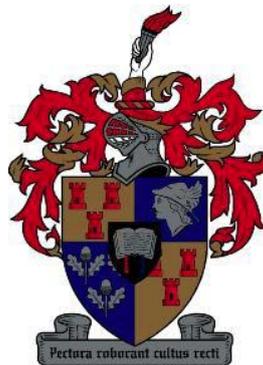


BUILDING SUSTAINABLE SETTLEMENTS IN CHIMOIO, MOZAMBIQUE

The Sustainability of Using Unfired Adobe Bricks to Construct Shelter

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Thesis presented in partial fulfilment of the requirements for the degree of Master of
Philosophy (Mphil) in Sustainable Development Planning and Management at the
University of Stellenbosch



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December 2009

DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the owner of the copyright thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Date: 18 February 2010

VERKLARING

Deur hierdie tesis elektronies in te lewer, verklaar ek dat die geheel van die werkhierin vervat, my eie, oorspronklike werk is, dat ek die outeursregeienaar daarvan is (behalwe tot die mate uitdruklik anders aangedui) en dat ek dit nie vantevore, in die geheel of gedeeltelik, ter verkryging van enige kwalifikasie aangebied het nie

Datum: 18 February 2010

ABSTRACT

Adequate shelter for the majority of the Mozambican population is still not a reality. Conventional building materials are not affordable for the poor and the governmental policies do not put much focus on the issue of housing. Also, the consideration of environmental issues in the construction industry is becoming relevant concerning the process of sustainability promotion.

In most instances, communities in Mozambique have been using local alternative materials to build their houses and unfired adobe brick is one of these materials. Compared to conventional materials, unfired adobe brick is relatively cheaper and has low negative environmental impacts. This study analysed the use of this material in Mozambique from a sustainability viewpoint to find out whether there were opportunities to construct sustainable housing for local communities.

To gather information regarding socio-economic, environmental and technical dimensions of the use of unfired adobe brick, the main research strategy privileged the use of a qualitative approach where the data collection methods involved interviews, focus group discussions, observation and direct involvement of the researcher in practical work.

Findings indicate that low costs related to the use of unfired adobe brick address the problem of affordability for the majority of local people. Local availability of suitable soils, minimal processing, use of renewable sources of energy for processing the material and recyclability/reusability all indicate that this material has very little environmental impact. Identified stresses (moisture) affecting unfired adobe structures can be avoided through low-impact methods of earth stabilization and specific design measures.

It is concluded that unfired adobe brick has the potential to contribute to the provision of sustainable housing in Mozambique. In order for this to happen, there needs to be:

- More research on construction methods applicable to the Mozambican context;

- The introduction of construction codes related to adobe construction;
- Training of local communities in adobe construction;
- The creation of housing policies; and
- Investigation into the opportunities offered by unfired adobe brick concerning sustainability.

OPSOMMING

Ordentlike behuising vir die meerderhede van die mense van Mosambiek is nog steeds nie 'n werklikheid nie. Die meeste mense van Mosambiek kan nie gewone bou materiale bekostig en die staat beleide fokus baie min op die verskafing van behuising of pogings om bou materiale meer toeganklik te maak.

Toegang tot bou materiale is een probleem maar bekommernis oor omgewings probleme is ook iets wat meer en meer in ag geneem moet word, spesifiek in terme van die bou industrie. Volhoubaarheid is ook iets wat 'n grote rol speel in ontwikkelings beluister en kan ook ander opsies vir arme gemeenskappe ontlok.

Plaaslike gemeenskappe van Mosambiek het vir 'n lang tyd, alternatiewe produkte gebruik om hul huise te bou, een van die is modder adobe bakstene. In vergelyking met konvensionele materiale is die modder bakstene goedkoper en het a baie kleiner omgewings impak. Die projek bestudeer die gebruik van die modder adobe baksteen in Mosambiek van 'n volhoubaarheid oogpunt en ondersoek of dit geleenthede skep in terme van volhoubare behuising vir plaaslike gemeenskappe.

Die navorsing het verskillende metode behels, die van persoonlike onderhoude, groep onderhoude, observasie en praktiese gebou van 'n huis met die modder adobe bakstene.

Die navorsing het bewys dat die gebruik van die adobe bakstene wel die probleem van toegang en hoe bou koste vir die arm plaaslike gemeenskap oplos. Plaaslike omstandighede werk ook om die vrag van volhoubaarheid op te los omdat die materiale en kennis plaaslik beskikbaar is. Die navorsing bewys ook dat opleiding en 'n samestelling van die plaaslike kennis kan ook lei tot 'n toename van die gebruik van die modder adobe baksteen tektologie wat volhoubaarheid oor die algemeen sal verbeter en dat dié 'n beter toekoms vir die plaaslike gemeenskappe van Mosambiek kan skep.

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LIST OF ACRONYMS AND ABBREVIATIONS

BREEAM	Building Research Establishment Environmental Assessment Method
BSRIA	Building Services Research and Information Association
CO ₂	Carbon dioxide
DEAT	Department of Environmental Affairs and Tourism
DNE	National Directorate of Edifications
DNHU	National Directorate of Housing and Urbanization
DPOPH	Provincial Directorate of Public Works and Housing
GHG	Greenhouse gases
INAM	National Institute of Meteorology
INE	National Institute of Statistics
IPCC	Intergovernmental Panel on Climate Change
LEED	Leadership in Energy and Environmental Design
TBL	Triple-bottom-line
UNDP	United Nations Development Programme
WCED	World Commission on Environment and Development

1 INTRODUCTION

“Over the centuries, indigenous, traditional ways of creating adobe shelter have developed throughout the world. Finely tuned to the culture and climate, the sun, and local resources, these regional adaptations have proven to be both practical and effective.” (Moquin, 2005: 88)

Considering the deteriorating situation of shelter of most poor dwellings in Mozambique, the above quotation suggests that by focusing on the use of adobe it is possible to attain sustainability in the provision of shelter. However, as also suggested, the use of adobe needs to be adapted according to the local context. Research can reveal the particularities of the use of adobe in Mozambique. Therefore, it is necessary to sketch the background to the research problem, justify the study, state the objectives and set out the structure of this thesis.

1.1 Setting the problem

It does not take much effort to realize that the majority of the Mozambican population is living in undesirable conditions. Basic needs that should be met for everyone today appear to be unattained treasures for the majority of the population. The need to provide food, basic education, health care, adequate water and sanitation and shelter make up the daily discourse of those who claim to be concerned with the cause, but in reality there is still a long way to go.

The provision of adequate housing is a task that is not showing significant progress and the majority of the population continue to live in informal houses. In fact, concerning poverty-reduction policies, the problem of housing is most often relegated to a secondary position. The Extreme Poverty Reduction Policy (2006-2009) focuses mainly on issues of agriculture, education and health (Government of the Republic of Mozambique, 2006). Housing does not necessarily have to be on par with these sectors, but it is axiomatic that adequate shelter plays a crucial role in improving the quality of life of individuals. Basic shelter is vital in that it provides safety, privacy and comfort to people.

Parallel to the discourse about poverty reduction, there is the universal discourse about the need to protect the natural environment. These two issues are closely related. Normally the process of poverty reduction is coupled with the process of economic development which in turn is supported by the existing natural resources (World Bank, 2008). The current patterns of development are intimately associated with most of the environmental problems the world faces today (Monbiot, 2007). In this sense, the reduction of poverty can constitute the end of a problem but there are risks that this reduction can impose serious damage to the natural environment (Loh and Wackernagel, 2004). There is, therefore, a need to harmonize the satisfaction of human needs with the integrity of the natural environment (Rogers, Jalal and Boyd, 2008).

Apart from environmental damages that can result from the use of conventional building materials (Roaf, Fuentes and Thomas, 2007), it is equally true in Mozambique that prices of conventional building materials such as cement, fibre cement and steel have been soaring depriving many people of the opportunity to get adequate housing at affordable prices. Changing oil prices are routinely blamed for changes in materials prices. Existing conventional building materials are transformed from their natural state (which implies the use of energy) and because this is not done locally, they need to be transported.

In order to face the challenges posed by the use of conventional materials, some schools of thought attempt to show that many solutions for local communities can be home-grown, thus providing better livelihood conditions for local communities, advancing well-being and reducing costs while being less harmful to the natural environment (Van der Ryn and Cowan, 1996). In order to attain development that is sustainable, local communities should pursue options of development that are economically affordable for them, that can satisfy their needs and that are integrated with fundamental processes occurring in the natural environment (Rogers, Jalal and Boyd, 2008).

Adobe is a building material traditionally used by local communities to construct cheap shelter. According to the literature on ecological design (Kennedy, Smith and

Wanek, 2002; Moquin, 2005; Woolley, 2006) this material, if compared with conventional materials, has less negative impact on the natural environment. Blinded by the perception that cement, steel and glass are the best options as building materials, the opportunities that adobe offer regarding sustainability are practically ignored at the local level. Consequently, one can propose that by focusing on the use of adobe there are possibilities to provide adequate shelter for the majority of a community's population more cheaply while at the same time ensuring that the natural environment is not affected negatively.

1.2 Justification for the study

Personal observations indicate that one of the major aspirations of any Mozambican is to have adequate shelter. By trying to fulfil this aspiration, individuals face serious financial problems. There is the complaint that construction costs have always constituted a constraint and local communities do not control the production and commercialization of building materials. However, some individuals living in local communities in Mozambique have proved that even without governmental support, they were able to find alternative ways to acquire housing.

Although there are local alternatives and local people have easy access to these options, little has been done to improve the use of local building materials. This study is motivated by the need to change this scenario and arouse interest for the use of local materials which potentially offer cheaper and unconventional ways of providing housing.

However, it is not only cost that concerns this study. Discussions about economic development and poverty reduction rarely include environmental issues as part of the equation. This is acknowledged by local institutions involved in the housing sector (Provincial Directorate of Public Works and Housing and Municipal Council), so that this study also constitutes an attempt to raise environmental awareness in these institutions and in the local construction industry.

1.3 Objectives of the study

This study aims to investigate the use of unfired adobe brick as an alternative building material from a sustainability viewpoint and to recommend actions toward the promotion of efficient use of these bricks in providing housing in Mozambique. In order to attain this aim the following three objectives are pursued:

1. Explore and describe the processes of production and use of unfired adobe brick in the local construction of houses. In this exercise the local availability of suitable soils for the production of adobe brick, methods of brick production, the relevance of the materials to local communities and the challenges facing the use of the materials must be given attention.
2. Gather data concerning aspects that directly or indirectly determine the sustainability of different building materials. It is assumed that the production and use of adobe brick are not disconnected from the natural environment from which the raw materials and energy for brick production are extracted and where waste products are disposed off. This objective also assumes that the use of unfired adobe bricks is not disconnected from the socio-economic and technical contexts that determine this use.
3. Assess unfired adobe brick concerning its sustainable use. Factors that contribute to making the use of unfired adobe brick a sustainable option are to be investigated to evaluate their roles in achieving sustainability.

1.4 Structure of the thesis

The report is divided into five chapters, namely literature review, methodology, findings, discussion of results, conclusions and recommendations. Encapsulations of chapters are given below.

The literature review constitutes the background of the study and covers published research results in the fields of ecological design and adobe construction. The first

section of the chapter presents some environmental and social reasons underlying the emergence of the concept of sustainable development. This is followed by a presentation of concepts and components regarding sustainable development. To help connect the concept of sustainable development to sustainable constructions and materials, the literature on the relevance of the built environment in the process of sustainability is reviewed. The extent to which the built environment causes negative impacts on the natural environment and the reasons for such unsustainability are given special attention. Some of the methods used to conduct sustainability assessments are discussed. The process of sustainability assessment is relevant because it aids an understanding of the aspects that should be taken into consideration before engaging in the process of sustainable construction.

The methodology chapter describes the overall strategy followed in doing the study. The methods used, the circumstances in which each method was applied and their relevance to the process of data collection are detailed. Four data collection methods were used, namely focus group discussions, interviews, observation and practical work. Focus group methodology aimed to explore the dynamics of group discussion and gather information from various people. Interviews were applied in cases where it was necessary to explore issues specific to certain interventions or actions by individuals, or in informal situations where its application was relevant. Observations constituted a method relying on the visual capabilities of the researcher. This was informed by reference to theory and personal experiences. Practical work constituted a process where the researcher acquired practical experience regarding the object of study namely adobe brick. It was done through involvement in the construction of the researcher's own dwelling.

The findings chapter records the results of the fieldwork conducted in Chimoio town. It details the findings made from interviews, observations, discussions with focus groups and practical work of constructing the researcher's adobe house in Chimoio town. This chapter is divided into three parts: First, there is a characterization of settlements in Mozambique, a presentation of statistical information about the use of adobe and a reporting of the current governmental actions regarding the application of alternative materials in general and unfired adobe bricks in particular.

Second, the chapter deals with the practical production and use of adobe in the construction of dwellings in local communities. This is the result of contact with people who have been directly involved with the object of this study: people who know how to use the material. The advantages and disadvantages of unfired adobe bricks are identified from their experiences.

Third, the findings of a practical case study of the production of adobe bricks and their use to build the researcher's house are outlined. The researcher participated directly in the construction of the house.

Finally, in the discussion chapter the results of the study are compared with those of similar studies conducted elsewhere to see whether they support established knowledge or shed light to the topic. The elements emanating from this discussion are used to draw conclusions and make recommendations for further action.

The next chapter is devoted to reviewing the relevant literature.

2 LITERATURE REVIEW

The establishment of a theoretical framework is the starting point of this study. This constitutes an overview of the way the study's research problem was approached in other similar studies. The literature review provides an opportunity to learn from other scholars (Mouton, 2001). In this case the studies gave clues about the elements for consideration when analysing building materials from a sustainability point of view. This chapter gives an account of the useful and relevant insights gleaned from the literature.

The literature review starts with a discussion of problems that informed the emergence of sustainable development thinking and proceeds to explore the concept of sustainable development. This is followed by an examination of the relevance of the built environment in the sustainable development process. This helps one to understand the reasons for the need to include design of the built environment in the process of sustainability. Also, because certain properties need to be taken into consideration when determining whether a building or the use of specific materials is sustainable, methods used in the process of sustainability assessment are discussed.

2.1 Contemporary environmental concerns and the sustainability paradigm

This section presents and discusses some environmental challenges facing the world, the problem of unmet needs of the poor and the integration of these challenges into the concept of sustainable development.

2.1.1 Raising environmental concerns

Our mechanistic view of reality (Macy and Young-Brown, 1998) made us forget to care for the environment where all plants and animal species are found. All species interact, change and co-evolve with their environment and the human species is no exception (Clayton and Radcliffe, 1996). As part of the environment, human beings cannot survive without some environmental resources such as food, water and air (Millennium Ecosystem Assessment, 2005). Besides these basic conditions, human

beings have always searched for comfort, convenience and material wealth. To some extent we have satisfied these needs with our capabilities to transform the natural environment, but this has often sacrificed our and other species' health (Van der Ryn and Cowan, 1996).

Hawken, Lovins and Lovins (1999) argue that the impacts of human action have become more critical since the Industrial Revolution. In fact, since the mid-eighteenth century more of nature has been destroyed than in all prior history. Some reported indicators of current environmental problems include the depletion of non-renewable sources of energy, global warming and climate change, and species extinctions (Bartelmus, 1994). Among all those environmental problems, the global warming and climate change debate generally appears to be a key topic fuelling discussions in different fields of knowledge such as the environmental sciences, economics and political science. Aside from other environmental problems that deserve attention, the current challenges that climate change poses to society are of cardinal importance.

The phenomenon of climate change is associated with the concentration of the greenhouse gases (GHG) in the atmosphere. According to Monbiot (2007) during the twentieth century, the levels of carbon dioxide (CO₂ being one of the GHG) concentration in the atmosphere had been increasing faster than at any time over the past 20 000 years and the primary cause was the burning of fossil fuels by human beings. All fossil fuels contain carbon and one of the outcomes of their burning is CO₂ production.

Apart from the increasing concentration of CO₂ in the atmosphere, indisputable evidence of climate change is found in the melting of ice in the polar zones. According to Flavin (2001), measurements indicate a 40% decline in the average thickness of polar ice since 1950 due to increasing temperatures. IPCC¹ (2007: 45) observed that “continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century.”

¹ Intergovernmental Panel on Climate Change

The United Kingdom Meteorological Office, as cited by Roaf, Fuentes and Thomas (2007), predicts significant consequences resulting from continuous emissions of CO₂ into the atmosphere and from rising temperatures. Besides the creation of more displaced people as a result of rising sea levels and flooding of coastal areas, the Office predicts a significant reduction of covered forest areas which in turn will represent a reduction of the earth's capacity to sink CO₂. Additionally, that institution sees that rainfall will decrease considerably in some areas of the world such as Australia, India, Southern Africa and most of South America, Europe and the Middle East. Contrarily, North America, Central Asia and Central and Eastern Africa will register increases in rainfall. Monbiot (2007) predicts that agricultural production is likely to reduce significantly in developing countries in the southern hemisphere, where droughts will be more frequent. Patt and Schroter (2008) assert that the climate in Mozambique has changed. Tropical storms, floods and cyclic droughts are becoming more frequent and they affect the production of food, contribute to disease propagation (e.g. malaria and diarrhoea), and destroy infrastructure and communities' shelter.

In order to reduce emissions of CO₂ into the atmosphere, it is necessary to reduce the use of fossil fuels, but given that oil has become so important to sustaining our energy-hungry socio-economic system (Lerch, 2007), reduction of our fossil fuel dependency is a hard task. Atkinson (2007) asserts that the most important functions of our society, especially in the urban lifestyle, are based on oil production and consumption. Taking the food production chain as an example it becomes clear that the processes of production, transportation, processing, distribution, disposal and conservation rely on technologies based on oil as the most important energy source (Patel, 2007). So while acknowledging that the increasing dependence on oil is behind the phenomenon of climate change, almost no one would accept giving it up.

Coupled to our reliance on oil and the difficulty to reduce that reliance on this resource, a second challenge arises forcing us to rethink about our energy sources because oil is a non-renewable resource and to date there is no a viable substitute for oil at current rates of consumption (Lerch, 2007). According to Roaf, Fuentes and Thomas (2007), the last big oilfield was discovered in the 1960s in the North Sea and

despite this we have been consuming 70 million barrels daily and it is estimated that we only have around 40 years worth of conventional oil left at current rates of consumption. This means that soon the availability and prices of oil will change and few will not suffer the consequences. Unfortunately, few realize and contemplate the dimensions of the impending crisis.

Apart from the challenges posed by the continuing use of oil, there are other environmental concerns offering important challenges for consideration in the agenda of the relationship between the natural environment and human beings. Here Rogers, Jalal and Boyd (2008) see the acceleration of the world's population growth as a crucial factor determining levels of resource consumption. The Millennium Ecosystem Assessment (2005) indicated that the demands on ecosystem services (such as water, food, timber, fibre and fuel) have grown explosively as the world population doubled to 6 billion and the size of the global economy increased more than six-fold.

However, population growth does not satisfactorily explain the reasons for the environmental problems the world faces today. Flavin (2001) argues that it is the rising per capita consumption rate of resources that applies inordinate pressure on the natural environment. According to him, highly consumptive practices (meat-based diets and automobile-centred transportation systems) common in developed countries are inevitably spreading to the developing world with dire environmental consequences.

There are many other characteristics that show that the relationship between human beings and the natural environment is not healthy and that significant interventions are necessary. Some of these characteristics include: the decline of fisheries due to overharvesting and the deterioration of water and air quality caused by pollution (Millennium Ecosystem Assessment, 2005). We need to consider our habits and harmonize them with the supportive capability of the natural environment (Rogers, Jalal and Boyd, 2008).

2.1.2 Unmet needs and the world's ecological footprint

It is often argued that the changes that human beings are creating in the natural environment are justified by the need to ensure well-being, but not everyone is experiencing this goal. According to the World Bank (2008) about half of world's population in 2002 were living on less than \$US1 a day. This means that most of them were deprived of fundamental human needs such as water, basic sanitation, shelter and access to education and food. By contrast, there are a few people who are progressively accumulating material wealth at the expense of the poor majority. Figures prepared by UNDP² (1998) indicate that globally 20% of the world's population in the highest-income countries accounted for 86% of total consumption expenditure while the poorest 20% accounted for only 1.3% of total consumption. Since 1998 the consumption inequality between wealthy and poor has reduced but it is still high. Based on World Bank data, Shah (2008) observed that in 2005 the wealthiest 20% of the world accounted for 76.6% of total private consumption while the poorest 20% accounted for 1.5%.

The consumption levels of different groups across the globe can be converted into the amount of natural resources needed to produce goods and services, and logically, the more an individual or group of people consume the greater is the demand for more resources from the natural environment. A study by the Global Footprint Network and Swiss Federal Agency for Cooperation and Development (2006) indicates that many countries with high levels of human development in Europe and North America present large levels of ecological footprints³ while many developing countries present small ecological footprints per person and they are still struggling to meet the basic needs of the majority of their inhabitants.

If the reduction of extreme poverty in developing countries is done by matching the patterns of consumption of developed countries it will require huge amounts of

² United Nations Development Programme

³ According to Wackernagel and Rees (1996) the ecological footprint is the sum of all land required for producing resources for all categories of consumption of a person, group of people or nation and to absorb the waste resulting from this consumption.

resources. Such attempts would be tragic because living at those high standards would exceed the environmental capabilities of the earth to provide the needed resources. To dramatize this assertion, Loh and Wackernagel (2004) point out that if everyone in the world adopted the North American lifestyle, five planets would be necessary to produce the resources and dispose of the waste; adopting Australian standards of consumption would require four planets; and living according to United Kingdom standards of consumption would call for three planets.

