TOWARDS A SUSTAINABLE BUILT AND NATURAL ENVIRONMENT

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EARTH CONSTRUCTION: ADAPTING AN ANCIENT MATERIAL TO APPLICATIONS IN SMALL AND MEDIUM HOUSING NEEDS

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ABSTRACT
Earth buildings are under the threat of near extinction because of the attitude of building industry professionals towards these structures. The advent of cement, in the mid twentieth century probably led to the relegation of interest in earthen structures, with the realization thatmassive structures are possibly enhanced through concrete technology. The truth remainshowever that earth is still relevant, especially for the construction of small to medium scaleconstruction developments. It is abundantly available, renewable and easily adaptable; it iseasily recycled in nature and lends itself to various applications for use in the building envelope. The sustainability of the environment is highly dependent on man and how he carries out his activities within it. Earth is a material that has always been used for building construction but little knowledge exists within the wider society about how earth can be used to interpret modernarchitectural designs. Manipulating earth for construction purposes includes adapting any of theknown earth construction technologies, while respecting the industrial requirements of mass production. The effective application of any material for construction purposes lies in a good understanding of its properties and how these properties can be manipulated for application within the building fabric. However, the lack of documentation of traditional know-how in earth construction also affects the effective use of earth in contemporary times. This paper will look at how the material can be manipulated effectively to enable its acceptance for buildingconstruction, especially with meeting the needs for housing construction. It will focus on theproblems associated with its use and the treatments needed to overcome these problems. Areas tobe examined will include surface finishes, on a general note and especially as pertains tovulnerable spaces such as kitchens and bathrooms.

Introduction

Man's affiliation with earth is as old as he is – biblical accounts refer to his creation from earth. Over 30% of the world's population live in earth buildings today but in spite of this the material is looked down upon as being fragile and unsuitable for building construction in modern, industrial society. This view became prevalent at the turn of the last century with the proliferation of industrial age materials – concrete, glass and steel – around the world. The ease of manipulation of these new materials made them highly popular. However in recent times, concerns have been raised about the environmental impact of the highly industrial and mechanized processes required for the production of these materials and their effects on the natural environment. In addition to this there is the fact that these production processes are capital intensive and these costs are passed along to the end user. These costs make it increasingly more expensive to build, especially at the level of the single-home builder.

Increasing urbanization across the world, which is greatest in the developing world – the UN-Habitat programme projects that by the year 2020, 52% of the African population will be living in cities, at the 2001 recorded rate of 5% urbanization per annum. This figure is alarming and it brings to fore the necessity to provide good quality shelter for the new urban populations. Shelter policies and regulations heavily influence the production, quality, availability and costs of housing. As a result, the majority of urban poor cannot afford to build according to prevailing formal standards because they are restrictive, exclusive or costly to implement (BASIN, 2001).

The difficulty of obtaining decent, affordable housing in our growing urban centres is not limited to the poor alone. An increasing number of the urban middle class also find it difficult to access affordable housing. Repeated low-cost housing programmes are not affordable for the target populations as the cost of the housing units are often exorbitant.

The realization of this has led to many governments formulating policies for the implementation of housing programmes for the growing urban populations. In Nigeria this strategy is enshrined within the National Policy on Housing and Urban development of 2002. One of the thrusts of this policy is the promotion of the use of local materials in the provision of housing. This thrust is also supported in the National Economic Empowerment Development Strategy (NEEDS). The NEEDS policy (2005) document outlines the following as means by

which the Nigerian population could be empowered economically, within the area of building construction:
i. facilitating property developers' access to purchase land for the provision of affordable housing;
ii. cutting the cost of housing construction by encouraging the use of local building materials;
iii. training a new generation of architects in designing low-cost housing;
iv. enabling the other levels of government (state and local), as well as construction companies, to assume responsibility for providing low-cost housing.
This paper focuses on item (iii) of this aspect of the NEEDS policy, looking at unburnt earth as a building material. This material may hold the answer to the sustainable development of our burgeoning urban centres: looking back to the precepts of traditional architecture to meet the requirements of urban populations. This becomes pertinent in view of Bhatia's (1991) book on Lawrie Baker's works in which Baker asks why "can't we be 'modern' with other materials besides reinforced concrete, glass and aluminium trimmings?" He wonders if we could go back 1BC (before concrete) and carry on with the history of research and development by applying 20th century knowledge and know-how while still showing love and respect for all that has gone before us.

