EARTH AS AN ALTERNATIVE BUILDING MATERIAL FOR SUSTAINABLE LOW COST HOUSING IN ZIMBABWE

Mohammad Sharif Zami , Angela Lee
Research Institute for the Built and Human Environment
University of Salford, Salford, M5 4WT, UK.
E-mail: m.s.zami@pgr.salford.ac.uk
a.lee@salford.ac.uk

ABSTRACT: Earth has been used as a construction material in every continent and in every age, largely due to its versatility and widespread availability. It is one of the oldest building materials. The use of earth on site as a building material saves manufacturing cost, time, energy, environmental pollution and transportation cost. As a result of Operation Murambatsvina (Cleanup campaign carried out in 2005) in Zimbabwe, the percentage of squatters has increased. A solution has to be found out to provide sustainable low cost housing for these squatter's that is 'eco'-friendly and will preserve the environment for future generations whilst catering for the needs of the present inhabitants. This paper discusses an alternative building material; earth can also be used in the construction of low cost sustainable houses in Zimbabwe which is significantly cheaper than using conventional bricks.

Keywords - Earth**,** Alternative building material, Low cost housing, Sustainable development.

1. INTRODUCTION

There is an urban housing crisis in most third world countries. This is largely attrible to the rapid urbanisation process amongst most of the developing nations. The urban population of Zimbabwe increased from 27% in 1992 to 42% in 2002 (Chakwizira, J. 2004). The majority of the urban local authorities and central governments did and do not have a tradition of providing shelter to a large permanent population; there has been a lag of supply to demand of urban housing. According to UN Habitat (1996), housing shortage in African cities ranges from 33% to 90%. To meet housing needs, many people have resorted to renting backyard shacks and squatting on illegal land. According to the South African census report of 1996, 1,049,686 households lived in informal dwellings. People reside in squatter settlements, where there are no provisions for social services and utilities. UN Habitat (1996) also estimates that approximately 60% of the African population reside in shantytowns, slums and uncontrolled settlements. According to Kamete (1999), in Harare, Zimbabwe, 10% of the city's population live in illegal settlements; 13.6% of these live along river banks, 48.6% live in permanent squatter settlements, 93% of all stands in high density areas have illegal out buildings, mostly shacks, 40% of the city population are lodgers in those shacks.

The objective of this paper is to promote earth as an affordable alternative material to housing in such a way, that if compared to established materials, it should prove to be an ideal alternative. The experiences and practice of using the earth construction will be borrowed from other societies and countries and to promote a new style of architecture, and demonstrate the dynamism of the material and construction in Zimbabwe. The higher the ratio of non-manufactured local materials the lower the ratio of man-made energy. Earth is nature's product; it requires no energy to produce, it saves man-made energy, it is labor intensive, and it is in plentiful supply and enduring. Rammed earth walls are ideally suited for passive solar construction. Contrary to popular belief, earth provides the natural comforts of balanced temperatures, humidity and noise control. Low cost housing projects could however succeed or fail depending on the level of community participation of both the individual and the community as a whole; in addition, earth building can be seen as a means of creating employment.

2. HISTORICAL BACKGROUND OF EARTH AS A CONSTRUCTION MATERIAL

According to Houben & Guillaud (1989), the history of earth building lacks proper documentation because it has not been highly regarded compared to stone and wood. Archeological findings reveal the use of earth dating back to several great civilizations. "Thirty percent of the world's population, or nearly 1,500,000,000 human beings, live in a home in unbaked earth. Roughly 50% of the population of developing countries, the majority of rural populations, and at least 20% of urban and suburban populations live in earth homes" (Houben & Guillaud, 1989, 6). Fig 01 illustrates the geographic locations of where earth structure is used in the world and Fig 02 shows the spread of different kinds/ forms of earth structure being used by different regions of the world.

Fig 1.
Geographic locations of earth structure.
Source: Houben & Guillaud, 1989, p 6.

Fig 2.
Different forms of earth structure being used by different region of the world.
Source: Houben & Guillaud, 1989, p 12.

