INHERENT DEFECTS ASSOCIATED WITH ORIGINAL CONSTRUCTION METHODS AND MATERIALS USED FOR EARTH BUILDINGS IN NIGERIA: CASE OF GBONGAN RURAL COMMUNITIES IN OSUN STATE

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ABSTRACT: *The durability and longevity of an earth wall is dependent as much upon the raw materials originally employed and methods of which the traditional building was constructed. This research addresses the analysis of the pathologies present in a sample of 120 cases of traditional earth building at Gbongan rural area in Osun State. The defects identified are related with construction methods in which they are detected. The soil particle distribution of earthen material was analysed, soil properties which make soil a suitable construction material are discussed. The paper then concludes on some earth property tests such as composition, consistency, dry shrinkage, coefficient of expansion that enhance durability of earthen structure.*

KEYWORDS: Earth, particle size, defect, soil properties, durability

INTRODUCTION

The term traditional earth building refers both to a material mixture of sand, gravel and clay in construction process, whereby walls are built using these materials in direct moulding in layers. The technique has been in use for hundreds of years and long standing traditional earth buildings remain standing to this day (P. Doat etal 1999).

According to G. M Reeves (2006), earth as a building material has a particle size or mineral structure based on process of formation, this leads to different properties, which distinguish constructional abilities of earth. According to Focus Group Report, the earth used in construction is mass earth-walled building were deficient in some way, for instance some earthen walls contained insufficient sand particles, combined with excessive amounts of clay with large quantity of silt, such walls lack compressive strength and resistance to the effects of excess moisture is very poor. However, Laurence keefe (2012) explained that the presence of a large quantity of clay in the fraction of 20 to 25 percent cause drying shrinkage, which unless controlled, leads to development of cracks known as vertical shrinkage cracks. The construction process of direct moulding where unmodified clay-rich earth has been employed, cracks and fissures usually developed at key points in the structure especially at corners around window and door openings. Other potential weak points in construction according to Matthew Hall (2012), is hollow and cavities created as a result of poor compaction and inadequate distribution of earth particles.

Construction methods of using direct moulding causes deterioration and damage usually confined to the external faces of unprotected walls. Laurence Keefe expanciates further that cohesion of earth particles is achieved primarily by means of surface friction and physical interlocking between particles. The earthen walls that the particle distribution is deficient of

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one particle or the other are susceptible to surface erosion and development of cracks that leads to dilapidation. Foundation defects of traditional earth architecture vary according to type and date of construction, for instance at rural areas surveying for this study foundation was bedded on shallow excavated trench with high tendency to settle. Good quality earth with well-graded particle distribution are often difficult to obtain, the earthen material employed for construction is not suitable. Importantly building methods of direct moulding do not give provision for cross-binding of walls together they are free standing and independent. Laurence Keefe confirmed further that poorly selected earthen material, with construction methods that allow further deterioration coupled with lack of proper foundation are both sources of problems for traditional earth building.

Theoretical Consideration

Earth material suitable for building is generally well-graded subsoil with a good distribution of clay, silt, sand and aggregate. According to Reeves et al (2006), clay content is essential for providing cohesion and plasticity during construction and strength during performance of earth building. Variation in soil types, diverse climatic conditions and wide range of building techniques and numerous architectural details have resulted in culturally distinctive architectural material characteristics. In this regards, a brief enumeration of applicable techniques for characterization of the earthen wall was highlighted in order to give support to interventions to be adopted in traditional earth buildings. In this process, survey-analysis is presented that are focused to identify physical and mechanical properties of earthen material that promote durability of earth as building material (Fodde et al, 2007).

Akinkunmi (2012) explained that because of increased erosion of earthen wall, shrinkage cracks of the earthen wall exposed to cycle of drying and wetting. The characteristics of the earth can be improved by addition of graded certain earth particles that counteract well with prevailing environmental conditions and promote durability (Gernot Minke, 2006). The paper presented an overview of earthen architecture and the use of earth as a building material, application of the earth in building construction, characterization of earth for building, performance of tradition of earth building and advantages of earth as a contemporary building material (Reeves, 2006).

