USE OF STABILISED EARTH IN THE CONSTRUCTION OF LOW COST SUSTAINABLE HOUSING IN AFRICA – AN ENERGY SOLUTION IN THE ERA OF CLIMATE CHANGE

Mohammad Sharif Zami and Angela Lee

Abstract

Stabilised earth is an alternative building material which is significantly cheaper than using conventional brick and concrete, and is also environmentally sustainable. Earth has been used as a construction material in every continent and in every age. 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. Most African countries do not have any well structured and effective program to address the global agenda of sustainability through the use of appropriate construction materials. In order to demonstrate stabilized earth as a sustainable appropriate construction material, the experiences and practices of using earth construction can be studied and harnessed from other subcontinents to demonstrate the dynamism of this material suitable for low cost house construction in the African subcontinent. This paper aims to identify and highlight potentiality of stabilized earth construction in the solution of low cost housing crisis in Africa and justify the use of this appropriate construction material is an energy solution in the era of climate change.

Keywords

Earth construction; sustainability; climate change; low cost housing.

Introduction

Cities in the third world have, since the 1950's, experienced unprecedented growth in terms of spatial development and population increase; urban population increase has particularly been high due to rural-urban migration (Dwyer et al, 1981, 33). The urban population alone in Zimbabwe increased from 27□ in 1992 to 42□ in 2002 (Chakwizira & Kuchena, 2004). Unfortunately, third world cities were never planned for these magnitudes of growth in population influx, nor do they in reality have the required jobs and facilities to support such expansion (Srinivas, 1999). Urban facilities, especially housing, have failed to meet the demand of the rural poor who migrated to urban areas (Kamete, 2006). According to UN Habitat (1996), housing shortage in African cities ranges from 33% to 90%. According to the South African census report of 1996, 1,049,686 households lived in informal dwellings. UN Habitat (1996) also estimates that approximately 60% of the African population reside in shantytowns, slums and uncontrolled settlements. A solution has to be found to provide sustainable low cost housing for the above stated squatter's and shack's inhabitants which is 'eco'-friendly and will preserve the environment for future generations; because climate change has been described as one of the most important environmental issues facing world today. There has been increasing consensus that this is attributable to human activity, which has been recognised and reflected by governments worldwide through implementation of various pieces of legislation.

A critical literature review method was adopted in this study to investigate how the use of stabilised earth in the construction of low cost sustainable urban housing in Africa can reduce carbon dioxide emission and contribute towards the solution to climate change. The paper begins with demystifying climate change and its influence on mankind including its environment. The paper critically analyses the benefits and drawbacks of earth construction in general and empirical evidence of environmental benefits in particular.

Climate Change

Climate change is fast rising up the international agenda, driven by growing scientific and political consensus that it is the greatest environmental threat and challenges of modern times. Governments, businesses, and the wider society are affected and all have a role to play in tackling it. This emergent need is evident around the world through the many international agreements such as the Kyoto Protocol, European agreements such as the European Emissions Trading Scheme and European directive on the energy performance of buildings (EPBD), and national measures such as the United Kingdom's Climate Change Programme (UKCCP) and Climate Change Levy (CCL). According to Oxford Reference Online (2001), the terms "Climate Change" and "Global Warming" refer to an increase in the average temperature of the earth, primarily because of the rise in concentration of various greenhouse gases in the atmosphere. The phenomenon of climate change includes both global and regional changes. The main cause of concern is the great increase in carbon dioxide released by the burning of fossil fuels around the world. Various other gases also contribute to the climate change which includes Methane, Nitrous Oxide, Chlorofluorocarbons, Hydro fluorocarbons and Sulphur Hexafluoride. Collectively these greenhouse gases contribute towards the enhanced greenhouse effect (Oxford Reference Online, 2001).

According to king (2005), it is often reported that scientists themselves cannot agree whether climate change is really happening, as the climate had changed naturally before, whether it is influenced by human activities and whether, even if both things are true, it really matters. However, the majority of credible scientific opinion is clear on all three points. There is inevitably much that remains uncertain in the science, given the enormous complexity of the earth and climate systems themselves, but equally a good deal of science is well-established. However, beyond any reasonable doubt the sceptics are wrong, climate change is a real and present danger and mankind is driving the process through combustion of fossil fuels (King, 2005).