In Europe, primitive dwellings were constructed of woven wood and clay evolving to un-burnt clay. The un-burnt clay brick was jointly used with tuff, gypsum, schist, marble and wood. Dark and deep colors and tints were used for rendering. Builders in this region seem to have developed unique earth structures like the brick dome at a very early time. During the Roman Empire houses were constructed using earth brick walls before stone replaced them for the rich, while the poor remained housed in buildings of earth until the time of Augustine who recommended the use of earth on a national scale. Raw earth construction was not a forefront building method until the 18^{th} century when an emerging use of cob, rammed earth and un-burnt brick could be observed. Building with earth continued until the 1950s and there was a sudden increase in the use of the material after the Second World War, as the demand of housing increased due to war displacements.

In the Americas before agriculture was established in Central America, the hunter-gatherer life style had houses built of light materials, such as wood, dub or balls of earth covered with palms. The use of sun-dried brick appeared between 500 and 600 BC depending on the degree of complexity and the hierarchy of society. Excavations on the outskirts of ceremonial centers have unearthed proof of dense residential areas. Remains of foundations in masonry leveled to the ground, suggesting that the upper walls were built in earth brick rendered in lime. The invading Spaniards helped spread the use of earth in Mexico, with stone reserved for palaces, religious buildings and defensive structures. Fig 03 shows a picture of an adobe home in Mexico. In South America earth building was commonly used in the alluvial plains due to the lack of stone. The majority of the rural homes are built of unbaked earth as adobe and rammed earth continue to be the main method of building in central and South America.

Fig 3.
An Adobe home near Santa Fe, NM
Mark Chalom, architect
Source: www.adobebuilder.com/index.html

Fig 4.
View of the village of New Gourna, Egypt
Source: Christopher Little, Aga Khan Trust for Culture.

Middle East excavations have revealed several millennia of earth building dating as far back as 8000 BC, of which the dwellings were of stone base and earth walls. Various kingdoms such as Assyria, Medo-Persia and Babylon made use of the earth in various forms. To date, earth is still a major building material, and earth vault and dome originated from the Middle East. In Africa, the Egyptian civilisation provides abundant evidence of the use of earth in building as found in the early human settlements at the Merimd and Fayum sites in the Nile delta, which dates from the fifth millennia before Christ. The dominance of the Egyptian dynasty promoted buildings of prestigious structures made of brick from the Nile clay, desert sand and straw from the grain fields. These bricks were made by hand and dried in the sun before the development of the mould. The excavation at Saggarah and Bbydos show the use of bricks which were covered by stone. The art of brick vaulting was also developed in the lower Nubia, between Luxor and Aswan.

The Egyptian architects, planner and artist, Hassan Fathy devoted himself to housing the poor in developing nations. According to Iskander (2005), Fathy aimed to create affordable and liveable spaces suitable to the surrounding environment, thus improving the economy and the standard of living in rural areas. His buildings were alarmingly inexpensive. He encouraged ancient design methods and materials and saw a more appropriate method of building in the Vernacular Architecture of the Nubians (region of southern Egypt), which influenced his ideas greatly. Nubian craftsmen were masters at constructing domed and vaulted roofs of mud brick which they also used for the walls. The structures were cheap, the walls were cool in the summer and were heat-retaining in winter. While implementing the Nubian building techniques, he aimed to train Egyptian craftsmen to build their houses using mud brick or Adobe, which was ideally suited to the local conditions of Upper Egypt and at a fraction of the cost.

Ishkander (2005) stated that the New Gourna Project is one of his best known housing projects; Fig 04 (see above) shows the view of the village of New Gourna. This is due to the international popularity of his book, "Architecture for the Poor" published originally in French, 20 years after the beginning of the project, in which he explained his vision for the village. The book details his thoughts, processes, dealings with the politics involved, and his theories behind the forms. His designs depended on natural ventilation, orientation and local materials, traditional construction methods and energy-conservation techniques. He carried out detailed studies of temperature and wind patterns. The "Gourna Village experiment" was not just an architectural experiment to him it was more like the development of a town on a cultural and social level following the regional traditions. Relating to the people and addressing their needs while asking them to participate in the construction of their town was a major part of the project.