Material Composition of Traditional Building

In this zone of carrying out this study, the common materials primarily used for traditional construction varied from earth to clay bricks (un-burnt), sand, wood was engaged as panel windows and doors, windows and doors frame, roof trusses and for stability (structural frame). In recent times however, sand-Crete for masonry were noticed.

Status of traditional earth building

The earthen traditional architecture has evolved through generation using local materials. The earthen material has proven its validity through ages, its efficiency in architectural solutions and ability to appropriate design against the influence of climatic and environmental factors (Momcmanova, 2007. Michael, F, 2008). The earth buildings at the study area are at advanced state of degradation, thus accelerated in by the action of many factors this includes: moisture, temperature variation, infiltration of rain water, erosion and loss of mass earthen walls, cracking walls and peeling of plaster coatings. It was noticed at the study area that most of the traditional housing stock has been either partly or totally plastered with Portland cement, the

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prevailing situations are characterized with lack of good quality control measure; this resulted in several multiple cracks failure, partial collapse and dilapidation. It was noticed that the behavioural elements of those building falls basically as traditional process that lacks maintenance (Akinkunmi, 2015). These findings therefore emphasize the need for a comprehensive programme of effective improvement of technical construction detail, choice of earthen material and construction methods that matched with standard which promote functional performance of the rural earth dwelling.

Background of Study Area

A Gbongan rural community in Ayedade Local Government area of Osun State is a typical traditional ancient town its geographical coordinates are 7°28'0"N, 4° 21'0"E. The morphological characteristics of the area exhibits features of typical traditional Yoruba towns which are king's palace (*afin*) and traditional king market (Oja Oba) in the front of the palace. Surrounding the king's palace is the high concentration of traditional residential houses for the indigenous occupants and intermediate zone of contemporary face-me-i-face-you vernacular earth dwelling, whereas the outskirt consist of sparsely distributed modern single family dwelling intercepted with few traditional and vernacular houses. Gongan rural communities have undergone considerable growth in the recent time as influxes of people were necessitate by spontaneous development such as advent of tourist centre as well as corresponding increase of commercial activities. House-form pattern commonly featured at Gongan community are typical courtyard housed and vernacular dwelling built from local earth materials. Many of those houses are still in their normal natural form while some of them have been plastered with Portland cement, either total plastering or lower part of the building; indigenous thatched system of roofing has been substituted with corrugated sheet due to technological innovation and improvement over the thatch roof used in olden day.

Research Methodology

The methodology chosen for the research is founded on the characterization of earthen material originally used in traditional earth building at the study area and execution of test for physical and mechanical characterization of collected samples. Also a quantitative method on the basis of abundant information gleaned from different primary sources (interviews and information directly provided by the agents involved in the construction of the earth building) and secondary source (project documentation, archives).

This case study analyses used focus group to engage rural dwellers in guided interview and discussion at Gbongan communities (Krueger, 1994). The rural participants are well-experienced local house builders. The focus groups were led by research fellows who are aided by a discussion guide developed through prior interview with earth consultants, experts in building local houses with indigenous materials, especially earth.

The focus groups are a form of quantitative researches in which purposely-selected participants in the field of study and interviewed in a group setting. Such setting increases the efficiency of interviewing and interaction among the group members, it leads to more insightful response than individual interview. Such a pattern suggests the probability of generalized view within the population studied. Focus group also carried out structural failure investigation, by collecting soil samples used for earth construction and conservation by local builders. This was done to determine the relative quantities of soil fractions in the soil samples aimed at identifying the intervention criteria, techniques used and evaluation of results, also to study the

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parameters related with the building itself as related to architectonic and construction characteristics of building and especially building techniques that compatible with durability.

At the Gbongan communities, earth buildings were rated according to constructional pathologies. 1,209 of earth dwellings were identified; Primary data on the earth buildings were obtained through the stratification of the study area using stratified systematic sampling methods (Dixon and Leach, 1977). The focus groups generated the following pathological constructional categories using 10% samples retrieved, 83% of material pathology, 92% of structural pathology, 80% of environmental pathology and 30% of anthropic pathology.

Sampling procedure of the earth buildings at the study area

This arises from the need to characterize the earthen wall at Gbongan, to determine its composition, its properties and the construction processes and reactions that might be producing deterioration (C. Mileto, 2012). The sampling procedure comprises of the following:

(a) **Maximum representative**

Earthen walls are building elements whose composition varied due to multiple factors such as imperfect batching, non-standard manual application, etc. Efforts are made to ensure maximum representative and samples are representatives of structures.

