Investigating the best methods for structural stabilization procedures for Historical earthen building conservation in Saudi Arabia: a technology–led construction analysis.

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Doctor por la Universitat Politècnica de València.
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Doctoral thesis

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ABSTRACT

Over time, the construction potentialities and traditional architecture of Saudi Arabia have declined substantially. The modern generation in Saudi Arabia has neglected the traditional structural and architectural designs for building towns, cities and homes. The materials used in the construction of traditional structures has been replaced by more westernized building materials such as concrete, cement and glass. Westernized methods of design and architecture often fail to last long due to the climatic and topographical conditions of the country, such as extreme heat and fast sand-blowing winds. Reviving traditional architectural and structural building married with westernized building technologies will yield strong structures that are capable of withstanding the harsh conditions of the country. This research seeks to identify the most applicable methods of structural procedures that can be used in historical earthen buildings in Saudi Arabia for conservation purposes. This dissertation addresses the important structural and architectural perspectives of traditional Saudi Arabian buildings. It also examines the perspectives of the Saudi population that affect the selection of building materials and architectural styles that are widely used. An examination of the old techniques employed in traditional Saudi Arabian buildings, how they can help in the formulation of a new approach for contemporary architecture and how this can be implemented in Saudi Arabia are also discussed in this dissertation.

In the preparation of this dissertation, conforming processes were performed in order to fulfil the set objectives of the study. The first step was configured to examine different earthen architectural structures in Saudi Arabia. This stage involved travelling to different locations, observing the structures and also conducting interviews with older contractors. To collect more information on the topic, visits to Yemen and South Morocco were made, as these are two countries that have already married earthen architecture with modern architecture. The traditional architecture of Morocco and Yemen is similar to that of Saudi Arabia, but it has taken longer for these countries to shift to modern architecture. A laboratory examination was carried out to examine the relationship between the soil composition, stability, and strength of the structures that are built. Empirical studies were also conducted to examine the compactness, solidity, dimensional steadiness and permeability of the materials used in the constructions. These factors influence the choice of building materials for the conservation of traditional architecture and to solve the current need for cheap housing in the urban fabric.

The results of this study indicate that the Adobe and Cob traditional architectural styles are two of the leading architectural styles in Saudi Arabia, with each style symbolizing the perspective of the people living in a particular locality. This dissertation also found that different architectural patterns were influenced by functionality, convenience, efficiency and availability of the construction materials needed. This explains the reason for different structural and architectural patterns in different parts of Saudi Arabia.

This study concludes that mixing traditional architectural methods with modern technologies would serve to construct stronger and longer-lasting houses in Saudi Arabia. The new houses would not only serve to conserve the magnificent architecture of the country but would also help in building cheap houses, hence solving the rising demand for housing in urban areas. This study will add to the literature available on architectures in Saudi Arabia, specifically informing on how a mixture of early architecture can be reinforced with modern technology to help solve the conservation of Saudi historical earthen architecture and the housing challenge.

RESUMEN

Con el tiempo, las posibilidades de construcción con técnicas tradicionales en Arabia Saudita han disminuido considerablemente. La nueva generación de Arabia Saudita ha dejado caer en el olvido los diseños arquitectónicos y estructurales tradicionales a la hora de construir pueblos, ciudades y viviendas. Los materiales utilizados en la construcción de las estructuras tradicionales han sido sustituidos por materiales de construcción más occidentalizados, tales como el hormigón, el cemento y el vidrio. Los métodos arquitectónicos y de diseño occidentalizados no suelen perdurar mucho tiempo debido a las condiciones climáticas y topográficas del país, tales como el calor extremo y las fuertes tormentas de arena. La revitalización de la construcción de estructuras y arquitecturas tradicionales, unida a las tecnologías de construcción occidentalizadas, dará como resultado unas estructuras sólidas capaces de soportar las duras condiciones del país. Esta investigación busca identificar los métodos de construcción de estructuras más aplicables que puedan ser utilizados en edificios históricos de tierra en Arabia Saudita para fines de conservación. Esta tesis aborda la importancia de las perspectivas estructurales y arquitectónicas para los edificios tradicionales de Arabia Saudita. La tesis también analiza el punto de vista de la población saudí frente a la selección de materiales de construcción y a los estilos arquitectónicos utilizados frecuentemente. En esta investigación también se examinan las antiguas técnicas empleadas en los edificios tradicionales de Arabia Saudita, cómo éstas pueden ayudar en la formulación de un nuevo enfoque para la arquitectura contemporánea y cómo pueden introducirse en la construcción actual en Arabia Saudita.

En la preparación de esta tesis se ha trabajado con una metodología que permite cumplir con los objetivos establecidos al inicio del estudio. El primer paso fue examinar las diferentes estructuras arquitectónicas de tierra de Arabia Saudita. Esta etapa consistió en viajar a diferentes lugares para observar las estructuras así como para realizar entrevistas a los antiguos constructores. Para recopilar más información sobre el tema se hicieron también visitas a Yemen y al sur de Marruecos, dado que en estos dos países ya se ha unido la arquitectura de tierra con la arquitectura contemporánea. La arquitectura tradicional de Marruecos y Yemen es similar a la de Arabia Saudita, pero en estos países la nueva arquitectura contemporánea se ha desarrollado más tarde. Se han realizado ensayos de laboratorio para determinar la relación entre la composición del suelo y la estabilidad y solidez de las estructuras construidas. También se realizaron estudios empíricos para determinar la compactación, solidez, estabilidad dimensional y la permeabilidad de los materiales utilizados en las construcciones. Estos factores influyen en la elección de materiales de construcción para la conservación de la arquitectura tradicional y para resolver la necesidad actual de construir viviendas económicas en el tejido urbano actual.

Los resultados de este estudio indican que las técnicas constructivas tradicionales del adobe y el cob (pared de mano) son dos de las principales técnicas de Arabia Saudita, y cada una de ellas tiene relación con las particularidades de las poblaciones que viven en un determinado lugar. Con esta tesis también se ha determinado que los diferentes patrones arquitectónicos estaban influenciados por la funcionalidad, la comodidad, la eficiencia y la disponibilidad de los materiales de construcción necesarios. Esto explica la razón por la que existen diferentes tipologías estructurales y arquitectónicas en distintas partes de Arabia Saudita.

Este estudio concluye que la unión de los métodos arquitectónicos tradicionales con las nuevas tecnologías puede servir para construir viviendas más sólidas y de larga duración en Arabia Saudita. Las nuevas construcciones no solo servirían para conservar la tradición arquitectónica del país, sino también para ayudar a construir nuevas viviendas económicas para así resolver la creciente demanda en las zonas urbanas. Este estudio contribuirá a la literatura disponible sobre la arquitectura de Arabia Saudita, en particular detallando cómo la unión de la arquitectura tradicional con la nueva tecnología puede ayudar a resolver tanto la conservación de la arquitectura histórica saudita de tierra como el desafío que plantean las necesidades de nueva vivienda.

RESUM

Amb el temps, les possibilitats de construcció amb tècniques tradicionals a l'Aràbia Saudita han disminuït considerablement. La nova generació d'Aràbia Saudita ha deixat caure en l'oblit els dissenys arquitectònics i estructurals tradicionals a l'hora de construir pobles, ciutats i habitatges. Els materials utilitzats en la construcció de les estructures tradicionals s'han substituït per materials de construcció més occidentalitzats, com ara formigó, ciment i vidre. Els mètodes arquitectònics y de disseny occidentalitzats no solen perdurar molt de temps degut a les condicions climàtiques i topogràfiques del país, com ara la calor extrema i les fortes tempestes d'arena. La revitalització de la construcció d'estructures i arquitectures tradicionals, unida a les tecnologies de construcció occidentalitzades, donarà com resultat unes estructures sòlides capaces de suportar les dures condicions del país. Esta investigació pretén identificar quins són els mètodes de construcció d'estructures més aplicables que es poden utilitzar en els edificis històrics de terra d'Aràbia Saudita amb fins de conservació. Esta tesi aborda la importància de les perspectives estructurals i arquitectòniques per als edificis tradicionals d'Aràbia Saudita. La tesi també analitza el punt de vista de la població saudita front a la selecció de materials de construcció y als estils arquitectònics més àmpliament utilitzats. En esta investigació també s'examinen les antigues tècniques emprades en els edificis tradicionals d'Aràbia Saudita, com estes poden ajudar en la formulació d'un nou enfocament per a l'arquitectura contemporània i com poden introduir-se en la construcció actual a Aràbia Saudita.

En la preparació d'esta tesi s'ha treballat amb una metodologia que permet complir amb els objectius establerts a l'inici de l'estudi. El primer pas va ser examinar les diferents estructures arquitectòniques de terra d'Aràbia Saudita. Esta etapa va consistir en viatjar a diferents llocs per a observar les estructures així com per a realitzar entrevistes als antics constructors. Per a recopilar més informació sobre el tema es van fer també visites al Iemen i al sud del Marroc, ja que en aquests dos països ja s'ha unit l'arquitectura de terra amb l'arquitectura contemporània. L'arquitectura tradicional del Marroc i del Iemen és semblant a la d'Aràbia Saudita, però en estos països la nova arquitectura contemporània s'ha desenvolupat més tard. S'han realitzat assajos de laboratori per a determinar la relació entre la composició del sòl i l'estabilitat i solidesa de les estructures construïdes. També es van realitzar estudis empírics per a determinar la compactació, solidesa, estabilitat dimensional i la permeabilitat dels materials emprats en les construccions. Estos factors influeixen en l'elecció de materials de construcció per a la conservació de l'arquitectura tradicional i per a resoldre la necessitat actual de construir cases econòmiques en el teixit urbà actual.

Els resultats d’este estudi indiquen que les tècniques constructives tradicionals de l’adob i el cob (paret de mà) són dos de les principals tècniques d’Aràbia Saudita, i cada una d’elles té relació amb les particularitats de les poblacions que viuen en una lloc determinat. Amb esta tesi també s’ha determinat que els diferents patrons arquitectònics estaven influenciats per la funcionalitat, la comoditat, l’eficiència i la disponibilitat dels materials de construcció necessaris. Açò explica la raó per la qual hi ha diferents tipologies estructurals i arquitectòniques en distintes parts d’Aràbia Saudita.