In the east, India has a rich history on the use of earth dating back to the 7^{th} millennium BC, and in this area earth has was mainly used in its unbaked state as bricks. The Great Wall of China believed to be man's greatest venture in construction was built of earth and stone 2000 years ago during the Qin dynasty (221-207 BC). The giant Buddhist temples and monuments, dating back several millennia before Christ, further reinforce the use of earth in this region. The Egyptian civilisation did not influence much on other cultures and continued mainly in Wattle and Daub construction until such a time the northern regions of Africa were influenced by the Mediterranean civilisation, which experienced the use of sun dried bricks and rammed earth.

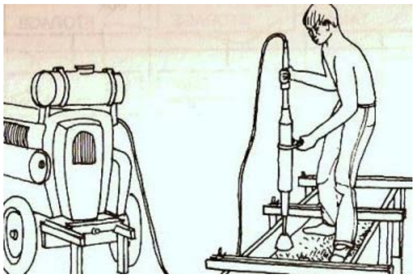
In eastern Africa, movements by the Indian Ocean, the migrating Kushites and the influence of the Axum Kingdom (3^{rd} to 8^{th} BC) from Nubia as far back as Kenya have spread the use of sun dried bricks and introduction of Islam in West Africa. As a result there was a great change in the architecture of the surroundings with the introduction of mosques. These were mainly built of earth using local expertise. In Zimbabwe building in earth dates back as far as the 12^{th} century. Earth was being used progressively mainly in the rural areas. Existing urban structures of earth can be seen mainly in the houses of the Crainbone suburb of Harare and in Bulawayo's Saurcetown suburb.

This paper has so far concluded that soil has been used in its natural state for a long time in construction and has produced satisfactory results. Nowadays, stabilisation of earth is a very common modern construction methods and it modifies the properties and characteristics of soil but does not improve quality. Where the soil is not disturbed, grouting and in disturbed various methods of stabilisation are used. These methods include three types, namely: - Mechanical, Physical and Chemical stabilisation. Mechanical stabilisation involves the application of force directly on the soil by compressing or ramming, thus changing the density, mechanical strength, compressibility, permeability and porosity. Physical stabilisation is the modification of the texture by varying the percentages of the mixed particles. Chemical stabilisation makes use of chemicals or other materials to modify the soil properties.

3. PRODUCTION OF RAMMED EARTH

As its name suggests, rammed earth is formed by compacting moist sub-soil inside temporary formwork. Loose moist soil is placed in layers 100-150mm deep and compacted using either a manual rammer, or with the advancement of technology, pneumatically powered rammers. Formwork is removed after the earth has been adequately compacted and left to dry out, leaving walls often exhibiting a distinctive layered appearance of successive compacted layers of soil within the formwork. Walls are typically 300-450mm thick, but this can vary widely according to design considerations and requirements.

Correct proportions of sand, clay and water are mixed together and poured into the formwork and compacted by ramming to the sufficient wall strength after which the framework is moved to another section of the wall, either horizontally or vertically, repeating the same process until the wall is finished. Fig 05A, Fig 05B, and Fig05C shows the wall construction formwork of rammed earth and different types of ramming techniques.



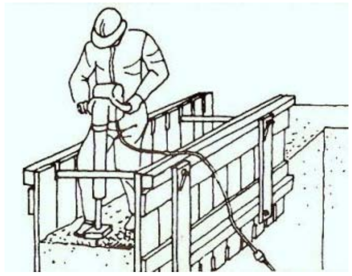


Fig 5A
Pneumatic ramming

Fig 5B
Pneumatic ramming

Fig 5C
Vibration ramming

Source: Houben & Guillaud, 1989, 211.

The quality of a rammed earth house depends on the quality of the soil used, and the soil is normally collected from the excavation. Excavation can be done manually using simple hand tools, or mechanical excavation employs a bulldozer and a high loader to collect the soil. The excavated soil is screened through a mesh to remove large stones and unwanted particles. The breaking down of small particles is necessary to ensure an even distribution of soil particles and in the case of clay soil; pulverisation affords the opportunity to mix with a sand proportion to attain an ideal mixture. Soil mixing produces a homogeneous mixture of soil at which point a stabiliser is added. Mixing can be manual using a shovel or mechanically using a concrete mixer. Formwork used in rammed earth construction varies in terms of style and shape. Formwork usually constructed from different materials such as steel, logs, aluminium, wood and fibre glass sheets. Ramming can be mechanically assisted (pneumatic & vibrating machines) or manually used using conventional rammers. Though mechanical ramming produces better results, conventional ramming is sufficient and more affordable. Fig 06 details the process of rammed earth production in construction.