(b) **Number of samples**

It is important to note that if only one sample was taken, there will be no basis for comparative analysis. Therefore, in order to affirm that a wall is typical of building elements, at least, three samples are considered. Once analysed, these samples produce result following within a suitable range, the result of the outcome can be reliable.

(c) **State of samples collected**

They are compact samples that allow the analysis of mineralogical composition and physio-mechanical properties.

(d) **Collection site**

The depth at which the sample is collected is extremely important. The deeper it is, the greater the probability that it is original, un-substituted and unrepaired.

In addition, the result will be less altered by environmental impact. In contrast, when the sample is collected near the surface, it is more likely to have been partially substituted or repaired, or to have been weathered by atmospheric agents. It is common to find crusts, efflorescence and more on the surface.

DATA ANALYSIS AND RESULTS

The data were analysed with SPSS, using frequency distribution and percentile method of analyses. The computed formula used is (f_i x 100)/n where f_i is the frequency of pathology categories; and n is the total number of represented sample. Further analysis was carried out

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using the Variance of (ANOVA) test to explain the linear relationship and determine the level of significance between earth building construction method and identified pathologies. The result is established at both 0.01 and 0.05 probability.

The analysis and discussion of results are based on the assessment of focus groups identified from the study area. The results are presented as follows:

Material Pathologies

Table 1 shows brief report from focus group it revealed that earth buildings from study area were 10-60 years old and above, from the report 120 of those building stock from stratified samples which amount to 83% were in a gradual dilapidation due to non-suitability of material composition for construction, environmental deterioration of earthen walls and lack of maintenance.

Table 1: Age range of the earth building

	10 – 20	*21 – 30*	*31 – 40*	*41 – 50*	*51 – 60*
Traditional Earth Building	08	9	20	19	27
Vernacular Earth dwelling	04	7	08	10	11
	12	13	28	29	38

Σ = 120

Table 2: Earthen wall deterioration

	Low level erosion	*High level erosion*	*Plastering disintegration*
Traditional Earth Building	70	75	76
Vernacular Earth dwelling	31	24	24
%	84.34	82.15	83.61

Mean value = 83.33%

Earth is made up of varying proportions of four types of constituents varying from, gravel, sand, salt and clay. The total porosity determines the behaviour of earth towards water and their vulnerability with respect to decay process. Thus the capillary rise and dry kinetics is indicative of the susceptibility of earth to moisture attack, earth behaves in a characteristic way so that when exposed to variation in humidity it become weak, some change in volume and others do not (Gernot, M. 2006), According to focused group it was evident from table 2 that the earth usually employed for construction at the study area is direct moulding construction system, which comprises of high clay content in order to achieve sufficient strength, it contain particle distribution of 25% clay, 5% silt, 23% sand and 3% gravel, thus usually creates swelling and shrinking problem upon wetting and drying respectively. The analysis revealed that high percentage of traditional earth buildings was affected with high and low level earth erosion.

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Structural pathologies

From the study, higher percentage of these buildings about 83 percent have been existed over 60 years without any maintenance measure administered over time of use. It was observed that 92% walls were cracked, partly collapsed and dilapidated, while those built in recent years constitute 8% however shows structural soundness, there exists a correlation between relative habitation and age of the building as illustrated in Table 3.

Table 3: Nature of maintenance and building defects

	Maintenance Status		***Observed Defect***	
	Steady	**Lack**	**Cracks**	**Collapse**
Traditional Earth Building	6	99	89	11
Vernacular Earth dwelling	4	12	18	3
Percentage	8%	92%	89	11

Σ = 92%

Construction pathologies

The focus group revealed that majority of those earth buildings lack structural foundation, where such exists, it was very shallow and vulnerable to rain water erosion. The usual practice of local builders is just to build without testing the suitability of the earth composition for construction, also, the appropriate depth that is suitable for land bearing on the ground is not attained, thus lead to structural failure as illustrated in Table 4.