Este estudi conclou que la unió dels mètodes arquitectònics tradicionals amb les noves tecnologies modernes pot servir per a construir habitatges més sòlids i de llarga duració a Aràbia Saudita. Les noves construccions no sols servirien per a conservar la tradició arquitectònica del país, sinó també per a ajudar a construir nous habitatges econòmics per a així resoldre la demanda creixent d’habitatge en les zones urbanes. Este estudi contribuirà a la literatura disponible sobre les arquitectures d’Aràbia Saudita, en particular detallant com la unió de l’arquitectura tradicional amb la nova tecnologia pot ajudar a resoldre tant la conservació de l’arquitectura històrica saudita de terra com el desafiament que plantegen les necessitats de nou habitatge.

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

1932 was the year marked for the establishment of the Kingdom of Saudi Arabia. Until the discovery of oil in commercial quantities in 1938, it was an extremely deprived country (Blake, 1980). Not considering oases and large cities, a great deal of architectural settlement on the Saudi Arabian Peninsula has to be traditionally managed for the climate, with the exclusion of a thin band of desert environment coastlines. Basically, people from diverse backgrounds who have settled this peninsula, have existed there for a time period of more than 5,000 years. With reference to this background, the Dilmun culture, which is located along the shores of the Gulf, was synchronous with the ancient Egyptians and Sumerians. Trade operations were reportedly carried out between the old territories and the states which were close to the peninsula, and these routes were considerably significant during those times (Info.gov.sa, 2012). The Kingdom of Saudi Arabia in its present shape began in central Arabia in or around 1750. To establish a new administrative party, a coalition was formed between Muhammad bin Saud (who was a local tribe member) and Muhammad Abdul-Wahhab. There were shifts in the destinies of this Saudi family over the period of the next 150 years and different rulers ruled over the Kingdom of Saudi Arabia. The modern-day Saudi kingdom was founded by the late King Abdul-Aziz Al-Saud. Since then, it has existed in almost the same form. However, a major socio-economic change has emerged because of the considerable increase in oil prices after 1973, as a result of which all aspects of life in typical communities were transformed. As far as the construction industry is concerned, its development was uplifted as a result of this new economic foundation, and a boom was observed in building activities (Dethier, 1982). The new building industry in Saudi Arabia and in most oil-rich states has been industrialized without any link to the ancient times. In these countries, there has been a rapid withdrawal of traditional building practices under the risk of exotic architectural forms and technologies, through which the social advancement is likely to happen, while they are especially inapplicable to the local climatic conditions and culture.

The modern architecture of Saudi Arabia has been shaped by the efforts of engineers, architects, contractors and planners from across the globe. At the present time, a weird picture regarding a complete loss of conventional architecture and a random transplantation of foreign building ispresented by the modern architecture. In fact, the cultural needs of the people and the climatic conditions are not addressed by the transplanted structural design. Factors such as confusion, illiteracy and resignation come through in the people's attitude to this matter. To bring modernization to the country is however the consideration of Saudi officials and architects. On the other hand, the identity of the people could be lost due to such practices, and serious trouble could be encountered when the oil starts disappearing.

While the built environment is severely affected by the climate of Saudi Arabia, the development process has not completely addressed this matter. Moreover, the unnoticed areas here are the choice of suitable building materials and the design concept. For instance, some modern buildings are entirely glass-fronted. Gel (2013) reports that their cooling systems have to be activated even during the wintertime. The author has learnt that AlMajal servise the annual expenditure of cleaning the facades of one of those buildings, on Prince Mohammed bin Abdul-Aziz Street, Jeddah, was more than 1,000,000 Euro in 2008. Those are a few illustrations of many non-operational modern buildings, due to which the natural and monetary resources of the country are being consumed and it can be claimed that it is being currently wasted in building and maintaining unsuitable structures across different areas of the country.

For the replication of unfitting western styles, the distinctive local construction systems representing long-standing knowledge and expertise in handling local conditions were overlooked across the different Saudi localities, and in this regard, lack of understanding was observed while copying and reconditioning those styles. To fulfil the local need in a cost-effective manner, these conventional building techniques were established from locally obtainable ideas. The conventional shelters were eventually materialized, illustrating a remarkable climatic response to the country's harsh environment. Moreover, this response is not only provided in their architectural forms and design concepts, but also in the building materials consumed. Moreover, the local construction techniques illustrated that thermal productivity of buildings consistent with people's lifestyles can be improved to a large extent by the careful usage of the available building materials within certain physical settings.

As an alternative to conventional building materials, cultural and climatic requirements have not been fulfilled in a successful manner by the widespread use of different practices and imported building materials in recent years. Therefore, copying inappropriate buildings and shifting them into each region, at random, is not an appropriate task: the person involved should analyse the requirements of a country experiencing rapid change and note how those needs can be met by developing the traditional techniques in the best way. An architectural heritage is portrayed by these building traditions, through which general guidelines are provided for the architects regarding conventional principles that should be preserved if the cultural and environmental frameworks are taken into account in developmental work.

1.2 Statement of the Problem

Due to rapid development in general, and particularly because of a considerably growing population, the housing need in Saudi Arabia has become increasingly significant in recent years. The high birth rate causes a high growth rate, which is an outcome of religious practices wherein early marriages are encouraged, besides a multiplicity of family members. However, birth control and family planning are discouraged by these teachings, except in special circumstances (mep.gov.sa, 2013). A shortage of health services, high mortality rates, colonization by neighbouring countries as well as the occasional drought, inter-tribal hostilities and scarcity, in addition to outbursts of epidemic diseases, are believed to be the factors behind the limited population growth in the past.

The aforementioned causes triggering the high population growth have been greatly controlled in the last few decades. The annual population growth rate is almost 1.536% (Harris and Lasker 2014). In terms of ethnic groups**:** Afro-Asians represent 10% of the native population and Arabs 90%. Islam is the religion followed in the Kingdom and the official languages are Arabic and English. In addition, the literacy rate is almost 78.8% (female 70.8%, male 84.7%). Health is another important statistic**:** almost 16.16 deaths/1,000 live births were recorded as the infant mortality rate

(2011 EST.) and the life expectancy is**:** females 76 years and males 72 years. The labour force was believed to be nearly 7.3 million, with foreign workers estimated in 2010 to make up about 80% of it. Its division is as follows: services (including government) 71.9%; industry: 21.4%; agriculture 6.7% (Harris and Lasker, 2014). According to these figures, strong demand for new houses will be observed in the near future, in addition to the current need for housing. Nevertheless, construction costs are likely to escalate beyond the reach of the average Saudi national under different constraints, for example, inadequate funds, the high cost of building materials and land in addition to the skilled workforce.

As far as the amount to be payable by the average male employee is concerned, the actual cost of construction appears substantial and has no similarity to the widespread living standard in the area. It is assessed that twenty years would be required as a minimum by the average employee to save adequate funds to construct a minimum standard home. Ultimately, many hardships are subsequently encountered by the citizen in this saving process. In recent times, traditional houses, villas, a floor in villa housing, apartments and other types of housing have been among the various categories of Saudi residential buildings. In 2004, 46.2% of non-Saudi and Saudi households lived in standard houses and villas and about 47.4% of the housing stock was represented by the households living in apartment or floors (Figure 1). Basically, small units comprise the vast majority of housing stock. Nearly 64.3% of the total housing stock is represented by residential units consisting of one or two bedrooms. Units containing three bedrooms represent 19.1%; and almost 16.6% are larger units more than three bedrooms (Harris and Lasker, 2014).

Figure 1. A sample of Saudi modern houses by Abu-Zead

Mistakes already made during the construction boom should not be repeated by the architects in response to the present and impending demand for housing. After the Second World War, Winston Churchill made a statement during the rebuilding process of London: "our buildings are built first and then they build us," and this statement must be understood by the designers and engineers. Various crucial factors determining suitable shelter in Saudi Arabia have to be taken into account by them. Moreover, they should carefully address economic, cultural, atmospheric and technological factors. The heritage fabric might be well-maintained by these factors.

A key factor in producing shelters is believed to be the 'culture' through which people's needs and their living standards are fulfilled. This study will not discuss this particular factor. On the other hand, these factors have a direct link with the suitable technological revolution, and through their usage, long-lasting and structurally sound buildings could be produced and these buildings may be able to:

- Boost the contribution of the local workforce.
- Use locally established materials to a large extent.
- Tolerate the dryness and extreme heat of the country.

- Keeping in view the green building theories, conserve energy and other resources.
- Require less maintenance and repair over the life of the building.
- Use simple construction techniques that can be easily understood by the local people.

Beyond the nostalgic aspect, a vital role can be played by conventional earthen construction techniques in delivering suitable shelters through which the above-mentioned criteria could be met.

In learning from the practices and achievements of previous generation, different concerns have been expressed by some government agencies and various individuals in recent years. Building professionals and architectural instructors should employ these concerns in understanding, analysing, developing and enhancing the potentials of the traditional construction systems, so that the modern needs can be fulfilled and an acceptable environment can be enabled for the best and larger interests of the public.

Saudi traditional architecture employs diverse construction methodologies. Nevertheless, the vital system that should be considered particularly for the central region is, no doubt, mud. As far as the adobe design of Saudi Arabia is concerned, there is some incomplete information, primarily in government publications and travel literature. Nonetheless, the impact of these publications is not seen as desired, since they give an unfocused and vague impression. During their estimations of the design, a few among these sources gave an overall image of the mud system or/and the thermal operation of earthen houses besides their appropriateness to climatic and cultural environments.

For a hot-arid country like Saudi Arabia, little and inadequate efforts have been observed in studying and developing earth as suitable building material, even though a rich heritage reportedly exists in the design and structure of mud houses. Therefore, we need a wide-ranging study wherein earth construction is documented / recorded and developed as the most important system of long-established architecture, since this would deliver the necessary data about the most significant performance attributes and, regarding the capacity of this system, awareness among the public and architects would be enhanced by this. Moreover, if an improved earth system is used in meeting the energy-efficient and low-cost housing needs of the country, besides fulfilling the best conservation technology methods, then the designers and builders should carefully take into account the aforementioned performance-based attributes.

1.3 Research Questions

The following questions are raised by this research on the basis of the above-mentioned discussion:

- As far as buildings conservation in the Kingdom is concerned, which procedures are adopted for developing technical standards?
- Regarding governing building conservation, what are the historical building regulations in Saudi Arabia? For earth buildings in the Kingdom, are there specific guidelines methodologies?
- In relation to heritage areas of Saudi Arabia, what systems are available for building conservation?
- As far as Saudi architecture building types are concerned, which historical building techniques methods are reducing and controlling of losing them?
- For earthen buildings in Saudi Arabia, how can viable restoration methods be promoted?
- What soil mixes or construction materials should be used for maintaining earthen buildings?
- While upholding the Saudi culture with innovation, how can the design of earthen buildings be developed in the Kingdom?