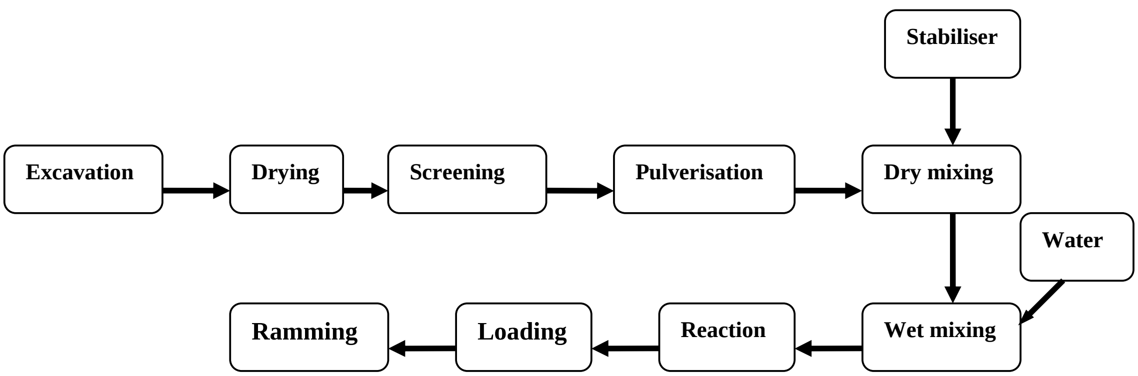


Fig 6.Production process of rammed earth.
Source: Author, 2007.

A rammed earth wall is about 40 percent cheaper to build than a standard stud wall, including labor. Rate of wall construction is typically between 5 and $10m^2$. Rammed earth is not just an economic construction technique, it also results in some of the most pleasant, comfortable, and energy-efficient buildings available at any price. Using tinted stucco, a builder can finish any house in almost any color or architectural style, combining economy, utility, and aesthetics. Untouched, the walls adopt the color of the natural earth used in its construction. There are also unseen ecological benefits. For example, using less wood allows more trees to live and provides all living things with more oxygen. Less paint and chemicals are used which might otherwise pollute our environment.

4. PRODUCTION OF COMPRESSED EARTH BLOCK (CEB)

Selected soil (sand & clay) is mixed with water to the correct proportions and then placed in a hydraulic or hand operated compressing machine to produce compressed blocks, which, after curing, is used for building walls. Some of the process stages in the production and construction with earth blocks are similar to rammed earth and these stages could be easily grasped and applied easily. Fig 07A, Fig 07B and Fig 07C shows manual and motorised press machines to produce earth compressed blocks.

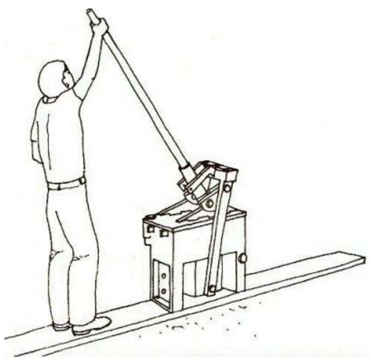


Fig 7A
Manual Press

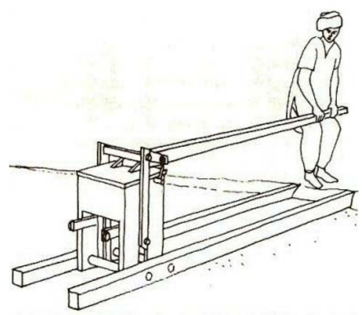


Fig 7B
Manual Press

Fig 7C
Motorised press

Source: Houben & Guillaud, 1989, 211.