Al Gore (2006) explained that out of a study of 928 (10% sample) peer reviewed scientific studies dealing with climate change in scientific journals during the past 10 years, there are zero disagreeing with the scientific consensus that green house gas pollution has caused most of the warming of the last 50 years. Subsequently, Al Gore (2006) believed there is a "misconception that there is disagreement about the science, deliberately created by a relatively small group of people, who's principle objective was found to be to reposition global warming as theory rather than fact". Upton Sinclair once stated that 'it is difficult to get a man to understand something when his salary depends on his not understanding it' (cited by Al Gore, 2006).

According to Edwards (2005, p3), fifty percent of all resources consumed across the planet is used in construction, making it one of the least sustainable industries in the world and the World Health Organisation estimated in 2003 that global warming was causing 150000 deaths a year. Edwards (2005, p9) also stated that by 2050 it is anticipated that the human race will have four times the environmental impact it had in 2000 (based on a 2 percent annual economic growth and a global population of 10 billion). The EU estimates that air pollution from traffic is the second biggest killer in Europe, leading to 60000 deaths a year from bronchitis, asthma and heart disease (European Environment Agency, 2001). According to Edwards (2005, p22), buildings are big users of raw materials and the environmental capital locked in them is enormous, as is the waste footprint:-

• Materials: - 60% of all resources globally are used for construction (roads, buildings, etc.).

• Energy: - nearly 50% of energy generated is used to heat, light and ventilate buildings and a further 3% to construct them.

• Water: - 50% of water used globally is for sanitation and other uses in buildings.

• Land: - 80% of prime agricultural land lost to farming is used for building purposes and much of the remainder has been lost through flooding due to global warming.

• Timber: - 60% of global timber products end up in building construction and nearly 90% of hardwoods.

Therefore, environmental damage resulting from current construction practices is clear, thus, it is imperative that environmental damage in the form of Global Warming needs to be addressed if we want to avoid disaster.

Consequences of Climate Change

The impacts of climate change, as identified by the IPCC (1995) include changes to human health and the environments, as well as the global and regional economy, therefore creating social and commercial costs to office based companies. Windell (2007) explains that the key consequences will depend on timescale, short term changes – between now and 2020 – will be no more than inconvenient, however in the long term there will be profound issues which will entail social, economic and political unrest. Al Gore (2006) explains that, "the most vulnerable part of the earth's ecological system is its atmosphere, the composition of which is now changing", and this is due to a small set of factors.

IPCC (2007) explain that 'warming of the climate system is unequivocal, as is now evident from observations of increases in global average air temperature and ocean temperatures, widespread melting of snow and ice, and rising global average sea level'. The Carbon Trust

(2005) describes the 'most clear, prominent and consistent indicator' as the retreat of mountain glaciers (Fig 1). According to Al Gore (2006), "40% of all people in the world get their drinking water from rivers and spring systems that are fed more than half by the melt water of the glaciers and within the next half century those 40% of people on earth are going to face a very serious shortage because of this continued melting".

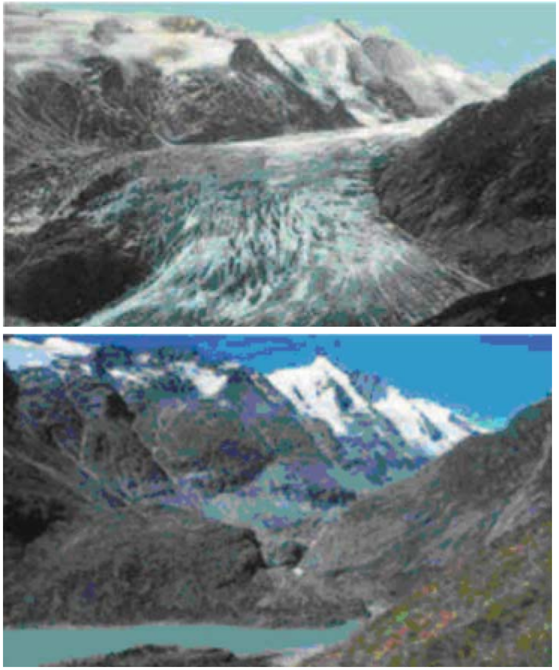

Figure 1: Alpine Glacier: comparison of present to 1900 Pasterze Glacier in Kärtnen, Austria. Photo Source: Munich Society for Environmental Research (Source: Carbon Trust, 2005).