Table 4: Constructional detail

	Sound foundation	***Shallow***	***Earth appropriate***	***Unsuitable***
Traditional Earth Building	-	99	-	100
Vernacular Earth dwelling	02	20	02	19
Percentage	1%	99%	1%	99%

Σ = 120

Poor Drainage Network

The focus group highlighted from table 5, those structural defects and failures are common during the rainy season. This is as a result of lack of rainwater drainage network, rain water becomes a threat to earth structures because earth has tendency to remix with water, thus making the earth to weak. Also, material composition encourages absorption of moisture by capillary action; the earth building deteriorates gradually as it absorbs moisture (Norton. J. 1997).

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Table 5: Drainage system

	Adequate drainage	*Lack of drainage*
Traditional Earth Building	-	99
Vernacular Earth dwelling	-	01
Percentage		100%

Also further analysis of the result was carried out using the analysis of variance (ANOVA) test to explain the linear relationship and verify the level of significance between construction method of earth building and pathological variables. The result (F-value) of the test presented in table shows that no significant difference and that there is a linear relationship exists between building construction method and pathologies, material ($F = 1.874$; $p<0.05$) structural ($F = 3.337$; $P < 0.01$), Age ($F = 2.429$: $P<0.01$), Construction Techniques ($F=3.249$; $P<0.01$), Moisture ($F= 3.591$: $P<0.01$).

These results indicate that building pathologies, construction techniques, material, lack of maintenance and moisture influences the dilapidation process of earth building.

EARTH CONSTRUCTION TECHNIQUES

Most of earth building techniques in use today differ from traditional practices which started several years from now; those technologies have enduring qualities which are most relevant to the construction method in Nigeria. The following constructional sequence has been identified by the focus group. In accordance with focused group specification the type of soil available usually determines the appropriate building technique to be used. Balancing of clay and other aggregates has been found to be essential for most earth building (Genort Minke 2006, Akinkunmi. J.o. 2014). Moisture content has also been identified to influence the nature and workability of the earth building. The following techniques have been identified.

(a) Mud Wall

This technique is most suited to heavy clay soil and is the most common form of earth construction found in Nigeria especially in south-western zone. The sub-soil is mixed with water until it reaches sticky but firm consistency. On some occasions straw may be introduced to avoid shrinkage or crack. The mix is then laid on strip layer of stone foundation, trodden down and shaped with hand by experienced builders to form a freestanding mass wall (Norton J. 1997). In Nigeria this type of construction is best carried out in dry season, so that each layer of mud can become firm before the next layer is laid.

Openings are formed as the walls are raised and load-bearing elements such as wood or already made wood opening frame may be inserted into the opening, such wood and frame act as supporting device for lintel and the last mud layer (Akinkunmi J.O. 2012).

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It was observed that majority of mud walls are unprotected without any breathable rendering except for the deep overhanging eaves. Also, the lower part of the external wall is identified with little lower erosion.

This type of building has stand out, most ancient palaces, town hall, communal hall, residential and the likes has been constructed with mud wall technique, such building has been stable and structurally sound, even till now, some have lasted for centuries, without any deformation, except routine maintenance, most of Nigerians cultural housing where cultural heritage are kept have been rendered mud wall typology. Critical analysis of those mud wall revealed that they are always bulky, the width of such wall are between (450mm – 900mm), which makes them structurally sound (Akinkunmi J.O 2014, Norton J. 1997). Mud wall is simple, labour intensive form of construction well suited to self-build and community participation.

(b) **Earth Brick**

This method of construction varies according to different contexts. Clayed sub-soils are mixed with water and/or fibre to a mud-like consistency before they are moulded with locally made formwork, which could be of different shape such as oval, rectangular, or square according to different contexts of use (Houben .H and Boubekeur. S. 1998).

The bricks are air dried before use, the density of the earth bricks can be varied according to different context of usage. Denser bricks can carry loads; it eliminates a large proportion of shrinkage and settlement which occurs in mass earth techniques. The courses of earth bricks are laid on stripped stone foundation, clayey mortar are usually used traditionally to act as binder between the bricks (Norton. J.1997).

Openings are formed similar to mud wall typology, wooden frame usually act as lintel supporting devices. Hand-made earth bricks have the advantage of being simple to make and is therefore appropriate for manufacture by unskilled labour, it can be produced in batches. The equipments necessary include simple wooden mould for low technology applications (P. Doat. etal. 1999).