To begin with, the subsoil should be excavated after the removal of the topsoil. Soil for block making should be reasonably free from organic material (root, humus, grass etc.) which may interfere with the setting and hardening of the cement (stabilizer), thus resulting in weaker blocks. The excavated soil is then dried and pulverised. After pulverisation, the soil is screened so as to use particles no courser than 6 mm in diameter. The volume of components (not mass) is normally used to measure the particles for mixing. Homogeneous colour is first obtained in mixing the dry components. Water is added gradually to the mixture to obtain a semi-dry blend reaching the optimum moisture content. Finally, blocks are made in a press machine; there are many types of presses, ranging from hydraulic, motorised, electrical and manual. The semi-dry mixture is loaded into the mould cavity and covered by the dress cover plate. Compaction is attained by pulling the lever down from the suitable height and the compressed block is ejected by removing the cover plate and engaging the lock mechanism to lift the block up. The fresh blocks are stacked in piles up to one meter in height where they are cured in two stages. After moulding the blocks, they are maintained under humid conditions for 7 days and then exposed to air to cure for a further 21 days. Fig 08 (below) shows the total process of Compressed Earth Block (CEB) production.

The advantages of constructing with CEB are: - the bulk raw material is abundant, production can be done close to the building site hence reducing time and transport costs, the production method has a low energy requirement, low skill requirements enable community participation in the construction process, technology is environmentally conscious in terms of pollution and deforestation, innovative block design can enable its use in earthquake prone areas, total construction cost is very affordable and raw component materials such as water is not required in large quantities.

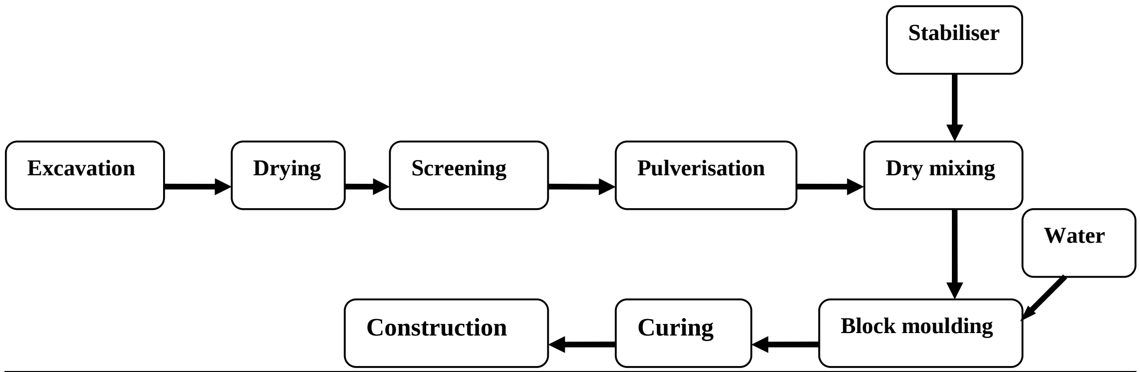


Fig 8.Production process of compressed earth block.
Source: Author, 2007.

5. POSSIBILITIES OF USING EARTH AS LOW COST CONSTRUCTION MATERIAL IN ZIMBABWE

According to Dwyer (1979), "serious physical deficiencies are all too obvious in almost every city, but in no aspect of provision is the task so daunting as in housing…. Over and above there are important political organizational and conceptual efficiencies. The very size of existing urban housing deficits and the probable extent of the future needs have now reached such staggering proportions in most developing countries as almost to induce a general state of mind among responsible officials that no practical solution of any kind is possible…" The housing situation is out of control in most third world nations and on the other hand the cost of building materials has sky rocketed in Zimbabwe making it very difficult for the majority of the people to build houses. Fig 09 shows how the construction cost in Harare and Bulawayo has increased astronomically between 2001 and 2002. Fig 10 shows how cement prices (one of the major building material) increased very rapidly between 2000 to 2002.

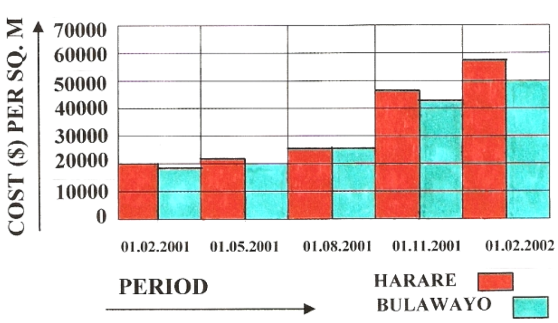


Fig 9.
Construction costs per sq. m. in Hre. and Byo.
Source: Author, 2003 (information gathered from Turner & Townsend Africa, Bulawayo)