Regarding the recent problems, the purpose of these questions is to discover effective and efficient solutions around earthen buildings. Besides a fieldwork study in the Kingdom, a comprehensive literature review is established to address these questions. In addition, detailed interviews are also conducted to explore these issues.

1.4 Objectives of the Study

Given below is the overall aim of the work concerning the problem assumed: the attention of the public, draftsmen and builders in Saudi Arabia is to be drawn towards the capability of long-established earthen architecture and they are to be given insight regarding the lessons delivered by vernacular buildings. Due to these lessons, the reintegration of modern architecture could be promoted into the local perspectives from which it has been excluded, and a coherent link re-developed between the past and future.

Hence, reintroducing earth construction technology to the Saudi building industry and conserving the earthen heritage fabric is the major goal of this research study. The following objectives were identified for achieving these goals:

- With special reference to the regional earthen construction procedures that have been used within earth conservation and traditional house construction, the purpose is to evaluate and document the disappearing regional styles of Saudi traditional architecture.
- To give concise information about the pros and cons of earth as a building material, the causes of its corrosion need to be examined, and the general aspects of the main soil types used for earthen building construction need to be measured in the different regions of the Kingdom and other countries.
- With the modern knowledge in the field of soil stabilization, the qualities of the traditional earthen system are to be combined and a major aim is to develop an appropriate building material (that can be used in producing energy-efficient and low-cost buildings in a desert region such as Saudi Arabia) through an experiment, keeping in view Green building theory.
- For residential and historical buildings in Saudi Arabia, the mechanism for establishing earth-building technology needs to be determined.
- By expanding the use of natural resources, the supervision of the natural environment can be improved.
- For Saudi earth building, the best sustainable conservation technology may be provided for optimum results.

- As far as the Kingdom’s environment is concerned, a smart and an intelligent Residential Green Building plan in line with earth technology may be produced.
- Regarding heritage significance, public awareness of their future and the next generation’s identity may be promoted.

1.5 Scope and Limitations

The long-established styles of Saudi architecture in this study are generally considered as a model in which the local skills and available building materials are adopted to provide shelter whereby the people's needs are fulfilled. This thesis will not directly discuss the aesthetic and socio-economic aspects of the traditional systems. Nonetheless, it is considered from their context reference, so that the worth of those unique structures can be highlighted, through which the restoration recommendations can be represented.

Owing to the nature of the study and due to limitations and constraints of time, it was necessary to choose one particular system for development even though the study was overall intended for Saudi Arabia. The widespread system in the central region and in other regions in the south-west of the country was adobe, sun-baked block construction.

During the early stages of the investigational part of this thesis, scientists collected and examined the sample of soils which were used for making adobe in the central regions. Nevertheless, shipping large quantities of different local Saudi soils to Valencia was a very hard task. The experimental work was carried out using artificial soils to address this problem, and to limit the number of variables regarding soil types. An abundant material in Saudi Arabia and in most desert regions of the world is believed to be sand. Therefore, higher substances of similar sand, both in chemical composition and gradation, were integrated with kaolinite, a well-known clay material that is used for making blocks for experimental purposes and has been widely used in soil research. Investigating all of the likely stabilizers was not possible while stabilization is recommended as a technique for improving earth as a building material.

Owing to the commercially confidential nature of some of the required data and because of privacy and security matters, problems were encountered in acquiring some of the information needed from a set of companies. In addition, it was very difficult to acquire information from some government authorities, because some of them think that information is merely maintained for official proposes and is not for sharing.

1.6 Research Methodology

Finding comprehensive sources was a challenge during this study. This difficulty was due to the inadequate number of research studies that have been carried out on the ideal conservation and restoration methods suitable for historical earth buildings in Saudi Arabia. The study employed two procedures. In 2013, the investigator travelled to Saudi Arabia and carried out exhaustive research on the remaining earthen architecture. The author looked at the general status of the buildings (dilapidation, corrosion, and decay), the construction materials and techniques as well as the architectural styles and decorations. In addition, laboratory studies were done to determine the composition of different earthen blocks used in the construction of traditional houses in Saudi Arabia as well as other countries such as Morocco and Yemen.

In many nations, earth constructions are mainly historical. Saudi Arabian earthen structures are unique in their architectural characteristics, culture, building technique and adobe. For instance, the At-Turaif District in ad-Dir'iyah, which was the first capital of the Saudi Dynasty, has distinctive architectural features in regards to structure, building technology and materials. These features are determined by the social fabric, culture and climate in this area. It is, therefore, hard to find recent buildings with the same earth materials and architectural structure used in historical Saudi Arabian buildings. After a long and intensive investigation, the researcher found two cities with similar earthen buildings, M'Hamid El-Ghizlane in Morrocco and Hadhramaut in Yemen.

Tarim and Shibam city in Hadhramaut Valley have earthen buildings that closely resemble the architectural properties and culture of Saudi Arabia. Here, builders had the pleasure of using adobe in their construction. The utilization of adobe turned out to be perfect and adaptable for them. Most of the buildings in this town were constructed using mud bricks. Many of the structures have five to eight stories. Shibam is one of UNESCO's World Heritage Sites. The earthen architecture of Yemen has been studied many times. This study looks at construction and conservation techniques. It focuses on the general history of traditional adobe buildings as well as the preservation efforts in these constructions.

M'Hamid El Ghizlanein is found on the south-eastern side of Morocco. This area has many earth constructions. Most of these buildings were constructed using rammed earth and adobe or a mixture of both. This area is of great value in investigating the strength of rammed earth and the flexibility of adobe. To inspect and study the earthen architecture and construction, the investigator visited Morocco and Yemen in April to August 2014.

Data was gathered through personal observation and interviews with artisans, old building masters, and other participants in the construction of traditional houses. The interviewees were asked to give their opinions about conventional and modern earth architecture, and the effects of culture, the climate, the economy and technology on construction techniques. The interviews also aimed at gathering information on attitudes and views concerning the ongoing conservation and restoration efforts of earthen architecture. Additionally, a survey was carried out to obtain a general understanding of the building materials and construction techniques used in the construction of traditional houses. The survey included a visual examination of the leading causes of corrosion in earth buildings, such as floods and decay. Photographic documentation of these observations was maintained. The researcher also gathered samples and sun-dried specimens from various building sites in both countries. At an early stage in the study, these samples were analysed with the aim of understanding the fundamental properties of different soils in the Kingdom.

The research process also involved a desk study whereby online library catalogues, electronic indexes, and Internet search engines were used to find additional information sources. A comparison was made between ancient and modern architectural characteristics of earth buildings. The researcher carried out a database review in Riyadh Municipal City, King Saud University Library, the Archaeology and Tourism Department, Ministry, and Spanish libraries. In addition, interviews were conducted with experts who have knowledge of the conservation of earthen buildings. The interviews involved issues concerning the various restoration techniques and their effectiveness in conserving the buildings as well as the Arabic heritage. Interviewees were asked for their opinion on the use of modern materials in the restoration of historical earth buildings. They were also asked about the cultural and physical challenges that are associated with recovery interventions on earthen architecture in Saudi Arabia.

These interview questions were based on the apparent disregard of traditional construction materials and technique in the restoration process. Although the intention of the rehabilitation is to conserve history and culture, neglecting traditional artisanship results in heritage loss due to the use of modern replicas (Cetin, 2010, 11). Traditional materials in Saudi Arabia such as wood, mud, straw, and palm tree gutters have been replaced with steel, cement, gypsum, and plastic pipes (Cetin, 2010, 10). Little attention is being given to the historic and cultural value of materials and techniques.

Laboratory studies were carried out to investigate the soil mix and concentration, and the creation process of earth blocks. These procedures checked for the proportion of sand, clay, silt and loam in the blocks. The composition of soil subtypes and moisture in earthen blocks vary with weather conditions, locality and culture. These variations explain the distinctiveness of earthen structures based on geographic, cultural and climatic conditions. Different lime stabilization techniques and simulated sandy soils were studied in the laboratory.

Artificial soil that resembles the sandy soils in the kingdom was used to make stabilized earth blocks. Modern architectural techniques and styles are often not compatible with the environment and culture. Mostly, they involve the use of foreign materials and labour and expensive methods. For these reasons, it is important for the Arabic population to adopt some aspects of ancient earth construction into the modern urban fabrics that align with their culture and environment. The above laboratory studies aimed to look at the best composition of soil blocks to be used in the construction and restoration of earthen architecture that is suitable for the Saudi people and environments. Changing lifestyles make adopting all the aspects of traditional design impractical. However, the Saudi people can obtain valuable lessons from ancient master builders. The incorporation of both modern and traditional knowledge and techniques will assist in maintaining the cultural heritage of the Arabs. Consequently, people will build structures that are better in quality and strength while respecting their culture and environment.

1.7 Research Structure

This thesis contains two self-contained but related sections. Besides the impact of the major lifestyle changes during the last few decades on building traditions, the introduction and the main geographical features of Saudi Arabia are described in the first section. Section two describes the demand for housing.

A narrative analysis of the regional design of the country, its capacities and its diverse architectural styles is provided by the next part. Subsequently, the old-style earthen construction systems of Saudi Arabia in connection with building materials are reviewed. A brief account of the modern housing system is also provided in this section, which has replaced traditional methods in Saudi Arabia and around the world. The inappropriate design of this modern system, which has led to social, technical and visual failures, is also emphasized in this section. Moreover, it has contributed to people's understanding regarding its suitability to local contexts, particularly when compared with the old-style structures.

Besides the natural and man-made causes of deterioration, this research presents the key strengths and weaknesses of earth as a building material. Some of the general attributes of soil and physical characteristics of soil samples and sun-dried specimens collected from the different regions of Saudi Arabia are also described in this paper along with their technical details.

Laboratory work is the next concern of this thesis. A brief description of soil stabilization laws, which can be used in improving earth as a building material, is provided. Moreover, the major stabilization procedures are also focused in detail with a review of the major efforts that have been undertaken by groups and individuals so that the mechanisms for building purposes could be utilized in the best way, since they were formulated for the maintenance of earth roads.

Furthermore, dimensional stability, strength, durability and permeability are discussed as the major performance attributes that should be taken into account in the hygiene problem of earth buildings and in the development of stabilized earth as a walling material.