(c) **Compressed earth bricks**

This type of earth bricks are produced in a manually operated press, which exerts a large amount of pressure on the earth in the mould. These are produced in standard sizes with soils that have lower proportion of clay usually less than 10% and higher proportion of sand. The drying time are speeded up in comparison to wet mounded bricks, the bricks can be stacked immediately, which eliminates the need for large drying and storage spaces. (Guilaud. H, Thierry. J and Pascal. O. 1985).

(d) **Earth infill in timber frame construction**

According to Norton, 1997 his type of construction is found in eastern part of Nigeria it is common among the *Igbos*. In this type, the timber frame provides the structural support for the roof and the earth is used as a non structural infill for wall. Traditional daubs (earth infill) are prepared as mud wall mixes and applied manually to skeletal structural support called wattle, which ranges from stakes to bamboo (G. Minke, 2000).

Local sourcing for suitable Earth for Building Construction

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Minke (2000) performed a series of test to establish a performance specification for building soil. Soil whose characteristics fall outside these guidelines can be modified by adding appropriate amount of earth particles such as gravel, sand or clay to obtain better mix as it applies to local traditional practices. They usually source earth for construction on the site, using the subsoil excavated from foundations, basements and septic tank location. The local builder will examine the earth *in-situ* to determine the nature of material available, if the properties are not suited for construction; relevant modification can be done to influence the property suitable for construction (Table 6) has reveal the specification performance of suitable earth for mud wall construction.

Where earth is not available in sufficient quantities this is sourced for from local clay pits nearer to construction site or road construction operation site where earth is often a waste product. This is preferable in order to reduce transportation and energy cost.

It has been observed during the study that raw earth building construction is prevalent in areas where clay soil and sands are abundant.

TABLE 6: PERFORMANCE SPECIFICATION:

Performance Indicator	Mud wall	Rammed earth
Clay content	10-25%	7-15%
Moisture content	18-25%	10-16%
Strength	400 - 1000KN/M^3	800 - 2000KN/M^3
Linear Shrinkage	Less than 6%	Less than 3%

(Centre for Earth Architecture, Plymouth University (2000))

Defects associated with mud wall construction techniques

Excessive water absorption of un-stabilized earth, causing cracks and deterioration by frequent wetting and drying (swelling and shrinkage) as well as weakening, disintegration and erosion by rain according to focus group report. High percentages of traditional buildings were affected with high and low level earthen wall erosion (Laurence keefe, 2012, Micheal Forsyth, 2008).

According to Akinkunmi (2014), low resistance to abrasion and impact of rain, thus lead to rapid deterioration of earthen walls and possibility of penetration of rodents and insects.

The specific issues generated by the rural dwellers are being developed into categories that could help to identify prevailing problems affecting the adequate performance of earth dwelling against agent of deterioration. The following issues were generated on the field carrying out this study.

(a) Inadequate strength attainment in the present of dampness

It has been established during the interview with local housing developers that excess moisture added to the earth when building or to the earth structure, causes shrinkage. According to focus group report, it has been reported that water has tendency of re-mix with earth to affect the strength. Furthermore the materials composition of earth allows the absorptions of moisture by capillary actions. The structure deteriorates gradually as it absorbs moisture, which weakened the structure and leads to total collapse (Norton, 1997, Laurence Keefe, 2012, Akinkunmi, 2015).

(b) Building site posed another greatest threat:

Focus group participants reported that earth structure vulnerable to cracks and decay in a location that always flooded, wet or in a terrain that encourage erosive effect of driving rain. Earth building exposes to decay which lead to crack, as the building site experiences differential settlement, cracks form the weakened point for moisture attack in earth structures (Barry .A. Richardson, 2002, Peace Corps, 1981). This study showed that the degree of compaction of the building site determined its load bearing capacity, instability of the site give rise to uneven settlement resulting in cracks both on the foundation and earthen walls. A similar experience happened when a firm soil strata has not been reached before construction of the foundation (David Watt, 2007).