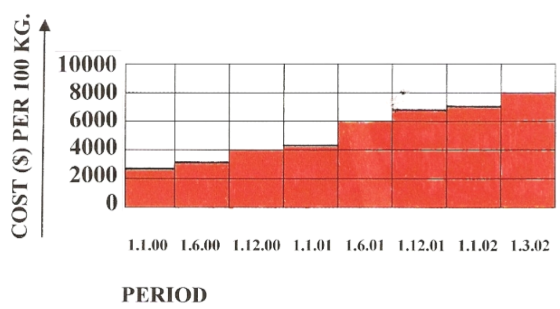


Fig 10.
Cement price increased very rapidly in Zimbabwe.
Source: Author, 2003 (information gathered from Turner & Townsend Africa, Bulawayo)

The use of common and established construction materials such as cement has contributed to push housing beyond the reach of most of the people in Zimbabwe, and nowadays many are realizing and prompting the need to look for affordable alternative materials and construction techniques. Apart from the high cost, the availability of building materials has become a cause for concern and this has led to the import of some materials. On the other hand the import of construction materials is practically impossible because of the lack of foreign currency in Zimbabwe. It is in the light of such arguments that it seems appropriate to consider looking into a materials approach to housing and the material to consider is earth. The idea of promoting earth as an alternative building material for comfortable, affordable and sustainable housing seems to be a noble one given the prevailing circumstances since the earth approach could prove a solution to the housing crisis in Zimbabwe.

According to Easton (1998), rammed earth construction is a cheap way of providing shelter since earth is an abundant resource. A simple mechanism is used with semiskilled labor. It is environmentally friendly, since no firing is required; hence conservation of wood, coal and electricity. Easton's statement proves that, the aspect of sustainability and environmental conservation of low cost housing is supported by the use of earth as a construction material. Frescura (1981) writes, "in addition to its political, economic, social and ecological advantages, earth has great cultural and architectural importance." Construction in earth has the uniqueness of manifesting the cultural heritage of any people and encouraging the continued use of the material helps to maintain and preserve the craftsmanship and cultural values embedded in earth building. However, when using earth as a low cost construction material for housing we should not assume that all housing problem will disappear. According to Denyer (1978), "earth architecture should not of course be considered a miraculous solution to neither all our housing problems, nor one which can be applied successfully anywhere, everywhere." Besides, it is very important to evaluate technical needs and social and economic requirements of the local production situation of earth before implementing such earth constructions. Before any building is constructed with earth, it is essential to identify the soil to be used. The identification process involves various tests, which may need the use of a laboratory. Apart from the laboratory identification process, local knowledge of the soil and traditional skills is necessary. In Zimbabwe, loam soils of different colours dominate the northern region while the Kalahari sand deposits cover much of the southern region. The unbaked earth can be used to make rammed earth and compressed earth blocks (CEB) in Zimbabwe to construct low cost sustainable houses.

According to Houben & Guillaud (1989, p 305), in 1976 alone seismic activity in the Philippines, Indonesia, Turkey, Italy and China caused the loss of more than 500,000 lives. Fig 11 shows the seismic areas of the world and Zimbabwe is not within seismic area. Hundreds of millions of people live in the cyclones and similar types of storm area in the world and it destroys so many infrastructures every year. Fig 12 shows storm regions of the world and the whole of Africa is almost out of storm area except Madagascar. Flood is another form of natural disaster which causes many deaths and the destruction of human settlements every year. During the Honshu Tsunami on 15 June 1896, 26000 people were killed in Japan (Houben & Guillaud 1989, 324). Fig 13 shows the flood areas of the world in which it is very clear that Africa is less affected by flood. So, from the above discussion it can be posit that earth construction and building is safe in terms of natural disasters in Zimbabwe.

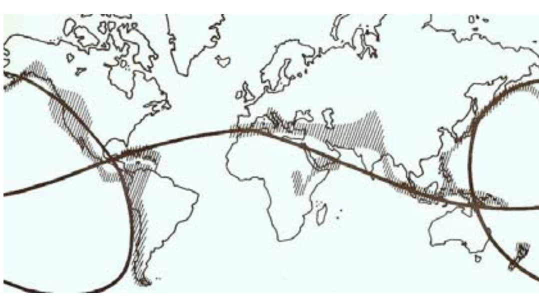


Fig 11
Seismic regions of the world.
Source: Houben & Guillaud, 1989, 306.