Moreover, to assess the dimensional stability, compressive strength, durability and permeability as the major performance attributes, it explains the materials and equipment used in the laboratory tests. In this regard, the researchers have conducted different tests and this part presents the results and discussions. This particular chapter also discusses the impacts of soil mix, which includes the basic quantities of the clay, sand, artificial soil and watering addition, on the main manufacturing factors, for instance, the effect of curing time, compaction, system and temperature on the compressive strength of stabilized soil blocks, and the developments in the other performance features are explained as a result of the stabilization. For earth architecture in foundation, making adobe, walling, coating, lime finishing and so on, several restorations skills are examined in the last part.

The study is dedicated to the appropriateness of earth as a building material. This part focuses on the major elements for popularization and principal reasons of non-acceptance. The recommendations and conclusion. It summarizes the study, and suggests further studies on its topic. This is followed by the appendices and bibliography.

CHAPTER TWO

ENVIRONMENTAL FEATURES AND REGIONAL ARCHITECTURE CHARACTERISTICS IN SAUDI ARABIA

2.1 Environmental Features of Saudi Arabia

2.1.1 Geographical Features

A. Location

An area of above one million square miles is covered by the territory of the Arabian Peninsula, wherein nearly 875,000 square miles pertain to Saudi Arabia. More than 80 per cent of the peninsula is represented by this vast area. It is roughly about one-quarter of the USA or almost the same size as Western Europe. The Red Sea is located to the west of the country and the UAE, Qatar and Arabian Gulf lie on the eastern side. Jordan. The north side covers Kuwait and Iraq, whereas Yemen and Yemen lie on the southern side.

Extending from the Gulf of Agaba in the north to Maydi in the south, the western coast is shown in Figure 2 (mep.gov.sa,2014) and is more than 1,100 miles long. The eastern coast is 300 miles long and extends from RasMishab to Qatar. The southern boundary is 800 miles long and extend from Maydi to the Arabian Gulf. The length of the northern boundary is 850 miles and it extends from Agaba to RasMishab (Mcloughlin, 1993).

Figure 2. Location of Saudi Arabia by mep.gov.sa

B. Topography

Diverse geographical features are observed in this vast area of the Kingdom, but the outline of the Kingdom is simple. A sandy strip of land basically forms the eastern coast alongside the Arabian Gulf, which is no more than a few hundred metres above sea level. Normally, it is encircled with a number of coral reefs and salt marshes. The double blessing of high-volume oil fields and abundant ground water is fully enjoyed by the region. The topographical surface and water table are very close to each other, and water seeps out from several places to form wide-ranging springs, which are gently utilized to meet the agricultural needs.

In the heart of the Arabian Peninsula, the Najd highland expands from the eastern coastal area to the Al-Hejaz Mountains, at a height of over 914 m above sea level. The Tuwaig rocky chain encompasses this plateau in a crescent shape from the north to the south. Nevertheless, a number of sand belts and shallow valleys extending between Al-Rub Al-Khali in the south and Al-Nufud desert in the north interrupt the plateau and it declines from west to east. Different elements, such as harbouring vegetation, strings of oases, both refined and natural, and springs collectively encircle the plateau, and due to these elements, the general aridity of the plateau is also relieved. Furthermore, comprised of a series of intervening sand strips and longitudinal escarpments, its sedimentary limestone, soft rock formations, shale and sandstones are easily bifurcated by weathering into silts, sands and ravels, and then they are carried by floodwaters into depressions and down the valleys. The settlers of central Arabia for at least 4,000 years have been residing in the valleys and depressions of the old Lower Najd. Many offshoots join the valley of Hanifah, when it winds its way towards the south. The surface has an abundance of ground water, due to which cultivation becomes possible with the help of irrigation from wells. Hence, farmers came to settle along the valleys and their arrival dates back to when agriculture first came to this part of Arabia. Hajr al-Yamamah, al-Uyainah, ad-Dir'iyah and Riyadh are some of these communities that have gained authority over the periods (Atlas, 2005).

The hilly chain of Al-Sarawat extends to the west of the Najd plateau, which is parallel to the Red Sea coast. Yemen lies on the southern side and Jordan to the north. From the Tihama coastal plain, the Najd plateau is separated by the chain. A gently sloping eastern side giving way to the high plateau of Najd and an unexpected western rise represents its geographical formation Al-Hejaz is the name given to this chain, which is situated along the central and northern part of the Red Sea coast, and the southern part is called Asir.

A number of lush oases are found in the Al-Hejaz area, while it comprises sometimes sandy landscape and mostly rocky land. It is also described by various large and hostile lava flow areas known as Harat. The highest altitude in Saudi Arabia is maintained by the southern continuation of Al-Hejaz, i.e., Asir. Its peaks rise up to 2,743 m above sea level.

The narrow, low and sandy plain of Tihama lies along the Red Sea. The Tihamat coastline is shared with the name of the area to which it belongs, i.e. Tihamat Asir in the south and Tihamat Al-Hejaz in the north. Several valleys extending from Al-Sarawat Mountains interrupt this coastal plain and it varies from 10 to 40 miles in width (Atlas, 2005).

Desert covers a large segment of the Kingdom's land and is a main attribute of its geography. The deserts, such as Al-Dahna, Al-Nufud and Al-Rub Al-Khali (the Empty Quarter) are among the three major deserts of the Kingdom and the Arabian Peninsula. Almost 25,000 square miles in the north are covered by Al-Nufud, which is made up of longitudinal dunes that soar to heights of above 91,44 m. The 643 km long Al-Dahna, a narrow strip of sand dunes, stretches south from Al-Nufud. The southern tip of Al-Dahna joins with Al-Rub Al-Khali, meaning more than 250,000 square miles are covered by this area. The sand dunes climb as high as 305 m in this desert (see Figure 3) (Atlas, 2005).

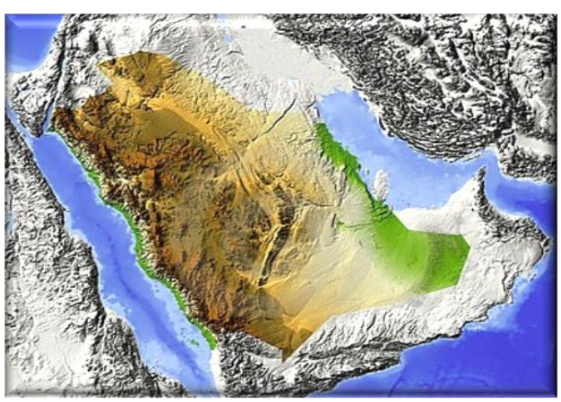


Figure 3. The topography of Saudi Arabia (Atlas, 2005)

C. Climate

The Kingdom of Saudi Arabia falls within the tropical zone at a latitude between 16° and 30° N. It lies between two major continents, Africa and Asia. Moreover, from the east and the west, it is protected from the maritime effect. Only a limited influence on the coastal area is exhibited by the Red Sea in the west and the Arabian Gulf in the east of the country. Saudi Arabia is one of the driest countries in the world . A desert climate of high temperature, light wind and low rainfall collectively describes this area. On the other hand, different climatic types are observed in the country. The hot tropical region is generally attributed to the eastern coast. High humidity is associated with high temperatures of summer, for example, a maximum of around 42°C, which usually reaches 100 per cent humidity in the summer season. In contrast with the west coast, the winter is normally cold, sheltered by the mountain chain. Rain falls mostly in spring and winter and is usually scarce. Because of the proximity of Al-Dahna and Al-Rub Al-Khali deserts, there are frequent sandstorms. The latter spread to the Gulf in the south of the area.

The most arid of all the large countries on Earth is believed to be the central plateau of Najd. It follows the desert belt, which comprises most of the Arabian Peninsula and Sahara Desert. The settlers, notwithstanding a great challenge to human endurance, have evolved diverse methods of farming and survival. A hot, long and almost totally dry summer is experienced in the Najd. With the average July maximum at 42°C, daytime temperatures can reach up to 50°C in the shade. There is a sharp variation in temperatures between day and night as well as between winter and summer as a result of its clear skies, and its position far removed from the regulating effect of the sea. On the other hand, the perceived effect of both heat and cold is mitigated by the low humidity.

The average daily minimum temperature between November and January reaches a comfortable 8-9°C in winter, but there is occurrence of hard frost, which leads to severe crop damage.

The prevalent summer wind is entirely dry and comes from the south. The dry and cold northern wind blows from central Asia in the winter season. These winds have lost most of their humidity, and there is very low rainfall as a result by the time they reach the Najd. From the Mediterranean side, depressions tracking south-eastwards replace the north wind in late winter on the other hand, and the small rainfall of Najd is carried by these winds, whereby it makes up the most valued, spring-based rains due to which the desert is radically brought to life. Precipitation across Riyadh is well below 250 mm, with an average of 84 mm per year, due to which dry farming has to be made conceivable. The use of animal-drawn wells, reaching ground water and the old-style sources of water for irrigation can bring the desirable outcomes for farming and for meeting water needs. When it does rain, this is representative of desert rainfall, usually arriving in ferocious thunderstorms/downpours. A single day witnesses half or more of a year's rainfall. These rainstorms can be confined to a small area, and are often as shattering to people as scarcity. Heavy downpours crash through the converging stream valleys to result in disastrous floods, which can cause heavy damage to entire communities besides sweeping them away. The Hanifah valley is turned into a temporary river due to four or five such floods in winter and spring, often as late as May. This may occur only once or twice in a dry year, while up to fifteen such storms might be brought by an outstanding season (Figure 4).

Mostly, the western hilly chain of Al-Sarawat is calm and cool in both winter and summer. Since there is a gradual decline in temperature, altitude is likely to increase southwards, and a pleasant summer is seen, especially in the Asir region. There is a relatively high rainfall on the western heights, whose expansion is seen from north to the south, and in the western chain of Al-Sarawat, it reaches a maximum of 500 mm.

Tihama, the western coast, is relatively warm in winter and primarily humid and hot in summer. There is a gradual increase in temperature from north to south. An uneven and fluctuating rainfall is normally reported on this coast; however, the average annual rainfall in most areas is less than 100 mm (Pme.gov.sa, 2011).