Climate change is a moral issue in all societies all over the world. If people and businesses worldwide continue to allow climate change to occur it is deeply un-ethical, as scientific studies have demonstrated the seriousness of the crisis we face. Climate change is therefore a critical business issue for commercial office companies today in the modern world. Such businesses significantly contribute to energy use and carbon emissions, however, through implementation of different measures driven by legislation there are many opportunities to make savings. These savings are both financial and reduction of the detrimental effect they have upon the environment.

Al Gore (2006) also explains that, "global warming paradoxically causes not only more flooding but also more droughts. Severe droughts occur at the same time as other areas are flooded. One of the reasons for this has to do with the fact that global warming not only increases precipitation worldwide but it also relocates that precipitation". Hunter, CEO of IAG, Australia's largest insurance company explains that 'there has been almost a linear increase in catastrophes occurring since global temperatures started rising in the early 1970's (Al Gore, 2006). Table 1 shows the recent effects and trends as aforementioned and an assessment of human influence on the trend and the likelihood of future trend (IPCC, 2007). According to Carbon Trust (2005), the potentially sensitive switch point areas concerning a number of the phenomenon in Table 1, in which local effects may trigger larger-scale changes. However, melting of the Arctic ice may have already reached a tipping point that could trigger severe weather changes around the world.

Phenomenon and direction of trend	Likelihood that trend occurred in late 20th century (post 1960)	Likelihood of a human contribution to observed trend	Likelihood of future trends based on projections for 21st century
Warmer and fewer cold days and nights over most land areas.	Very likely	Likely	Virtually certain
Warmer and more frequent hat days and nights over most land areas.	Very likely	Likely (nights)	Virtually certain
Warm spells/ heat waves. Frequency increases over most areas.	Likely	More likely than not	Very likely
Heavy precipitation events. Frequency increases over most areas.	Likely	More likely than not	Very likely
Area affected by droughts increases	Likely in many regions since 1970's	More likely than not	Likely
Intense tropical cyclone activity increases	Likely in some regions since 1970	More likely than not	Likely
Increased incidence of extreme high sea level	likely	More likely than not	Likely

Table 1: Recent trends, assessment of human influence on trend, and projection for extreme weather events. (Source: IPCC, 2007).

Conventional Brick Manufacturing Industry and Carbon Dioxide Emission

According to Allinson and Hall (2007), it is estimated that the construction and the operation of buildings is responsible for around half of all global Carbon Dioxide emissions, thereby contributing the largest single source attributable to climate change. Besides, Africa needs millions of affordable houses for the majority of its population. The conventional construction of low cost houses utilizes factory manufactured ceramic brick in Africa.

Majority of these brick manufacturing industries uses wood to burn the brick. A few industries use coal for burning the brick. This contributes deforestation in most of the African countries. Fig 2 shows a typical and very common view of brick manufacturing industries in most of the African countries. During the process of burning, large amount of Carbon Dioxide and other gases are emitted to atmosphere and an enormous amount of waste is generated (Barbosa et al, 2007). If a two bed roomed low cost house needs three thousand bricks and Africa needs millions of housing units, it can be

Figure 2: A common view of brick manufacturing industry in Africa and Carbon Dioxide emission. (Source website: eLivermore.com, 24.07.2008.).

imagined how much wood is needed to burn all these bricks. According to Barbosa et al (2007, p30), the use of unburned earth in construction will contribute to reduce energy consume, Carbon Dioxide emission, amount of residues and desertification process.

The BBC Climate Website (2007) explain that in order to stabilise climate change all together, emissions would have to be reduced around 70% globally and one of the main problems with Carbon Dioxide is the length of time it remains in the atmosphere as it can take about 100 years for it to disperse, targets set out by the Kyoto Protocol are nowhere near this. Therefore, all that can be done is to reduce the effects of climate change. Even if the concentration of all GHGs and aerosols had been kept constant at 2000 levels, a further warming of about 0.1 degree centigrade per decade would be expected according to emission scenarios (IPCC, 2007).