Use of earth in construction

Earth is an abundant building material and very few places in the world do not have access to use this material for the provision of housing. The material is viewed with disdain by the average urban dweller – this also extends to the aspiring rural dweller – who views it as a 'dirty', 'local', 'traditional' material which cannot compete with the new 'modern' and 'clean' materials. This perception can be said to be valid when viewed in the light of the traditional earth building techniques with which the observers are familiar. The new materials are easier to use while most traditional earth construction methods are labour intensive and more time is needed to prepare them for application in the building frame. In addition, the question that usually arises is how possible is it to use this 'dirty' material to construct houses that are clean and adapted to the realities of contemporary lifestyles.
Houben and Guillaud (1994) identify 12 main methods which are applied in traditional earth construction methods across the world. Of these twelve, seven are very commonly used and represent the main classes of techniques. These seven methods are described briefly below:

1. *Adobe* is sun dried earth brick and is made using a thick malleable earth to which straw is often added to improve tensile strength and reduce cracking due to shrinkage. In the northern parts of Nigeria, adobe blocks are referred to as "block lakka" and it is common to see them being produced along dried river/stream beds during the dry season. Production is with wooden or metal moulds although the use of machines is widespread in certain parts of the world.

2. *Rammed earth* consists of earth compacted in wooden or metal form work. The use of formwork in concrete technology is borrowed from this technique. It makes it possible to build monolithic walls in compacted earth.

3. *Straw clay* involves the use of a clayey soil. The clay is dispersed into water to form a greasy slip which is then added to the straw, acting as a binder. It is easily adapted to the prefabrication of various building components e.g. bricks, insulating panels and flooring blocks.

4. *Wattle and daub* is a composite system which consists of a wooden bearing structure which is filled with a daubed lattice/netting from vegetable matter. A very clayey soil, mixed with any type of vegetable fibre, is used. This method is very commonly used in coastal and forest areas in Nigeria.

5. *Direct shaping* involves the use of plastic earth which is directly shaped into thin walls with the hands, without any kind of mould or formwork. Walls can be as thin as 5cm. it is a method of construction which is very commonly used in the middle belt regions of the country, especially around the Plateau, Niger and Benue regions.

6. *Compressed Earth Blocks* are produced by compression in a mechanical press: which could be operated either manually or hydraulically. This makes it possible to produce shaped solid, cellular and hollow blocks/bricks.
7. *Cob* consists of stacking balls of moist, plastic earth, reinforced with vegetable fibres, on top of one another and lightly tamping them with the hands and feet to form monolithic walls.

Denyer (1978) describes this as the "puddled mud" system. In the northern parts of the country.
this is referred to as "*bani-bani*".

Earth as a building material

Earth is a mixture of various grains (stones, gravels, sand, silt and clay), air and water.
It is the product of the weathering of parent rock material which has undergone physico-chemical evolution (Houben and Guillaud, 1995). It is an astonishing material that is very difficult to understand with respect to its behaviour as a building material: this material that is trampled underfoot can be manipulated into giant structures to house man's activities. Earth is also useful for agricultural purposes but it is the part that contains no organic material that is useful for construction activity. In its granular form, earth behaves both as a fluid and as a liquid (Anger and Fontaine, 2005). It can be piled up, because of its structure whose form and solidity depends partly on the percentage of the constituent grains present in it. This property makes it possible to completely fill up a space such that the material is compressed and no voids are left between its grains. This is the case with rammed earth.
Generally earth is considered as a natural concrete in which clay acts as a binder. However Anger and Fontaine (2005) have, through extensive laboratory research which can be demonstrated through pedagogical means, shown that a closer look at the material will reveal that water is the true binder in earth. When water is added to dry sand, the capillary forces responsible for surface tension in liquids are brought to play. This surface tension is the factor that makes it possible to build sand castles. This binding activity is attributed to the clay fractions of the soil because their size and specific forms allow for the greater action of these capillary forces between them. Earth building units have shown high resistance to compressive pressure, when dry, of between 5 – 50kg/cm². In tension however, resistance is reduced to between 25 – 500g/cm². The resistance of earth surfaces to abrasion is poor and its modulus of elasticity lies between 600 – 700kg/mm².
Earth possesses specific properties which can be subjected to scientific tests, just as other materials can. It has its own properties which have to be understood for it to be properly exploited within the building frame. Minke (2000) outlines the major advantages and disadvantages of earth construction and these are shown in table 1.