We are faced with a situation where the inequalities among human beings are accentuated, the basic needs of a considerable fraction of the world's population are not met and the planet is running out of fundamental resources. There is a need to reduce poverty and inequalities, but concomitantly we must consider the implications for the natural environment. Only a strategy that considers the environmental, social and economic concerns as linked parts would lead us to addressing and resolving the problem.

2.1.3 Integrating three related challenges into one concept - sustainable development

The current environmental problems resulting from human action and the imperative to improve the living conditions of poor people across the world give us enough reason to shift our strategies and methods to attain widespread well-being. The crucial issue in this shift is the complex task of designing strategies where we try to find a balance between our needs and current environmental concerns simultaneously.

The intention to create harmony between environmental, economic and social concerns is reflected in the concept of sustainable development. There are many definitions of sustainable development, but Rogers, Jalal and Boyd (2008) claim that the best known and most widely quoted definition of sustainable development was elaborated by the World Commission on Environment and Development (WCED). This organization, according to Rogers, Jalal and Boyd (2008: 42), suggests that sustainable development is "...a development that can meet the needs of the present generation without compromising the ability of future generations to meet their own

needs.” This definition makes it clear that it is necessary to balance the economic and social needs of human beings (both now and in the future) without negatively affecting the natural environment.

From a philosophical perspective, the relation between economic, social and environmental systems is illustrated by the triple-bottom-line (TBL) approach that advocates the idea that sustainability rests on the intersection between the three systems (Vanclay, 2004) (see Figure 1).

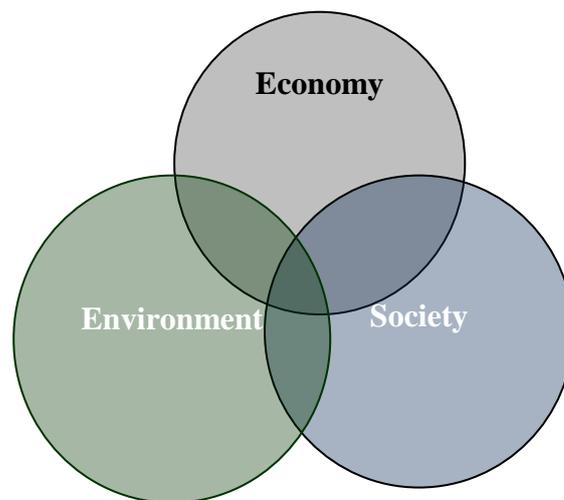


Figure 1: The triple-bottom-line relationship

Source: Based on Mebratu (1998).

The Strategic Framework for Sustainable Development in South Africa does not represent the process of sustainable development as a simple intersection between economy, society and environment (DEAT⁴, 2006). Figure 2 “...represents a systems approach to sustainability because the economic system, socio-political system and ecosystem are seen as embedded within each other, and then integrated via the governance system that holds all the other systems together within a legitimate regulatory framework” (DEAT, 2006: 19). In order to attain sustainability, this institution argues that the integration of these systems needs to be continuous and mutually compatible.

⁴ Department of Environmental Affairs and Tourism

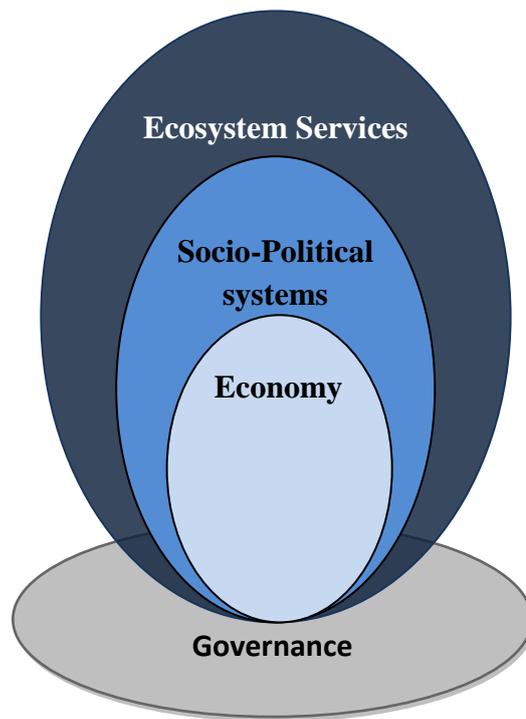


Figure 2: A systems approach to sustainable development

Source: DEAT (2006)

In practice, the required balance in the relationship between the economy, society and environment is difficult to attain. The concept of sustainable development has foundations in human and environmental concerns (Hattingh, 2001). Frequently, it becomes difficult to attribute the same weight for each of these two concerns. Therefore it becomes complicated when we are called to make some trade-offs between the imperative to satisfy our needs and to protect the natural environment. Our choices are frequently affected by the degree of relevance we assign to our concerns and those of environmental protection. At least two different approaches can be used to illustrate the different perspectives on this issue.

According to Wackernagel and Rees (1996), weak sustainability allows a substitution of human-made capital for depleted natural capital. The loss of natural resources is not a problem as long as they are invested in material wealth. Neumayer (1999: 1) states that according to this approach “...it does not matter whether the current generation uses up non-renewable resources or dumps CO₂ in the atmosphere as long as enough machineries, roads and ports are built up in compensation.” This approach makes clear that the satisfaction of human needs is non-negotiable.

Changes in the composition of the atmosphere as the result of CO₂ emissions become critical given that a chain of events can take place. These events include the increasing of temperatures, ice melting in polar areas, floods in coastal areas, increasing numbers of displaced people, propagation of new plagues, and changes in the conditions for food production (Roaf, Fuentes and Thomas, 2007; Monbiot, 2007; IPCC, 2007). Deforestation is a harmful process that reduces nature's ability to sink CO₂ (Edwards, 1999). The availability of drinking water has been affected by changes in the water cycle (caused by climate change) and by water pollution (Segrave *et al.*, 2007). It is questioned whether reliance on human-made capital can effectively control the negative impacts resulting from changes in the natural environment. It can be argued that there are few possibilities to purchase a substitute for ecosystem services such as climate regulation, flood regulation, disease regulation and water regulation (Millennium Ecosystem Assessment, 2005).

Strong sustainability is contrary to a weak sustainability viewpoint and advocates the idea that human-made capital or other forms of capital cannot substitute natural capital (Wackernagel and Rees, 1996; Neumayer, 1999). Strong sustainability advocates the notion that the socio-economic system is a subsystem of a finite ecosystem (Arman *et al.*, 2009). According to Gallopin (2003) the sustainability of social and ecological systems is consistent with a strong sustainability approach. The view that it is possible to attain social and ecological sustainability is reflected in approaches regarding the relation between the built environment and the natural environment. The next section reviews the relation between the built environment and the natural environment.

2.2 The built environment and sustainability

This section is divided into two subsections. The first reviews the environmental impacts of the built environment and the second presents solutions to building ecologically.

2.2.1 Environmental impact of the built environment

Nowadays, in order to attain a state of well-being it is necessary to create some specific material conditions that support multiple aspects of our daily life. Most people living in developing countries are still questing after adequate shelter, sanitation, water services and transport for commuting from one to another place. All these material elements, that constitute our built environment, make people's lives easier in different ways (Bartuska, 2007). We assume that these conditions create comfort, safety and speed of movement in our daily lives.

Incontestably, the provision of comfort conditions is related to the interaction between human beings and the natural environment, not only in the sense that the natural environment provides resources to build and operate different kinds of physical structures, but also in the sense that after use, these natural resources become waste which is disposed of in the natural environment.

Van der Ryn and Cowan (1996) see that the ways we build and run different systems in the built environment are implicated in most of the environmental problems discussed earlier in this literature review. This reflects that "the current patterns of design are wasteful of non-renewable resources, create toxic materials and by-products, require excessive energy for production, harm biodiversity at the source extraction, and often involve energy-intensive long distance transport" (Birkland, 2002: 13).

The construction and operation of buildings are responsible for 40% of energy consumption in the world and a high percentage of resources that enter the global economy end up in the form of buildings and structures (Beatley, 2000). It is important to note that most of the energy needed to construct and operate buildings comes from non-renewable fuel sources and the combustion contributes to global warming and climate change. The servicing and the use of buildings result in the production of 50% of the world's output of CO₂ (Moughtin, 1996; Roaf, Fuentes and Thomas, 2007), amounting to about one quarter of GHG (Moughtin, 1996; Birkland, 2002).

In addition to the energy being consumed by buildings and the impacts that this potentially represents, other resources are being depleted to provide materials that constitute the physical structure of buildings. For example, it has been observed that vast areas of rain forests have been destroyed to supply wood for the building industry (Girardet, 2004). Despite wood being a renewable resource, Roodman and Lenssen (1995) have observed that the exploitation of wood was far above sustainable levels and it has contributed to the elimination of thousands of plant and animal species and it has destroyed the homelands of many indigenous people.

In this process, human beings are also victims of their own actions because some elements of the built environment constitute an attack on people's health. Smith (2002: 8) avers, for instance, that "...the main stream press carries frequent stories of cancers and respiratory problems linked to formaldehyde-based glues, plastics, paints, asbestos and fibreglass." Roaf, Fuentes and Thomas (2007) observe that dust mites, organic solvent vapour, wood preservatives and even some garden plants can trigger respiratory problems such as asthma. According to Harris and Borer (2005), there is currently an increasing interest in the relation between buildings and human health. Materials such as stone, wood, straw and earth offer immense opportunities to create healthier environments because they are non-toxic (Smith, 2002).

Our built environment constitutes one of the means of attaining our well-being in the sense that it can provide the needed comfort, shelter, happiness and security (Meadows, 1999). It is also clear that the built environment is responsible for the most challenging environmental problems of our times. We cannot disconnect the process of satisfaction of our needs from our houses, hospitals, roads, bridges and other infrastructure, but there is a need to search for new strategies to create the built environment without harming the natural environment.

2.2.2 A new paradigm for the built environment

The consideration of natural processes in design is not a novel idea. People of various cultures across the world have tried to understand the fundamental processes occurring in the natural environment and have built physical structures which take

into account the ties between contextual environmental processes and human needs (AIJ, 2005). However, the dominant paradigm for conceiving shelter today does not explore this diversity in terms of solutions to integrate the design of buildings with fundamental processes occurring in the natural environment (Van der Ryn and Cowan, 1996). It is necessary to see buildings as part of complex interactions between people, buildings themselves, the climate and the environment (Roaf, Fuentes and Thomas, 2007).

The comfort a modern house provides its occupants depends on mechanical processes based on the consumption of energy from non-renewable sources, but by knowing better how the environment behaves it is still possible to create comfort without the use of these appliances (Harrington, 2002). The sun and wind are two natural elements that can provide the same service as the conventional heating and cooling systems thereby reducing negative environmental impacts and costs (Van der Ryn and Cowan, 1996). The consumption of other resources used in the various systems of the built environment can be put into service more wisely (Roaf, Fuentes and Thomas, 2007). For instance, water is one of the most consumed resources in the built environment, but waste water is seldom recycled and reused.

A different approach assumes that the built environment is essential for the comfort of human beings and at the same time this notion sees the natural environment as an element to be protected and as a source of solutions to our basic needs. Different approaches concerning the relation between the built and natural environments have been discussed in a wide range of literature (Van der Ryn and Cowan, 1996; Kennedy, Smith and Wanek, 2002; McLennan, 2004; Woolley, 2006; Roaf, Fuentes and Thomas, 2007) and various terms are used to qualify these relationships.

In order to bring environmental issues into the process of design, McLennan (2004: 4) proposes the term *sustainable design* which he defines as “a design philosophy that seeks to maximize the quality of the built environment, while minimizing or eliminating negative impact to the natural environment.” Another term reflecting the need to integrate environmental concerns into the built environment is *ecological design* that Van der Ryn and Cowan (1996: 33) define as “any form of design that

minimizes environmentally destructive impacts by integrating itself with living processes.” Ecological design as described here seems to focus on the environmental concerns of our built environment. Even if it is not their intention, this definition can be misinterpreted and lead us to relegate socio-economic concerns of design to a secondary position. The definition presented by McLennan (2004) has one element not directly referred to by Van der Ryn and Cowan (1996). It refers to the need to maximize the quality of the built environment while considering the integrity of the natural environment, however it does not mention the one aspect that a poor person in a developing country would like to hear, namely the cost savings that can result from the application of these designs.

The tendency to relegate socio-economic issues is often reflected in the contemporary guides concerning design and sustainability (Bennetts, Radford and Williamson, 2003). Thomas (2006) has noted that analyses of informal discourses tended to show that poverty and design are invariably approached as mutually exclusive. Sustainable design and ecological design should both be affordable for people living in developing countries, otherwise we would have a situation where only the wealthy would be living sustainably (Thomas, 2006).

Related to the concept of sustainable design is the definition of *sustainable construction* which, according to Hill and Powen (1997: 225), “was originally proposed to describe the responsibility of the construction industry in attaining sustainability.” It involves balancing social, environmental, economic and technical concerns. As part of buildings, materials are often used as indicators whether a building is sustainable or not (Froeschle, 1999).

2.3 Building materials and sustainability assessment

To find whether a design, building or material is sustainable it is necessary to apply a methodology that considers some assessment criteria. Concerning sustainable development, Rogers, Jalal and Boyd (2008) point out that there are three basic criteria, namely environmental, economic and social. No criterion must be maximized at the expense of the others. However, any consideration of these criteria can be

influenced by different approaches to sustainable development. Logically, in a weak sustainability perspective the assessment method is likely to be informed more by human indicators, while a strong sustainability perspective would be informed by human and natural indicators.

Various tools have been developed to assess the sustainability of buildings and materials. Scott (2006) has explained the methodologies applied in Europe and United States of America. One of these methods, BREEAM (Building Research Establishment Environmental Assessment Method), originated in the United Kingdom in the 1990's, while more recently LEED (Leadership in Energy and Environmental Design) was developed in the United States. Most of these assessment tools work on the basis of an extensive list of attributes that projects can achieve through a points-based system.

However, a comparison of the categories considered for sustainability assessment in these two methods (see Table 1) make it clear that both BREEAM and LEED concentrate on environmental issues rather than on social problems, but it is necessary to understand the contextual reasons that led to their design.

Table 1: Assessment areas of BREEAM and LEED

BREEAM	LEED
<ul style="list-style-type: none"> • Management • Health and well-being • Energy • Transport • Water • Materials • Waste • Land use and ecology • Pollution 	<ul style="list-style-type: none"> • Sustainable sites • Water efficiency • Energy and atmosphere • Materials and resources • Indoor environmental quality • Innovation and design

Source: BSRIA (2009)⁵

Considering that the challenges facing developing and developed countries differ in many respects, it is fair to assert that they require different environmental assessment

⁵ BSRIA: Building Services Research and Information Association

tools. Instead of a list comprising only environmental categories, a sustainability assessment tool for a developing country should include issues of affordability because affordability drives most decisions of the poor regarding building materials.

Hill and Powen (1997) have proposed useful principles that can be used to define an integrated method to assess a sustainable construction. According to them a building should be constructed while taking four pillars of sustainability into consideration, namely social, economic, biophysical and technical aspects which when combined constitute a set of sustainable construction principles (see Table 2). These principles have foundations in integrated and systemic approaches of sustainability (John, Clements-Croome and Jeronimidis, 2005).

Table 2: The principles of sustainable construction

Pillars of Sustainability	Principles of Sustainable Construction
Pillar One: Social sustainability	<ul style="list-style-type: none"> • Improve the quality of human life, including poverty alleviation. • Make provision for social self-determination and cultural diversity in development planning. • Protect and promote human health through a healthy and safe working environment. • Implement skills training and capacity enhancement of disadvantaged people. • Seek fair or equitable distribution of the social costs of construction. • Seek intergenerational equity.
Pillar Two: Economic sustainability	<ul style="list-style-type: none"> • Ensure financial affordability for intended beneficiaries. • Promote employment creation and in some situations, labour-intensive construction. • Use full-cost accounting and real-cost pricing to set prices and tariffs. • Enhance competitiveness in the marketplace by adopting policies and practices that advance sustainability. • Choose environmentally-responsible suppliers and contractors. • Invest some of the proceeds from the use of non-renewable resources in social and human-made capital, to maintain the capacity to meet the needs of future generations.
Pillar Three: Biophysical sustainability	<ul style="list-style-type: none"> • Extract fossil fuels and minerals, and produce persistent substances foreign to nature, at rates which are not faster than their slow redeposit into the earth's crust. • Reduce the use of the four generic resources used in construction, namely energy, water, materials and land. • Maximize resource reuse/recycling. • Use renewable resources in preference to non-renewable resources. • Minimize air, land and water pollution, at global and local levels. • Create a healthy, non-toxic environment. • Maintain and restore the earth's vitality and ecological diversity. • Minimize damage to sensitive landscapes, including scenic, cultural, historical and architectural.

Continued overleaf

Table 2 continued

Pillars of Sustainability	Principles of Sustainable Construction
Pillar Four: Technical sustainability	<ul style="list-style-type: none"> • Construct durable, reliable, and functional structures. • Pursue quality in creating the built environment. • Use serviceability to promote sustainable construction. • Humanize larger buildings. • Infill and revitalize existing urban infrastructure with a focus on rebuilding mixed-use pedestrian neighbourhoods.

Source: Hill and Powen (1997)

As integral parts of buildings, materials determine the level at which a building complies with the principles of socio-economic, environmental and technical sustainability. Hence, a complete assessment to determine whether a building material is sustainable should be based on criteria that reflect the impact of a building material on environmental, economic, social and technical sustainability.

2.3.1 Environmental dimension of building materials

To assess the environmental impact of building materials, different methods have been developed. The environmental assessment of a building material is done considering the impacts resulting from its extraction at the source, transportation, processing, construction phase and when the building is demolished (Roaf, Fuentes and Thomas, 2007). In all these activities different kinds of environmental impacts can be identified.

Initially, when raw materials are extracted, some impacts that can affect the natural environment are expected because extraction implies the reduction of reserves of natural resources. For example, Edwards (1999) sees that the exploitation of wood contributes to deforestation which implies the destruction of habitats of certain species and of the environmental capability to sink carbon emissions. The same happens in the production of bricks: extraction of soils for brick production causes large land losses for agriculture.

One of the requirements for classifying a material as green is the renewability of its source (McLennan, 2004). The sources of organic materials can recover after time and

continue to provide resources, but the same does not happen to metals and other non-renewable resources (Harris and Borer, 2005). Despite their regenerative character, renewable sources of materials also need to be used sustainably. “To ensure that succeeding generations have as much access to these as we have, we must utilize them at rates lower than, or at most equal to, the rates at which they regenerate.” (Reid, 1995: 94)

Most building materials are not used in the raw form found at source. They are subjected to some processing to acquire a needed quality. To do this, more energy is required. Roaf, Fuentes and Thomas (2007) observed that the less processing a material goes through, the less the amount of energy spent and therefore the negative environmental impact is reduced. As opposed to cement and steel, wood, unfired adobe brick and bamboo are materials that require less energy for their processing and consequently contribute less to climate change (Smith, 2002).

However, when selecting building materials it is necessary to consider transport to the building site. If the material is processed closer to the building site the need for transport will be reduced meaning that less energy will be required (Roodman and Lenssen, 1995). Some building materials may require less energy for their production, but the energy spent in transportation can make their impacts greater.

After incorporation into buildings, materials perform in ways that can contribute to the thermal performance of a building and the health of its occupants (Roaf, Fuentes and Thomas, 2007). As referred to in section 2.2.1, some processed building materials contain toxic substances harmful to human health. In most instances natural building materials do not emit toxic substances (Harris and Borer, 2005).

When the time comes to demolish a building, materials that cannot be recycled or reused become waste. “Waste disposal leads to environmental degradation and possible human hazards” (Harris and Borer, 2005: 99). Materials that can be recycled or reused are beneficial to the natural environment in the sense that they reduce the need for the extraction of more raw materials, save energy for processing and avoid the accumulation of waste.

In summary, building materials are regarded as 'green' when they can be recycled, have salvaged material content, are made from waste streams, contribute to energy efficiency of buildings, are free from ozone-depleting chemicals, do not contribute to global warming, are derived from renewable resources, are natural and not toxic, and present low-embodied energy (McLennan, 2004).

Many conventional building materials are regarded as non-compliant with the above requirements, whereas many traditional materials do comply. From an environmental viewpoint, traditional building materials possess clear advantages because of their local availability, low negative environmental impact in their production, renewability and even natural dissolution (Renping and Zhenyu, 2005).

2.3.2 Socio-economic dimension of building materials

The current situation in developing countries poses challenges that go beyond simple environmental problems. A main challenge for most people in the developing world is access to basic facilities, of which shelter is primary (UN-Habitat, 2003). Many different factors contribute to the problem of access to shelter, one of which relates to building materials and construction methods. World Bank (2008) data indicate that at least half of world's population is living on less than US\$2 a day, therefore implying that few people can afford a house or even buy materials for its construction.

One of the solutions to this problem is to improve the financial capability of poor people or to introduce housing subsidization. The South African experience in mass housing delivery through subsidization, for instance, has shown that limited budgetary resources allied to some planning shortcomings can lead to the delivery of unsustainable forms of housing (Irurah and Boshoff, 2003).