The Advantages of Earth Construction

Today approximately 30 percent of the world's population lives in earth houses (Roaf, 2004). If these dwellings had been built in so-called modern materials like aluminium, plastic, or concrete we would have been far closer to a global ecological breakdown (Minke, 2001). 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. Stabilized rammed earth materials have low embodied energy content because approximately 95% of the raw materials are unfired and are locally available (Allinson and Hall, 2007). 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. The advantages of a mastery of earth construction are multiple and complementary and are as follows: -

1. Appropriate use of material considerably reduces construction cost (Lal, 1995; Zami & Lee et al, 2007) and hence stimulates the economy. Earth construction allows appreciable economies to avoid excessive expenditure of energy.

2. Earth construction products have the potential to reduce energy used in production by 80-90%, with efficiency increasing with scale of production (Morton, 2007).

3. Earth is easy to work with using simple tools and less skill. So, it encourages and facilitates self-help and community participation in house building (Kateregga, 1983).

4. It is strong in compression and so makes good walls and can also be made strong in sheer and tension through additives and reinforcement (Lal, 1995, p119).

5. The higher the ratio of non-manufactured local materials the lower the ratio of man-made energy. Earth is nature's product (Lal, 1995, p119); 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 (Alphonse et al, 1985).

6. Earth has such a low rate of thermal conductivity (it's actually near zero); warmth takes almost 12 hours to work its way through a 300mm thick wall. The half-day rate of heat transfer makes the material a perfect substance for providing thermal mass in passive solar construction (Cassell, 1993). The sun's warmth will actually be reaching the interior of the house during the cold hours of the night, yet the walls insulate the interior from summer temperatures (Kateregga et al, 1983).

7. According to Lal (1995, p119), earth construction provides excellent heat insulation, so the interior space is cooler in summer and hotter in winter than a building made of conventional building material such as, concrete and brick. Due to this property, earth constructions are suitable in tropical and sub-tropical climatic condition.

8. According to Cassell (1993), besides insulating and storing heat, rammed earth also allows

more air exchange than does any comparable material. A rammed earth house breathes without suffering any significant heat loss. This is especially important today because the interior of houses are 5 to 7 times more polluted than the outside.

9. Earth materials ability to regulate indoor air humidity is highly significant in creating healthy indoor climate, especially in relation to Asthma, where UK has some of the highest rates of in the world (Howieson, 2005).

10. Earth is a good noise absorbent which is a desirable quality in house design (Kateregga, 1983)

11. According to Morton (2007), earth bricks and blocks can substitute for concrete blocks in most internal applications, where it is not suitable for external use due to the severe climatic reasons.

12. The thick walls also provide a feeling of security which goes beyond their warmth and strength. Moreover, putting metal grills on window and door openings can make a house fortress. The compression strength of rammed earth is higher than that of a concrete wall of similar thickness (Houben & Guillaud, 1989) thus making a rammed earth building nearly as durable as a bomb shelter.

13. A rammed earth wall is about 40 percent cheaper to build than a standard stud wall, including labor (Cassell, 1993). Rammed earth is not just an economy construction technique it results in some of the most pleasant, comfortable, and energy- efficient buildings available at any price (Zami & Lee, 2007). Using tinted stucco, the pise builder can finish his house in almost any color or architectural style (Houben & Guillaud, 1989).

14. According to Morton (2007), earth brick can be produced with minimal investment in new plant and processes. Earth bricks can follow the standard fired brick manufacturing process, but are removed from the cycle before firing.

15. Since this natural material can be used locally with reduced transport costs (Kateregga et al, 1983) and without secondary industrial transformation.

16. Earth building can be seen as a means of creating employment (Zami & Lee, 2007).

17. Given basic guidance, building designers could easily incorporate it (earth construction techniques) into current building design (Morton, 2007).