TABLE 1: MAJOR ADVANTAGES AND DISADVANTAGES OF EARTH CONSTRUCTION

Advantages Disadvantages

It balances air humidity as it is able to absorb and give
off humidity faster and to a higher extent than all other
building materials. By so doing, it balances indoor
climates. Experiments at the University of Kassel in
Germany have demonstrated that when the relative
humidity in a room was raised suddenly from 50% to
80%, unburnt earth bricks were able to absorb thirty
times more humidity than burnt bricks in a period of
two days.
It is not a standardised building material as its characteristics may change from site to site, with varying proportions of constituents. This could affect the preparation of the correct mixes for specific applications

Advantages Disadvantages

Earth stores heat and this property is very important in
regions where diurnal temperature differences are high
or where it becomes necessary to store solar heat gain
by passive means.
Earth mixtures tend to shrink on drying. The linear shrinkage is between 3% - 12%, depending on the amount of water in the earth mixture for the specific construction technique chosen. Shrinkage level can be reduced by reducing the clay and water content, optimising grain size distribution and using additives.
Unburnt earth construction saves energy and reduces Earth is not water-resistant and has
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environmental pollution. Its preparation, transportation
and handling on site requires only about 1% of the
energy needed for the same with burnt bricks or reinforced concrete, producing very little

environmental pollution.
Earth can always be recycled and poses no danger to
the natural environment
It is ideal for self-construction as earth constriction
techniques can usually be executed with little professional help. Techniques are labour intensive and
need inexpensive tools and machines. This feature
makes it very viable for use in the development of
housing units for planned urban development.
Earth walls can absorb pollutants dissolved in water.
This has been demonstrated in Germany where a demonstration plant in Berlin-Ruhleben removes phosphates from 600m3 of sewage per day using clayey
soil. The phosphates are bound by the clay minerals
and extracted from the sewage. The phosphates are
then converted to calcium phosphate and can be reused
as fertiliser.
to be sheltered against rain and
capillary rise.
Source: Authors' adaptation from: Minke (2000): Earth construction Handbook