(c) Attack of low level and high level erosion:

The rural dwellers frequently emphasize the base of the wall just above the foundation level is highly susceptible to low level mass earth erosion. This is as a result of rain water dripping from roof levels to ground surface and splashing into the lower part of the earth structure, thus weakens the earth. This resulted in decay and deterioration of the affected lower part(s), it often leads to partial or total collapse of the building (Fernado Pacheco.T and Said. J. 2011). The rural dwellers comments on the increase of erosion of the surface of the wall at higher level showed that it is usually caused by inadequate roof eaves overhang, dripping of rain water splashing on the surface of the wall at higher level. Thus weaken the earth, resulting in decay and deterioration of the building fabric this confirm the notion of John. H and Geoff Cooks 2003.

(d) Inappropriate roof covering and inadequate foundation detail:

The reports from focus group showed that some of the roof coverings are inappropriate while others have been won out over time due to weathering effects. They are ineffective, causing ineffective covering to the earth structure; therefore moisture from rain remains a threat to earth structure. In all the rural areas surveyed 99% of earth building lack basic foundation because rural housing builders start construction of foundation on shallow excavated top soil that lack load bearing capacity. This resulted in multiples cracks due to differential soil settlement as a result of pressure of earth wall on compressible top soil. Also because of lack of proper maintenance practice of local dwellers such cracks lead to absolute collapse of earthen wall (Mark Miller etal. 2004, Peixoto.v, etal. 2013).

(e) Cracks defect in earth structure

The report from focus group shows the complaint of rural dwellers of low tensile strength of the earth building materials as the commonest problem with earth dwelling. Cracks are found at corners where tensile stresses are greatest, such as in window and door opening. It was also reported that once cracks occur each adjacent wall is free to move, so differential movement resulted in falling apart of the wall (Bernard. F. 2003).

The focus group participants reported that unsuitability of earthen materials and poor workmanship could be responsible for weakness at the corners. They also reported that algae,

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lichens and other micro organisms grow colonize outside the surface of the earth structure. Their presence also causes surface erosion and micro-cracking on the building. (G. Minke 2000)

(f) Common problem of wattle and daub

Wattle and daub are vulnerable to structural rottenness; they are common to Southerners and Easterners. It could be attacked by damp causing damp rotting of wattle skeleton; also it could be attacked by termite and insect feeding on them. This creates a situation of no structural support which leads to collapse of the earth structure. (Norton. J. 1997)

(g) Lack of Routine Maintenance Practice

With the general observation of focus group, majority of the rural dwellers just build and inhabit the house until total collapse of the structure. No adequate planned programme of maintenance practice from time to time on earth dwelling, this lead to absolute dilapidation of indigenous earth dwellings in rural areas. (Max. R. Terman, 1985, Matthew Hall, 2012, Hill. J.F. 1969. Chanter.B and Swalow.p. 2001)

Earth particle distribution analysed

Hydrometer test at the laboratory reveal that there is a relatively low sand fraction below the recommended limits in the soil sample collected from the study area. The average sand fraction content of 48.5 percent is lower than the acceptable and recommended limits which show outright cracking as the structure are drying out. This must have affected bonding properties of the earth structure. (Matthew Hall, 2012, Vincent Rigass, 1985)

Furthermore many of the earth structure have no proper foundations design in structural detail they were constructed on bare earth after shallow excavations. Then due to settlement of the applied earth load, cracks resulted because of no foundation to transfer the load to the ground this eventually leads to absolute wall collapse. (Akinkunmi. J.O, 2014)

Suitable mix

Earth building practice is extremely varied in terms of quality of earth material available, the way they can be used, the functions to which they are applied, and how they will perform at different context. According to local builders, which was substantiate by Micheal Smith suitable earth for construction is found in the sub-soil layer. Topsoil is unsuitable because of organic matter content which will decompose, however it is possible to modify earth mix to suit particular use, (Table 7) has revealed the appropriate decimal grading of earth particles that suitable to mud wall construction.

TABLE 7: DECIMAL GRADING:

Performance Indicator	Mud wall
Clay content	Less than 0.002 mm
Silt Content	0.002 mm to 0.06 mm
Sand Content	0.06 mm to 2.00 mm
Gravel	2.00 mm to 60.00 mm

(British Standard Grading)

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Basic earth properties field test for suitable earth construction.