18. Earth is very good in fire resistance (Alphonse et al, 1985).

The use of earth with an innovative approach would apply well to the African context considering that the modern earth construction technology reflects all the above advantages. In the light of all the above advantages and benefits of earth construction it can be posited that, earth construction is sustainable solution to low cost housing crisis in Africa. Earth, as a construction material (mixed with a certain amount of clay), has a low ecological impact (Minke, 1984). Earth building methods are highly refined and developed in un-industrialised countries, and interest is growing in Europe (Roaf et al, 2004). Roaf et al (2004) also listed the arguments in favour of earth constructions as a strategy for the future: -

1. They are based on resources available in practically unlimited quantities in most places.

2. Only low energy inputs are required in the building process, approximately 1-3 percent of that used in similar concrete buildings (Berge, 2001).

3. Earth houses are long lasting if built correctly, and when the house is scrapped the earth returns to its original state without any degrading of quality.

4. Earth houses are labour intensive rather than cost intensive.

The Disadvantages of Earth Construction

According to above description earth construction is advantageous, but there are some drawbacks of earth construction technology which makes it sometime unpopular amongst professionals, clients, and decision makers. According to Dunlap (1993), a significant problem associated with the construction of earthen buildings is the lack of standard criteria to evaluate the finished product. For conventional brick and concrete block houses, there are specifications and methods of tests for evaluating nearly every item of construction material that goes into the house from gypsum sheathing to roofing shingles. It is very rare to find such specifications for adobe blocks or rammed earth walls in African countries. This certainly serves as a deterrent to potential owners of earth homes. More importantly, it deters the lending institutions from investing money in such a home when they have no guarantee that the structure will be standing halfway through the life of the loan.

According to Cassell (1993), the two historical disadvantages to rammed earth has been water damage and labor intensity. The Australians have solved the water damage by spraying the wall with a transparent plastic Ideal for wall cleaning with a hose or damp sponge. Labor intensity has been solved by the use of gasoline and pneumatic powered tamping devices (Beyond 2000). Selma Robinson, a magazine writer, in her article “Houses Dirt Cheap” states, “And if the houses of Pise de terre are scarce, architects and builders who know about this type of construction are scarcer still. The low cost of Pise de terre construction work may, paradoxically, tend to limit its acceptance. There is very little money to be made from it by contractors and the skilled building trades. Even the architects, collecting their customary percentage on total cost, made less on this type of building” (Robinson, 1939). Kateregga (1983) listed the following weaknesses of earth (unstabilised) in building construction: -

1. It has extremely low tensile strength (Blondet & Aguilar, 2007) and its poor and very low load bearing capacity makes it unsuitable for supporting heavy roofs from large span building.

2. It has a very high moisture (water) absorption ratio which also contributes to its structural failure.

3. Earth has a low binding strength for its particles and this contributes to its low compression strength.

4. Earth has a very high shrinkage/ swelling ratio resulting in major structural cracks when exposed to different weather conditions.

5. It has a low resistance to wear and tear, less durable and calling for frequent repairs and maintenance when used in building construction works.

Beside the above weaknesses, Lal (1995, p119) stated some more weaknesses of earth construction. These are as follows: -

6. It is eroded easily by water, which makes it use difficult in areas with high rainfall or possibilities of flooding.

7. It is susceptible to mechanical damage. Rodents can easily make hole in mud walls and under the floor, thieves can dig their way into the house.

8. Mud does not grip wood properly, so gaps often develop around wooden doors and windows in mud walls.

9. Mud houses behave poorly in the event of earthquakes.

Most of the above weaknesses are derived and mentioned from the experience of unstabilised earth construction. Most of the disadvantages associated with mud houses can be overcome by suitable improvements in design and technology, such as soil stabilisation, appropriate architecture, and improvement in structural techniques (Lal, 1995, p120). Problem of earth wall erosion by rain and flood water, rodents making hole in wall and floor, and poor performance during earthquake can be solved by making the earth stabilised. Vernacular earthen houses located in seismic areas are at risk because of their inherent structural vulnerability, and it is possible to provide reinforcement to earthen buildings in order to improve their structural performance and to prevent their collapse during earthquakes (Blondet & Aguilar, 2007).

