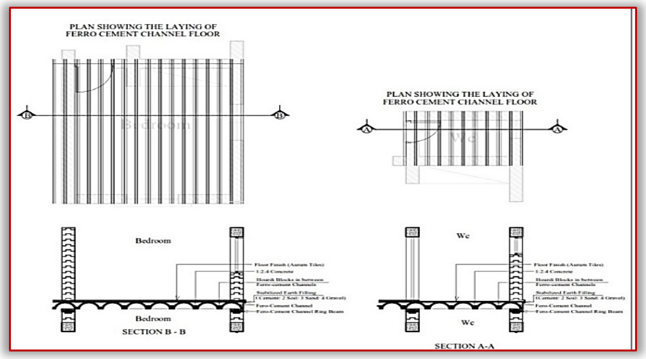

Figure 22: Floor plan showing the laying of ferro cement channels

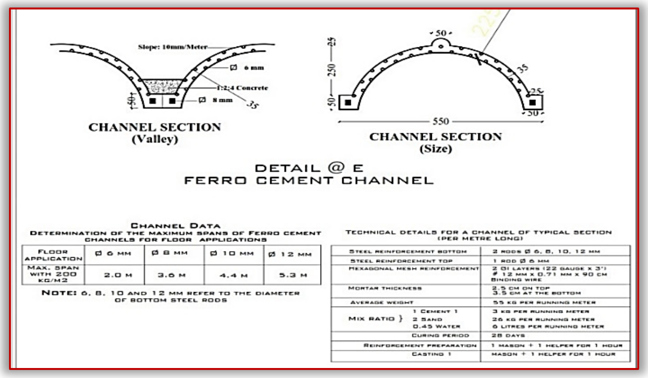

Figure 23: Detail of ferro cement channel

As seen in Figures 22 and 23, different floor applications require certain span of ferro cement channel. It should be noted that 6, 8, 10 and 12 mm represent the diameter of bottom steel rods. The maximum spans with 200 kg/m^2 are 2.0, 3.0, 4.4 and 5.3, respectively. The technical details for a channel of typical section must include steel reinforcement.

— Compressed Stabilized Earth Foundation, Composite Plinth Beam, Floor Slab, Floor Finishes and Column Composite Designs

The designs of compressed stabilized earth foundation, composite plinth beam, floor slab, floor finishes and column composite designs are presented in Figures 24, 25 and 26.