Most building materials now regarded as being 'green' have long been used in different cultures around the world to provide shelter (Oliver, 2003), but with the introduction of conventional building materials and methods of construction the indigenous know-how and experience have been lost (Gut and Ackerknecht, 1993). Indigenous knowledge is often related to materials that are available locally (Van der

Ryn and Cowan, 1996). It means that local people can have easier access to them, have the know-how to process them and use their knowledge to build their houses, inevitably reducing costs (Bolman, 2002).

It is important to note that cost cannot be used alone to define the social sustainability of a building. Hill and Powen (1997) insist that to attain social sustainability a construction must also improve life conditions, provide safety and comfort, reflect local cultural aspects, protect and promote health for its occupants and facilitate intergenerational equity. Natural building materials have the potential to comply with these requirements (Smith, 2002; Evans, 2002; Bolman, 2002).

2.3.3 Technical dimensions of building materials

Hill and Powen (1997) use the term technical sustainability to refer to principles of performance and quality of a building or structure. According to one of these principles it is necessary to consider the durability and reliability of structures. As building materials constitute the physical component of buildings, they contribute to ensuring these requirements. Furthermore, these technical requirements are important to social requirements such as the comfort and safety of a building's occupants.

Oliver (2003) sees that all buildings, whatever their function, have to meet certain physical constraints, so it is necessary to understand some aspects that affect the structure of a building (e.g. physical laws) and the methods for assembling materials used in its construction. Different building materials have different masses and all buildings are affected by the laws of gravity (King, 1996). Buildings also need to withstand various forces from nature such as wind, rain and earthquakes and areas might be affected differently by some of these natural stresses (King, 1996; Oliver, 2003).

Each building material behaves differently to natural factors because that which constitutes stress for one does not cause stress for another (Oliver, 2003). For instance, mud is less resistant to humidity (Baker, undated) or earthquakes (Sassu, undated) but these drawbacks are offset by this material being fireproof and rot-

resistant (Roodman and Lenssen, 1995). Wood is an ideal building material in areas where earthquakes are frequent but it is vulnerable to fire (Roaf, Fuentes and Thomas, 2007), humidity and some insects (Sassu, undated).

Regarding the idea that buildings should be durable and flexible, Roodman and Lenssen (1995) argue that it is true that inorganic masonry (e.g. stone) tends to be more inflexible but durable, making it an ideal structural material. Whereas wood is more perishable than stone, the former is flexible which makes it ideal for building components that are changed every few years.

Given the weaknesses and strengths of different building materials, construction methods are required which ensure that when using these materials the disadvantages are minimized and advantages maximized. Without proper methods and techniques of construction some materials regarded as either green or cheap can be inadequate for building reliable houses.

2.4 The relevance of adobe in the promotion of sustainability

King (1996) reminds us that adobe and other earth construction methods (e.g. rammed earth, wattle-and-daub and cob) are not novel. Harris and Borer (2005) state that archaeological evidence shows that 10 000 years ago earth was used to build entire cities such as Jericho and Babylon. The same applies to China's well-known Great Wall, construction of which began 5 000 years ago basically using earth.

Oliver (2003) says that adobe brick is one of the main building materials used in Africa, parts of Central and South America, India, China and Southeast Asia. It has long served people in developing countries that do not have access to more sophisticated building materials (Moughtin, 1996).

The production of adobe brick does not involve complicated techniques. Adobe bricks can be hand-moulded but a mould is required to produce a sharper edge and standard dimensions (Oliver, 2003). As adobe dries it behaves more like stone and it can be fired or not. According to Baker (undated) the production of adobe bricks is

determined by the quality of soils. There are different types of soil, some suitable for making adobe bricks, others not. Suitable soils for adobe brick production should have clay content, but when this is excessive the adobe bricks tend to crack (Sanchez and Sanchez, 2008). When the soil does not produce adobe bricks of good quality, it is necessary to add some stabilizers, for example cow dung, cement, straw, some plants juices and asphalt emulsion (Baker, undated; Moquin, 2005).

Adobe and other methods of earth construction are renowned for their low environmental impact. Normally, the soil required for adobe brick production can be found locally and processing does not need much energy input other than human effort (Moughtin, 1996). For unfired adobe brick the sun and air are the essential elements of the drying process but if the intention is to increase brick strength by firing, access to and availability of wood are necessary for burning the bricks (Oliver, 2003). Note that the two options for making adobe brick each lead to different environmental impacts. Unfired adobe brick needs less energy for its production. According to Moughtin (1996), the energy content of earth is zero but when it is burnt the energy content is 0.4KWh/kg. Compared to fired adobe brick, unfired adobe can contribute to reducing the energy consumed in the operation of buildings due to the superior thermal properties of materials made of raw earth (Moughtin, 1996).

Despite the positive role in the natural environment it is important to be aware of the limitations of the use of unfired adobe bricks. Baker (undated) stresses that although water is very important for moulding unfired adobe bricks, it is the constant enemy of unfired adobe brick construction. When exposed to water unfired adobe bricks tend to melt and return to their natural state making necessary to protect unfired adobe brick walls against water. Well known techniques to do this are the use of stone or concrete for foundations, overhanging roofs, and the choice of places for house construction where the risk of flooding is minimal (Moquin, 2005).

In Latin America, Asia and the Middle East (and even in part of the review area in Mozambique) where earthquakes occur frequently, it has also been reported that adobe constructions are vulnerable to this natural phenomenon (Dowling, 2004), but

with proper construction techniques earthquake vulnerability can be reduced (Roodman, Malin and Nicholas 1995).

Concerning unfired adobe structures in earthquake areas, Moquin (2005: 106-107) suggests that “...regular floor plan layouts or shapes exhibit better performance than irregular shapes,...wall openings should not be unduly large, and they should not be concentrated on just one or two sides of the building...roof beams should be positively attached to bond beams, and the bond beams should be bolted to the tops of the walls to prevent them from slipping out from beneath the roof...wood and reinforced cement bond beam should be continuous.”

2.5 Conclusions

Current knowledge indicates that we are reaching the limits of natural resource consumption, yet we have been unable to satisfy human well-being needs. Widespread poverty and inequalities in the world make the task of reducing the negative environmental impacts more difficult in the sense that such reductions imply the consumption of more resources. To address environmental and human concerns, sustainable development has been proposed as an integrated strategy to find a balance between environmental, social and economic goals. Although there are various sustainability approaches, the views are valid that the human system is embedded into the natural system and that sustainable development can be attained by ensuring the sustainability of both systems.

The built environment, as part of human-made capital, contributes significantly to increasing the negative impacts on the natural environment. A sensible approach to designing the built environment is one that assesses various alternatives of design and supports those that contribute to human well-being and a reduction of environmental impacts. Various sustainability assessment methods have been developed but there is still a tendency to focus on environmental indicators rather than on social problems such as poverty. Where poverty is an important challenge, it is necessary to consider issues of affordability.

Some dimensions of sustainability were examined to provide clues of how to assess the sustainability of unfired adobe brick. From the literature review it was concluded that the information to be collected in the field should include data on the four dimensions of the process of sustainable construction. Thus the environmental assessment must include aspects related to the source and amount of energy required to produce and transport adobe bricks, the renewability of the adobe source, the recyclability/reusability of this material, the emission of toxic substances and the health issues of the use of adobe. The socio-economic dimension of sustainability focuses on issues of affordability, comfort, safety and compatibility with local skills. Finally, the technical dimension of sustainability covers the methods to deal with stresses, durability and flexibility of adobe buildings. The next chapter deals with the research design and methodology applied to conduct this study.

3 RESEARCH DESIGN AND METHODOLOGY

This chapter presents the research design used to address the problem under investigation and the methodology used to conduct the study. Mouton (2001) distinguishes research design from methodology as summarized in Table 3.

Table 3: Differences between research design and methodology

Research Design	Research Methodology
Focus on the end of product: What kind of study is being planned and what kind of result is aimed at?	Focus on the research process and the kind of tools and procedures to be used.
Point of departure = Research problem or question.	Point of departure = Specific tasks (data collection or sampling) at hand.
Focus on the logic of research: What kind of evidence is required to address the research question adequately?	Focuses on the individual (not linear) steps in the research process and the most “objective” (unbiased) procedures to be employed.

Source: Mouton (2001: 56)

The first part of this chapter describes the process of research design while the second part focuses on the methodology adopted to conduct this study.

3.1 Research design

Before engaging in the process of research it is necessary to consider the nature of information required to address the research question (Mouton, 2001). The main aim of this study is to understand the use of adobe at the local level and to relate it to the basic elements characterizing sustainability. The literature on sustainable development (Meadows, 1999; Lerch, 2007; Rogers, Jalal and Boyd, 2008) suggests that an understanding of the origins of the current environmental crisis and the promotion of sustainability relies on analyses of what human beings have experienced in their daily lives and the consequences of these experiences.

Better than anyone else, individuals can explain how they experience life or why they make certain choices. The appropriate way people express their experiences is through words, pictures or other narratives that reflect the subject’s genuine experience (Ruane, 2005). According to Maykut and Morehouse (1994: 2), qualitative

research “examines people’s words and actions in narrative or descriptive ways or more closely representing the situation as experienced by the participants.”

Most of the information used in this study is derived from people’s words and observations making qualitative research the main strategy used to address the research problem. The production of adobe bricks, their use in house construction, the decisions people make regarding the use of a material and the feelings people experience when using the material are better described and explained by the participants’ words and actions than by statistical analyses.

It is important to note that because qualitative information is in the form of words or pictures it does not mean that people do not talk about numbers during interviews or that we do not pay attention to numbers when observations are made. In this study quantitative data is considered useful to complement qualitative information.

The stages followed in the study are based on the qualitative research approach (see the research design in Figure 3) comprising the literature review, selection of data collection methods, fieldwork, data analysis and conclusions. The next section describes the methodology used.

3.2 Methodology

This section describes the study area, the material under investigation, the study variables and the data collection methods and analyses.

3.2.1 The study area

Given that time and financial resources were limited it was necessary to choose a small area to conduct the study. Among many places in Mozambique where communities use alternative materials to construct houses, the researcher had to identify a study area that suited the objectives of the study. It should be a place where local communities use adobe to build houses and where the access to information is easy.

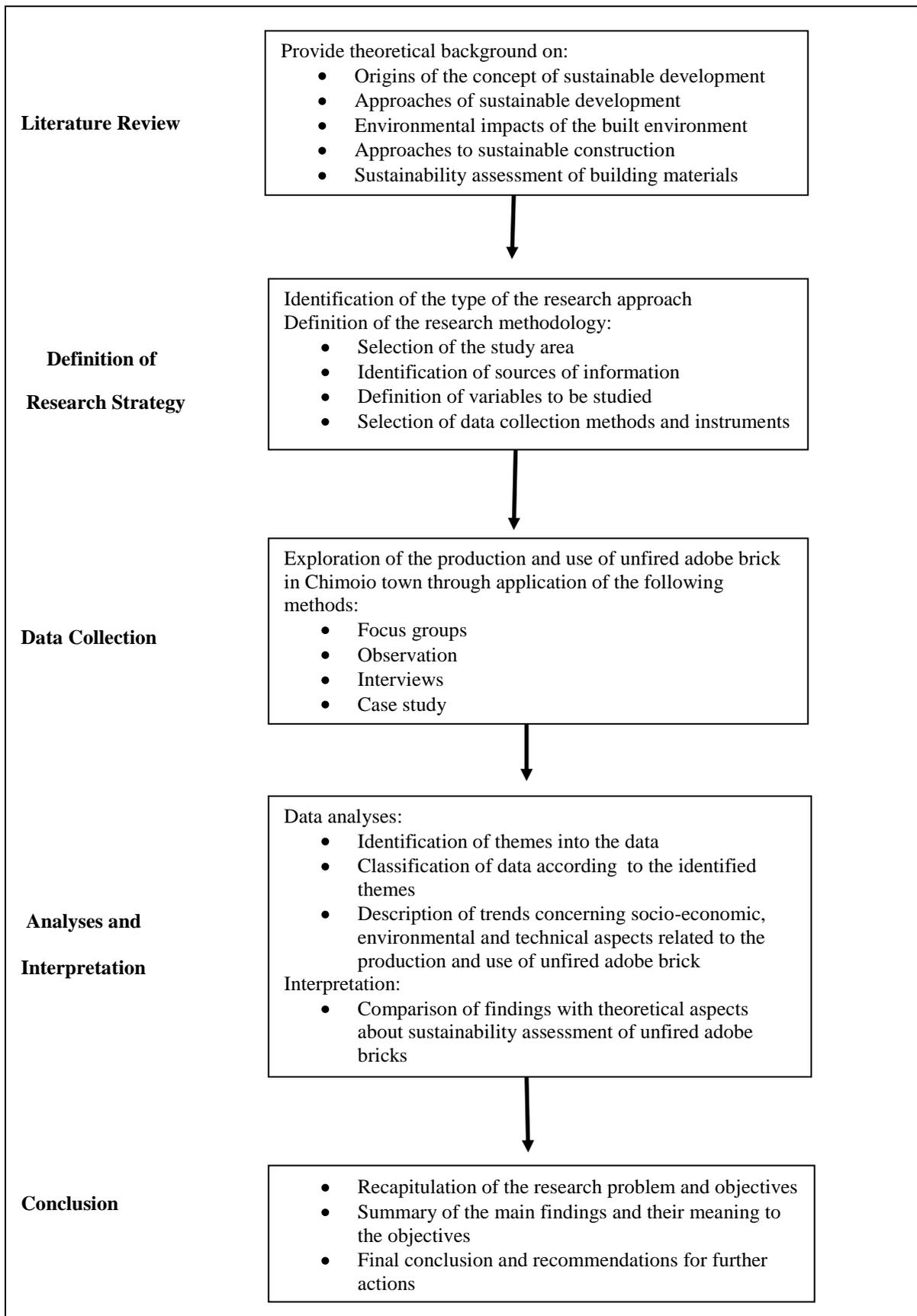


Figure 3: Research design for assessing the sustainability of adobe bricks

Located in the central province of Manica (latitude 19° 30' 0" S and longitude 33° 15' 0" E)⁶ in Mozambique (see Figure 4) the town of Chimoio (latitude 19° 7' 0" S and longitude 33° 27' 0" E)⁷ was selected as the study area.



Figure 4: Location of Chimoio in Mozambique
 Source: Based on *Encyclopaedia Britannica* (2008).

Chimoio is a place where adobe is used to build houses and as a member of the local community the researcher knows the area and people well which facilitated making observations and interviewing local experts on adobe construction. Additionally, the researcher had built his own adobe house in Chimoio making this a good option for a

⁶ Information found at GeoHack-Manica:
http://stable.toolserver.org/geohack/geohack.php?pagename=Manica_Province¶ms=19_30_S_33_15_E

⁷ Information found at GeoHack-Chimoio:
http://stable.toolserver.org/geohack/geohack.php?pagename=Chimoio¶ms=19_07_S_33_27_E_tpe:city_region:MZ

case study given that the information about the construction process was readily available.

The conclusions and recommendations of a study conducted in Chimoio can be reliably applied to other areas in Mozambique where adobe brick is used given that the natural conditions and socio-economic profile of local communities are similar.

The town is located in a highland area which experiences two main seasons, namely winter (between May and September) and summer (between October and April). According to the National Institute of Meteorology (INAM), summer is the rainy season with average monthly rainfall reaching 237mm in February. The least rainy month is June with rainfall of 12.5mm (see Figure 5). The number of days with precipitation is also high during the summer. February, with 16.5 days of rain, is the rainiest month and June, with 4.4 days of rain, the least (see Appendix 1).

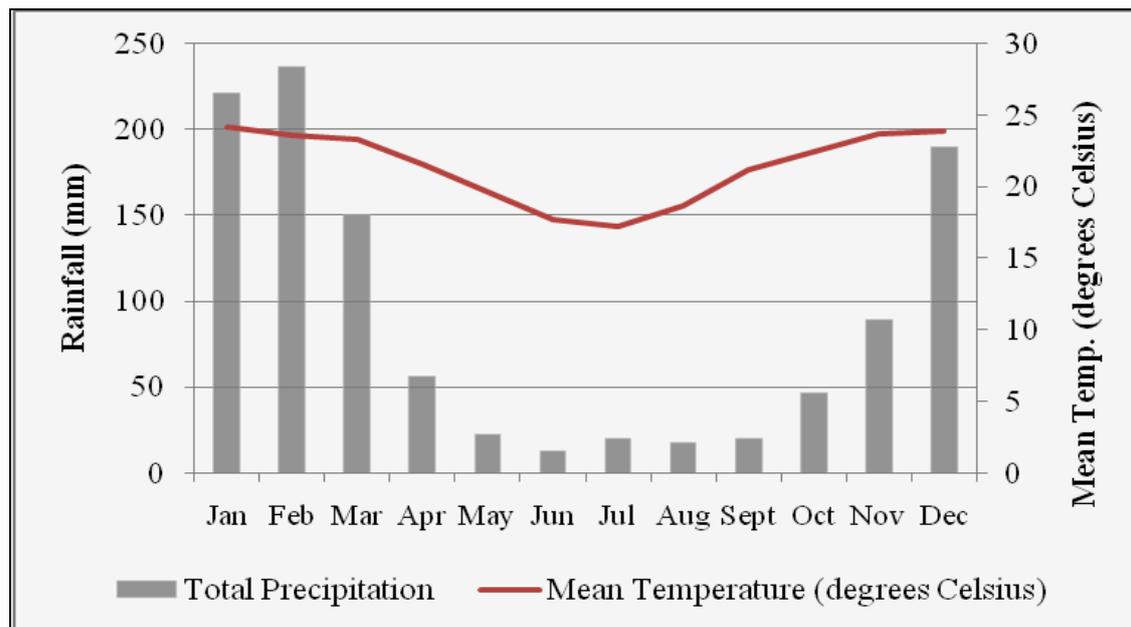


Figure 5: Monthly mean temperatures and rainfall in Chimoio, Mozambique
Source: Based on INAM (2009) data.

In contrast to the coastal areas, Chimoio is not affected by tropical storms (cyclones) and given its elevation and relief it is not prone to flooding (the highland area interspersed with valleys provides an efficient water drainage system).

It is estimated that Chimoio has 172 000 inhabitants (ANAMM, 2010) and most of the population live in houses made of alternative materials located in suburban neighbourhoods. The main local livelihood strategy is based on natural resources and agriculture.

3.2.2 The building material under study

To select the building material to be studied, one must first differentiate between two groups of materials, namely alternative and conventional building materials. Natural materials such as adobe, bamboo, grass and palm leaves are considered as alternatives to conventional materials such as cement, steel, fibre cement and glass. When compared to conventional materials, these alternative materials inflict less negative environmental impacts on the natural environment (Kennedy, Smith and Wanek, 2002; Harris and Borer, 2005). Therefore, the distinction between the two groups of materials is informed by the negative environmental impacts that can be caused by each group of materials.

Because there is an array of alternative building materials that can be studied at local level, time, financial constraints and access to information compelled the researcher to select only one specific material, namely unfired adobe brick. Adobe is a method of earth construction and it differs from other earth construction methods such as wattle-and-daub, rammed earth and cob. According to McHenry (2002: 120) “adobe bricks are blocks made of earth and water that are dried in the sun.”

In contrast to other alternative materials, adobe is one of the most often used building materials in the study area. Studying a material in its source is expedient because the researcher can easily participate in all the adobe-related processes from the extraction of the material through to incorporation in buildings. The distances to the sources of other materials were greater than those to adobe, making the latter a wise choice.

Because adobe is frequently used at local level, information about the use of this material is readily available. The researcher has also acquired experience in adobe

construction so that the study of unfired adobe brick is an opportunity to consolidate his knowledge about this material.

3.2.3 The study variables

Based on methods of sustainability assessment of building materials presented in the literature review chapter, the variables used to make assessment of the use of unfired adobe bricks in Chimoio were defined. Table 4 presents the variables related to each sustainability dimension.

Table 4: Variables studied in each dimension of adobe brick sustainability

Sustainability Dimensions	Variables Related to Sustainability Dimensions
Environmental Sustainability	<ul style="list-style-type: none"> • Renewability of the material source • Impacts caused during the material extraction • Location of the material source and the need for motorized vehicle to transport the material • Type and amount of energy used to process the material and incorporate in buildings • Recyclability and reusability of the material • Energy required for recycling the material • Contribution of the material to reduce the need for mechanized heating and cooling systems • Health problems related to the use of the material
Socio-economic Sustainability	<ul style="list-style-type: none"> • Material costs • Affordability of unfired adobe brick for local communities • Costs to build an unfired adobe brick structure • Access to the material by local communities • Characteristics of unfired adobe houses • Contribution of unfired adobe brick to the comfort of adobe house dwellers • Fulfilment of dweller's aspirations in terms of shelter • Factors driving the acceptability of unfired adobe brick at local level • Availability of skills in adobe construction
Technical Sustainability	<ul style="list-style-type: none"> • Stresses affecting unfired adobe structures at local level • Extent to which stresses affect unfired adobe houses and the safety of dwellers • Methods to cope with these stresses • Effectiveness of these methods in reducing vulnerability of unfired adobe brick houses to stresses • Durability of unfired adobe structures

3.2.4 Data collection methods

Four methods were applied to collect data during fieldwork, namely focus groups, observation, interviews and participation in practical work. This subsection describes all of them.

3.2.4.1 Focus groups

In Mozambique it is common for people to underestimate the importance of traditional knowledge regarding local building materials and construction methods. The fact that traditional knowledge is different from the scientific knowledge guiding the use of conventional materials does not necessarily mean that traditional knowledge is invalid. Actually the traditional knowledge has served generations for millennia and today continues to inform most Mozambicans about meeting their needs for shelter.