Environmental Benefits of Stabilised Earth Construction in Low Cost Housing

The above sections analysed the benefits and drawbacks of stabilised earth construction in general and it is notable that the drawbacks of earth construction can be addressed positively if earth is stabilised. This section is going to analyse critically the existing literature particularly on the environmental benefits of stabilised earth in the construction of low cost urban housing.

According to Maini (2005), some studies have shown that, in the Indian context, building a square metre of masonry with CSEB (compressed stabilised earth block) consumes 5 times less energy than a square metre of wire cut bricks masonry and 15 times less than country fired bricks. Maini (2005) also stated that the compressed stabilised earth blocks (CSEB) are more eco-friendly than fired bricks and their manufacture consumes less energy and pollute less than fired bricks.

Energy consumption

4.9 times less than wire cut bricks
15.1 times less than country fired bricks

Pollution emission

2.4 times less than wire cut bricks
7.9 times less than country fired bricks

Table 2 shows a comparative analysis of energy consumption and carbon dioxide emission of four types of building material. According to the numerical data shown in Table 2, CSEB consume the lowest energy and lowest carbon dioxide emission if compared with Wire Cut Bricks, Country Fired Bricks, and the Concrete blocks.

Product and thickness	Number of units (Per square metre)	Energy consumption (MJ per square metre)	Carbon dioxide emission (Kg per square metre)
CSEB – 24 cm	40	110	16
Wire Cut Bricks – 22 cm	87	539	39
Country Fired Bricks – 22 cm	112	1657	126
Concrete blocks – 20 cm	20	235	26

Table 2: A comparative analysis of energy consumption and carbon dioxide emission of four types of building material. (Source: Maini, 2005.)

Adam and Agib reported that compressed stabilised earth blocks were successfully used for low cost housing in Sudan (Hadjri, 2007). According to Adam and Agib (2001), low energy input in processing and handling soil - only about 1% of the energy required manufacturing and processing the same volume of cement concrete. This aspect was investigated by the Desert Architecture Unit which has discovered that the energy needed to manufacture and process one cubic metre of soil is about 36 MJ (10 kwh), while that required for the manufacture of the same volume of concrete is about 3000 MJ (833 kwh) (Adam and Agib, 2001).

According to Vroomen (2007), there are two important aspects playing a role in the ecological impact of a construction technique, and they are as follows: -

- The energy required to construct a house and
- The carbon dioxide emission resulting from the total process.

In order to be able to assess the performances of the construction materials on the above aspects, a computation is made in Vroomen's (2007) research and to make the computations as transparent as possible, the values that were applied in different construction materials are given in Table 3.

	Energy required in MJ/ Kg	Carbon dioxide emission in Kg carbon dioxide per Kg material
Gypsum (NBVG, Herpen)	1	0.01
Cement (Adobemachine)	4.8	1.25
Soil (Adobemachine)	0.028	0
Fired bricks (Houben)	3.16	0.19

Table 3: The characteristics of the materials as applied in the computation. (Source: Vroomen, 2007).

The resulting totals are given in Table 4. The complete computation with all sources is added to the CDrom.

	Adobe	CSEB	Fired brick	Hollow concrete blocks (HCB)	Gypsum stabilised earth wall in sections	Gypsum stabilised earth massive blocks
Energy required (MJ/ fu)	36	233	1026	390	191	161
Carbon dioxide emission (Kg/ fu)	0	55	118	98	2	1

Table 4: The totals of the environmental computation. (Source: Vroomen, 2007).

Vroomen (2007) identified the following conclusions on the energy requirement and carbon dioxide emission from the above tables:

-The energy requirement of Gypsum Stabilised Earth is about half of the energy requirements of HCB.

- Adobe is indisputable the most environment friendly material.

- The firing of bricks is a very energy consuming process.

- Both cement stabilized products (CSEB and HCB) cause a large carbon dioxide emission. Due to their lower Wet Compressive Strength and high amount of gypsum required, the CSEB is no better alternative than HCB.

- A lot of carbon dioxide is released in the production of fired bricks.

- The release of carbon dioxide is almost nil in the production of Gypsum Stabilised Earth walls.