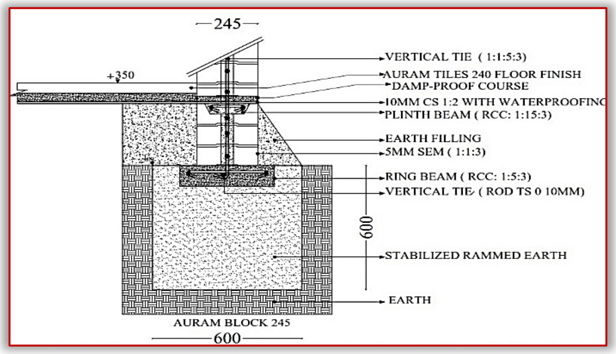

Figure 24: Compressed stabilized earth foundation and composite plinth beam

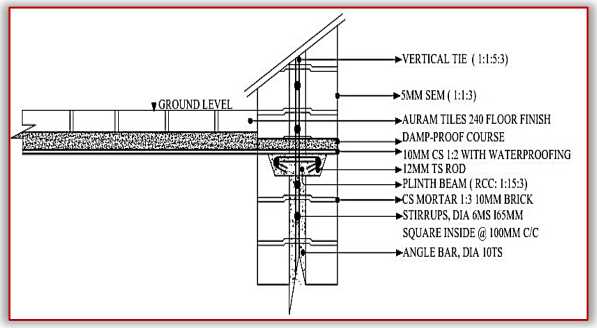

Figure 25: Floor slab design and floor finishes

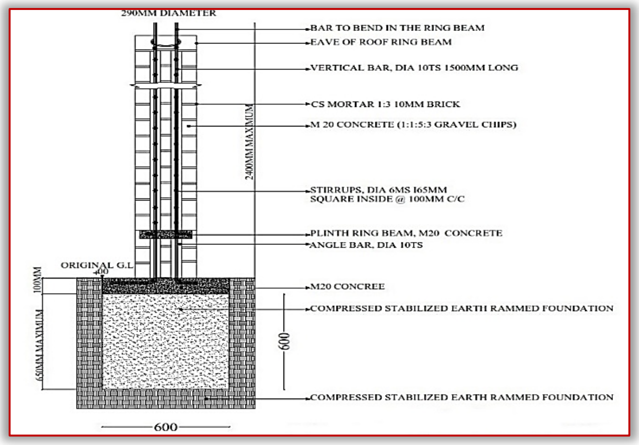

Figure 26: Column composite design

The construction of compressed stabilized earth foundation and composite plinth beamshall involve trench digging, soil levelling, water–cement addition (200 litre of water with 1 bag of cement), and ramming; and the construction of floor slab design and floor finishes shall be according the method described by Auroville Earth Institute (2017). For column composite, vertical reinforcements should be ø10 mm for the blocks 290; stirrups must be ø 6 mm and placed every 20 cm c/c. The holes, where reinforcement, are inserted cast with concrete 1 cement: 2 sand: 4 (chips gravel).The columns 290 can be linked only on 1 side of the building (through a beam or ring beam) (Auroville Earth Institute, 2017).

— Beam and Staircase Designs

The design ofbeam and staircase are presented in Figure 27 and 28.

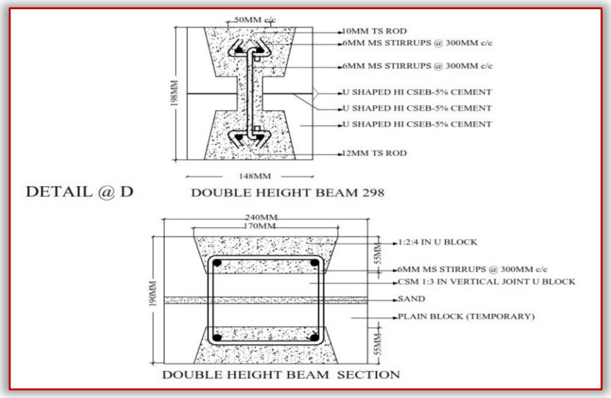

Figure 27: Beam design

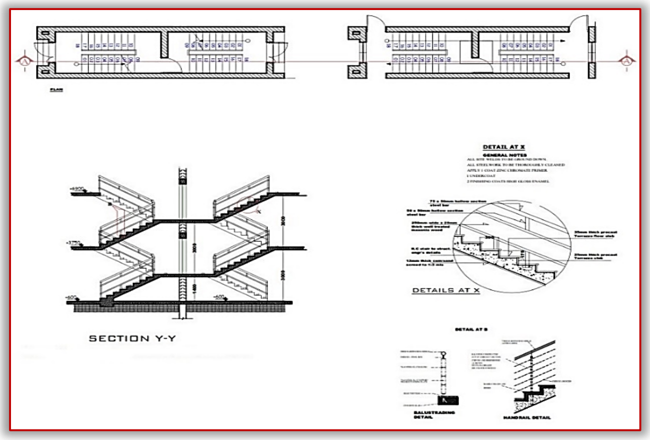

Figure 28: Staircase design

The bottom of the double height beam (Figure 27) is cast first in a reversed position and after 1 month it should be returned. Either on the ground or the top part is precast in other U blocks or the incomplete beam is lifted with care and the concrete is cast in situ into other U blocks. Staircase construction shall be built using modern conventional techniques.

— Models of Exterior Views of Low, Middle and High Income Earners' Apartment Buildings

The models of exterior views of low, middle and high income earners' apartment buildings are presented in Figure 29 to 31.

Figure 29: Model of exterior view of low income earners' apartment building

Figure 30: Model of exterior view of middle income earners' apartment building

Figure 31: Model of exterior view of high income earners' apartment building

CONCLUSION

Based on the literatures search and case studies conducted on the evolution and principles of earthen architecture, it was observed from the findings, that the earthen architecture has been improved upon. This innovation is the utmost expressions of earthen architecture since they allow the material to be used to its very best advantage. Hence, earthen architecture was proposed for building of housing scheme where all architectural and structural designs were spelled out and could be managed by public private partnership (PPP).