Local people have discovered and learnt how to use local building materials and they have experienced the advantages and disadvantages of the various materials. It is beneficial that different forms of knowledge be applied to real-life situations and the wealth and applicability of traditional knowledge has often shown its worth. This kind of knowledge has proven potential to contribute to fulfilling human needs, making it a body of knowledge from which we can learn. Van der Ryn and Cowan (1996) agree that traditional knowledge is important, especially when the issue at hand concerns sustainability and they assert that much traditional knowledge has developed under specific natural conditions of a place and the limits imposed by the surrounding environment.

Because most of the knowledge regarding local building materials has not been formally systematized in publications nor much discussed in academic or government circles in Mozambique, it was necessary to gather the required information for this study directly from primary sources. To accomplish this, discussions with focus groups consisting of local people were carried out. As a requirement for participation in the focus groups discussions, each member had to have some knowledge about and

experience in the use of adobe. The focus group discussions produced information about the production of unfired adobe bricks; methods of construction; reasons for the use of adobe; advantages and disadvantages of adobe; solutions to improve the performance of adobe; and aspirations of the participants regarding shelter.

According to Marshall and Rossman (2006), focus groups are normally composed of seven to ten people although sometimes a minimum of four and a maximum of twelve participants have been involved. The plan was to organize two focus groups of six to eight members each. However, experiences in the field showed that gathering together the number of people was not an easy task due to various constraints.

A first constraint concerns the topic of discussion. Most of the people contacted for inclusion in a focus group were of the opinion that the use of mud is to be snubbed and they regarded the idea of discussing it unappealing. The second constraint is that some local producers of adobe brick were reluctant to participate because they thought that the researcher wanted to get information about their businesses or decide whether to buy their products or not. The third constraint is that each person organizes time in a different way making it difficult to schedule a discussion at a time when everyone was available and it also happens that some participants did not make an appearance on the programmed day because of emergencies that occurred. Consequently, only four people participated in the first focus group discussion and five in the second one (see the particulars of the discussants in the list of focus group participants following the list of interviewees).

Despite these difficulties, assembling the discussants was achieved and the discussions were fruitful. Denscombe (2007) acknowledges that this method is useful to exploring group dynamics. In this study's focus group facts were named and discussed, opinions given and arguments presented so that eventually the participants and the moderator had all learnt something about adobe construction.

During the discussions the researcher acted as moderator and performed the tasks of keeping the discussion on track and taking notes. Sometimes focus group participants tended to lose track of the core discussion and talk about issues not directly related

with the research problem. Discussion of irrelevant issues consumes time and makes the task of data cleaning and analysis difficult. A good way to keep discussions on course was to provide a discussion programme (see Appendix 2) by which time could be allocated for each subtopic to ensure that all aspects were covered. Of course it was difficult to follow the schedule rigorously because the behaviour of participants in the discussions also determined how the time was managed. There were participants who were more fluent in expressing their ideas, while others took more time to voice the same ideas.

3.2.4.2 Observation

According to Denscombe (2007) observation does not rely on what people say, do or think but on direct evidence that the eye provides. Additionally, he sees that participant observation produces qualitative data and it is useful to understand the processes involved. Observations made in this study helped to clarify aspects that were poorly covered in focus group discussions and interviews. Conversely, some unclarified aspects of the observations were clarified through the interviews and focus group discussions.

Most of the interviews were conducted informally during the process of observation because the circumstances in the field created the need to do so. Informal interviews became an important adjunct to observation when the observer was not sufficiently familiarized with the object being observed. In some instances the researcher had to ask questions that led to a better understanding and accurate description of the phenomenon under observation.

According to Marshall and Rossman (2006: 100), “participant observation demands firsthand involvement in the social world chosen for study.” Given that the researcher acted as a member of local community and because he participated in the production of adobe bricks, the observations are seen to be participant. This method allowed the researcher to explore information about environmental impacts in different phases of adobe brick production, adobe construction methods, design shortcomings of local adobe houses and the frequency of adobe use at local level.

3.2.4.3 Formal interviews

Formal interviews were aimed at exploring issues related to technical aspects of adobe construction, environmental impacts resulting from the use of adobe, the situation of housing in Mozambique and current housing policies.

For programmed interviews the interviewee was identified prior to the event and a list of broad questions was compiled (see Appendix 3). According to Maykut and Morehouse (1994: 86) “the interview guide format is especially suitable for exploring phenomena through interviewing when little is known about the topic.” Because little was known about the topic, an interview guide helped to introduce the topic to the interviewee but when the interviewer started exploring the research problem more deeply the reliance on the guide decreased.

The formal interviews were conducted with people working in Provincial Directorate of Public Works and Housing of Manica (DPOPH-Manica) and adobe brick producers (see the list of interviewees following the reference list). Because the researcher was engaged in a short-period internship in DPOPH-Manica and had successfully contacted some adobe brick producers, he could easily schedule the interviews. It was also possible to explore the topics in more depth because the interviews could be interrupted and continued on the following day and unclarified answers could be made clear at a follow-up meeting.

It was expected that the DPOPH-Manica personnel would give more technical insights about the use of unfired adobe bricks because it was assumed that they possessed knowledge or had done training regarding building construction, but it became clear that most of them had been trained only about conventional construction. Fortunately, they were enthusiastic about research on alternative building materials because it represented an opportunity to provide adequate and affordable houses for local communities. Thus the interviews succeeded in providing information about existing studies and becoming aware of those in progress.

3.2.4.4 Practical work

To experience first-hand use of adobe as a building material, the researcher organized and participated in practical work to produce unfired adobe bricks and use them in the construction of his adobe house. During the whole process the researcher made copious notes from which to report in this study.

The researcher did direct observation to hear and see events as well as to get a feeling of what he heard and saw. The practical work was important and the phenomenon could be explained using the knowledge and understanding gained by the researcher through direct involvement in the action. Of course, the researcher's involvement in the construction of the house could not provide answers to all the questions about its sustainability, but light was shed on relevant questions. Preliminary concerns about the stresses affecting the building were raised and an evaluation of the costs was made concerning this kind of construction.

Compared to observing and interviewing, practical work was more time-consuming and it was only possible because sufficient funding was available and an appropriate opportunity existed. Practical work became a risky method of learning because it was difficult to predict whether the project being undertaken would be successful. Fortunately, the practical work was successful given that the researcher achieved his learning goals and the construction has performed well contrary to the negative assumptions made about adobe construction at local level.

3.2.5 Data analysis

“The aim of analysis is to understand the various constitutive elements of one's data through an inspection of the relationships between concepts, constructs or variables, and to see whether there are any patterns or trends that can be identified or isolated, or to establish themes in the data” (Mouton, 2001: 108).

The fieldwork was conducted in three different contexts, a fact taken into consideration in the data analyses. The researcher conducted the research in local

communities of Chimoio, participated in a practical exercise of building his adobe house and collected information during an internship in DPOPH-Manica. The information was organized according to these contexts of data collection. Themes related to each context were created to accommodate information about variables that describe socio-economic, environmental and technical trends in the use of unfired adobe bricks. Table 5 presents the themes of study and the objectives of each theme.

Table 5: Themes of study and their objectives

Context of Data Collection	Themes	Objectives
Data collection in DPOPH-Manica	Characteristics of housing in Mozambique	<ul style="list-style-type: none"> • Estimate the frequency of the use of unfired adobe brick in Mozambique and compare with other options of building materials. • Describe the basics conditions of alternative housing. • Analyse the relevance of alternative building materials in general and unfired adobe brick in particular for local people.
	Alternative materials and local natural conditions.	<ul style="list-style-type: none"> • Identify natural conditions that determine the use of alternative materials at local level. • Relate the frequency of use of alternative materials to local natural conditions.
	Housing and institutional awareness.	<ul style="list-style-type: none"> • Find out if there is a housing policy in Mozambique. • Relate the frequency of use of unfired adobe brick to governmental initiatives in terms of shelter provision.
Data collected in local communities	The production of unfired adobe brick.	<ul style="list-style-type: none"> • Indicate the ingredients used in the production of unfired adobe bricks. • Show the steps followed in the production of adobe bricks.
	Characteristics of adobe brick houses.	<ul style="list-style-type: none"> • Identify different elements that comprise adobe houses. • Describe these elements.
	Socio-economic aspects of adobe bricks.	<ul style="list-style-type: none"> • Compare prices of adobe bricks to other local options in terms of bricks. • Relate the price of adobe bricks to their application in the construction of houses of financially-dispossessed people. • Relate the use of unfired adobe brick to the existence of local skills. • Gain an understanding about the reasons for the acceptability of adobe brick by local communities.
	Environmental impacts of adobe bricks.	<ul style="list-style-type: none"> • Get a sense about the environmental awareness of local communities. • Identify environmental impacts related to the production and use of unfired adobe brick.

Continued overleaf

Table 5 continued

Context of data collection	Theme	Objectives
Data collected in local communities	Challenges of unfired adobe brick.	<ul style="list-style-type: none"> • Identify the main stresses affecting adobe constructions; • Indicate the major problems related to the performance of unfired adobe brick houses; • Identify local approaches to deal with the problems presented by adobe structures.
Construction of Dieter's house	House design.	<ul style="list-style-type: none"> • Describe aspects taken into consideration in the construction of Dieter's house.
	Production of adobe bricks and construction of the house.	<ul style="list-style-type: none"> • Detail the steps followed in the production of unfired adobe bricks and their incorporation in the building; • Describe the challenges faced during the construction of the house and the solutions applied to deal with the problems; • Find out if these solutions address the problems presented by adobe structures.
	Environmental aspects and construction costs of the house.	<ul style="list-style-type: none"> • See if the environmental advantages observed on the production and use of unfired adobe bricks in local communities is reconfirmed in this case; • Analyse the costs to produce adobe bricks and to build an improved adobe house; • Compare the costs resulting from the option to use unfired adobe bricks with other options of bricks.

The separation of information according to the context of its collection allowed the researcher to reflect around the perceptions of local communities and local institutions regarding the problem of housing and the use of unfired adobe brick. To come up with an argument about the phenomenon under investigation the researcher related these perceptions with what he observed and learnt during the fieldwork. The interpretation of the findings was done by relating them to the results from other similar studies in order to find out whether this study supports the existing knowledge about the use of adobe or not.

3.3 Conclusions

This chapter described the nature of information required to address the research problem and the methodology used to conduct this study. Considering that the

necessary information will be based on people's experiences and on what can be observed in daily life, a qualitative approach will be applied.

The data collection methods involved focus group discussions, observation, interviews and participation in practical work. The application of these data collection methods in local communities was reasonably successful. The coincidence of the study area with the residence of the researcher and the fact that adobe brick is frequently produced and used by the local communities made access to information relatively trouble-free.

The description of the data collection methods helped to understand that they are suitable for acquiring the necessary information. Focus group discussions and interviews were used to explore viewpoints held about the production and use of unfired adobe bricks by local community members and the local housing sector institution. On the other hand, observation and participation in practical work required direct involvement of the researcher in the production and use of unfired adobe bricks. After the fieldwork was finished the collected data were analysed. The way the information was collected also influenced the analyses in that the researcher considered the different contexts in which he conducted the fieldwork. The findings emanating from the analyses are presented in the next chapter.

4 RESULTS

This chapter is divided into three sections. The first section reports on housing in Mozambique; the second presents information collected in local communities of Chimoio; and the last one is a case study of the construction of the researcher's adobe house.

4.1 Housing in Mozambique

Alternative construction is an issue that matters not only for local communities or single individuals but also government as a whole and the respective institutions responsible for the provision of basic services to vulnerable people.

This section reports on a three-week internship in DPOPH-Manica. The internship was intended for gathering information about the use of adobe from the directorate's perspective and for getting insights into their activities regarding housing and the use of alternative building materials. Observations in the field and interviews with key housing practitioners were used to acquire relevant information.

4.1.1 Characteristics of housing in Mozambique

A brief history of housing in Mozambique (see Appendix 4) shows that during the colonial period at least two types of housing evolved side by side. DNE⁸ (2008) indicates that the first type, in which the majority of population dwell, is made of natural materials, whereas the second type is a colonial heritage quite different to the former type regarding building materials and construction methods. The materials used to construct the first type of housing are generally regarded as alternative while those used to build the second type are regarded as conventional.

Nowadays most houses in the central part of urban areas are constructed with conventional materials like cement, steel, glass, galvanized metallic sheet and fibre

⁸ National Directorate of Edifications

cement. These materials are regarded as being the most recommended for the construction of safe and durable houses. By contrast, as one moves away from the nucleus of urban areas there is a radical change in the materials used to construct dwellings. Most houses in the suburban landscapes and rural areas are made of alternative materials such as adobe, bamboo, sticks, wood, grass or palm leaves. Adobe, bamboo, wood and sticks are principally used as wall materials, while grass and palm leaves are used as roofing materials (see Figure 6).



Figure 6: Examples of houses built with alternative building materials
Source: Photographed by the author.

In the 1997 census, the National Institute of Statistics (INE) gathered data on housing in Mozambique. The picture might have changed since then. However, the INE 1997 on building materials in Mozambique is supported by observations and information collected in an enquiry conducted in 2002/2003.

Alternative construction constitutes the dominant form of housing in Mozambique in urban and rural areas (see Appendix 5). Scrutiny of these figures shows that unfired adobe bricks, sticks, bamboo and stakes or combinations of these materials were intensively used for the construction of walls. In a total of 3.5 million houses, 87% are built using these alternative materials for walls and 67% are houses built from unprocessed earth. Similar proportions apply for roofing and flooring materials with natural roofing materials such as grass and palm leaves being used in 82% of the houses. In 86% of the houses the floors were made of earth, in 12% of the cases floors

were made of cement, 1% of the houses had wooden floors and 1% used other flooring materials.

The Household Enquiry (IAF) conducted in 2002/2003 (DNHU⁹, 2007) supports the findings by INE. Table 6 compares some results from the two sources.

Table 6: Frequency of use of building materials according to the 1997 census and an IAF survey

House Component	Census 1997	IAF 2002/2003
Wall Material	%	%
Bricks (cement and fired adobe brick)	9	14
Unfired adobe brick	19	31
Wood/Galvanized metallic sheet	2	2
Wattle-and-daub	48	38
Bamboo/Peg	20	13
Other materials	2	2
Roofing Material	%	%
Concrete slab	2	1.5
Tile	0	0.3
Fibre cement	3	2.6
Galvanized metallic sheet	12	20.4
Grass/Palm leaves	82	74.3
Other materials	1	0.9

Source: Based on information from INE (2009) and DNHU (2007).

Despite the relative increase in the use of cement and fired adobe brick, the use of alternative materials was still prominent. Contrary to the decreasing use of wattle-and-daub, unfired adobe brick use increased by 63%, revealing that this material was becoming more popular as an alternative building material.

Observations in the field indicate that alternative building materials are predominantly used in rural areas. INE noted a similar finding for 1997. Figure 7 shows the distribution of building materials used for walls in urban and rural areas. Of the 1 695 500 wattle-and-daub houses, 89% were located in rural areas. Three quarters of the 719 656 bamboo/peg houses were located in rural areas and 68% of the 669 770

⁹ National Directorate of Housing and Urbanization

unfired adobe houses were in rural areas. By contrast, 83% of the 252 481 houses with cement brick walls were located in urban areas.

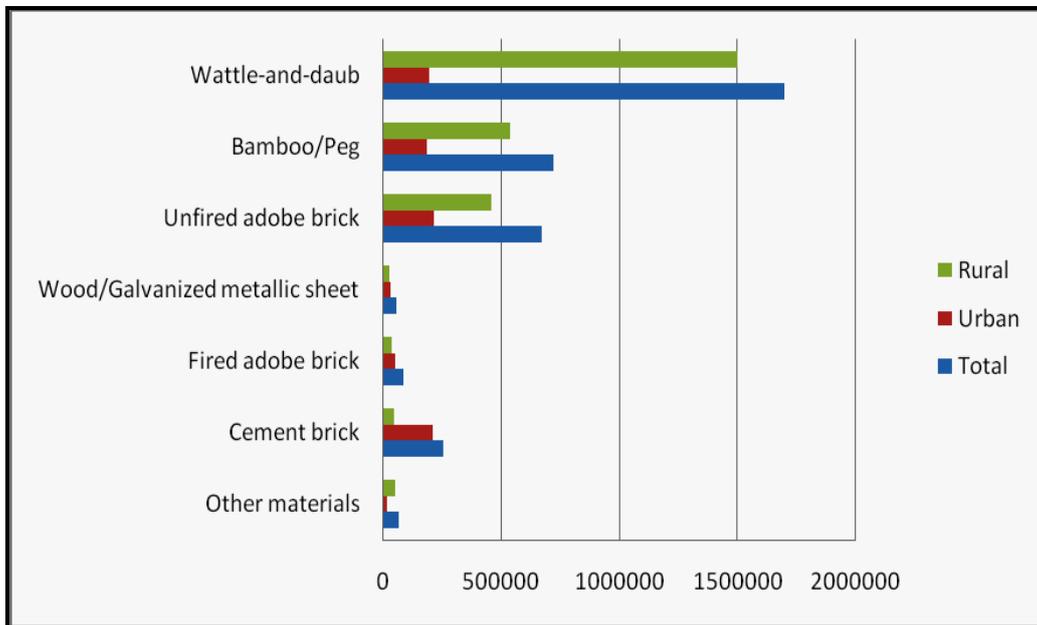


Figure 7: Frequency of use of different wall materials in urban and rural areas
Source: Based on 1997 census data from INE (2009).

Concerning roofing materials, there is a prominent use of alternatives in rural areas (see Figure 8). Of the 2 895 862 houses using natural roofing materials, 85% are in rural areas, whereas 69% of the 433 634 houses using galvanized metallic sheet (the most used conventional roofing material) are in urban areas.

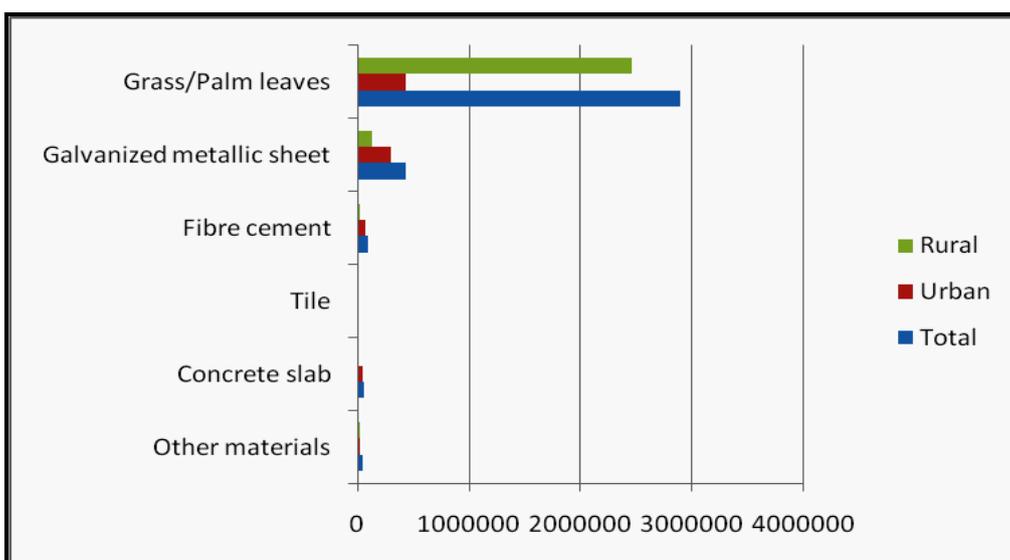


Figure 8: Frequency of use of roofing materials in urban and rural areas
Source: Based on 1997 census data from INE (2009).

The provision of electricity, water and sanitation is an indicator characterizing dwellings in Mozambique. The majority of dwellings in Mozambique do not have access to these services (see Appendix 6). Of a total of 3 540 700 houses only 5% had access to electricity and 92% did not in 1997 (the remaining 3% constitutes missing observations). Only 8% had access to canalized water, while the rest of dwellings got water from wells (67%), rivers or lakes (17%), fountains (7%) or other sources (1%). With regard to sanitation, 2% had a flush toilet with sewerage, 1% had a flush toilet with septic tank, 31% had a pit latrine and 66% had neither a toilet nor a latrine. Appendix 6 shows that the provision of these basic amenities is concentrated in urban areas.

Available data do not show whether the provision of basic services is a characteristic of conventional housing or not, but considering that the highest frequencies of these services occur in urban areas and that people living in alternative housing are less likely to have the means to buy electricity or toilet equipment, it is fair to assume that conventional housing is best provided with basic services.

4.1.2 Alternative building materials and local natural conditions

In contrast to cement, steel or glass, most of the alternative materials are not subjected to much processing and the availability of specific natural resources is an important determinant of the use of such resources. Adobe, bamboo, grass, palm leaves (known as *macuti*) and wood are materials considered to be local natural resources in Mozambique, particularly in the area of study. Their processing and use is also local. It is important to note that the frequency of use of each of these materials is not the same everywhere.

Earth is a resource that is used by the majority of the population across the country and is normally used to produce bricks, to plaster adobe brick walls and even in stake- or bamboo-framed walls. However, the suitability of soils used in adobe brick production can vary regionally. In some areas along the Mozambique coast it was observed that adobe brick houses occur infrequently. One reason mentioned by local people was that local soils contain very small amounts of clay. Additionally, many

areas along the coast are prone to floods during the rainy season making the use of unfired adobe brick inappropriate. In most of these areas, bamboo or stakes or reeds are used to make walls instead of unfired adobe bricks.