Conclusions

It is notable from this paper that there has been increasing levels of Carbon Dioxide and other greenhouse gases in the earth's atmosphere over recent years causing the climate to change, which will in some way affect every individual person worldwide. Besides, it is evident that earth construction is environmentally sustainable compare to the conventional (fired brick, concrete, etc.) building materials and would be appropriate in the case of low cost house construction in Africa. Promotion and implementation of earth as an alternative low cost urban house construction material is worthwhile and significantly helpful in achieving environmental sustainability (less carbon dioxide emission and less energy used). It is also notable from this paper that stabilisation of earth doesn't only mean the cement stabilisation. Gypsum is also one of the stabilisers which are discussed in this paper proved to be more environmentally sustainable than the cement stabilised earth. It is possible to use un-stabilised raw earth as rammed earth or compressed earth blocks; this paper described why the stabilised form is more suitable for the African situation in terms of overcoming the drawbacks of earth construction, 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, climate change and energy conservation would help them change their attitudes and views towards earth building. Besides, in earth construction individuals and community as a whole can easily participate in building their own homes in affordable ways addressing their moral obligation to climate change.

References

Adam, E. A. and Agib, A. R. A. (2001). Compressed stabilised earth block manufacture in Sudan. France, Paris: Printed by Graphoprint for UNESCO.

Alphonse, S. S. (1985). Proceedings of a symposium held in Nairobi, Kenya, 1983 Volume II: Appropriate Building Materials for Low cost Housing, African region. Nairobi, Kenya.

Allison, D. & Hall, M. (2007). Proceedings from the International Symposium on Earthen Structures: Investigating the optimisation of stabilised rammed earth materials for passive air conditioning in buildings. Bangalore, India: Indian Institute of Science.

Barbosa, N. P., Swamy, N. & Mattone, R. (2007). Proceedings from the International Symposium on Earthen Structures: Potentialities of earth construction in Latin America. Bangalore, India: Indian Institute of Science.

Berge, B. (2001). A Norwegian architect with the firm of Gaia Lista, is the author of the best book I know on materials: see Berge, B. (2001). Ecology of building materials. Architectural Press, Oxford.
Beyond 2000. Discovery Channel. 1993.

Blondet, M. & Aguilar, R. (2007). Proceedings from the International Symposium on Earthen Structures: Seismic protection of earthen buildings. Bangalore, India: Indian Institute of Science.

Carbon Trust (2005). The climate change challenge. Retrieved November 15, 2006, from www.carbontrust.co.uk

Carbon Trust (2006). The Carbon Trust three stage approach to developing a robust offsetting strategy. Retrieved November 15, 2006, from www.carbontrust.co.uk

Cassell, R. O. (1993). A traditional research paper: Rammed Earth Construction, The compaction of successive layers of earth between forms to build a wall. Retrieved August 12, 2007, from http://webs.ashlandctc.org/jnapora/hum-faculty/syllabi/trad.html

Chakwizira, J. & Kuchena, J. C. (2004). Proceedings from the First International Appropriate Technology Conference: Appropriate Low Cost Building Materials in Zimbabwe. Bulawayo, Zimbabwe.

Dunlap, W. A. (1955). Soil analysis for earthen buildings. Texas A. & M.: Austin, USA.

Dwyer, D. J. (1981). People and housing in third world cities: Perspectives on the problem of spontaneous settlements. London and New York, Longman Group Limited.

Easton, D. (1996). The rammed earth house. White River Junction, Vermont, USA: Chelsea Publishing Company.

Edwards, B. (2005). Rough guide to sustainability - 2nd edition. London, UK: RIBA Enterprises Ltd.

Frescura, F. (1981). Rural Shelter in Southern Africa. Johannesburg, South Africa: Ravon Press,.

The Concise Oxford English Dictionary (2008). Global warming, n. Retrieved February 2, 2008, from www.oxfordreference.com

Gore, Al. (Author) (2006). An inconvenient truth: A global Warming [Motion picture]. United States: Paramount Classics, Participant Productions.

Hadjri, K., Osmani, M., Baiche, B., and Chifunda, C. (2007). Proceedings from the ICE Institution of Civil Engineers, Engineering Sustainability: Attitude towards earth building for Zambian housing provision.

Houben, H., & Guillaud, H. (1989). Earth construction. London, UK: Intermediate Technology publications 1994.