APPENDICES

Appendix 1: Comparative Analysis of ISSB

Properties	Interlocking Stabilised Soil Block	Sun-dried Mud Block	Burned Clay Brick	Stabilised Soil Block	Concrete Masonry Unit
General Info					
Block Appearance					
Wall Apperance (not rendered)					
Dimension (L x W x H) (mm)	265 x 140 x 100 mm	250 x 150 x 70 mm to 400 x 200 x150mm	200 x 100 x 100 mm	290 x 140 x 115 mm	400 x 200 x 200 mm
Weight (kg)	8-10 kg	5-18 kg	4-5 kg	8-10 kg	12-14 kg
Texture	Smooth and fl at	Rough and powdery	Rough and powdery	Smooth and fl at	Coarse and fl at
Blocks needed to make up a sq.m.	40	10 to 30	30	21	10
Performance					
Wet Compressive Strength (mps)	1 - 4	0 - 5	0.5 - 6	1 - 4	0.7 - 5
Thermal Insulation (W/m C)	0.8 - 1.4	0.4 - 0.8	0.7 - 1.3	0.8 - 1.4	1 - 1.7
Density (kg/m3)	1700 - 2200	1200 - 1700	1400 - 2400	1700 - 2200	1700 - 2200

Appendix 2: Cost Analysis of Sand Crete Block

	Material	Quantity	Calculation	Cost (₦)
1 unit 225mm Sandcrete block	Cement	1 bag		2550
	Sharp sand	18 head pans	@ 200 each	3600
	225mm block	25 blocks		6150
	Sandcrete block	1 unit	$\frac{6150}{25}$	250
	Assume 10% for Labour		$\frac{10 \times 250}{100}$	25
	Assume 20% for plants and others.		$\frac{20 \times 250}{100}$	50
	Total cost FOR 1 unit 225mm sandcrete block 250 + 25 +50			=325
The cost per sqm of 225mm Sandcrete block	10 sandcrete blocks cover one square metre = 10 X 325 Assume 10% for cost of mortar for laying the blocks Assume 10% for labour for laying the blocks Total cost per square metre for 225mm sandcrete blocks			3250 = 250 = 250 =3750
1 unit 150mm Sandcrete block	150mm block	30 blocks		6150
	Sandcrete block	1 unit	$\frac{6150}{30}$	200
	Assume 10% for Labour		$\frac{10 \times 200}{100}$	20
	Assume 20% for plants and others.		$\frac{20 \times 200}{100}$	40
	Total cost FOR1 unit 150mm sandcrete block 200 + 20 +40			=260
The cost per sqm of 150mm Sandcrete block	10 sandcrete blocks cover one square metre = 10 X 260 Assume 10% for cost of mortar for laying the blocks Assume 10% for labour for laying the blocks Total cost per square metre for 150mm sandcrete blocks			2600 = 260 = 260 =3120

NOTES: The unit cost of the Sandcrete hollow blocks was computed based on the following assumptions:
Mix Ratio = 1:9 (that is; one headpan of Ordinary Portland Cement to nine head pans of sharp sand). This translates to one bag of ordinary Portland cement to eighteen headpans of sand, since there are two headpans in a bag of cement.

Appendix 3: Cost Analysis of Compressed Stabilized Block

Material	Quantity	Calculation	Cost (₦)
Laterite	1 cement Bag		550
Cement	1 bag		2550
Laterite	One 4Litre container	$\frac{550}{8}$	68.75
Cement	One 4Litre container	$\frac{2550}{8}$	318.75
Laterite	19 parts	19 parts @ 68.75 each	1,306.25
Cement	1 part	1 part @ 318.75 each	318.75
Polythene sheet for curing	1	318.75	318.75
CSB	40No of CSB	1,306.25+318.75 +318.75	1943.75
Unit of cost 1 CSB block	1N o	$\frac{1,943.25}{40}$	48.59
Labour	10% of unit cost of block	$\frac{48.59 \times 10}{100}$	4.86
Plants and others (Water)	20% of unit cost of block	$\frac{48.59 \times 20}{100}$	9.72
Total cost 1 unit Compressed Stabilised Blocks 48.59 + 4.86+9.72			= 63.17
The cost per sqm	39 CSEB cover one square metre = 39 X 63.17 = 2463.63 No mortar required Assume 15% for labour (more blocks involved) = 7.28 Total cost per square metre = 24.70		