The use of adobe bricks can also have its limitations in areas having suitable soils and that are not prone to flooding. A visit to the Machaze district (Manica province) allowed the researcher to observe that while the area had appropriate soils for the production of adobe bricks and it was not prone to flooding, adobe did not constitute the preferred building material for the construction of houses locally. Another local material – stick – is the leading material for wall construction.

On investigation, it was pointed out by David Mandevu (pers. com., 2009), a technician of Public Works and Housing in the district, that the reason for the preference of sticks over adobe brick was that the district had been affected by seismic activities (a rare phenomenon in Mozambique) and buildings made of unfired adobe bricks are vulnerable, whereas buildings made of sticks or stakes tended to be more resistant. Furthermore, adobe is not extensively used because the district has serious water-shortage problems. Every day women and children have to travel more than 30km by bicycle to find water for cooking, drinking and hygiene purposes. When it is difficult to find water to satisfy the most basic human needs, it becomes excessively difficult to find water to produce enough bricks to build a house.

The problems of unavailability of suitable soils for brick production, flooding and earthquakes do not occur everywhere, hence there are areas with favourable conditions for building with adobe. Most of the highlands areas are not vulnerable to floods or earthquakes and they have good soils for the production of adobe bricks. Apart from districts such as Machaze and Mossurize (regions where seismic activities occur), most of Manica province has ideal conditions for adobe construction. Chimoio town and Sussundenga, Manica and Gondola districts are among the places where the production and use of adobe brick is part of local tradition.

There are areas where bamboo is an abundant building material. The area of chief Mahate (Sussundenga district) is, for instance, covered by extensive areas of bamboo

forest. In this and adjacent areas, bamboo is widely used for purposes such as making framed walls, roof frames, bridges, baskets and furniture.

Stone occurs in abundance in the mountainous areas of inland Mozambique but it is used infrequently as an alternative construction material. In contrast to other materials, stone is difficult to extract and shape and its processing requires much energy (either human or mechanical). Normally, before stone is used for construction purposes it has to be cut and dressed to suit the needs of construction. Local people do not have the tools to do these masonry tasks easily or quickly and they resort to using firewood to heat the rock and hammers to break the rock into smaller stones.

For roofing material, palm leaves and grass are the most common choices. Palm leaves (*macuti*) are normally used in coastal areas where coconut palms grow abundantly. Inland, grass is the favoured material for making roofs. *Macuti* and grass are not permanent roofing materials but their local availability makes their use feasible.

4.1.3 Prevalence of alternative construction and the raising of institutional awareness

In an interview, Vicente Muechumo (pers. com., 2009) stated that DPOPH-Manica does not have a housing policy aimed at providing adequate shelter for local people. The majority of the local population do not have a formal job and most of those who are informal workers cannot afford to build or buy adequate housing. Surprisingly, INE (2009) reports that almost all Mozambicans have a shelter – only about 0.1% of Mozambique's 15.3 million people did not have a shelter.

Why continue discussing shelter when so many inhabitants have a residence? Data presented in section 4.1.1 and the real situation show that most dwellings in Mozambique cannot be called adequate shelter. Alternative housing presents precarious conditions and does not comply with construction regulations and municipalities seldom enforce building by-laws against such inadequate buildings. Any attempt to enforce the by-laws regarding informal construction without any

housing policy favouring poor residents would cause a catastrophic situation with most of these people becoming homeless.

DNE (2008) sees that about two thirds to three quarters (5.1 million) of the urban population live in informal settlements and most of them belong to a low-ranking social stratum characterized by very low incomes. But, according to DNE (2008), it is not expected that the government will apportion adequate shelter for a significant number of people with the implication that the local population will have to continue using alternative building materials. This does not mean a total abandonment of its responsibility for addressing the needs – in this case adequate shelter – of the local population because the government intends to mobilize, organize and help families in a vast housing programme of self-building activity (DNE, 2008).

Considering the possibility of using local resources to provide easy access to shelter, the government created the National Strategy for Application and Dissemination of Materials and Alternative Construction Systems of which the main objective is to “define ways to build more public, social and private infrastructures through alternative construction methods that are feasible and durable, and through the promotion of the construction industry gradually, continuously and sustainably” (DNE, 2008:8, author’s translation) This objective has five components as described in Table 7.

Table 7: Components of the objectives of the National Strategy for Application and Dissemination of Materials and Alternative Construction Systems

Component	Objective of the Component
Quality and regulation	Ensure that alternative materials and construction systems are standardized in order promote quality, safety, comfort and easy application.
Research, database and knowledge management	Create a favourable environment for the realization of research, generation of knowledge and the application of the results to the construction industry.
Training and short-term training	Create conditions for training people in the system to give them knowledge and abilities for the production and application of alternative materials and construction systems.
Divulgence and multiplication	Establish a system of dissemination of experiences, accumulated knowledge and innovations in the domain of production and application of alternative materials and construction systems.
Institutional development	Ensure major coordination and synergies between the institutions for the production and application of alternative materials and construction systems.

Source: DNE (2008)

4.1.4 Research and dissemination of information about alternative materials

The intention to make alternative materials a solution to the problem of inadequate shelter is still in its preliminary stage of implementation. At present there are not many visible practical actions regarding the concretization of the stated objectives. Vicente Muechumo (pers. com., 2009) says that his institution is still researching local opportunities regarding alternative building materials as well as considering global success cases pertinent to the Mozambican challenge.

Earth has been identified as a material offering immense opportunities for the creation of durable houses for poor dwellers while ensuring their safety and comfort. Currently, DPOPH-Manica is exploring the possibilities of introducing the use of pressed and stabilized earth bricks. It has been found that soils in the research area are appropriate for the production of adobe bricks which are suitable for building durable houses.

The technologies being tested include the use of cement to stabilize the soil to increase the strength of the bricks and their resistance to water. According to DNE (2007) the process of chemical stabilization involves adding 10% cement to the soil after which the mixture is compressed with a machine.

However, because the local communities are unfamiliar with this, it is necessary to provide training before the technology is disseminated (Vicente Muechumo, pers. com., 2009). Interviews and focus group discussions revealed that these technologies have still not been disseminated at local level. Unlike the traditional method of unfired adobe brick production, soil-cement brick production involves complicated steps that need to be followed carefully. According to DNE (2007), this method of brick production involves the following steps: excavation, preparation of soil, preparation of the mix, the moulding, disposal, and drying and curing of bricks (see the description of each phase in Appendix 7).

Preliminary experience with this technology is showing that although the quality of the bricks is high compared to that of unfired adobe bricks, the costs are relatively higher. It was observed that the price of a soil-cement brick (20x9.5x5cm) was

estimated to be 5.00Mt. An unfired adobe brick with bigger dimensions (24x12x7cm) costs only 50 cents, while a burnt brick had an estimated price of 1.50Mt. Clearly, the use of cement as a stabilizer is an expensive option.

As an alternative to cement, DPOPH-Manica has been studying the possibility of introducing lime. It has been observed that most of the colonial administration buildings had been constructed using this material. Exploratory trips undertaken by teams of DPOPH-Manica have found that limestone is an abundant resource in most parts of Manica province such as Machaze, Macossa, Tambara and Mossurize districts. As the local people in these areas have been producing lime by means of a process of limestone burning, it can be assumed that the costs of using this material as a stabilizer can be relatively low compared to cement stabilization, but this remains to be confirmed. Research on the real cost-benefit of this has not been completed so that empirical evidence cannot be provided on the comparative costs of lime stabilization compared to cement stabilization.

4.2 The production and use of adobe brick in local communities

Studying adobe construction in Mozambique without consulting the local communities is unthinkable because some members of these communities have a wealth of experience and expertise in the production and use of this building material. This section presents the results of fieldwork done in local communities living around Chimoio where a considerable number of people rely on unfired adobe bricks to build their shelters.

The findings cover the following topics: the characteristics of local unfired adobe constructions; basic methods of adobe brick production; socio-economic reasons for using adobe; the process of knowledge transfer regarding adobe construction methods; challenges concerning the use of adobe; and finally, some considerations pertaining to environmental issues about the use of adobe at local level.

The information was gathered using three data collection methods. Discussions with two focus groups were carried out: the first group is designated as A and the second group B (see focus group participants following the list of interviewees). Informal interviews were held and observations made.

4.2.1 The application of adobe in house construction

Mud as a building material has various applications. The focus group discussions confirmed the observations made in the field that adobe is traditionally used to produce bricks for making walls in which the bricks are bonded using mud mortar made of the same soil used to make bricks. Plaster is also made from the soil. Mud plaster is used in cases where the walls are made of unfired adobe bricks and is also normally applied to bamboo- or peg-framed walls. Mud is also used for flooring and for painting and decorating walls. While this study focuses on the use of adobe bricks, it also reports on some other uses of adobe.

4.2.2 Local factors determining the production of adobe brick

There is consensus that soil is the crucial element to consider before starting to produce adobe bricks. There are different types of soil but not all of them can be used to produce bricks. According to both focus groups, suitable soils are those containing some proportion of clay, but it is essential to make sure that it is in the right proportion. When the clay content is too high the bricks tend to crack and if the clay content is too low the bricks can be effortlessly broken by hand.

Unfortunately, neither the interviewees nor the focus group discussants were aware of any method that is universally used to test the quality of soil and the soil clay content. Two different perspectives regarding the analysis of soil suitability were presented. Focus group A proposed that colour is a soil property used to assess the suitability of local soils for brick production. According to them grey soils are the most appropriate for making bricks. Red soils can also be used for this purpose, but compared to grey soils they present low clay content and are not resistant to water. However, they agree that these ideas are inconclusive about the suitability of soils. The option used by

communities reflected in focus group A was to produce some bricks and test whether the bricks crack or not. Should they crack it means that the soil has excessive clay content and measures must be applied to reduce or eliminate cracking.

Focus group B agreed that they gain a first impression about soil quality by touching the mud (mix of soil and water). If the mud is sticky the soil contains some clay. Similar to the advice given by focus group A, focus group B determine whether the soil contains excessive *dongo* or clay by producing a sample of bricks and establishing whether they crack or not. The idea that cracks in bricks is an indication of excessive clay contained in the soil was supported by the informal interviews made during observations in the field.

By observing the process of adobe brick production it became clear that although soil is a crucial resource for brick production, an essential ingredient for which there is no substitute is water. To make soil workable it must be mixed with water. When water is applied to the soil the *dongo* or clay acts as the glue between the soil particles.

An aspect that focus group B identified but not mentioned by focus group A nor in the informal interviews, is the inclusion of human power as an important element of adobe brick production. It was observed that in almost every stage of adobe brick production the work was supported by human power. Human fitness and individual commitment are factors that determine the number and quality of bricks that can be produced daily.

The weather is a natural factor that determines when to make adobe bricks. It is obviously inadvisable to produce adobe bricks in the rainy season. There is clear evidence of critical damages afflicting unfired adobe brick when it rains. As shown in Figure 5 the rainy season in Mozambique begins in October and extends until April. Bricks produced in this period are affected by excessive moisture causing them to melt, weaken and deform. Normally, winter is the season for brick production and the building of unfired adobe brick houses.

4.2.3 The production of adobe bricks

After making sure that all the basic conditions for brick production are satisfied, the next step is to produce the bricks. It was observed that the production of adobe brick follows a basic formula that combines soil and water. The water is added to the soil and a shovel is used to mix the two elements. According to the producers, better results can be attained when the soil is mixed with the right amount of water. Normally, the producer gradually adds water to the soil until he gets the feel that the mud is workable. It is difficult to handle mud containing excessive amounts of water in one's hands and the bricks cannot hold their shape. By contrast, insufficient water causes a lack of adherence between the particles contained in the soil.

The mud is put into moulds to shape the bricks and immediately are left to dry (see Figure 9). Adobe bricks are sun- and air-dried. The bricks tend to crack when exposed to excessive direct sunlight.



Figure 9: The use of moulds to shape bricks
Source: Photographed by Mercio Germano.

The focus groups and five interviewees proposed that after being removed from the moulds, the bricks should be protected from direct sunlight by covering them with grass or by placing them in a well-ventilated open shady area. These measures are

applied for a period of two days. After this the bricks can be exposed to direct sunlight until completely dry (see Figure 10).



Figure 10: Bricks drying in the sun after removal of the grass
Source: Photographed by the author.

To reduce cracking caused by excessive clay contained in the soil, sand is used as the only stabilizer for unfired adobe bricks. However, in most instances producers do not stabilize adobe bricks. Of the 13 cases observed in the field, 92% did not stabilize bricks while only 8% used sand to stabilize their bricks. Some local producers argue that sand has the disadvantage of being unavailable locally and must therefore be transported from elsewhere. Furthermore, given that sand is seldom used as an ingredient in the production of unfired adobe bricks, some producers ignore its use.

After drying, some local producers prefer to burn the bricks to improve their strength and reduce the sensitivity of the material to moisture. This is an optional measure because the bricks can be used for building even without burning (see Figure 11). Observations confirmed that most times adobe bricks are not burnt. The burning of bricks depends on access to firewood which if not available locally, must be brought in from elsewhere which implies transport costs.

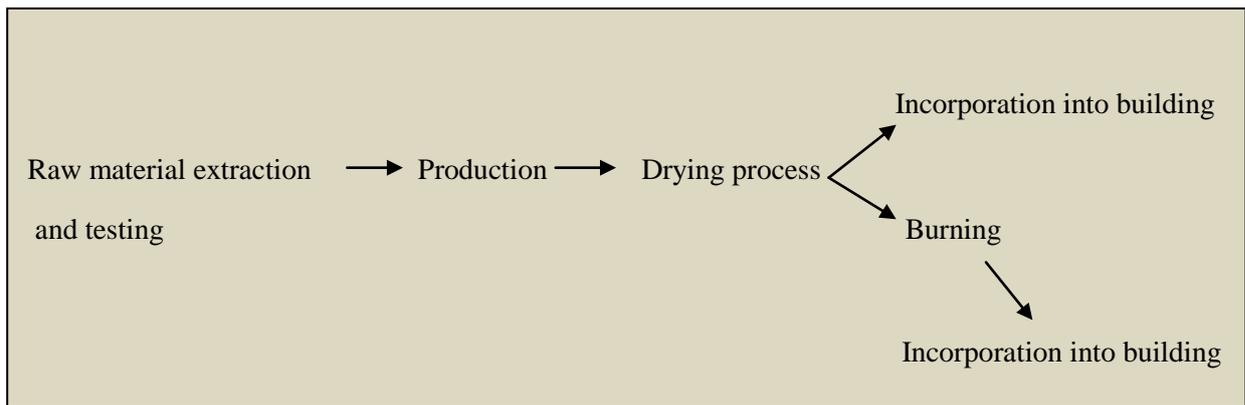


Figure 11: The process of adobe brick production and use in building houses

Source: Fieldwork information

Normally producers prefer to make adobe bricks at the construction site to reduce transportation costs. It was observed that the production of adobe brick away from a construction site is a disadvantage because during transportation a number of the bricks are damaged (this relates to stresses encountered during transport and is associated with the poor quality of rural roads).

4.2.4 Characteristics of adobe construction

It was observed that various materials are options for making foundations for unfired adobe brick houses. Cement brick, fired and unfired adobe bricks and stones are examples. Both focus groups and personal observations confirmed that unfired adobe brick is the material most often selected for foundation construction.

The mortar used to bond the bricks is the same as the mud used for making bricks. Plaster for walls is a mixture of soil and water. In cases where the proportion of clay in the soil is too high sand is added to stabilize the plaster to prevent cracking when the plaster dries. According to experienced adobe builders in focus group B, cement is not an advisable option for making plaster since it does not adhere to walls made of unfired adobe brick. Observations also confirmed that when cement was used as plaster for adobe walls it tended to crack and to separate from the walls.

Soil is also used as paint for adobe brick walls. Local people use soils with a different colour from the one used to make the plaster. The primary reason for this is aesthetic as the colour beautifies walls as opposed to protecting them from storms and water. Instead of painting walls using soils, walls are sometimes painted with waste engine oil which in turn protects the walls against water. Although not used as plaster, cement is mixed with water and the resulting liquid is frequently used as an exterior paint for adobe walls. According to Constancio Armindo (per. com. 2009), a brick producer and builder of adobe houses, this measure has proven to be effective as a way to reduce the impact of storm water on external mud walls.

The local unfired adobe house is normally a single-storey construction. The provision of a roof is an important design aspect as it protects the walls from storm waters. When someone intends to build an unfired adobe house he must make sure that he has budgeted to provide a good roof for his house. In most instances, grass is used as roof material and is affordable for most of the poor adobe dwellers. The roof frame is made of bamboo which is cheaper than wood.

Martinho Tenday (pers. com., 2009) observed that grass roofs are not resistant to weather and wear and they need maintenance every few years, therefore the height of the building can be a constraint when needing to make constant changes. Additionally, grass roofs are vulnerable to wind damage and so ideally, houses should be protected by trees and other buildings.

The perception exists that the qualities of unfired adobe bricks dictate that walls made of this material should not be too high. Vicente Muechumo (pers. com, 2009) argued that an unfired adobe brick wall should have the maximum height of 2.5 metres. Almost all the focus group members voiced their doubts about the possibility of building two-storeyed houses using unfired adobe brick and they had never tried to build such multi-storeyed houses. However, Carlos Aguacheiro (member of focus group A) did not discard the possibility of increasing the height of adobe houses or building a double-storeyed house using unfired adobe brick. He believes that it is a matter of finding appropriate techniques for this purpose. One of these techniques is to increase the thickness if walls are to be built high.

4.2.5 Functionality of unfired adobe brick houses

Several visits to unfired adobe houses in the local communities established that houses comprise bedrooms and a dining room. There are no kitchens or piped water in the main buildings. The cooking place is normally located on a veranda and kitchen utensils are washed at a specific place in the backyard. The owners of the houses stated that given its low cost, firewood is used for cooking and food is prepared outside because the smoke from firewood combustion indoors would lower indoor air quality.

Bathrooms and toilets are separated from the main buildings. Grey water from a bath is drained through a hole in the bathroom wall. Latrines are far more common than toilets. In most cases, bathrooms and latrines have no roofs so that their interiors are exposed to the sun and precipitation.

Members of both focus groups said that latrines are usually constructed at a distance from houses to avoid the proliferation of insects and odours near to the main building. Bathrooms are not located inside the main house because, in the absence of piped plumbing, it is necessary to avoid the potential negative impact of bathwater damaging adobe bricks. Normally the walls of latrines and bathrooms are not made of adobe bricks but rather from grass, bamboo, wood and hard plastic which are the preferred building materials.

Compared to housing where all the rooms are under one roof, people living in local unfired adobe brick houses have to make an effort to get to their bathroom or latrine, an inconvenience that is made worse on rainy days or during the night. Obviously, one of the challenges with facilities located away from the main house, as mentioned by the focus groups, was the fact that using a latrine when it rains means that residents run the risk of getting wet and the normally unilluminated path at night increases the possibility of stumbling over obstacles. House dwellers also said that there is a perception that when they use these toilets and bathrooms the neighbours or people in the street are watching them, resulting in a perceived and real lack of privacy.

4.2.6 Adobe brick and socio-economic life of local communities

The decision to use unfired adobe brick in construction is informed by reasons well known to the inhabitants of these houses. As persons who live in and build houses using adobe, the members of both focus groups agreed that the primary reason for choosing alternative building materials is their affordability. Adobe is not chosen because it is the first preference of poor people, but because it is the material that most of them can afford. Table 8 indicates that, compared to other brick options, unfired adobe brick is the cheapest and it costs less to build a square metre of a wall with it. An unfired adobe wall is three times cheaper per square metre than a fired brick wall and eleven times cheaper per square metre than a cement brick wall.

Table 8: Relation between dimension, unit price and cost/m² of building a wall (currently 4.10Mt=1ZAR)

Type of Brick	Dimensions	Price (Mt)	No of Bricks/m ²	Cost/m ² of a Wall (Mt)
Unfired brick	24x12x7cm	0.5	35	17.5
Fired brick	24x12x7cm	1.5	35	52.5
Cement brick	40x10x20cm	15	12.5	187.5

Source: Data gathered from field observations.

It appears that instead of spending scarce resources to buy unfired adobe bricks, local people have managed to significantly reduce the cost of this material because generally poor people have access to suitable soils and water located at or near the construction sites and they prefer to produce bricks themselves. The same applies in the construction process where they prefer to build on their own or use a contractor for whose services they pay a minimum.

The interviewees and focus group members pointed out that although the cost of bricks can be significantly reduced it does not necessarily mean that a person automatically has the opportunity to own a house. It must be borne in mind that unfired adobe brick is not the only material used to construct a house. Components such as doors, windows and roofs are made of other materials such as wood, grass, plastic and bamboo. These materials must be acquired, usually at a cost.

4.2.7 Training for alternative construction

Opposed to conventional construction, unfired adobe brick production and construction are dominated by people who have no formal training. Regarding this issue Martinho Tenday (pers. com., 2009), a local building foreman, said that most qualified builders know little about unfired adobe brick construction and if a qualified builder does know something about adobe it was learnt through experience and not through formal training.

Asked about training for alternative construction, Silvino Ratia (pers. com., 2009), a civil construction technician, confirmed that adobe and other alternative materials did not form part of the training programme he participated in at the Industrial and Commercial Institute in Beira. Furthermore, he admitted that he and his colleagues know less about unfired adobe brick construction than rural self-taught builders who have been working with alternative materials more frequently.

All the focus group members and interviewees who work with adobe have never undergone formal training in alternative construction. They have learnt about adobe through their active participation in activities related to the production and use of this material. Observation, practice and oral explanation by experienced builders are the methods used in the transmission and acquisition of the knowledge.