Howieson, S. (2005). Housing and asthma. London: Spon Press,

IPCC (2007). Climate change 2007: the physical science basis. Retrieved February 16, 2007, from www.ipcc.ch

Kamete, A. Y. (2006). Revisiting the urban housing crisis in Zimbabwe: some forgotten dimensions? Habitat International, 30, 981-995.

Kateregga, J. K. (1983). Proceedings of a Symposium Appropriate Building Materials for Low cost Housing, African region: Improvement and use of earth construction products for low cost housing. Nairobi, Kenya.

King, D. (2005). Global warming: a clear and present danger. Retrieved November 23, 2006, from www.opendemocracy.net

Lal, A. K. (1995). Handbook of low cost housing. New Delhi, India: New Age International Publishers.

Maini, S. (2005). Earthen architecture for sustainable habitat and compressed stabilised earth block technology. Programme of the city on heritage lecture on clay architecture and building techniques by compressed earth. Saudi Arabia & India High Commission of Riyadh City Development, The Auroville Earth Institute, Auroville Building Centre.

Minke, G. (2001). Earth institution handbook. Tisbury, UK: Cathedral Communications Ltd.

Morton, T. (2007). Proceedings from the International Symposium on Earthen Structures: Towards the development of contemporary Earth Construction in the UK: drivers and benefits of earth masonry as a sustainable mainstream construction Technique. Bangalore, India: Indian Institute of Science.

Roaf, S. (2004). Closing the loop, benchmarks for sustainable buildings. London: RIBA Enterprises Ltd.

Robinson, S. (1939, August). Houses dirt cheap. The Rotarian, 24..

Srivinas, H. (1999). Sites and services in urban squatters and slums. Retrieved December 15, 2006, from http://www.gdrc.org/uem/squatters/s-and-s.html

UN Habitat (1996). Women's empowerment: Participation in shelter strategies at community level in urban informal settlements. New York: UN Habitat.

Vroomen, R. (2007). Gypsum stabilised earth: Research on the properties of cast gypsum-stabilised earth and its suitability for low cost housing construction in developing countries (Master thesis in Architecture, Building & Planning, Eindhoven University of Technology, The Netherlands, 2007).

Zami, M. S. & Lee, A. (2007). Proceedings from the 7th International Postgraduate Research Conference: Earth as an alternative building material for sustainable low cost housing in Zimbabwe. Salford, Greater Manchester, United Kingdom.

Zami, M. S. & Lee, A. (2007). Proceedings from the 7th International Postgraduate Research Conference: The influence of housing standards in the development of low cost sustainable housing in Zimbabwe. Salford, Greater Manchester, United Kingdom.

Mohammad Sharif Zami

Mohammad Sharif Zami is a Teaching Assistant and PhD candidate at the School of the Built Environment, University of Salford, United Kingdom. He has worked as a lecturer at the Harare Polytechnic, University of Zimbabwe, and National University of Science and Technology, Zimbabwe for eleven years. He also worked as an architect with architectural practices in Zimbabwe for ten years. His research interests include architectural design, landscape design, urban design, earthen architecture and housing. He has published over 20 journal and conference papers in these fields. Mohammad Sharif Zami completed a B.Arch. (Bachelor of Architecture) degree from Khulna University, Bangladesh. He also completed an MPhil. (Master of Philosophy) degree in architecture at the National University of Science and Technology, Zimbabwe. Currently Zami is doing the last stage of a PhD study at the University of Salford, United Kingdom. He can be contacted at m.s.zami@pgr.salford.ac.uk

----

Angela Lee

Dr Angela Lee (School of the Built Environment, University of Salford, UK) is the Programme Director for BSc (Hons) Architectural Design & Technology at the University of Salford. She has worked on various EU, CIB and EPSRC funded projects, including Revaluing Construction, nD Modelling and the Process Protocol. Her research interests include design management, performance management, process management, product and process modelling and requirements capture. She has published over 100 journal and conference papers in these fields, including 3 books. Dr Lee completed a BA (Hons) in Architecture at the University of Sheffield, and a PhD at the University of Salford. Dr. lee can be contacted at a.lee@salford.ac.uk