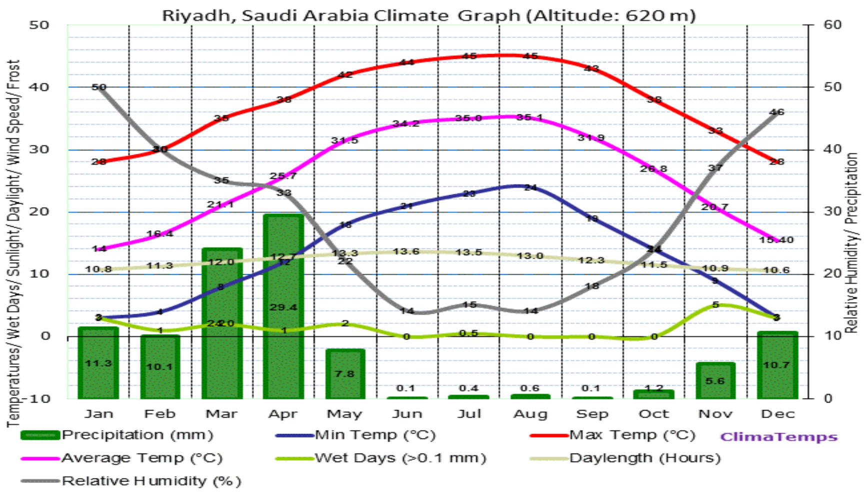


Figure 4. General climate of Riyadh 2011 (Pme.gov.sa, 2011).

2.1.2 Socio-Economic Change

Saudi Arabia was established in 1932 and was a poor country until oil was discovered. The socio-economic situation of the country was that of self-sufficient societies prior to the exploration of oil in the early 1930s. In most regions of Saudi Arabia, the main sources of income were herding, agriculture, pearl diving and fishing (Mcloughilin, 1993).

The Middle East had been producing oil since the start of the twentieth century, however this was in small quantities. With a stated life of 66 years, a business agreement was signed by the SOCAL (Standard Oil Company of California). SOCAL and Texaco established the Arabian American Oil Company, ARAMCO, in 1936, and Mobil and Jersey Standard joined them in 1948. The desirable results were not achieved in the early exploration; however, the team of scientists discovered commercial quantities in the Dammam area in 1938. They gained more success in the early 1940s in the form of more fields, but Al-Ghawar field, which was the biggest milestone, and is the world's largest single oil-bearing structure, was achieved in 1948.

A new source of income emerged with the discovery of oil in commercial quantities when on 3rd March 1938, oil poured from Dammam Dome Well No. 7. Prior to this, the performance of the oil industry in the country was not up to the mark. However, in later years, the main symbol and source of national wealth was occupied by oil for the country and it became the largest across the Gulf region. ARAMCO kicked off oil production in 1938. While ARAMCO is run together with the four major US oil companies, who were its original partners, this company was gradually acquired by the Saudi government authorities with their proprietorship and it now has 100% state-owned assets (Greene and Heidrich, 1986).

The Kingdom's economy remained uncertain until 1950. At that time, the builders established the buildings in a conventional manner, using only indigenous building materials. Moreover, to serving the oil industry, designers had constructed various housing schemes. A prestigious symbol of modernity is illustrated by ARAMCO's compound in the eastern region. An extensive influence on the local population was reportedly seen as a result of its suburban-pitched roofed bungalows, wide straight, tree-lined avenues and plants laid out in lawns irrigated with desalinated water (see Figure 5) (Green and Heidrich, 1986).

Figure 5. Saudi Aramco 1950 (Greene)

On the other hand, major socio-economic change was seen and largely influenced the traditional society with the considerable rise in the price of oil after 1973. The development of all systems including housing, transportation and other expansion schemes was accelerated by the new economic base. The entire country seemed like a huge construction camp (Al-Rasheed, 2010).

The custom started to take on a distracted blind replication of western technologies and architectural stereotypes in this rapidly changing environment. Building customs were among them. Moreover, modern building technologies and architectural forms were now replacing the old traditions, and through these new technologies, social advancement is being represented, even though they are mismatched to the local climatic and cultural settings.

This particular trend was appreciated by a number of technicians and architects, who had travelled to Saudi Arabia in pursuance of jobs. In short time, a rift was reported between the new values and the ancient concepts. For instance, if we are talking about structural design, the house plan, which normally faces inward to the courtyard, was replaced with the one that looked away onto the street. The noise and dust of the street replaced the clean and cool air besides the peacefulness of the courtyard. The authorities concerned had overlooked the long-established house design which shielded against the climatic troubles for the sake of designs which were subjected to mechanical aids and were unfit to the environment. There was a quick withdrawal of any appearance of old-style character in structural design.

Regarding such old building traditions, there was little time to worry during that period of opulence. These civilizations belonged to the past eras according to many people and modem signs of affluence and success replaced the old traditions. Currently, the infrastructure is largely based on such an intermediate period. Unlike the 1970s and early 1980s, the housing shortage is not that serious. Nonetheless, more suitable and comfortable housing is the demand of today's youngsters, but this will be a relatively systematic process and a meticulous approach will be followed to build the standard houses, unlike the buildings that were established in the last twenty years. Therefore, examining the time-honoured past of the country comes under the responsibility of the building authorities and instructors, so that those neglected aspects of traditional architecture can be developed that have been tested throughout the centuries and which are still relevant today, and so that they can understand the lessons of its popular and historical building traditions (Al-Rasheed, 2010).

2.1.3 Housing Demand

The changes experienced by the country during the last four decades can be reflected by the change in Saudi Arabia's housing stock. To make way for modem reinforced concrete villas in most of the cities, the old-style houses are being demolished, which were randomly relocated.

In the period following 1973, prompt increases in the price of housing resulted from the rapid increase in demand for housing units. The cost of housing in 1976 was approximately five times the 1971 level and 153 per cent greater than in 1974. This rapid increase in housing prices prompted three types of government action. Firstly, rent controls were imposed on existing structures. Then, to increase the stock of housing, direct actions were taken. A role was played by government agencies in the building of housing units; they provided housing for employees, and this project was achieved by establishing mobile homes and other types of provisional structures. Lastly, the government provided numerous incentives for private individuals so that they could build their own housing units. The establishment of the Real Estate Development Fund was the most important measure in this regard. Nonetheless, partly in response to higher prices and also in response to government plans, there was quite a rapid expansion in the housing stock during the late 1970s and early 1980s, and a slump in prices was also observed. There were a number of reports of vacant properties in 1979 (Blake, 1980)

While the almost 170,600 houses units besides the large number of vacant units in the country (estimated at 100,000 units at that time) exceeded the Third Development Plan's targets in 1980, there was a need for an additional 285,000 units to be constructed in addition to the 100,000 vacant units, as per the details of Fourth Plan (1985-90). From these figures, we can infer that there was a demand for 325,000 new households by 1990 along with 60,000 replacements of inadequate dwelling units. Lately, almost 500,000 houses have been planned by King Abdullah to be built for the public and the Ministry of housing will oversee this project. In addition, a nonprofit mortgage of $150,000 for each Saudi family was also decided on by the government (Al-Utani, 2011).

A stable demand for new housing will emerge in the future because of the high birth-rate in Saudi Arabia, which is among the highest in the world according to the United Nations. Youth in the country (below the age of 15) are reported to make up over half of the population. According to Saleem, a large number of citizens coming of age and demanding houses will be observed along, due to which more nuclear families will appear, and ultimately, this phenomenon will lead to an upsurge in the number of houses corresponding to the population. Inappropriate or old design could be another factor through which demand for housing will be increased for some time, since many people need renovations and are not satisfied with their villas, which were built during the early years. They have discovered the incompatibility of such villas with their living standards and the surrounding environments. Their mistakes during that transitional period have made them learn many new aspects. Currently, they are seeking properly designed and cosy and comfortable houses through which their needs and response to their environment can be accommodated in a desirable way.

2.2 Regional Architecture of Saudi Arabia

To realize the increasing demand for buildings, the import of modern architecture has been accelerated by the speedy rate of development following the oil boom in Saudi Arabia, as in other Gulf States. In these countries, the so-called International Style of architecture is rapidly replacing the traditional architecture, although the conventional architectural design is suitable for the local cultural and climatic atmospheres. This standardized concept has been praised internationally as being fit. Besides exhibiting a lack of thoughtfulness concerning the bond between buildings and their environments, most of the resulting structures have resulted in technical, social and aesthetic failures. Loss of identity and the consistency monotonous loss of national character have been reported as a result of the adoption of such ideas in Saudi modern architecture.

A regional survey conducted in Saudi Arabia is described by this part, which has further resulted the discussion of two main conventional earth styles. Earthen technology is the basic construction material of these styles, which is discussed in detail in the following chapters.

The Potentials of Indigenous Architecture

As far as so-called developing countries are concerned, the professional bodies have overlooked the potentials of traditional buildings. As an alternative, the modern international style has replaced them, which is often unsuitable to local settings and needs. For Third World countries, this has become the evident model as a result of the visible material success of the new modern industrialized world.

Real evidence of the complete interaction between humans and their environment is thought to be found in Saudi vernacular architecture. Experience and information were gathered to manage with local conditions, which were subsequently handed from one generation to another throughout the centuries, and a wonderful range of architectural languages emerged as a result. Unluckily, in the Kingdom of Saudi Arabia and in other oil-rich states, the major achievements of previous generations have started vanishing in the face of replication of modern architectural technologies and stereotypes. Moreover, Saudi vernacular architecture is “one of the most impressive feature in the world” according to Ronald Lewcock.

Academics, experts and the new generations can learn so many things from the modern and rich Saudi local architecture found in the different regions. Moreover, new students (who are willing to find out the principles based on the long-established architecture) studying architectural design can learn from the time-tested techniques and their demonstration. In addition, with a full reintegration of new architecture into cultural and other prevalent customs, a logical link between the past and the present can also be established to gain the desirable results.

Over the centuries, traditional builders have carried out developments which are in accordance with their lifestyle, climate and cultural and economic conditions. Technology and materials were quite limited at that time, and keeping this aspect in mind they developed their architectural vocabulary and used their capabilities with full potential. On the other hand, the modern building industry consists of a wide range of technical expertise and building materials, however, they are still not able to fully use their technical abilities. In earlier times, local communities experienced significant problems in architectural development owing to limited building resources and the use of traditional methods (Al-Fadil, 1993).

The local architecture is neither based upon formal building principles nor does it employ detailed sketching. This shows the increased response of people towards the effects of the physical, cultural, economic and social environment on construction and gave rise to the development of an architectural culture which is rich, simple and functional. Moreover, using local building materials adds further substance to the exclusivity and distinct character of the respective buildings (Al-Jaded, 1994).

For over half a century, the traditional knowledge and techniques have been criticized as well as left unattended. The international architecture style required that progress was attained at any price. Hence, the regional traditions were ignored in nearly all regions. The cultural aspects were forgotten and the traditional expertise stopped being practised. It is necessary to rediscover these traditions as they are a cultural heritage. Moreover, this may help in integrating previous and modern knowledge (Al-Bini, 1990).