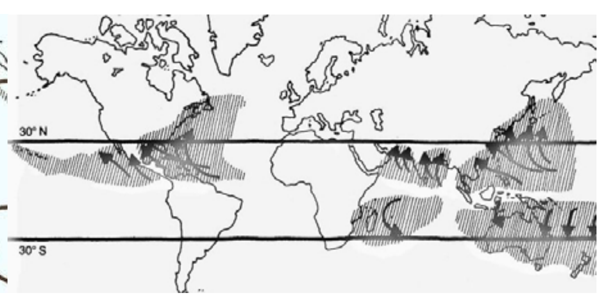


Fig 12
Storm regions of the world.
Source: Houben & Guillaud, 1989, 320.

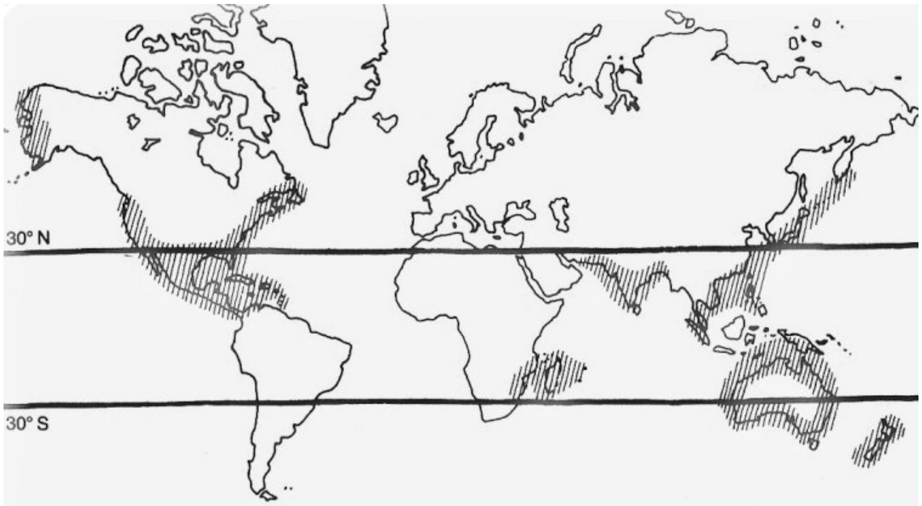


Fig 13
Flood regions of the world.
Source: Houben & Guillaud, 1989, 324.

6. USE OF EARTH AS A MODERN CONSTRUCTION MATERIAL IN ZIMBABWE

Zimbabwe did not recognize the use of earth for construction of 'descent' shelter for the urban environment. The Zimbabwe Standard Code of Practice for Rammed Earth Structures was started shortly after publishing the Code of Practice in 1996. The In-situ Rammed earth Company led by Mr. Rowland Keable who has over 15 years' experience working with rammed earth in Africa, Australia and the UK, initiated the request to the Standards Association of Zimbabwe[SAZ] and was seconded by the then newly formed Scientific and Industrial Research and Development Council [SIRDC]. The In Situ Rammed Earth Company Founded and directed by Mr. Rowland Keable promoted the use of rammed earth as a green, sustainable material for the future. He pioneered many rammed earth projects in Zimbabwe among them some of the first officially recognized in Zimbabwe since the country's independence. He worked largely in conjunction with the SIRDC in the late 90s to revive rammed earth construction in Zimbabwe. One of his first projects in Zimbabwe was the British government, Overseas Development Administration (ODA) funded; DfID School block (Fig 14) at the Scientific and Industrial Research and Development Centre (SIRDC), Hatcliffe, Harare, Zimbabwe. This project was mainly constructed to demonstrate that rammed earth could successfully support a roof span of 8m whilst at the same time being a test bed for the publication of Rammed Earth Structures: A Code of Practice. The building also incorporates boron treated timber roof, which was designed by the Timber Research and Development Association TRADA. The building was inexpensive, and showed that wide span roofs are possible with the technology, important for classrooms and clinics. The low carbon dioxide emissions also make it a good choice environmentally, particularly saving forest resources from being used for brick production.