From the life stories told by people involved in adobe construction it became quite clear that the main motivations to learn about adobe were the need to develop a profitable activity to sustain the family and the prospect of building their own house. Housemaid Laura Marina (pers. com., 2009) mentioned that before she became a waged worker she produced and sold adobe bricks. It was her only way to get money to pay school fees and buy food for her children (see Box 1).

Box 1: Laura Marina's story

Laura never had the opportunity to attend a formal school when she was young. When she got married she did not have a waged job. Her husband was employed but the wage was not enough to support all the basic needs (such as school, food and housing) of the family. Given this situation she realized that she had to do something to earn an income and help her husband support the family.

Stealing or prostitution were not options as these were against her moral principles. Laura highlighted her position saying that “*acreditei que deveria haver alguma forma de ganhar dinheiro sem ser desonesta*” (I believed that it was possible to make money honestly).

Fortunately, after some time of reflection there was an idea: make adobe bricks to sell and build her family's house. It was a good idea, but the practice would imply something different to what she was thinking given that she had never before worked with adobe. This was not an insurmountable obstacle and learning by doing was the immediate solution. So, she observed, she tried to make adobe bricks several times until the quality of her work improved sufficiently.

Today she has built her own house without recruiting anyone else and most of her children's school bills have been paid with money coming from the production and commercialization of adobe bricks. She believes that despite formal training being important, practical life is the best school to obtain basic knowledge about adobe brick production and use. By working with it daily she got the real sense of the material and an understanding of how it behaves.

The same happened with Constancio Armindo (pers. com., 2009) and Gaspar Matequenha (pers. com., 2009). They got married before they were able to get a waged job. They had to learn how to produce adobe bricks to guarantee the sustenance of their families. Martinho Tenday (pers. com., 2009) had a different story. He was trained as a builder of conventional buildings, but he was forced to learn and build his own house using adobe because he could not afford a conventional house.

4.2.8 Adobe bricks and environmental impacts

The interviews and focus group discussions established that environmental issues are not main concerns of local people. Vicente Muechumo (pers. com., 2009) argued that environmental concerns do not normally influence decisions regarding the choice of building materials as it is cost that chiefly determines the choices that the poor make.

For this reason it was necessary to observe the stages of adobe brick production and its use in buildings. It became clear that in almost all the stages of adobe brick production and use, renewable sources of energy that have less impact on the surrounding environment are used. Only in cases where motorized transport is used does the non-renewable petroleum used to run the vehicle constitute an impact. But because most adobe bricks are produced on-site this type of impact is minimal. Table 9 summarizes the possible environmental impacts of adobe brick production.

Table 9: Environmental impacts associated with the different phases of adobe brick production

Environmental Indicators	Phase of Adobe Brick Production			
	Soil Extraction	Production	Drying	Burning
Source of energy	Human power	Human power	Sun and air	Firewood
Renewability of the energy source	Renewable	Renewable	Renewable	Renewable
Gas emissions	No gas emission	No gas emissions	No gas emission	Gas emission (CO ₂)
Impact on raw material source	Use of soils for agriculture, erosion	–	–	Deforestation and destruction of habitats
Recyclability/Reuse of material	–	–	Recyclability/Reuse still possible	Only reuse is possible

Source: Field observations and interviews

The environmental impact of the production of adobe brick increases considerably when this material is burnt. The process of production of unfired and fired bricks follow similar stages until the drying process. The burning process is an optional continuation of the process of adobe brick production and is practiced to give more strength to the final brick. Nevertheless, as Figure 12 illustrates, the decision to strengthen bricks has its implications in that the negative environmental impacts and production costs tend to increase.

Felix Tomé Miguel (pers. com., 2009) commented that two of the disadvantages of burnt adobe bricks are deforestation and loss of biodiversity, but it is not possible to assert whether the production of adobe is contributing to the unsustainable use of forest resources or not.

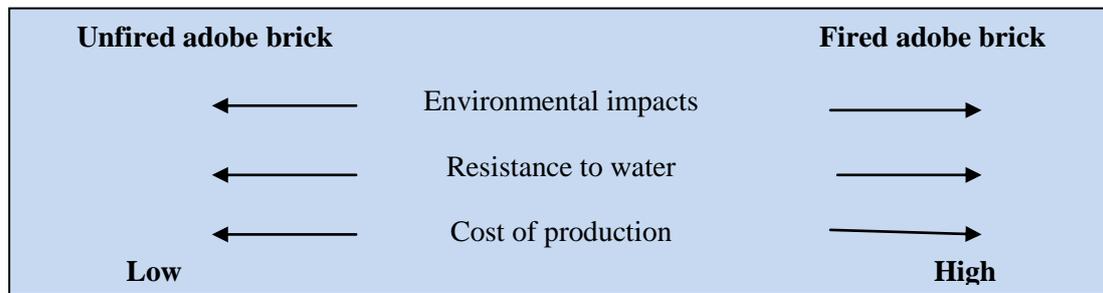


Figure 12: Tendencies of sustainability indicators in the process of fired and unfired adobe brick production

Source: Compiled by the author.

Constancio Armindo (pers. com., 2009) and Gaspar Matequenha (pers. com., 2009) have been working for eight years as adobe brick producers and they are not aware of any significant negative environmental impacts resulting from their activity. They say that the popular method to burn bricks is to use dried firewood and fresh firewood. Dead trees or branches constitute dried firewood while fresh firewood is obtained by cutting branches from living trees without killing the entire tree. The way the kilns are made determines the amount of firewood necessary to burn bricks. Kilns should be made to use the heat from the combustion efficiently.

Transporting firewood to places where bricks are burnt also impacts the environment through CO₂ emissions when motor vehicles are used. Depending on the place where firewood is harvested the degree of impact will vary: the closer the place, the less the impact.

The negative environmental impact of fired adobe brick does not stop with the simple problem of firewood use. Fired adobe bricks forfeit an important property that unfired bricks have, namely a fired adobe brick cannot be returned to its natural state. Unfired adobe brick can be decomposed and used to produce another brick with a different shape or even be returned to its natural state. In other words, there is no waste with unfired adobe brick.

The extraction of soil in erosion-prone areas can trigger erosion. Large-scale extraction of soil can lead to the creation of large holes that are not filled with other elements to substitute the removed soil. This was observed in sites where adobe bricks are produced for commercial purposes. During the rainy season the walls of the holes tend to collapse progressively affecting extensive areas of land and the elements in it.

Sometimes the holes are used for purposes such as dumping sites for waste or places to build latrines.

Fortunately, there were no reported problems related with negative health effects resulting from the production and use of unfired adobe bricks, and compared to the views about conventional buildings, opinions informed by the daily life experiences of residents confirm that thermal comfort of unfired adobe houses is noteworthy in that the interior of the houses is relatively cooler in summer. However, it was not confirmed whether unfired adobe brick houses are warmer or not in winter.

4.2.9 Reported challenges to the use of unfired adobe bricks

The use of non-fired adobe brick provides many challenges. One of these relates to the perceptions that people have about the material. Mud is often regarded as something dirty and only used by the poor. Martinho Tenday's experiences (pers. com., 2009) illustrate this way of thinking (see Box 2).

Box 2: Martinho Tenday's story

Martinho has acquired experience both in adobe brick construction and conventional construction. Contrary to conventional construction he was never taught how to build an adobe house in a formal school. He learnt it by participating in the processes of adobe house construction. In formal schools, adobe and other alternative materials are mostly regarded as inadequate to construct reliable houses and it is not seen as relevant to the professional builder.

He sees that among builders there is a sense that building an unfired adobe brick house is not good for their career. He notes that owners of unfired adobe brick houses usually cannot afford conventional materials because they are financially dispossessed, meaning that most times they are not able to support the prices proposed by builders.

A builder who works with adobe is also seen as having a very low reputation. It is common to hear sneers like "*Se ele fosse um bom pedreiro teria sido contratado para fazer uma casa de cimento*" (If he was a good builder he would be recruited to build a cement house). Tenday's view is that this is just a perception that people have about different building materials. Nowadays, for many people, building with cement means life improvement and achievement of a better social status.

The perceived issue of safety is also influenced by the weaknesses of adobe when exposed to natural hazards, especially storm water. During the rainy season it is common to witness events where walls of adobe houses collapse. The focus group discussions concluded that because adobe is perceived as a dirty material, primarily for the poor and given the reported accidents caused by the use of this material, unfired adobe house dwellers put greater effort into earning, saving or loaning money to build conventional houses in order to solve the perceived problem of safety and to attain a higher perceived social status.

It is important to point out that the weak performance of local unfired adobe brick constructions is often the result of shortcomings in the design of some components of adobe houses. Martinho Tenday (pers. com., 2009) supports this warning (see Box 3).

Box 3: More of Martinho Tenday's story

Martinho believes that all materials (including cement and steel) have their own strengths and weaknesses. The important thing is to know how to reduce the weaknesses and explore the advantages of each material. When you do not follow rules of correct use of a material the result is that it performs badly. To support this argument he states that “*vivo numa casa de matope desde 1981, mas as paredes nunca ruiram. Vi casas de cimento que foram construidas muito recentemente e ja apresentam rachas e correm risco de desabar*” (I have been living in an adobe house since 1981 and the walls have never collapsed. I have recently witnessed the construction of some cement houses of which the walls are already cracked and running the risk of collapsing).

It is true that adobe is a weak material when exposed to excessive moisture and most people are negligent when it is time to protect their houses from storm water. This is probably one of the most serious disadvantages of adobe and sometimes people judge the material by problems that could have been avoided. According to him the secret of a resistant adobe construction is the provision of good roofing, construction of verandas and provision of sloped surfaces to drain storm water away from the external walls.

According to observations made in the field, the most common shortcomings of adobe houses are related to deficiencies in roofing, foundations, the way walls are raised and the construction of houses on inappropriate sites.

Roofs and foundations are the two main building features where moisture gets into the walls. Often, when a roof does not have an overhang, external walls are easily

affected by storm water which contributes to their erosion. If the roofs do not have overhangs and there are not gutters storm water accumulates close to the bottom of the walls. In cases where foundations are made of unfired adobe bricks and there is water ingress, the walls can easily collapse because the base that supports the vertical load of the house is weakened. Such situations can be seen during the rainy season where collapsed walls indicate that the bottom of the wall has absorbed excessive moisture while towards the top the wall tends to be dry.

Regarding this problem, a number of solutions have been implemented. Daily experiences of adobe house dwellers and builders provide evidence that when a roof is overhung it is less probable that the walls will be affected by storm water. This measure can be complemented by verandas and channels to evacuate the water that accumulates in the bottom of external walls. The experience has also shown that unfired adobe brick is not an ideal material for building foundations. The appropriate materials for foundations are stone, fired adobe brick or cement brick. As referred to previously, to protect walls from water, local communities either paint mud walls with waste engine oil or cement paint (a mixture of cement and water).

Apart from the problems related to shortcomings in roof and foundation construction, the walls are also raised in ways that can easily result in collapse. In most cases adobe houses have inclined walls. It was observed that many adobe house builders (the rural poor) do not use the necessary equipment (e.g. spirit levels) to ensure that walls are perfectly vertical or level.

Some builders have realized that the speed at which a wall is raised contributes to its inclination. Constancio Armindo (pers. com., 2009) has explained that different to cement mortar, mud does not dry as quickly as desired by many builders. Normally, after laying three rows of adobe brick it is necessary to stop building and wait for the mortar to dry otherwise the wall can start leaning to one side. Another factor is that mortar that contains excessive water will not support a brick.

An assessment of the building site is a vital aspect neglected by some builders and dwellers of adobe houses. There are cases where adobe houses have been built in

areas with a high flooding risk or where the foundational soils are weak. Antonio Mussalamba (pers. com., 2009), a physical planning technician, acknowledges that it is common to find unfired adobe houses built in flood- or erosion-prone areas or those with weak soils. These conditions contribute to increased vulnerability of buildings and reduce the degree of resistance. These aspects are often neglected and when a house collapses people do not always relate the event to the unsuitable conditions offered by the place chosen for the construction.

4.3 The construction of Dieter's house

To witness and understand the use of adobe as a building material, a challenge was taken up to build a two-storeyed unfired adobe house in Chimoio. This initiative was made even more challenging in that the participants in the project had never before participated in any form of adobe construction at the scale of this project. Significantly, this is the first two-storeyed unfired adobe house built in the study area thereby constituting a learning process where the researcher contributed with the theoretical and limited practical knowledge and learnt about adobe construction through physical engagement in the process. This was seen as a critical part of the research as the researcher felt that it was necessary to immerse himself in the process and fully understand the context he was reviewing.

More than being a simple exchange of experiences it involved an exercise aimed at bringing more insights to this study. By participating in the operation as an active observer it was possible to better understand the real challenges to using adobe and to recognize the advantages and the potential of this material in terms of sustainability. This section describes and analyses the design process, the practical execution of the project, the challenges faced in building the house and the costs of the main materials used.

4.3.1 The design process

Many elements need to be considered before beginning the construction of an unfired adobe brick house. Aspects such as functionality; dimensions of the house; the conditions of the building site; and existence of skills in adobe construction methods were the elements taken into consideration during the decision-making process. Each of these aspects is examined below.

Functionality. The house should include basic areas such as a bathroom, three bedrooms, a kitchen, a living room, a dining room and a study. Each of these elements should be designed in a way that maximizes the comfort of the occupants. The rooms should be positioned to maximize interior sunlight and to provide inspiring outside views for the occupants. Unfortunately, not all rooms can have these features, so trade-offs were necessary. The living room and the main bedroom are the rooms that, given their position (without obstacles in front) and window design (large windows), got more benefits in terms of daylight. The kitchen was positioned closer to the dining room and the bathroom near to the bedrooms. A study, staircase and corridors were included.

The construction site. Scrutiny of the dimensions of the site provided for the house made it clear that it would be difficult to include all the functional elements the owner desired in a single-storeyed building. The house had to be eight metres long and six metres wide and be double-storeyed to accommodate all the functional elements. The design process also considered that the construction site was surrounded by obstacles (trees and other buildings) that would affect the maximization of daylight in the building. The on-site existence of suitable soils for the production of adobe bricks was an advantage because it obviated the need to produce them elsewhere.

Availability of skills. The availability of skills was a critical issue in the decision-making. Construction technicians trained in official schools were contacted and invited to participate in the project, but they did not consent because they felt they had inadequate knowledge about vernacular construction in general and adobe brick construction in particular. People who had no formal training in adobe construction but who had acquired it through experience, constituted the most viable solution

concerning skills. In contrast to builders trained in formal schools, the latter group showed interest to apply their adobe-related knowledge and also, due to the slightly different design (specifically the double-storey construction) the adobe builders were interested in learning something new.

Because none of the builders had any experience of building a double-storeyed house, it was necessary to establish some working principles. The first principle was that adobe behaves differently to cement so that construction methods would have to take this into account. Construction methods had to be chosen that would improve the performance of the material, increase the durability of the house and ensure the safety of its occupants. The second principle was that the construction process would involve a dialogue in which all the participants would be encouraged to air their views.

Considering that adobe has unique characteristics as a building material and owing to the failed and successful experiences of the group members, some important decisions regarding the design of the house were made. Because the foundations had to be made of a material that was less vulnerable to water, stone or fired adobe bricks were the immediate options. The upper floor had to be made of wood and be supported by unfired adobe brick walls and vertical wooden posts. The roof had to be supported by the walls and vertical posts. Based on the participants' experiences, it was also decided that the mud should be used as mortar and as plaster.

4.3.2 Brick production

It was necessary to produce 5000 adobe bricks. Two persons engaged in the production – the builder and the house's owner (the researcher) – had previously been involved in brick production and were capable of producing between 300 and 400 bricks per day. It took them almost two weeks to reach the target. The bricks consisted of a mixture of soil and water and no stabilizer was added.

In order to reduce cracking, some bricks were dried in a shady place and others covered with grass for the first two days after the production, after which the bricks were transferred to places exposed to direct sunlight. The bricks which were covered

with grass had no need to be transported to another place as they were dried on-site. Bricks placed in shady areas had to be transported to places with direct sunlight and because these bricks were moved too early and had not dried completely, some were damaged. To transport bricks required human effort and time. Covering bricks with grass is more efficient than putting them in shady places.

Some bricks were rough and did not have a definite or regular form rendering the work of builders more difficult. The deformities in the bricks were caused by the place where the bricks were deposited not being level and in some instances because the mud contained too much water.

4.3.3 The construction phase

This stage provided an opportunity for the participants to interact and to learn from one another. During the construction process various challenges confronted the working team. Most of these problems were unforeseen and called for quick resolution. Problems were discussed and every participant had something to say about possible solutions. The challenges at this stage included stresses and technical shortcomings of the construction process and even reactions of people who were not involved in the project.

When the idea of building a two-storeyed house came up and during its construction, opinions were voiced about using unfired adobe brick as a building material. Mud was dismissed as vulnerable to water, a dirty material and a material for use by people with a low social status. Even those who were invited to participate actively in the building exercise expressed their doubts about the possibility of attaining the results that the promoter of the project expected. Some extracts of these utterances are given below in the original Portuguese followed by an English translation:

“Este homem so pode estar maluco. Esta casa vai cair e lhe matar.” (This man must be crazy. This house will collapse and kill him).

“Nunca vi uma construção dessa natureza. O meu instinto diz-me que não vai dar certo.” (I have never seen a similar mud building. My instinct tells me that it will never work).

“Quando a primeira chuva vier este homem vai desistir desta ideia maluca” (When the first rain comes this man will give up this mad idea).

Contrary to these views, there were people who were enthusiastic about the idea of building a two-storeyed adobe house. The concretization of the plan would be a revolution in their minds and get them to think differently about mud and even convince them to invest in this kind of construction.

As the project progressed, opinions of people who watched the construction of the building began to change. They witnessed and understood that it was possible to improve the performance of unfired adobe brick and at the same time comply with the aesthetic and functional requirements. When they realized that it was possible to build an improved adobe house, they showed their satisfaction and contributed with ideas about creating a better result to the project.

The opinions about the use of unfired adobe bricks concentrated on the durability and safety of the material. Quite frequently people asked whether the building would last for many years or if it was safe for the future occupants of the building. As they started believing that the construction methods used would contribute to making the house more durable, they started to accept mud as an alternative to fulfil their aspirations for shelter without having to spend much money.

Considering the reported problems that the use of mud represented in the local context and the relatively limited knowledge about the use of this material, the promoter and his work team had to consider each real challenge encountered during the construction process and find solutions for each one.

Apart from the problems people expressed, other challenges to the use of adobe bricks were experienced during the construction process. The first was that construction coincided with the rainy season. When adobe was exposed to moisture, it took a long

time to dry and bricks disintegrated. Because the walls were unprotected against the weather during the construction process, they were affected by storm water and this contributed to the weakening of the structure.

Despite the foundations of the house being made from stones, cement and fired adobe bricks a critical threat was the accumulation of water in the bottom of the walls. As it can erode the first unfired adobe layers and destabilize the structure, water concentrated in the bottom of walls is more damaging than storm water that falls on the top of walls and seeps down (see Figure 13).

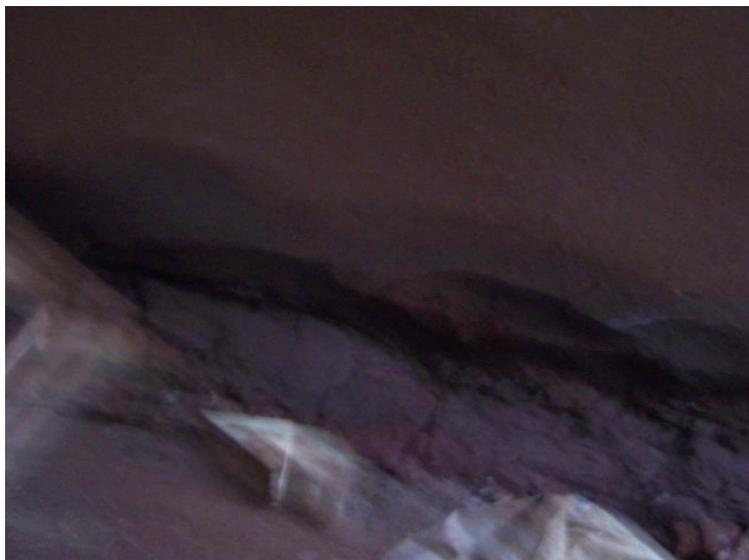


Figure 13: Bottom of a wall being eroded by water
Source: Photographed by the author.

It was possible to reduce the concentration of water at the bottom of the building as the building site was on an incline and a pavement had been constructed around the foot of the house to drain water. Also, an fired adobe brick ‘footer’ was provided at a height that running water could not reach (see Figure 14).



Figure 14: Introduction of 'footers' to protect the base of walls against water
Source: Photographed by the author.

However, this was not enough to protect the walls sufficiently. The roof of the house was not given an overhang, a decision that soon proved to be bad because water from the roof tended to gradually wash out the plaster from the walls. It was soon agreed that an overhanging roof and gutters were effective solutions to the problem (see Figure 15).



Figure 15: Overhanging roof.
Source: Photographed by the author.

While trying to raise walls quickly it became clear that they tended to bend. Mud does not dry as quickly as cement mortar, so the builders realized that they could not build the walls with the same speed as they did in cement construction.

Regarding mud plaster, it was known that the soil contained excessive clay but an unknown factor was the amount of sand necessary to stabilize the plaster. Therefore, it was necessary to test the mud plaster mixed in varying proportions of sand to find out which one worked well. This testing took up a lot of time until the right proportion of sand to be added in the mud plaster was found.