In the contemporary world, the lifestyle of the people has changed drastically, which is why it would not be realistic to maintain the traditions and cultural heritage of the past. However, these traditions could be adapted to present requirements by making them extra-efficient. The building industry must be educated and essential aspects must be taught to the public and architects. This would help in creating a cultural bond between people and their environment.

Saudi Architectural Heritage

The international and national construction organizations in the developing nations have been analysed by Jim Antoniou. According to his article on the world construction market based on this analysis., construction activity has achieved spectacular growth in the Gulf region. The development of buildings and infrastructure based on the western style have shown rapid growth, embedding western technology into the traditional environment.

Modern building materials and techniques have become essential after the increase in oil prices in 1970 called out for more housing. Foreign labourers were employed and building materials were imported. The buildings were mostly designed by the engineers or architects who were not concerned with the local conditions. Hence, traditional forms or systems employing local sources of material which served to cater to the local needs and complied with the natural environment, were ignored by following the international styles of infrastructure. Moreover, the local conditions were not taken into account and international style models were copied without thorough understanding. The climatic conditions and various environments were not assessed when the modern villas were constructed in the regions. The main issue of this technique was that the new buildings were not in accordance with the Saudi social needs and constructional conditions (Figure 6).

Figure 6. Saudi Arabia in the 1980s (Sami.2011)

This issue has become quite visible and many Saudis are aware of it. Modern architecture has been criticized in the Middle East by architects, planners and critics as well as the western architectural literature regarding the Middle East. Professor Jansen (Department of History of Architecture at University of Aachen) is one architect who mentioned this problem in the book *Traditional Architecture of Thatta*. Professor Jansen's foreword stated that over the past 40 years, urban architectural projects have maintained their slogan of "the future in the past". This also accounts for various nations of the world. However, the international style requires that the older constructions are removed and newer ones introduced. This method has been used for fashion, language and food as well as for city planning, house construction and social behaviour. The crisis of architecture in Europe ended in the 1960s. The people of the nations recognized that they were losing their former identity, which must be preserved through traditional architecture. In this case, the form of development is not being criticized, but the loss that has been incurred by Europe in the name of progress is being highlighted. After realizing that much of the architectural heritage has been destroyed, the Europeans have learnt that conventional solutions are not the answer. Prevention would prove to be much more appropriate, in this regard.

A. Architectural Style

Owing to its vast population, Saudi Arabia is divided into four geographical regions.:

- The Eastern province which borders the Arabian Gulf or Al-Hasa and the Gulf coast
- The central region, Najd or high land on the high plateau in the middle of the Arabian Peninsula
- The western and northern regions or Al-Hejaz (the barrier) that consist of various mountains situated parallel to the Red Sea
- The south-eastern region or Asir which is on Yemen's northern border

The architecture of each region is specific to its natural resources, climate, cultural needs and lifestyle of the citizens. The generations which have passed seemed quite knowledgeable regarding the development of buildings in accordance with the environment, cultural conditions and economic aspects of the region (Al-Jawhari, 1996).

Political boundaries did not hinder the architectural development of the previous generations. Cultural boundaries were responsible for the background of these architectures. In all regions except Najd, the main material for construction was adobe and the rest of the construction methods were based on the features of architecture of the neighbouring nations, considering that they shared same social values, culture and climate conditions.

In Saudi Arabia, most of the regions had similar economic and cultural conditions. However, due to the climatic conditions and the material availability, the constructed houses were unable to endure the harsh environment of the specific region. The local communities tend to isolate themselves to an extent, on the basis of which the region-specific architecture of Saudi Arabia has developed. This isolation is mainly due to the presence of physical barriers like mountains and deserts which cause communication and transportation issues (Al-Bini, 1990). Hence, the following section takes into account the Najd and Asir regions since there is a strong presence of Adobe and Cob materials (Figure 7).

Figure 7. Location of Asir and Najd

B. Regional Characteristics of Najd

In the heart of the Arabian Peninsula is a central plateau. The plateau covers around 640 kilometres and spreads between the inland flank of the Al-Hejaz Mountains in the west and the Al-Dahna desert in the east, and from the northern Great Al-Nufud desert to the southern Empty Quarter desert or the Al-Rub Al-Khali, a distance of 800 km. There are various sand belts present within the plateau along with uplands like the Salma, Tuwayq and Aga mountains. There are also various oases scattered within the region with their own village and town clusters. The oases includes Al-Riyadh, Hails, Al-Qasim, Al-Whashm and Al-Aflaj (Atlas, 2005).

In winter, Najd has an extremely cold climate, whereas it is extremely hot in summer. In both summer and winter, the temperature is graded with daily and seasonal variations from north to south. Within the hot-dry region, there are clusters of houses built in a traditional manner as settlements of the people. The houses have a common wall and very few openings to reduce the effect of the harsh climate. Dust is unable to enter easily through the restricted opening. The climate moderator is the interior courtyard, which is built for family activities in a quiet, unique and secluded area. The streets are built through dense settlements in a narrow manner to provide shade to the people. These are irregular and develop visual interest as the people wander through the streets (Al-Jaded, 1994).

The architecture of the neighbouring urban areas of other nations has not been able to affect the Najd region, as it is quite far from the coastal areas. The three deserts and their sand dunes also serve to physically isolate the region. These deserts are the Great Al-Nufud desert, Al-Dahna desert and Al-Rub Al-Khali desert that are responsible for secluding it from the rest of the regions. Foreign powers have no political interest in this region as there is scarcity of water and aridity of land as well as the remote location (Figure 8).

The Najd is the heart of the timeless Arab East, as stated by Salem. This is the only region on the peninsula which has not been affected in terms of conquering and settlement by the outside culture. Hence, the architecture of Najd is entirely based on local conditions and signifies the connection between the people and their local environment. The culture and climate needs of the local communities were taken into account for the traditional architecture. The techniques and characteristics are summarized as follows

Settlement Pattern

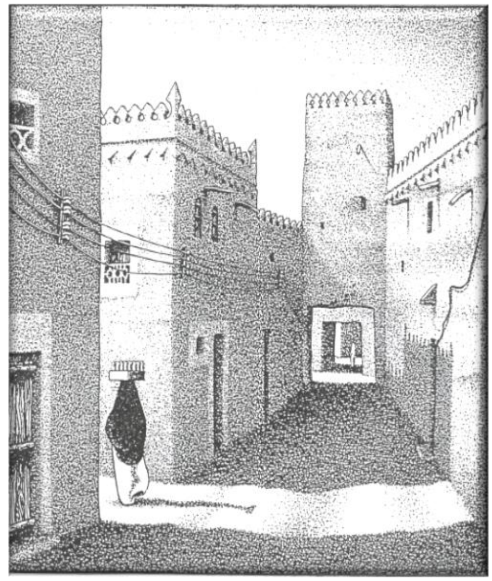


Figure 8. Najdi urban fabric (Ragette, 2012)

The neighbours share the outer walls of the houses as towns have been made compact. The streets are curvy and narrow which acts as a cooling well for semi-private streets and settlements (Figure 9) (Costa, 1994).

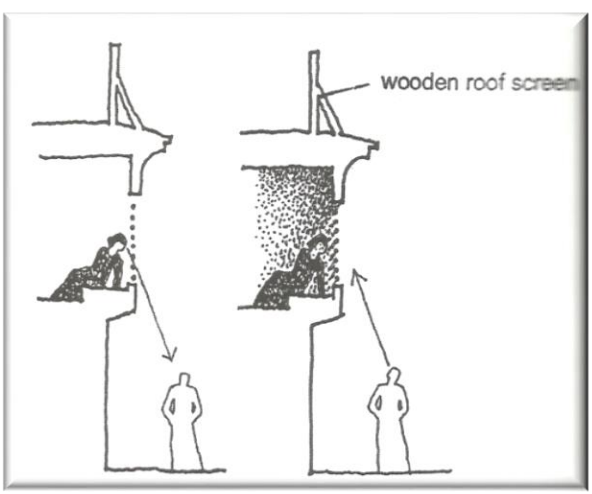


Figure 9. Islamic windows or small opening system in Najd (Ragette, 2012)

House Design and Construction

Design

- Against the harsh environment, an efficient element which provides shelter is the courtyard. It is an outdoor extension which remains private for the family activities (Figure 11).
- For the summer nights, there are different sleeping places established through flat roofs at different levels and high parapet walls which throw shadows onto the roof.
- For privacy, the women have a separate entrance.
- Within the thick external walls, there are few small openings and the rooms have high ceilings. This helps evade glare and increase ventilation and privacy (Figure 10)