NOTE: The unit cost of the CSBs was computed based on the following assumptions:
- Mix Ratio = 1:19 (that is, one part of Ordinary Portland Cement to nineteen parts of laterite by volume)
- A 4 litre container was used as the gauge in measuring the composition of Compressed Stabilised Block.
- 4No containers (each 4litre capacity) = 1 head pan.
- 2No head pans = 1 bag of cement,
- 8No containers (each 4litre capacity) = 1 bag of cement.
- Cost of labour is 10% of a unit cost of block
- Cost of Plants and Others (Water) is 20% of a unit cost of block

References

[1] Abimaje, J.,Akingbohungbe, D. O. and Baba, A. N. (2014).Housing Affordability in Nigerian Towns: A Case of Idah, Nigeria. International Journal of Civil Engineering, Construction and Estate Management,Vol.1,No.2,pp.31–38,
[2] Adam, E.A and Agib, A.R.A. (2001). Compressed Stabilised Earth Block Manufacture in Sudan. United Nations Educational. Scientific and Cultural Organization 7 Place de Fontenoy, 75352 Paris 07 SP, France Paris.
[3] Ahmed, K. I. (2005). Handbook on Design and Construction of Housing for Flood Prone Rural Areas of Bangladesh, Published by Asian Disaster Preparedness Centre (ADPC) in partnership with Bangladesh Disaster Preparedness Centre, CARE–Bangladesh, Bangladesh Ministry of Food and Disaster Management and BRAC University with support from United States Agency for International Development.
[4] Akeju, A. (2007). Challenges to Providing Affordable Housing in Nigeria, Paper Presented at the 2nd Emerging Urban Africa International Conference On Urban Housing Finance in Nigeria, Held at ShehuYar'adua Centre Abuja, October 17–19, 2007.
[5] Amasuomo, T.T. and Amasuomo, J.O. (2014). Improving Durability of Rural Buildings in Riverine Niger Delta Region: A Case Study on Need to Utilize Appropriate Technology. International Journal of African Society, Cultures and Traditions, 4(1), 17–43.
[6] Auroville Earth Institute (2017). Earth Building Works Available Online http://www.earth– auroville.co
[7] Filemio, V. (2009) The Architecture and Mechanics of Earthen Structures. Proceedings of the Third International Congress on Construction History. May, Cottbus, Germany. pp. 579B586.
[8] GIS, University of Calabar (2017). Department of Geographical Information System, University of Calabar, Calabar, Nigeria
[9] Joseph, F. K. (2017). An Overview of Natural Building Techniques. Online at http://www.networkearth.org/naturalbuilding/overview.html
[10] Morgan, W.N. (2008). Earth Architecture from Ancient to Modern. University Press of Florida, USA.
[11] Morris, H.W. (2012).Natural Disasters and Earth Buildings: Resistant Design and Construction. Modern Earth Buildings, Materials, Engineering, Construction and Applications. Ed Woodhead Publishing Limited, United Kingdom.
[12] Minke, G.(2006). Building with earth, design and technology of a sustainable architecture. Birkhauser Publishers for Architecture. Basel, Berlin, Boston
[13] National Bureau of Statistics [NBS] (2016). Nigerian population. Online at https://www.nigerianstat.gov.ng/ (Accessed on 3rd Jan., 2017)
[14] Obande, M. O. (1990). BlockLaying and Concreting, Longman, Nigeria Ltd, Ikeja–Lagos.
[15] Onyike, J. (2007). An Assessment of Affordability of Housing by Public Servants in Owerri, Nigeria, Journal of Land Use and Development Studies, 3: 21–34.
[16] Osasona, C.O. (2007). From Traditional Residential Architecture to the Vernacular: The Nigerian Experience.
[17] Parry, J. M. P. (1980). Building Materials and Components in Appropriate Industrial Technology for Construction and Building Materials. Monograph, No. 12. Vienna: UNIDO.
[18] Walker, B. and McGregor, C. (1996) Building with Earth in Scotland: Innovative Design and Sustainability. Edinburgh: Scottish Executive Central Research Unit.

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