Seeing that the plaster was not stabilized against moisture, storm water could easily destroy it, making necessary to add an impermeable layer. Two options were known. The first was to use waste engine oil and the second was to paint the plastered walls with *goma* (mixture of cement and water). The second option was chosen and it proved to be an effective waterproofing method.

4.3.4 Environmental impacts

The process of producing adobe bricks and their respective incorporation into buildings has observable environmental impacts. Because the raw material (soil) was available locally the need to spend energy to transport it from elsewhere was obviated. The energy needs of the brick production process were met by renewable sources of energy. The digging of soil, mixing water and soil, introduction and removal of bricks from moulds were all done manually. The bricks were sun- and air-dried. The incorporation of the materials into the building was done by manual labour. Thus the production of the adobe bricks and their incorporation in the building was done with minimal emission of CO₂.

Although unfired adobe bricks could be considered to be carbon free, the building made of this material cannot be considered to be totally carbon free as the building incorporates materials that were processed, not produced locally and have higher

embodied energy¹⁰. The cement and fired adobe bricks used for foundations, the roofing materials and the windowpanes are processed materials which were transported to the construction site. The timber used is from a renewable source but its transportation to the site increased its embodied energy. However, compared to a conventional house this adobe house has less negative environmental impact considering that the use of cement and other materials with high embodied energy was minimal.

It is not only the embodied energy that determines the environmental sustainability of unfired adobe brick, but the bricks also have the advantage of being renewable, it being possible to use a discarded brick to produce another brick many times over.

4.3.5 Costs

It was estimated that to produce an unfired adobe brick (measuring 25x15x10cm) costs 1.00Mt. This means that to produce 5000 adobe bricks it would be necessary to spend 5000Mt. Clearly the use of unfired adobe bricks reduces construction costs. Table 10 presents a comparison between unfired adobe brick, cement brick and fired adobe brick that were sold at the local market.

Table 10: Cost comparison of unfired adobe brick, and fired adobe brick and cement brick (4.10Mt=1ZAR)

Type of Brick	Dimensions (cm)	Price (Mt)	No of Bricks/m ²	Cost/m ² of a Wall (Mt)
Unfired brick	25x15x10	1.0	35	35.0
Fired brick	24x12x7	1.5	59	52.5
Cement brick	40x10x15	15.0	12.5	187.5

Source: Notes taken on the construction process

According to these figures, unfired adobe brick is a most viable alternative in terms of cost. A square metre of unfired adobe brick wall was one and half times cheaper than

¹⁰ According to Harris and Borer (2005: 94) embodied energy is defined “as the primary energy used in all the different stages of materials processing, from the extraction of raw materials, through manufacture, processing and packaging, transportation at all the different stages, installation, and, finally, demolition and disposal.”

a square metre of fired adobe brick wall and more than five times cheaper than a square metre of cement brick wall.

Although the cost of unfired adobe brick was relatively low one must beware of surmising that the overall cost of materials would also be low. Other components used in the house increase the final cost (see Table 11).

Table 11: Overall cost of materials (4.10Mt=1ZAR)

Material	Cost (Mt)	% Share
Wood	42 742	56
Cement	5 895	8
Sand	3 300	4
Unfired adobe brick	5 000	7
Fired adobe brick	1 125	1
Fibre cement (Roof)	12 800	17
Glass	2 500	3
Stone	2 700	4
Total	76 062	100

Source: Notes taken on the construction process

In this comparison between the elements it is clear that unfired adobe brick constitutes a small part of overall costs, implying that the use of this cheaper material does not assure that everyone can build a house of this dimension.

According to Table 11 unfired adobe brick constituted only 7% of the total expense and represents the fourth highest cost after wood, fibre cement and cement. The two costliest items made up 73% of the cost. It is important to note that expenditure on materials would be significantly reduced if the design of the house did not include a wooden upper floor that constituted about half of the money spent on wood or if the roof was made of bamboo and grass. Bamboo and grass are cheaper than fibre cement but the construction period of the house did not coincide with the season that dry grass and bamboo were available.

Had unfired adobe brick been substituted with another type, the total cost of materials would have increased considerably (see Table 12).

Table 12: Construction costs using different types of brick (4.10Mt=1ZAR)

Brick Type	Number of Bricks ¹¹	Unit Price (Mt)	Total Price of Bricks (Mt)	Total Construction Cost (Mt)
Unfired adobe brick	5000	1.0	5 000	76 062
Fired adobe brick	8429	1.5	12 643	83 705
Cement brick	1786	15.0	26 790	97 852

Source: Based on notes taken during the construction process.

Compared with the use of unfired adobe bricks, the option to use cement brick would increase the overall material cost by 21 790Mt or about 29%. If we take into account that cement would be used to bond cement bricks and to plaster the walls the cost would increase above 29%. With fired adobe brick the material costs would increase by 7 643Mt (10%). Unfired adobe brick is clearly a viable option for reducing the overall cost of building a house.

Apart from materials, it is necessary to add labour to the final construction cost. Labour accounted for about 40 000Mt. Adding labour to the total costs of materials the final construction cost is estimated at 116 062Mt with labour accounting for 34% of the final cost and materials accounting for 66%. Regarding labour cost, it is not the work with adobe that entailed most spending: raising and plastering adobe walls constituted 25% of labour costs, while making other house components such as roof, windows, doors, floor and staircase constituted 75% of labour costs.

4.4 Conclusions

The findings help one to understand the extent to which unfired adobe brick and other alternative materials are important to local communities. Observations and data collected by INE affirm that compared to conventional construction, alternative forms of housing are a viable option for the majority of Mozambicans. Most of the

¹¹The estimate of the total number of fired adobe bricks and cement bricks needed for the entire construction was based on the ratio that to build a square metre of wall 35 unfired adobe bricks are necessary which would be substituted by 59 fired bricks or 12.5 cement bricks. To calculate the number of fired adobe bricks necessary to substitute 5000 fired bricks 5000 unfired bricks was multiplied by 59 fired bricks and then divided by 35 unfired bricks. The same procedure was applied in the case of cement bricks.

alternative building materials are natural and they are found locally. Although the government does not have a policy aimed to providing shelter for poor people, available information shows that almost all Mozambicans have some form of shelter and that the majority of Mozambicans inhabit houses made of alternative materials.

Unfired adobe brick is a cheap material and in most instances local communities in Chimoio have the material for free. However, the characteristics of alternative housing in Mozambique lead one to some important concerns about the basic conditions they present. The majority of these houses do not have basic services such as electricity, adequate water and sanitation. Apart from statistical data, observations and interviews with people living in this kind of structure advanced our understanding of the situation.

As argued by local communities and confirmed by the construction of Dieter's house, building improved adobe houses and providing basic services contribute to increased construction costs. Even so, adobe houses still remain cheaper than conventional housing. Furthermore, the environmental advantages of this material are evident and the use of adobe is beneficial to the local economy as it fosters the consumption of local materials and creates job opportunities for local adobe house builders.

It is true that in some instances local unfired adobe brick houses do not perform well. This issue is however related to the skills applied in the construction phase as well as other aspects such as weather conditions which all need to be considered when building. Information given by interviews with experienced builders and the experience of constructing Dieter's house are testimony that it is possible to make better use of adobe.

The findings of this study need to be compared with those of other studies to find similarities and differences. The next chapter discusses the results.

5 DISCUSSION OF RESULTS

This study of adobe house construction in Mozambique is not the first one undertaken as there is a body of research results of studies conducted on this topic in different regions in the world. The findings of this study need to be compared with those results, especially the studies of the use of adobe and its significance for sustainable development. Consequently, this discussion covers five topics, namely the socio-economic reasons for using the material elsewhere in general and Mozambique in particular; a comparison of methods of adobe brick production; the advantages and disadvantages of adobe; solutions for the problems that adobe constructions pose; and the environmental issues of adobe use.

5.1 The relevance of adobe brick in local socio-economic contexts

Harris and Borer (2005) have noted that there is evidence that adobe has been used for millennia. Cities built of earth (some 10 000 years ago) such as Jericho and Babylon are part of the archaeological evidence. In Mozambique, local people have reported that many generations have been using adobe and other alternative materials to provide shelter and protect themselves against rain, strong wind, cold and heat or even wild animals. Indeed, the use of adobe predates the colonial history of Mozambique.

It is estimated that more than one third to over half of the world's population today lives in dwellings made of earth (Moquin, 2005). The most common explanation presented in the literature (Moughtin 1996; Moquin, 2005; Blondet and Villa Garcia, undated; Baker, undated) for the massive use of earth as building material by the majority of the world's population is that it is one of the cheapest alternatives for people who cannot afford conventional materials. Krisprantono (2007) points out that "the production of cement and bricks cannot fulfil the demand of millions low-cost houses and is therefore out of the question for the poor."

The findings about the widespread use of adobe by financially dispossessed people in Mozambique supports the argument that this material is cheaper than conventional materials thus contributing to the reduction of construction costs. Some pertinent

factors make unfired adobe brick a cheap alternative. As Moquin (2005) observed globally and evidenced in the study area, the existence of suitable soils for the production of adobe bricks obviates the need to transport the material because local people produce the bricks at the construction site which in turn reduces transport costs. Krisprantono (2007) has observed that conventional construction methods are complicated. Opposed to this, the processing of adobe is simple and there is no need for much training so that local people can easily become self-builders.

According to INE (2009), buildings made of unprocessed earth account for about 67% of all houses in Mozambique: a clear reflection of the importance of this building material in the lives of many Mozambicans. However, it is important not to misinterpret this figure as saying that unfired adobe brick is the most used building material in Mozambique. Wattle-and-daub is the most used method of earth construction accounting for 48% of houses while unfired adobe brick houses constitute only 20%.

Although mud is apparently a free material and local people have developed skills for adobe construction, it does not necessarily mean that these people are all able to build as they intend. The discussions with local community members and the experience gained during the construction of Dieter's house support the perspective advocated by Sanchez and Sanchez (2008) that the costs of any adobe house primarily depends on the size, design and finishes rather than on the use of adobe per se. Building an adobe house does not mean that the entire building is made solely with adobe. An adobe brick house means that the walls are of adobe brick, but the roof, windows and floors are made of other materials that are not obtained for free (Baker, undated).

5.2 Methods of unfired adobe brick production

A primary factor determining the production of adobe brick is the existence of suitable soils. According to local people it is possible to find soils containing different proportions of clay. Simple methods have been developed to test for the presence of clay in the soil but not for determining the proportion of clay in the soil. Furthermore, different soil types and different clay contents mean that the exact content of clay in

the mixtures is something that relies largely on trials and testing of mixtures and bricks to ascertain the correct mix. Local knowledge in Mozambique does indicate that excessive clay in the mixture will generally result in cracking of the final adobe brick. Moquin (2005) argues that the soil for making the best adobe bricks should contain between 8 and 15 per cent clay. Knowledge of the proportion of clay contained in the soil is important because it can help to specify the amount of stabilizer to be added to the soil or even if it is necessary to add clay.

The local methods used to detect the existence of clay in soil have proved to be effective and similar methods have been used elsewhere in the world. The touch test is similar to the method Baker (undated) describes as the hand-washing method because both test methods are based on the assumption that when mud is sticky it contains clay. Colour is also used as a test for clay, but the yardstick for acceptability is subjective. For instance, Baker (undated) tells us that in India deep yellow, orange and red, ranging to rich deep brown soils are appropriate for mud construction. The focus groups discussants in Chimoio said that red and grey soils are the most appropriate. One must agree with Oliver (2003) that chemically speaking there is a variety of soils that contain clay.

DNE (2007), in its orientation handbook for the production and use of soil-cement brick, proposes other soil tests (see description of soil tests in Appendix 8). These tests are simple to conduct, they do not require an outlay on equipment and not much expertise is necessary to conduct them.

The procedures to produce unfired adobe bricks in Mozambique do not differ much from procedures followed elsewhere. The basic ingredients are water and earth and solar heat is used to dry bricks (Moquin, 2005). However, in other regions of the world mud is mixed with straw or cow dung or lime (Baker, undated). Regarding equipment, wooden moulds are commonly used to shape bricks in the study area and in other places where communities produce adobe bricks.

5.3 Advantages and disadvantages of unfired adobe brick

Around the world, adobe constructions are known to be subjected to various stresses. Two of these are identified in the literature on unfired adobe brick construction, namely water and earthquakes. Importantly, not all regions in the world are affected by earthquakes or are vulnerable to excessive precipitation or flooding. Dowling (2004), for instance, notes that in Latin America, Asia and the Middle East where earthquakes occur frequently, it has been reported that adobe constructions are very vulnerable. Fortunately, earthquakes are not a major hazard for the dwellers of adobe constructions in Chimoio. Moisture is the greatest threat to unfired adobe constructions as it can greatly reduce their durability. As observed locally, unfired adobe bricks tend to melt and lose shape and strength when exposed to water. Olotuah (2002: 127) also observes that "...clay absorbs water and swells and it later shrinks when the water dries off. The process eventually results in cracking after a while."

Baker (undated) notes that water can act either as the best friend or as the major enemy of adobe. This study's findings support Baker's (undated) perspective that water was identified as one of the fundamental resources in adobe brick production. It is practically impossible to produce adobe brick without water but, surprisingly, this essential role is not recognized. Most of the local communities' members in Chimoio argue that water acts as an enemy of unfired adobe brick. But, as Baker (undated) observed, the vulnerability of adobe houses to the damaging impact of water is related to poor application of adobe construction methods.

This focus on the disadvantages of unfired adobe construction often leads to the advantages over other materials such as wood, bamboo or stakes being forgotten. Roaf, Fuentes and Thomas (2007) and Sanchez and Sanchez (2008) note that in regions where wildfires are a hazard, adobe has a clear advantage over these combustible materials. Sanchez and Sanchez (2008) point out that in the United States fire kills more Americans every year than all other natural disasters and 80% of these deaths occur at home. Houses that are mostly composed of adobe elements rather than wood are more likely to perform better when affected by fires. With the onset of

climate change, wildfires could become an issue in Mozambique and the use of adobe for construction would represent a safe option. Moreover, adobe is rot-proof, a quality that bamboo and wood do not have (Roodman and Lenssen, 1995).

5.4 Solutions to adobe's problems

This section discusses some solutions to the challenges facing unfired adobe houses in Mozambique. The first subsection discusses adobe brick stabilization and the second focuses on the design of adobe houses.

5.4.1 The use of stabilizers

Although clay is the most important soil component for brick production it can become a problem when it is present in excessive quantities. Experiential know-how accumulated by adobe brick producers and findings of research done on this field show that soils containing excessive clay should be stabilized as a measure to reduce cracking of bricks. Sand is the only stabilizer used to reduce adobe brick cracks in Chimoio, but it is seldom used by local communities.

Despite it being possible to reduce cracking of adobe bricks, it remains important to ensure that unfired adobe bricks are resistant to exposure to excessive moisture. Sanchez and Sanchez (2008) point out that adobe tends to melt or erode when it is not stabilized against water absorption. Normally the local people prefer to burn bricks to increase their resistance against water, but the burning of bricks impacts on the natural environment. It is possible to make unfired adobe bricks more resistant to excessive moisture without burning them. Published research on this issue provides useful alternatives for stabilizing soils against moisture and cracking.

Baker (undated) suggests the use of cement and lime as stabilizers. DNE (2007) has also been proposing the use of these stabilizers, but preliminary experiments show that while cement is effective in strengthening bricks, this option is still expensive for local communities. Lime's effectiveness has never been tested in Mozambique, but

the literature on adobe construction reveals that it can be used as a substitute for cement.

Other natural stabilizers available in rural areas and which do not require much processing are straw, cow dung, urine and oil. Baker (undated) reports that straw accelerates drying, minimizes cracking, helps wet adobe bricks to hold their shape, and moderately increases the tensile strength of adobe; cow manure in mud plasters is used in various parts of the world to improve bonding and waterproofing; and coconut oil is used to waterproof the surface of adobe walls. These stabilization methods are not used in the study area.

Asphalt emulsion¹² is an effective stabilizer, especially when the problem is caused by moisture or storm water (Moquin, 2005; Sanchez and Sanchez, 2008). Sanchez and Sanchez (2008) note that fully stabilized adobe bricks contain 5 to 12% asphalt emulsion and semi-stabilized bricks about half that amount. Asphalt emulsion stabilization is an effective way to make houses more durable by waterproofing. Moquin (2005) agrees that regarding water absorption asphalt emulsion stabilized adobe brick is more effective than most other materials. Table 13 makes this comparison clear.

Table 13: Water absorption levels of different wall materials

Material	Absorption level (%)
Asphalt-stabilized adobe	0.5 - 3
Wood	4 - 8
Average concrete	8
Cement stucco (render)	8 - 11
Burnt clay brick	8 - 12
Light-weight cement brick	20 - 25
Untreated soil brick	25 - 30

Source: Moquin (2005)

Stabilization is not only done by using these substances individually as they can be mixed or the adobe bricks can be compressed using specialised machinery to give

¹² According to Moquin (2005) asphalt emulsion is obtained by mixing asphalt solids and water (60:40 by weight) with an emulsifying agent (1 per cent soap).

them more strength. Compression of bricks is practiced around the world, but in the study area this method is not applied although it does form part of government thinking. The problem is that these machines are currently not available within the existing local market and training (which is presently limited at the local level) will be necessary in order to operate the machinery.

Stabilization materials are not only used in adobe bricks, but they are also necessary for plasters. Although the use of cement plaster is acceptable to some adobe dwellers in Chimoio, Crews (2005) warns that plasters should consist of ingredients that are compatible with the wall materials to ensure adherence. Local mud plaster consists of soil, sand and water. Woolley (2006) affirms that mud plaster can also be mixed with straw to give a smooth or texture finish to walls. To increase its resistance to water, mud plaster can be mixed with cow dung, lime or well-fired wood ash (Harris and Borer, 2005; Roaf, Fuentes and Thomas, 2007; Baker, undated). Woolley (2006) points out that easy maintenance or repair is one of the key advantages of mud plasters.

Compared to cement bricks, stabilized bricks have less environmental impact. Straw and cow dung are natural forms of stabilization which need no processing. Adobe bricks stabilized with cement have more environmental impacts as opposed to natural stabilizers because cement processing consumes much energy. Nevertheless, cement-stabilized brick is a better option than cement bricks. Asphalt emulsion is a form of stabilization, but asphalt is toxic and a pollutant.

5.4.2 Some considerations about design

The performance of unfired adobe houses is reduced when wrong decisions are made regarding the design of foundations and roofs and the choice of a construction location. These aspects are confirmed in the literature as being contributors to the reduction of the durability of unfired adobe structures. It is not possible to apply the same methods to adobe construction as those used in cement construction. Baker (undated), Moquin (2005) and Sanchez and Sanchez (2008) all agree that it is not a

good idea to keep non-stabilized adobe brick constructions exposed to excessive moisture.

Proper foundations are fundamental to adobe constructions. Local experience has demonstrated that neglect of this crucial feature has resulted in walls collapsing. Research suggests that for buildings made of unfired adobe bricks and mud plaster it is always necessary to incorporate an overhanging roof and waterproof foundations such as stones, burnt bricks, and gravel or even fully stabilized bricks with asphalt emulsion (Moquin, 2005; Sanchez and Sanchez, 2008; Baker, undated).

Gutters are seldom used on adobe homes to channel rainwater so that without overhanging roofs rainwater tends to erode the mud plaster of the walls. Gutters are needed on the roof to reduce this destructive impact. Furthermore, McLennan (2004) reports that the use of gutters is an effective way to collect rainwater for irrigation during the dry season and for flush toilets.

The literature rarely recommends the addition of verandas as a solution for rain damage to walls, but in the study area they are commonly used as an effective way to protect adobe walls from rainwater. Some local adobe buildings even have verandas on all sides and these houses have lasted for a long time. As observed in the study area, Baker (undated) asserts that waste engine oil is one alternative commonly used to protect mud walls. Although effective, there are the obvious ecological issues (pollution) with the oil option.

Concerning the choice of a construction site, Moquin (2005) advises that it is important to build an adobe house in the right place. Ideally, the house should be located on the highest part of the land and if the terrain slopes, a trench should be dug upslope from the house to divert rainwater away (Baker, undated). However, it remains important to consider all factors that may influence decisions about the location of a house. Local communities in Mozambique might primarily decide to choose construction sites close to water sources, farms, hospitals, schools, roads and job opportunities or even according to their ability to afford stable construction sites.

5.5 Adobe brick and the green movement

Regarding environmental concerns, the findings about the production of unfired adobe bricks can be related to the findings of similar studies (McHenry, 2002; Moquin, 2005; Harris and Borer, 2005; Woolley, 2006; Shukla, Tiwari and Sodha, 2009) done elsewhere. According to these studies, unfired adobe brick is one of the materials with a low negative impact on the environment and it is a prime candidate for people looking for green materials.

Roaf, Fuentes and Thomas (2007) established some simple principles to help assess the environmental impacts of building materials without having to rely on methods requiring measurements. Their method takes account of the complete cycle that a material goes through, that is the steps from extraction of the raw material through to the use and eventual demolition of a building. For each step in this cycle the possible impacts are identified and analysed.

Normally, local communities produce unfired adobe bricks at or as close as possible to construction sites as it is beneficial concerning transport cost reduction, but it also accords with good environmental practice advocated in the literature on ecological design. Harris and Borer (2005) note that the transport of soil for brick production is potentially energy intensive so that the collocation of the source of the raw material, the place of brick production and the construction ensures a saving of energy and, of course, less CO₂ is released into the atmosphere.