Building with earth

Going by the earlier remarks of Baker on applying twentieth century know-how to knowledge, and the realities of contemporary building practise, it then behoves us to use the knowledge of the physical properties of the material to come up with building systems which can easily be reproduced. Mathissen (1995) acknowledges the physical properties of earth and recommends its use in walls and construction forms which resist high tensional stresses through compression e.g. arches, vaults and domes. By using these techniques, it is possible to construct buildings several storeys high exclusively of earth, a fact demonstrated in traditional architecture
across Nigeria. Houben and Guillaud (1994) set out design guidelines for earth
wall systems. A general rule is that an earth building requires a "good hat" (roof) over "good shoes" (foundation).
A primary concern for earth wall systems is the compatibility between the
mechanical stresses to which the material and the system of the structure ar
subjected to. The major points of mechanical stress issues arising from the use of earth as a building material are outlined in table
2 which is adapted from
Houben and Guillaud, 1994. Table 2 Basic design guidelines for earth
walls Mechanical behaviour. Avoid off centre loads, bending and the
possible resultant bulging and point loads.
The size and stability of main, load-bearing walls and partition walls,
pillars and buttresses as well as the support of arches and vaulting must be
considered. Dimensional design. The thickness of walls should be at least
one tenth their height. Thus the minimum thickness of rammed earth walls in
single-storey structures should
be taken as 30cm and 45cm with a double storey building. The distance
between partition walls, buttresses or expansion joints should not exceed 5 –
6 cm. The quality of mortar and care taken in laying can enhance the
strength of the walls. The use of cement-stabilised mortar increases the
compression strength of adobe walls by 25% and doubles their shear
strength. The mortar used for joints should have the same compression
strength and erosion resistance as the masonry units. If the strength of the
mortar is less, erosion and infiltration will occur and the units will
deteriorate. If the inverse is the case, the bricks will erode and water will
remain on the exposed surface of the mortar, causing further erosion of the
bricks. Good practices for mortars are that the texture of the mortar must be
sandier than that of the brick with a maximum grain size of 5mm. the
thickness of joints should be 1 – 1.5cm for compressed earth bricks and
maximum tolerance of 2cm for adobe blocks. This also ensures good
bonding with applied surface finishes.
Source: Authors' adaptation from Houben and Guillaud, 1994. Earth construction: a comprehensive guide
Houben and Guillaud (1994) emphasize that ring beams are important to ensure the
stability of earth walls as it helps to control the effects of differential settlement, expansion, rotational and shear stress as well as lateral wind pressure from pitched roofs, arches, vaults and domes. It also helps to evenly distribute loads.
Materials which can be used for tie beams are

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wood, steel and concrete. With compressed earth bricks and adobe blocks, it is possible to devise composite earth-concrete tie beams in which the earth units serve as in-situ formwork for the reinforced concrete beams. This helps to reduce the amount of concrete used and eliminates the cost of steel or wooden formwork.
The following should be avoided with earth walls: oversized openings, accumulation of openings in the same walls section and excessive variety of sizes which could weaken the
walls, openings too close to the building corners and openings placed too close together. Arches can be used to span openings, thus further reducing costs of concrete lintels.

Surface finishes for earth walls

Various types of surface finishes are possible with earth walls, depending on the context within which it is used (Guillaud, Joffroy and Odul, 1995). The main functions of a surface finish are to protect the wall against bad weather and impact, extend the life of the walls, for aesthetics and improving thermal comfort. A good coating should adhere well to the wall support without provoking the loss of wall material, be flexible in order to allow for the deformation of the support without cracking, be impermeable to rain, permeable to water vapour in the wall itself and have a colour and texture compatible with the surrounding built environment. With earthen plasters, the concern is usually for external walls and how the surface finish can take on decorative finishes such as paints and tiles. In traditional architecture, it was required to renew earth plasters on an annual basis though examples abound of earth plasters, usually applied to the houses of royalty and nobility, which could stay on without renewal for as
long as five years. It is this concern about the need for renewal that makes earth construction unacceptable today.
For ease of referencing, a brief summary of various possible types of earth wall plasters is provided in table 3.
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Table 3 Earthen wall plasters

Earthen plasters	Usually applied in two or three coats on unstabilised earth walls (Ujege, 2005). The first coat or two level out the wall surface. The finish coat provides a smooth finish and colour. When the finish plaster is dried, paints made from powdered clay mixed with earthen pigments are applied, especially in traditional architecture. Minke (2000) asserts that earth plasters stick well on brick, concrete and stone surfaces, as well as on earth surfaces, provided the surfaces are rough enough.
Lime plasters	Made up of a mixture of lime, sand and fibre. Lime is first slaked for a day or two after which the lime putty is separated from the water layer on top, mixed with sand and applied to the wall, either by hand trowel or thrown from a distance of about one metre. As the plaster cures, the calcium hydroxide in the mix slowly hardens into a rock like material. The resultant surface is extremely durable and highly protective and allows for the escape of water vapour.
Gypsum plaster	Calcium sulphate. It is usually applied in two coats: base coat and finish coat. It expands slightly as it dries and sets, eliminating cracking. This plaster sets very hard requiring little maintenance in the long run. Its high solubility in water is a major disadvantage which makes it unsuitable for use on external wall surfaces.
Cement plasters	Cement plasters can be used on earth walls. Should however not be too rich in cement. The best type of cement-stabilised mortar to use on an unstabilised earth wall is one which contains at most 20%, by constitution, of the parent soil used in the wall support Where the parent earth is very clayey, it is advisable to increase the fine sand component of the mix as clayey soils undergo extensive shrinkage on drying. It is advisable to apply cement mortars to interior surfaces only, thus allowing good evaporation towards the outside. Figure 1 shows the effect of moisture when an impermeable plaster is applied to an earth wall. To ensure that the plaster experiences thermal movements without cracking, small quantities of lime can be added.