According to Martijn S. (2009), the first basic test is to make use of our eyes by studying the structure, colour, and hand to feel the earth samples, also nose to smell and mouth to taste the soil. These checks are perhaps 20% accurate, to give a rough and first general idea of the structure and texture of the samples (Doat. P. etal. 1999, Peace Corps, 1985). Also Peace Corps, (1985), Martijn S. (2009) presented further the basic field tests for suitability of earth as construction and conservation material:

1. **Visual test**

   Samples collected are spread out in a thin layer as flat surface examined with a naked eye to estimate the relative proportion of soil particles distribution of either granular, fragmented or continuous or balance of soil particles.

2. **Touch test**

   Having removed the largest soil particles from the samples, soil are rubbed between the fingers and palm of the hand, clayey soil feels smooth and powdery, like a flour this shows that there a lot of fines particles with dry shrinkage as it is drying out. Therefore not suitable for building construction it can easily be eroded by rain except being modified.

3. **Ball drying test**

   Handfuls of the soil sample with slight water to mould the soil into moistened balls to keep the soil particles together. Then the sampled soil ball is sundried. It quickly crack as it dries out, this is an indication that sample indeed contains more clay and silt.

4. **Compression test**

   With handfuls of soil samples and small drops of water and pressing the ball in hand for about five times. This makes it clear about amount of pressure that must be applied and also about cohesion. The outcome shows that the compressibility is very low, which reveals cay soil requires strength to press for long period.

5. **Drop test**

   The prepared sampled ball from the above dropped from a shoulder height on a hard surface, the ball stays in one piece, showing that it contains much proportion of clay particle distribution.

6. **Crumbling test**

   This is to test for dry strength of the earthen wall aiming at determining the percentage distribution of clay content. The tests are carried out on the fines of the soil sample. The procedures are as follows: water is added enough to mix the fine soil samples into a plastic state to make ball, balls of 25mm and 6mm diameter were made, then allowed to dry completely. When drying, the balls are grabbed between thumb and index finger, and crushed. The result shows that neither of sizes of the ball breaks easily. This indicates a high dry strength and the clay content is probably greater than 20%. (Matthew Hall, 2012, P. Doat 1999)

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7. **Elasticity test**

Another ball sample was made from the cohesive sample above; the ball was pulled into two-like elastic band to test for elasticity of earthen material. The soil breaks apart after a long pull and very elastic; this also confirms that the earthen material used in construction of earthen walls is clayey in material composition.

8. **Adhesion test**

Also, another ball from the cohesive soil, a stick knife blade was inserted to penetrate the ball, the result shows that the knife is difficult to penetrated and the knife was stained is indication that soil composition is clay.

9. **Consistency test**

According to Norton, the test is performed on the fines of the soil; the sample is sieved with a 425 micron sieve. Water was mixed with a small portion of the soil sample according to procedure, in such that it is easily shaped and does not stick to the finger. A roll of less than 33mm in diameter is made from flat surface. The soil thread is remoulded into small balls then squeezed between the thumb and index finger. The outcome of easily rolled out soil thread of less than 3mm diameter is an indication of higher percentage of clay and very little sand.

10. **Absorption test**

The very sample used to test for consistency was used without adding water to it, it was moulded into balls and a small hole was made in the middle of the ball. Water was poured slowly and the water stayed for long time, is an indication that it is a clayey soil distribution.

11. **Sedimentation test**

Sample soil was sieved with 5mm mesh to remove larger parts, a clean bottle was filled with one quarter of water then the bottle was filled with one third of sieve sample soil, and then filled to the top with clean water. Then according to Norton, a teaspoon of salt was added to enable separation of particles. The bottle was closed and shaken well for 2 minutes. The bottle was placed on an even surface of table for the experiment and allowed to rest for an hour. It was then shaken again and allowed to rest for 24 hours. According to sedimentation, there are hard coarse grain sediments at the bottom of the bottle with layers of fine grains that is more than 50% on top of hard grain. The soil is not suitable for earth construction.