The second step in the cycle is processing. Roaf, Fuentes and Thomas (2007) remind us that the more a material is processed the more energy is required but this is not the case in unfired adobe brick production at local level. The processing is simple and based on renewable sources of energy. Moughtin (1996) has pointed out that the energy required in the production of adobe brick is human effort something that is potentially clear in the field. The drying process uses the sun's heat and air.

Harris and Borer (2005) contend that the use of energy provided by human beings and animals is becoming outdated. Mechanical digging and mixing are becoming the more probable methods. These methods imply more environmental impacts, but because

these materials are produced locally the impact remains low compared to conventional materials. It is important to note that mechanical digging and mixing is not beneficial in terms of job creation because less human power is required.

At local level, burnt adobe brick is made using firewood. Local adobe brick producers argue that the use of dead trees as firewood contributes to reduce deforestation. However, it is still questionable whether there are enough dead trees to burn bricks to satisfy the increasing demand of fired adobe bricks. Apart from deforestation, Woolley (2006) observed that the production of fired bricks constitutes a significant source of CO₂.

One of the requirements for classifying a material as green is the renewability of its source (McLennan, 2004). Soil is considered to be a non-renewable resource, but when it is not subject to great amounts of processing and the introduction of other materials or chemicals it can still be converted to its natural state. In practice this low-input approach happens, as observed, when unfired bricks are produced because unusable bricks revert to soil without altering its properties and the soil is used to make other bricks. This is not the case with fired bricks. The more processing a material goes through the more its natural properties are lost rendering reversion to its natural state impossible. Attempts by local producers to use broken fired adobe bricks to produce other bricks by local producers have failed.

Research has shown that adobe material does not pose danger to human health and this study also found that local communities are not concerned about this issue. On the contrary, the material contributes to providing thermal comfort to the occupants of adobe houses. Adobe possesses optimal thermal-mass storage and heat transmission properties for winter heating and summer cooling, an integral part of passive solar design (Moquin, 2005).

5.6 Conclusions

A comparison of findings from the fieldwork and results from other similar studies shows that adobe construction in Mozambique faces challenges by natural stresses

also typical of other regions of the world. The solutions that local communities have developed to reduce the weaknesses of adobe construction are not much different from the solutions developed by people elsewhere, but the literature does provide an opportunity for local communities in Mozambique to learn about additional methods that can help improve the performance of adobe constructions.

This study's findings regarding the impacts of adobe on the natural environment concur with those of other studies. The findings also confirm the contention that adobe constitutes the viable resource to providing shelter for considerable numbers of poor people in the developing world.

The assessment of the use of unfired adobe brick from a sustainability point of view is informed by findings about the current use of this material in local communities and other possibilities presented by the literature. The final conclusion whether unfired adobe brick can contribute to construct more sustainable housing in Mozambique is made in the next chapter.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This thesis has addressed a practical issue that affects the lives of people living in developing countries in general and Mozambique in particular. It is about poverty manifested in terms of the lack of access to basic services such as adequate water and sanitation, education, adequate shelter and a waged job. It is evident that poor people in Mozambique cannot fulfil their aspirations concerning shelter due to the high prices of conventional building materials. This study has focused on providing shelter for the poor – more specifically the use of adobe to construct houses economically and sustainably.

From an environmental viewpoint the conventional conception of our built environment in general and the housing sector in particular is related to negative environmental impacts. So, this research is also based on the assumption that it is possible to use adobe to provide shelter while avoiding significant negative impacts on the natural environment. However, a holistic approach to sustainable construction made it clear that it is also necessary to determine whether the material complies with technical requirements.

To investigate the use of unfired adobe brick from a sustainability viewpoint three objectives were pursued, namely explore and describe the process of production and use of unfired adobe brick in the local construction of houses, gather data regarding aspects that directly or indirectly determine the sustainability of unfired adobe brick and assess this material concerning its sustainability.

The objective to explore and describe the production and use of unfired adobe bricks was attained in the sense that findings brought real information about local conditions for the production of adobe brick and methods applied in the production of this material and its application in buildings. The attainment of the first objective provided information about costs, technical aspects and environmental implications related to the use of unfired adobe bricks. The data about socio-economic, environmental and

technical aspects of the use of unfired adobe brick in Chimoio town are compared with theories about adobe construction. This comparison allowed the assessment of the use of unfired adobe brick at local level in socio-economic, environmental and technical dimensions and it indentified possibilities to make the use of adobe more sustainable.

The fieldwork conducted in the local communities of Chimoio and a review of the literature found that, compared to conventional options of bricks, the use of unfired adobe brick is sustainable regarding costs. However, this study reminds us that the final cost of an adobe house can vary according to the use of other materials to build components such as a roof, floor and windows. Despite the existence of cheaper alternatives to these house components, another study would reveal the extent to which it is possible to reduce the construction cost without affecting the quality of adobe houses.

Self-building is a clear indication that methods of adobe construction are simple and it contributes significantly to reducing construction costs. However, limitations in terms of skills and ignorance of proper construction methods are constraints to the attainment of technical sustainability in the use of unfired adobe bricks. Due to the existence of methods to deal with stresses that affect adobe structures, it is fair to state that the provision of training for local adobe house builders is the viable solution to eliminate the negative aspects of adobe construction in Chimoio in particular and Mozambique in general. Here, technical sustainability is vital to raise interest in the use of unfired adobe brick for current adobe house dwellers and those who can afford conventional housing. As local communities dominate the use of this material, the increasing interest on adobe construction would represent an opportunity for job creation or business for adobe house builders.

It is evident that unfired adobe brick has minimal environmental impact. But findings show that this advantage of unfired adobe brick is not known by local communities. The decision to use different building materials should not only be driven by technical and socio-economic aspects but also through environmental education to raise awareness among local communities. The realities of natural resource depletion and

the economic and environmental costs involved must be made clear so that these communities can gain a clear picture of the advantages unfired adobe brick offer concerning sustainability.

Observing the possibilities the literature suggests for improving the performance of adobe constructions, the experience gained during the construction of Dieter's house, the relatively low cost of unfired adobe brick and the irrefutable environmental advantages of this material, it is concluded that unfired adobe brick is a material that can play a role in the provision of sustainable dwellings for communities living in Chimoio in particular and Mozambique in general. So, this study confirms Moquin's assertion about adobe brick quoted in the introduction to this thesis.

However, the findings also show that the advantages this material offers regarding sustainability need to be linked to other initiatives such as the provision of basic services (electricity, adequate water and sanitation) and the choice of appropriate construction sites (areas that are less prone to floods and erosion). A focus on the use of unfired adobe brick is an opportunity to be explored by local government when designing programmes to address the issue of adequate shelter for poor Mozambicans. With the use of unfired adobe bricks, resources that would be used to make conventional houses can be efficiently used to provide better living conditions for the poor.

6.2 Recommendations

Considering that there are aspects that the local unfired adobe brick construction industry can learn from other cases in the world, it is necessary to explore in more depth the different alternatives of adobe brick production and construction methods. Research is needed to test different adobe construction methods and recommend those which are suitable for the local context. By participating in this process, local communities can benefit from the opportunity to exchange experiences with other communities that are familiar with living in unfired adobe structures. Favourable experiences of other communities could enhance the ability to participate more positively in the promotion of this material at local level.

The creation of a database about unfired adobe construction in the Mozambican context will help to perpetuate the knowledge about unfired adobe construction. This action is justified because most of the traditional knowledge about adobe construction in Mozambique is not systematized in publications. The promotion of debates in the academic arena is necessary to raise awareness about the potential that the material has regarding sustainability. It would include the presentation of research findings in seminars and workshops held at local academic institutions.

The creation of codes to orientate the production and use of unfired adobe bricks is important as they will emphasize that the material is technically accepted. Furthermore, codes allow a better control of the quality of structures made of this material. Construction codes should not only be used by engineers or architects but also by local communities. Traditionally, local communities possess knowledge about adobe construction and with the introduction of more insights into unfired adobe brick construction they will be empowered to participate more actively in the construction of their own houses. So, it is important to provide training and raise awareness about the need to correctly apply the construction codes to improve the performance of unfired adobe structures.

The construction of some unfired adobe houses according to innovative design principles could serve as examples for those interested in this kind of construction. As witnessed in the construction of Dieter's house, this is a way to promote the material and change people's perceptions about unfired adobe brick constructions.

The promotion of the use of unfired adobe brick at local level needs to be complemented with the creation of housing policies. As there is still no defined housing policy in Mozambique, there is a dire need to create one. Housing policies would have to articulate the real needs concerning shelter with the social conditions (including cultural and indigenous knowledge systems) of local communities and the opportunities unfired adobe brick offer for the provision of sustainable housing.

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LIST OF INTERVIEWEES

Antonio Mussalamba: Technician on Physical Planning - Provincial Directorate of Public Works and Housing. Interviewed on 20 May 2009.

Constancio Armindo: Adobe brick producer and builder. Interviewed on 06 June 2009.

David Mandevo: Technician of Economic Infrastructures on Machaze district, Provincial Directorate of Public Works and Housing. Interviewed on 27 May 2009.

Félix Tomé Miguel: Provincial Directorate of Public Works and Housing. Interviewed on 20 May 2009.

Gaspar Matequenha: Adobe brick producer and builder. Interviewed on 06 June 2009.

Laura Marina: Ex-producer of adobe brick. Interviewed on 25 April 2009.

Martinho Tenday: Building foreman. Interviewed on 20 April 2009.

Silvino Santiago Ratia: Technician of Civil Construction - Provincial Directorate of Public Works and Housing of Manica. Interviewed on 04 June 2009.

Vicente Muechumo: Provincial Directorate of Public Works and Housing. Interviewed on 18 May 2009.

FOCUS GROUP PARTICIPANTS

Focus Group A: Discussion conducted on 28 April 2009.

Carlos Aguacheiro – adobe brick producer, 5 years of experience.

David Gereti – adobe brick and bamboo houses builder, 3 years of experience.

Jorge Candieiro – adobe brick producer and builder, 3 years of experience.

Mário Pamissira – adobe house builder and brick producer, 6 years of accumulated experience.

Focus Group B: Discussion conducted on 15 May 2009.

Chicamba Marapira – carpenter and bamboo-framed wall house dweller since 1981.

Januário Costa – conventional house builder, 8 years of experience.

Làzaro Simao – carpenter, adobe brick producer and builder, 4 years of experience.

Saide Candeeiro – conventional and adobe houses builder, 7 years of experience.

Ze Mbalane – conventional and adobe houses builder, 10 years of accumulated experience.

APPENDICES

Appendix 1: Mean temperatures and rainfall in Chimoio, Mozambique

Month	Mean Temperature (°C)		Mean Rainfall (mm)	Number of Days with Rain
	Maximum	Minimum		
Jan	19.8	28.6	220.8	15.8
Feb	19.6	27.7	236.6	16.5
Mar	19.0	27.6	150.2	14.4
Apr	17.0	26.2	56.0	8.7
May	14.4	24.9	22.4	6.3
Jun	12.3	23.2	12.5	4.4
Jul	11.8	22.7	20.2	6.1
Aug	12.9	24.4	17.5	5.4
Sept	15.1	27.4	19.8	5.1
Oct	16.7	28.3	46.6	8.0
Nov	18.4	29.1	89.1	10.3
Dec	19.3	28.6	189.9	14.1

Source: INAM (2009)

Appendix 2: Focus group discussion programme

Planning of focus group discussion

Number of members: 12 members divided into two groups of discussion

No of discussions: 2

Place: Chimoio, Dr. Araujo de Lacerda Street

Duration of each discussion: 2 hours

Dates: 1st focus group discussion – 28 April 2009; 2nd focus group discussion – 15 May 2009

Materials: Pen and notebook, a room with chairs for at least seven participants

Compensation for participants: transport from and to their houses and a meal

Discussion agenda

1. Welcome
2. Explanation of the reasons for the discussion
3. Introductions
 - a) Introduction of participants (name, origin, job)
 - b) Explanation of how the discussion will be done
4. Discussion session
 - a) Each member describes his experiences of the use of unfired adobe brick
 - b) Presentation of methods of unfired adobe brick construction
 - c) Debate about weaknesses and strengths of each method

d) Debate about the reasons underlying the use of the material

e) Diverse

5. End of the discussion

a) Last considerations and thanks

Appendix 3: Interview questions

Interview with Vicente Muechumo

- What is the situation of housing in Mozambique in general and Chimoio in particular?
- Is there a housing policy in place? Which role does this policy play at providing shelter for local people?
- Which role does unfired adobe brick play in terms of shelter for local communities?
- How often do local people use unfired adobe brick to build houses?
- Which factors determine the choice of building materials by local communities?
- What has been done by this institution to promote the use of adobe brick and other alternative materials?

Interview with Antonio Mussalamba

- What problems affect adobe brick structures?
- Why do these problems occur?
- How does the choice of construction sites affect the performance of unfired adobe brick structures?
- Which sites are more appropriate for building unfired adobe brick houses?
- Have you identified and mapped areas where structures made of adobe or other materials cannot be built in Chimoio?
- Is there a law that prohibits the construction of adobe brick structures on these sites?

- Is the law enforced?

Interview with Felix Tome Miguel

- Are environmental issues taken into consideration in the design and construction of houses?
- How are the environmental impacts of adobe bricks measured?
- What are the negative environmental impacts of adobe bricks?
- What are the environmental advantages of unfired adobe brick?
- How can the environmental impacts caused by unfired adobe bricks be reduced?

Interview with Silvino Santiago Ratia

- Are there codes for unfired adobe construction?
- Which performance goals do adobe buildings have to meet?
- Do unfired adobe brick structures meet these goals?
- Which technical aspects should be considered in the design and construction of unfired adobe brick structures?
- Do you have training in adobe construction? Where were you trained?
- Is it relevant to discuss the role of unfired adobe brick in providing adequate shelter for local communities? Why?

Appendix 4: The history of housing in Mozambique

Period	Housing Policy
Colonial (until 1975)	At the beginning of twentieth century most of the Mozambican population lived in constructions of short durability. The colonial occupation led to the emergence of some urban areas where the houses were built using conventional materials and modern construction methods. These urban areas were inhabited by colonizers whereas the peri-urban areas were characterized by informal settlements.
Nationalization (1975-1991)	After independence, the new Mozambican government nationalized all properties that were abandoned by ex-colonizers. A large number of people living in peripheral settlements, attracted by the need to get a good job, education and other basic conditions, moved to these houses. This occupation was not followed by an adaptation process of urban living, either through incentives to residents or other government support, so that the quality of most of these houses deteriorated. At this time the number of urban dwellers grew, most of whom were civil war refugees. Worsened by the lack of any formal spatial planning, this situation triggered disorganized urban growth.
Liberalization and Alienation (post-1991)	Since 1991 the government has alienated all houses that had been nationalized and liberalized property ownership, thereby creating the opportunity for Mozambicans to buy previously nationalized houses.
Current Situation	Currently it is possible to find a variety of constructions (precarious and permanent in urban areas and houses made of non-durable materials in rural areas). The majority of Mozambican houses are considered to be precarious constructions: some 94% in rural areas and about 62% in urban or suburban areas. The insecurity of precarious houses imposes the need for cyclic maintenance due to their poor durability and high vulnerability to natural stresses.

Source: DNE (2008)

Appendix 5: Materials used in housing construction in Mozambique

Building Components	Number and Proportion of Houses					
	Total		Urban		Rural	
	3 540 700	%	894 200	%	2 646 500	%
Wall Materials						
Cement brick	252 481	7	210 137	24	42 343	2
Fired brick	84 480	2	50 075	6	34 405	1
Wood/Galvanized metallic sheet	54 185	2	27 720	3	26 465	1
Unfired adobe	669 770	19	211 925	24	457 845	17
Bamboo/Peg	719 656	20	182 417	20	537 240	20
Wattle-and-daub	1 695 501	48	194 936	22	1 500 565	57
Other materials	64 627	2	16 990	2	47 637	2
Flooring Materials						
Wood	42 921	1	42 921	5	0	0
Marble	894	0	894	0	0	0
Cement	434 998	12	334 431	37	100 567	4
Mosaic	8 870	0	3 577	0	5 293	0
Earth	3 035 313	86	507906	57	2 527 401	95
Other materials	17 704	1	4 471	1	13 233	1
Roofing Materials						
Concrete slab	57 157	2	51 864	6	5 293	0
Tile	16 023	0	10 730	1	5 293	0
Fibre cement	91 850	3	73 324	8	18 526	1
Galvanized metallic sheet	433 634	12	298 663	33	134 971	5
Grass/Palm leaves	2 895 862	82	437 264	49	2 458 598	93
Other materials	46 174	1	22 355	3	23 819	1

Source: INE (2009); 1997 census data

Appendix 6: Access to basic services in Mozambique

Basic Services	Number and Proportion of Houses					
	Total		Urban		Rural	
	3 540 700	%	894 200	%	2 646 500	%
Electricity						
With electricity	179 554	5	166 321	18	13 233	1
Without electricity	3 247 916	92	704 630	79	2 543 286	96
Missing observations	113 230	3	23 249	3	89 981	3
Water						
Canalized water (inside or outside house)	301 020	8	277 202	31	23 818	1
Fountain	242 211	7	168 110	19	74 101	3
Well	2 353 683	67	397 919	45	1 955 764	74
River/lake	603122	17	44 710	5	558 412	21
Others	40 664	1	6 259	1	34 405	1
Sanitation						
Flush toilet with sewerage	76 829	2	71 536	8	5 293	0
Flush toilet with septic tank	38 234	1	22 355	3	15 879	1
Pit latrine	1 088 167	31	492 704	55	595 463	22
Without latrine or toilet	2 337 470	66	307 605	34	2 029 865	77

Source: INE (2009)

Appendix 7: Steps in soil-cement brick production

Steps of Brick Production	Description
Excavation	This step involves the extraction of soils for the production of bricks. The soil should not contain organic matter like grass, roots or humus because these elements interfere with the endurance of cement (stabilizer) and they weaken the bricks. So the top soil, which varies in depth from place to place, should be removed to a depth of 0.5m. The extraction must be done vertically to allow the mixing of different layers of the soil.
Preparation of soil	The soil needs to be dried to reduce its humidity and then the fine particles are separated from the coarser ones by mean of a sieve. For good drying the soil should be spread in a uniform layer of 30cm thick. The fine particles are the most suitable for producing soil-cement bricks.
Mixing soil and cement	The soil that is mixed with the cement should have a low moisture content. Soil and cement need to be blended until the mixture has a uniform colour. The mixture is then spread in a layer of 30cm thick before adding water.
Moulding the bricks	The moulding process comprises three stages: filling, pressing and ejection of the brick.
Disposal of bricks	The brick is expelled from the pressing machine. Then it must be removed by hand, taken firmly by its sides using wooded pallets and put on a flat surface in a shaded place. The bricks can be stacked in layers until they reach a height of 1.5m.
Drying and curing	In the first phase of drying the bricks need to be kept moist: so it is necessary to irrigate them with water, two times a day on a period of 7 days. During this period the bricks should be under a porch, covered by grass or plastic to protect them from direct sunlight and excessive rain. After the humid drying, the bricks can be deposited in a place with direct sunlight to dry for 21 days. After 28 days the bricks are ready to be used.

Source: Based on information from DNE (2007)

Appendix 8: Soil tests

Soil Test	Objective	Equipment	Method
Smell test	Detect the existence of organic matter in the soil.	Fire, stove and frying pan	Take a soil sample and smell it. If it smells mouldy then there must be organic matter present. The smell is more intense when the soil is heated. Soils containing organic matter are not appropriate for making bricks. It is better to use this kind of soil for agriculture.
Visual test	Inspect the occurrence of gravel, sand, silt and clay in a soil sample.	No equipment	After removing large particles and stones, the soil is examined to see how much gravel, sand and fine particles the soil contains. Soils with loose grains contain few fine particles. Normally these are sandy soils or gravel. Cannot be used to produce adobe bricks without adding clay.
Touch test	Determine the size of particles in a soil sample.	No equipment	Take out stones and large particles from a soil sample. Put the soil in one hand and break it down with the fingers of the other hand. A rough feeling indicates that the soil is sandy and it is not smooth when moist. A smooth feeling indicates presence of clay.
String test	Assess the occurrence of clay.	A flat surface	Add water to a sample of earth. Make a roll with the mud and place it on a flat surface. With straight fingers, apply uniform pressure over the roll to make a string. If it is not possible to make a string the soil must contain an insignificant amount of clay. If it forms a string with a 3mm diameter, the soil contains a significant amount of clay. A string with more than 3mm diameter indicates that the soil contains particles of sand or silt or the clay does not have much plasticity.
Cigar test	Assess the occurrence of clay.	No equipment	Take enough soil and roll it in the form of sausage or cigar with an almost 12mm diameter. With the thumb and forefinger press the end of the cigar and before the cigar breaks off see how long it is. If it just falls and cannot be shaped and pushed out it is too sandy. If a cigar 50-100mm long is obtained with difficulty then the soil has low clay content. A cigar 250-300mm long indicates that there is high clay content.
Bottle test	Obtain percentages of soil components.	A large transparent bottle, about 65mm of diameter, a chronometer and a ruler	Fill the bottle halfway with sand and add clean water until the bottle is almost full. Shake the bottle for a minute and place it on a horizontal surface. After an hour shake it again and leave the soil particles to settle at the bottom of the bottle for an additional 45 minutes. After this the gravel and sand will have settled at the bottom. The next layer is silt and the last layer is clay. The limits of each soil component can be identified, measured and the percentages calculated. A good soil for producing adobe brick should have 10-15% clay.

Source: Based on DNE (2007) and Baker (Undated)