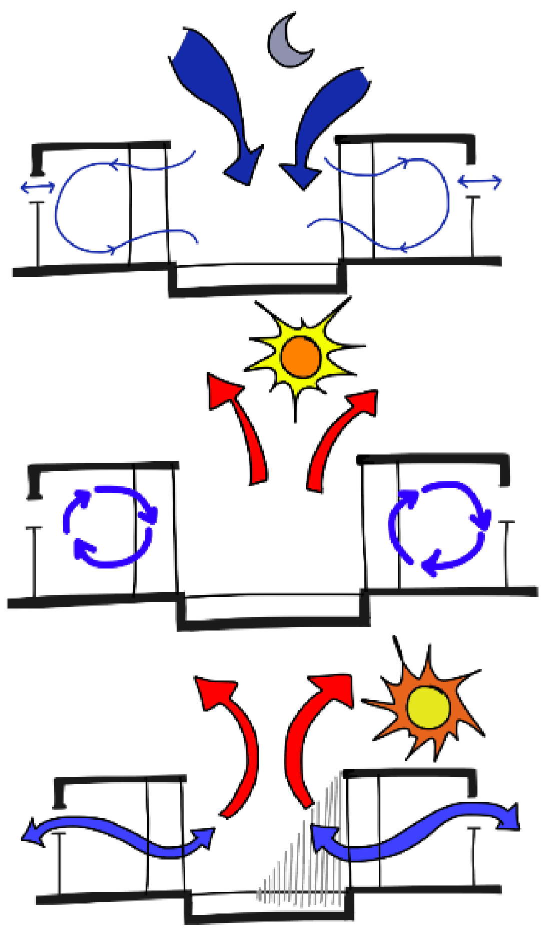
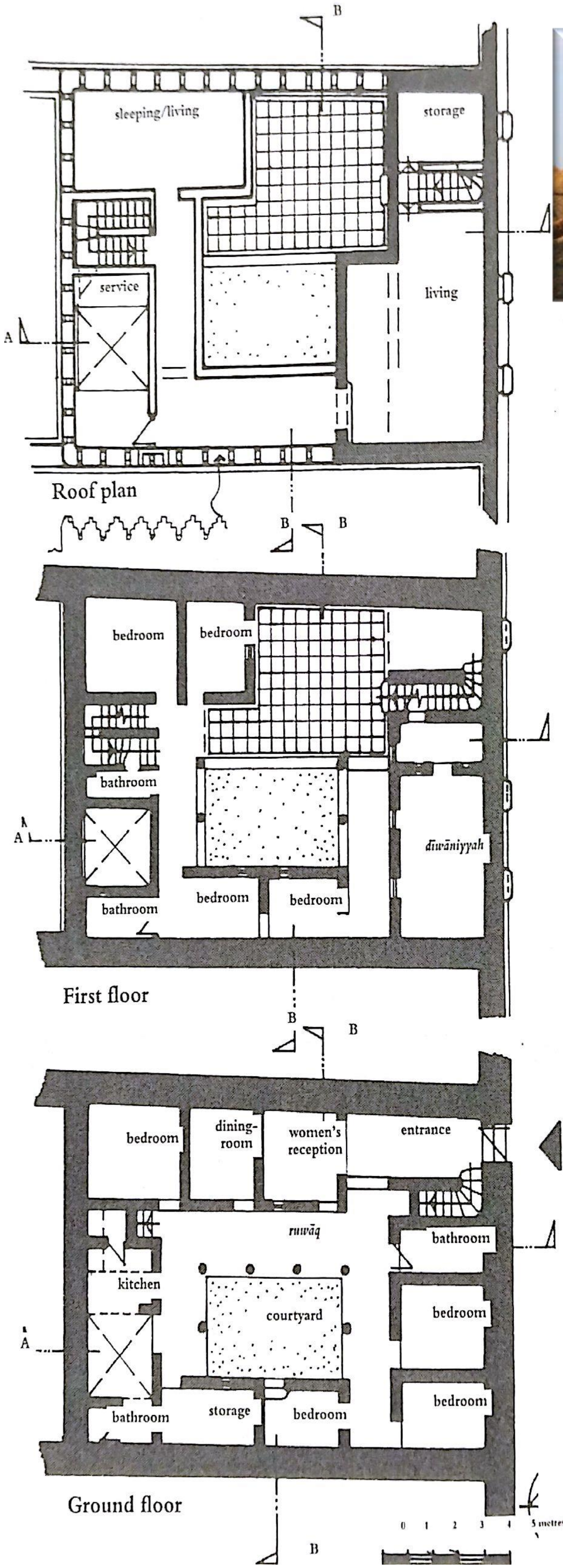


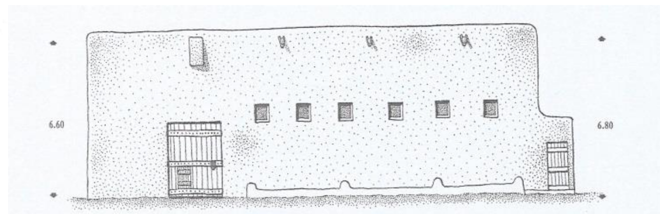
Figure 10. Ventilation and privacy (Facey, 1997).

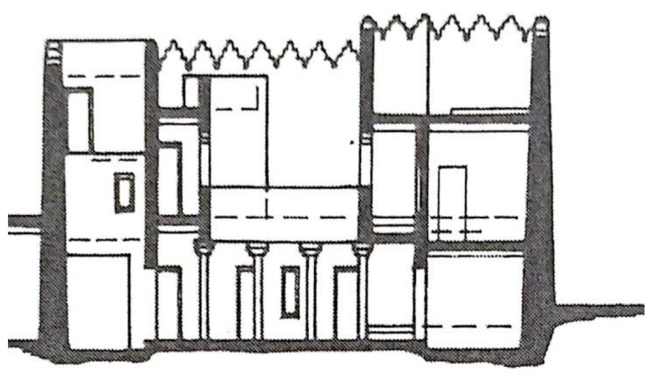
Figure 11. Courtyard and small opening (Al-Aidarous,2013)

Construction

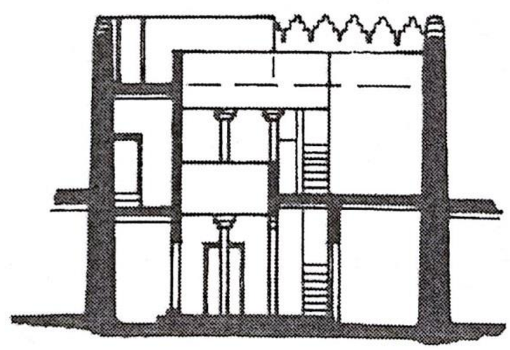
- In the house, thick adobe walls allow the heat to sink as well as repel rapid temperature changes (Figure 12).
- Mud Plaster.
- Wood framed floor and roof made of mud (King, 1977).







Section AA



Section BB

Figure 12.Model of an ad-Dir'iyah mud house (Facey, 1997)

C. Regional Characteristics of Asir

In Saudi Arabia, the highest mountain range is the southern extensions of Al-Hejaz. The area is known as Asir, which means 'the difficult region'. The Asir has various similarities with its neighbour on the southern end, Yemen since it has an abrupt western rise, the Great Red Sea Rift which is part of the coastal wall, and a gently sloping eastern side that allows for a high plateau. Asir has been divided into three areas:

- The rocky landscapes with high mountain tops and deep valleys
- The Tihama or coastal plain
- The eastern part of the region including the famous oasis, Njaran

A mild tropical climate exists in Asir as compared to the nautical-desert and hot-dry climate in the Kingdom overall. Most of the year there is irregular but frequent rainfall. The summer seasons have the most rainfall. The coastal plain, Tihama, has a hot and humid climate and the rainfall is also irregular. Through the building materials found across the region, it is possible to observe the various communities and their traditional architecture (Figure 13) (Pme.gov.sa, 2011)

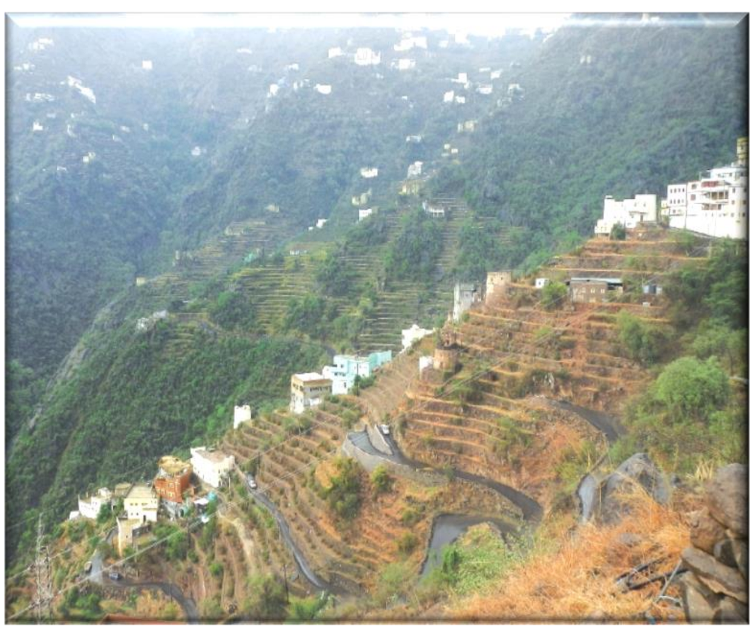


Figure 13. Asir environment by Saleem

The rest of the Asir region is separate from the Tihama or coastal strip in terms of architecture and geography. This is a semi-desert strip where along the coast villages have been established by small farmers, horsemen and fishermen. The areas are fertile, which allows for irrigation along the valleys. Reed is the traditional building material for such villages. To create the compound walls or finish the interiors, mud is mixed with reed, as it acts as an insulating agent (Saleh, 1998).

There are mostly small villages in the region except for a few cities. At times, there are only be five to six houses spread along a valley or on a hill slope. The Asir region has a terrace cultivation which is quite eye-catching and this is considered an outstanding feature of the highlands. The communities of local farmers have placed stone walls upon the fertile soil since it is scarce, and this extends up to the mountain slopes. Hence, arable terraces are formed that rise above another. The eastern part of Asir and the highlands' vernacular building are divided into three zones (Figure 14).

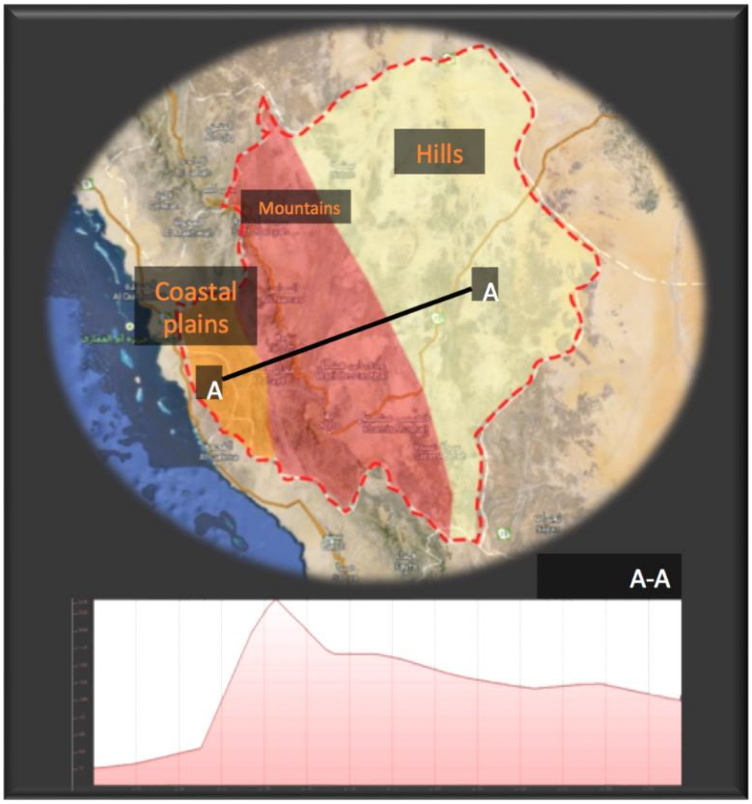


Figure 14. Section A-A, different vernacular architecture in Asir

The stone villages were formed in a defensive and tight manner, since the mountains are steep with rock-strewn slopes and the rainfall can be quite heavy. For the free village groups, the construction was done using mud-slate, which was unique. This was possible because the central plateau had light rainfall and the terrain was levelled. Plain mud houses are present in the Asir eastern plain; they defended themselves through independent fort-like dwellings and did not use the settlement grouping approach. The strategic location of settlements and indigenous architecture in Asir were created because of the foreign invasions that have occurred along with inter-tribal hostilities in the past.