Source: Authors' survey

Plumbing fixtures

Within special 'water' areas like bathrooms and kitchens, the requirement is to prevent the deterioration

of the earth walls through water splashing on them. Ogunsusi et al (1994) recommend that it is not advisable to incorporate water pipes inside earth walls as leakage may cause serious damage, especially with unstabilised earth walls. Good ventilation is also very important to allow a good evaporation of damp and avoid condensation.
Walls must be protected with a ventilated waterproof coating such as ceramic tiles. The base coat for the tiles can be prepared by applying a cement plaster over metal lath/chicken wire nailed into the earth wall. This ground plaster is finished rough and the tiles subsequently applied to it. The proper ventilation of an earth wall linked to plumbing is assured when the interior surface of the wall is water proofed through the use of tiles or oil-based paints while the exterior surface is finished off with a "breathable" surface coat.

INTERIOR
EXTERIOR
_ The pavement and the wall base do not allow water evaporation. The wall absorbs water.
_ Accumulation of humidity. The resistance of the wall is reduced.
_ Decay of the plaster (cracking, peeling off, ...)
Fig 1 Effect of moisture on impermeable plasters applied to earth walls
The general rules for using wooden blocks in earth walls are outlined in figure 2. With regards to
fixing plumbing fittings to earth walls, it is usually better to fix wooden blocks within the earth.
The size of the wooden block depends on the weight of the equipment to be fixed to it
The dimension of the wooden blocks should respect the earth masonry module
Wooden block in wall for anchorage of fittings
Fig 2 The use of wooden blocks for attaching wall fixtures
Fig 3 The use of wooden blocks for plumbing fixtures
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wall structure, as shown in figure 3, to which the plumbing fittings can be safely secured without damage to the earth wall.

Conclusion

The potentials of using earth as a building material to solve the prevalent housing shortage in urban centres across the world cannot be overlooked. It suffices that its inherent properties be well understood for it to be suitably applied within the building frame.
The present attempt to recognise this material within the new National Building Code (2005) is commendable. A closer look at the "other materials" section within which earth is mentioned will show that the details on the material are not up to date and do not take into cognisance the wide range of possibilities with the material. Earth construction has become more
technical and scientific than ever before and our Building Code needs to be updated in this regard.
There is a fundamental need to shift emphasis in the training of building industry professionals to include earth construction – the basic structure of the material, its structural applications, techniques of construction, aesthetic and environmental values. This need becomes
understandable when viewed in light of the fact that few of the building industry professionals are well-equipped to deal with the challenges of social housing, architectural conservation and sustainable development as a result of the deficiencies in current training practices. Some attempts have been made in certain quarters to address this but more still needs to be done.
That unbaked earth construction is a highly sustainable practise is not in doubt. It also holds the key to sustainable development within the built urban and rural environment. The constant growth of urban centres in Nigeria, as highlighted in the introduction, shows that the emphasis and point of urgency is for urban development. Earth construction could also be very
important in tackling economic empowerment issues as its labour-intensive requirements, in its most basic form, could be an answer to driving a vibrant construction industry. This is not to say that the rudimentary methods widely utilised in earth construction in Nigeria cannot be improved upon so that the production of units becomes highly industrialised within the context of the local
environment.

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