12. **Shrinkage test**

Wooden mould of 60cm long in internal dimension, 4cm wide and 4cm deep was constructed, the top is open and the sides were greased so the soil will not stick to it. Having removed the large particles from the soil sample, the soil was mixed with optimum moisture content. The soil was pressed into the corner of the wooden mould using spatula, neatly smoothened at the top. The filled box is exposed to the sun for three days. On examination, the soil had dried and shrunk and surface exceeds the top of wooden mould in a curved shape. The result shows that the soil composition contains a lot of clay.

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Testing Summary

The samples analysed show the composition and characteristics of soil, which shows that it has shrinkage cracks and particle distribution of clay which are very unsuitable with direct moulding construction techniques adopted. Cracks and dilapidation accompany the earth structure without routine maintenance. The earthen building erodes very easily.

Understanding Earth as a Building Material

The focus group report suggested that adequate understanding of earth as a building material will enhance performance evaluation of indigenous earth dwellings as its passionate advocates but not just to build with earth because of its availability but must understand the nature and behavioural pattern of earth under different conditions.

Earth is vulnerable to weakness according to rural dwellers, in the presence of damp it loses much of its comprehensive strength. Earth dwellings has tendency of re-mix with water to reduce its strength, it extremely susceptible to heavy rainfall, splash-back erosion, seasonal and non-seasonal flooding. This will either cause shrinkage or decay to earth structure (John Norton, 1997). It is important to note that adequate draining of water away from earth dwelling will eliminate the threat posed by the presence of water. Furthermore, according to focus group reports, it was established that earth is weak in tension but has appreciable compressive strength. The critical constraint in using load bearing earth is the slenderness of the structure, since the lack of resistance to bending has to be compensated for by greater width in the structure to maintain stability as specified by Norton, wall width dimension between (600-900) mm will be effective. Their reports corroborate further that soil composition of the earth construction is paramount important; majority of rural housing developers have no adequate knowledge about the right earth composition for the earth walling. They use earth in wrong context that will not guarantee strength, durability and quality control of earth dwelling. In effect, soils are extremely sensitive to the effect of water, expanding greatly when wet and shrinking when drying out this is destructive in earth dwelling with a great deal of multiple cracking. Observations of existing rural earth dwelling at the study area provide best information about the local soils; rain and wind had destructive effects on these local buildings with multiple cracks, low and high level erosion and absolute collapse. This is as a result of inappropriate soil composition, poor workmanship, poor roof cover, inadequate roof eaves overhang and lack of maintenance.

A great variety of construction techniques have been identified by focus group in response to local soils and weathering actions. In accordance to this study, inappropriate construction techniques resulted in poor quality earth structure associated with cracking and structural defect dwelling.

Constructional detail of earth building.

According to focus report, structural failures in the earth structures are common and of great concern to this study. Raining season leaves evidence of collapse of earth structure and multiple cracks often observed. The following limitations were raised by the participants of focus group.

- Complete absence of adequate constructional knowledge from design to construction.
- Lack of building professional impute in supervision

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- Incompetent builder and the use of poor materials
- Low standard of workmanship and lack of quality control in the construction process.

FINDINGS AND DISCUSSIONS

In the content of this study, focus group was engaged with local housing developer in interview and discussions. Comments from the discussion are categorized into the following performance indicators.

(i) Suitability of building site for earth structure.

(ii) Selection of preferred earth building technique and suitability of workmanship that matched with standard, as showed in the field test.

(iii) Consideration of suitability of soil for construction work.

(iv) Designing an-earth building that will enhance structural strength and durability.

(v) Detailing precautions.

(vi) Effective external Fabric protection.

(vii) Frequent repairs and maintenance measures.

CONCLUSION AND RECOMMENDATION

The predominant cause of defect and loss of functionality in earth wall is the loss of surface area due to erosion or physical attack by wind driven rain. The field tests carried out are reflection of form of soil used in construction. Material properties is the major factor that leads to various defects in earth buildings, for these buildings, their clay soil particle distribution is more than the required percentage, the cohesive properties is lower than what can cause resistance against surface erosion of earthen walls. Loose earth material provides little resistance to the erosion of rain. In general, a clay soil for earthen construction cannot compact well, which makes the earthen wall vulnerable to surface erosion.

This paper presents with the result of field test analysis carried out, the properties of the earth for construction must be improved upon, through the addition of sand particles that can increase the cohesive strength of the soil that will enable durability of the earthen wall.

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