Each bag of cement produced results in 7kg of carbon dioxide being released into the atmosphere. An average $70m^2$ house built from concrete blocks will cause almost a tonne of carbon dioxide emissions. Rammed Earth on the other hand is not burned and does not cause chemical reactions which produce carbon dioxide. Using newly developed polymers Rammed earth will become a zero emission material, while at the moment it has only very low emissions. These come from stabilisers principally in the foundations. In the Hatcliffe building, concrete was used for the foundations at the insistence of the host organisation.

Fig 14.
Rammed earth DfID block at SIRDC, Hatcliffe, **Zimbabwe. Source: In Situ Rammed Earth Co. Ltd, Zimbabwe, 2005**

Fig 15.
Bonda Classroom. Source: In Situ Rammed Earth **Co. Ltd, Zimbabwe, 2005.**

This house/classroom block built on SIRDC premises attests to the versatility of rammed earth construction. The creation of this was a milestone in illustrating how rammed earth can be used to lower construction costs. This building technology was 60% cheaper than concrete blocks and could provide double the number of built units for the many African school building programs, as well as clinics, homes and a range of commercial buildings. The In Situ Rammed Earth Company also carried out a number of rammed earth projects in the country among some of them were a classroom block (Fig 15) in Bonda, Manicaland commissioned by pioneering passive solar architect Mick Pearce in 1997, Office and housing (Fig 16) in Chimanda on the North East border with Mozambique.

Fig 16.
Chimanda House under construction
Source: In Situ Rammed Earth Co Ltd

Fig 17.
House built by SIRDC at Rukanda School, Mutoko
Source: The Herald, ZITF Supplement (25 April 2006)

SIRDC built a rammed earth teacher's house at the proposed site of Rukanda Secondary School in Mutoko in Mashonaland East province. As seen form the picture (Fig 17), the house’s appearance is impressive. An analysis of the costs incurred in building the two-bed roomed Rukanda teacher's house shows that construction using rammed earth and roofing with MCR (micro-concrete roofing) tiles resulted in a low cost of 18 million Zimbabwe dollars compared to $45 million when using conventional technologies. An important point to note is that a good part of the $18 million was used for peripheral expenses such as transport, accommodation and allowances for the SIRDC technical staff who supervised the project. Besides making housing affordable to the majority of the population, these two SIRDC initiatives have the added advantage of employment creation. Young people will be trained to construct structures using rammed earth as well as making and laying the MCR tiles under the supervision of SIRDC qualified staff (as was the case in the Mutoko project).

The use of compressed earth block construction technology is fairly new in Zimbabwe. The Chitungwiza house is one of the few known and meaningful developments using this form of building. The wall of this house is built of compressed earth blocks and roofed with micro-cement tiles. This was a deviation from the normal burn clay bricks or cement bricks/ blocks which are usually used with an asbestos roof for most of the low income housing projects in Zimbabwe. This pilot project by the Intermediate Technology Group was implemented with the participation of the Chitungwiza municipality in 1993 as a low income house. The aim of this project was to evaluate the response of the people towards earth structure and the performance of low tech and sustainable materials used in the construction of low cost housing. The use of local labour and the absence of imported materials sent a message to the local communities. The message was that the solution of affordable sustainable and low cost housing is possible. Up to now this structure stands as a success to all players working in the housing industry in Zimbabwe.

7. CONCLUSIONS

Earth is affordable and available and would be appropriate in the case of low cost house construction in Zimbabwe. This paper has argued the promotion and implementation of earth as an alternative material is worthwhile. It is possible to use un-stabilised raw earth as rammed earth or compressed earth blocks; but the stabilised form is more suitable for the Zimbabwean situation in terms of by-laws and housing standards. The only challenge that prevents earth becoming the preferred choice of building material amongst the general population is the acceptability of this material by that same population. An awareness and understanding by people to environmental issues such as air pollution, deforestation, land degradation and energy conservation would help them change their attitudes and views towards earth building. The flexibility and simplicity in technology incorporated in earth building affords adaptability and easy transfer of knowledge between different stakeholders in the building industry. Individuals and community as a whole can easily participate in building their own homes in affordable ways.

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