The farming communities were quite self-sufficient in terms of the nature of the population's activities. There was also poor transportation available. Hence, the region entirely depended upon local building materials.

Analysis of the construction methods and the building forms indicates that the coastal strip, Tihama, had a strong connection with eastern Africa and the uplands and eastern Asir plains were connected to Yemen (Galea, 1987).

Using the following techniques and characteristics, Asir's eastern plain and highland traditional houses were formed, keeping in mind the local community, cultural, political and climatic needs.

Settlement pattern:

Dwellings were independent and fort-like and the houses were grouped as tight and defensive against potential threats (Figure 15).

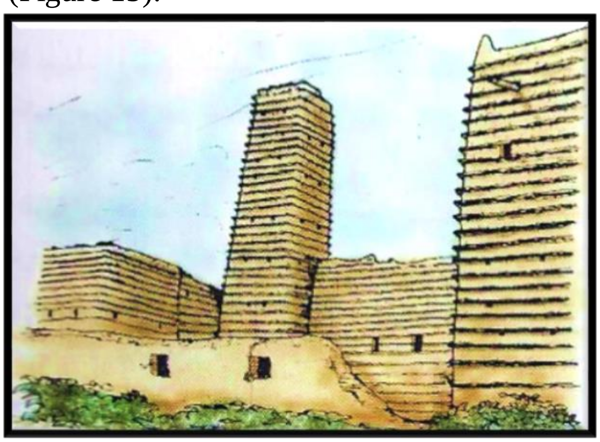


Figure 15. Asiri urban fabric

House Design and Construction:

Design

- A fine tower-like structure having a square plan with 3 to 5 stories.
- The people live in the upper floors and the lower floors are for farming tools, storage and keeping animals, respectively.
- To resolve the issue of rain erosion, projecting slate slabs are placed in a horizontal position at an angle between the mud courses.
- For maximum security, a defensive character is maintained by including only a few small windows at ground level.

Construction

- Stone or cob (midmakh) or both used for the building of thick load-bearing walls (Figure 16).
- Using a stable and wide base, the walls are built moving towards the top.
- Wood framed floors and a roof made of mud.
- The staircase is supported through the inclusion of a vertically mounted structure through the floors (Ragette, 2012).

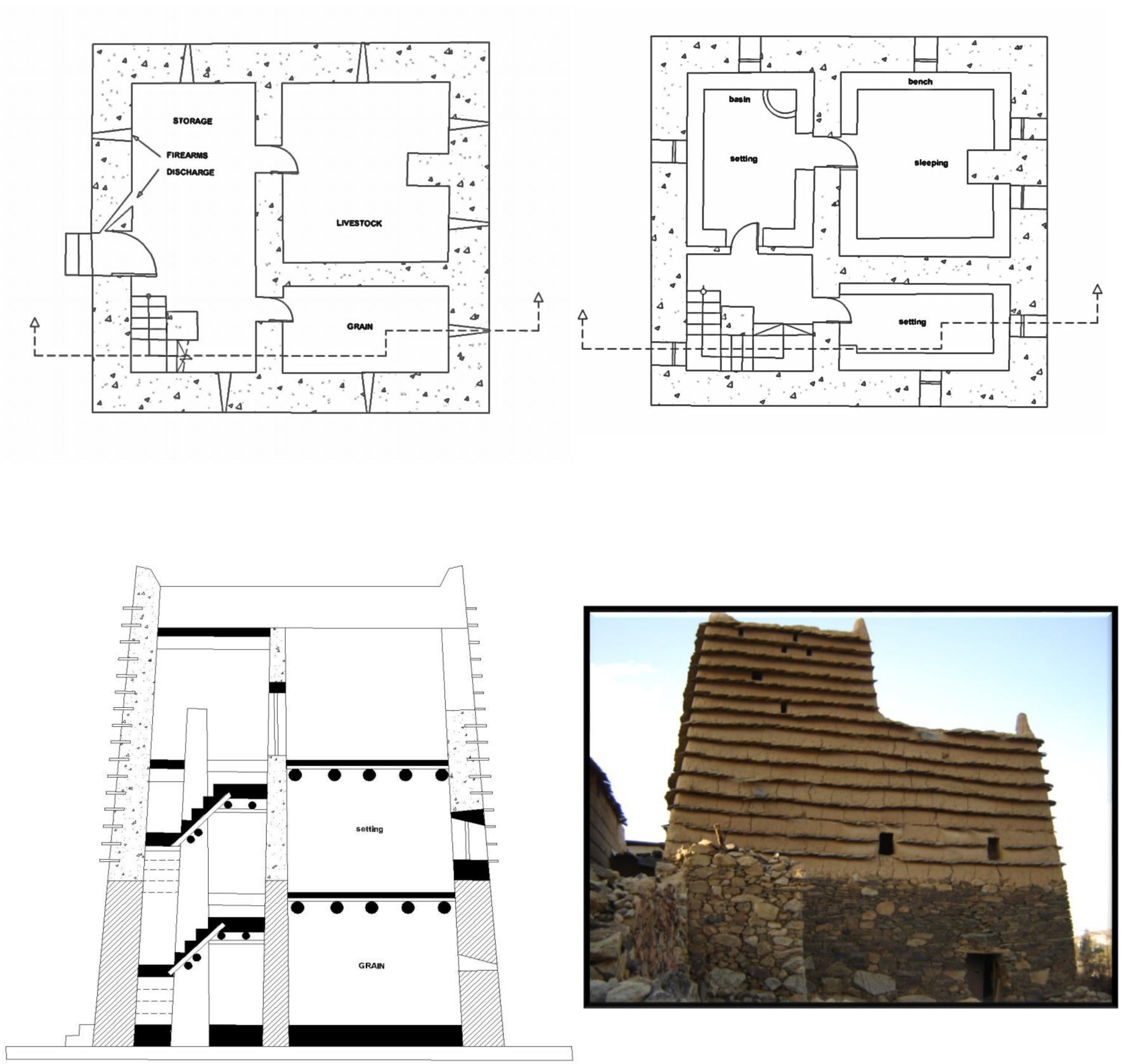


Figure 16. **Model of a Asiri cob house (Sahaaheri}**

2.3 Review of Construction Systems of Saudi Arabia

The objective of this research is to analyse and present the traditional architecture of Saudi Arabia that is disappearing from the state in the current period. The regional earthen construction techniques being used when houses were constructed are kept in mind specifically. In the 1970s, the country experienced an oil boom and since then there has been hardly any use of the vernacular building and techniques. Owners have abandoned old buildings for new, updated and modern ones. They have made sure that the fragile buildings have been destroyed using bulldozers to provide wide roads and more space for the development of flat-roofed international villas and high-rise towers. Throughout the period, demolition of interesting and old architecture has been occurring in Saudi Arabia. The citizens apparently do not appreciate the presence of these traditional and heritage buildings (Zami, 2014).

The growing interest towards a modern look for the nation compelled people to remove all traditional earthen buildings. Those present in the middle of the big cities were focused on significantly in this regard. The use of traditional techniques and building materials is also prohibited. Many of these traditional buildings had already been abandoned and were quite damaged before being demolished. Therefore, the indigenous earthen buildings have been wiped out rapidly, even though they represent the identity and dignity of the nation at large.

The builders and craftsmen of the modern world are quite knowledgeable and have the distinct expertise to establish modern architecture based on local needs. However, the traditional materials or techniques have no longer remained in use. The invaluable heritage of the people of Saudi Arabia is dying and the knowledge which has been developed over so many years that specifically catered to local needs using local resources is not being used.

There are various forms of traditional earthen buildings of Saudi Arabia. The regional and cultural characteristics of the builders have also been included in these buildings. These earth buildings have been formed to manage the diversity of the climate, ranging from the northern Hail to south Najran and east Al-Hafuf to the west in Khiber. A local character is maintained for the earth buildings, which is not the case for modern industrial materials. The earth provides maximum thermal comfort and natural regulation of indoor/outdoor temperatures. Hence, it is possible to avoid the over-heating and heat loss issue of materials such as concrete. Architecture designers must appreciate the earthen Saudi Arabian buildings since they make use of materials and ideas that have produced a rich heritage. Greek architect, Constantine Dioxides, suggested that trained designers have provided input into only 4% of the buildings in the world. However, for the rest of the 96% buildings, little is known regarding their non-pedigree nature. They do not make use of vernacular, anonymous or spontaneous architecture (Agarwal, 2001).

In the past few decades, traditional building materials and other crafts which contributed towards traditional architecture have not been used. Modernization has developed rapidly, which is why the traditional builders are no longer teaching their children or others their job secrets. People are more inclined towards modern techniques and developments. During an interview conducted by the researcher, a builder stated that their skills were mainly acquired from adults or their seniors whom have acquired them through training over the years. For instance, Mr. Al-Sadai, Mohammed. stated that it is a family tradition to use cob during building in Najran and this has been done for the past 300 years or more by his forefathers. His family also constructed with the Bani Harith Tribe, however, for a while they became famous for the mud skyscrapers in Al-Sadai in the city Sada in north Yemen.

The income of families in the modern world today has become quite high. Children are sent to public schools where they spend most of their day, and the rest of the day they are busy studying. Hence, the transfer of expertise and knowledge from one generation to another does not take place any more. It has also been observed that the master builders of olden times are employed in positions which do not extract their complete potential. These jobs may be to serve coffee or tea to the younger generations who have better education, or to be security guards in schools and offices.

In the present research, the aim is to recognize the importance of losing this expertise and how the modern processes in the last decades for progress and necessity have destroyed the heritage of the nation. With an increase in construction, concrete has replaced stone, cob and adobe load-bearing walls. General construction techniques have also replaced the craftsmanship which allowed each region to have its own sense. Engineers and architects of the modern world must realize the local traditions and conditions and not remain unfamiliar with them. The building traditions which may still be relevant in the modern world should be included. Moreover, they must consider the vernacular forms, techniques and materials to manage the rapid changes taking place in the nation. In 2013, a field survey was conducted as part of the research to understand the country's building heritage. The objective of this research was to extract information on the major builders and traditional construction techniques of various regions; however, it was not possible for this research to be sufficient or comprehensive enough. It must be considered a beginning to help start a discussion rather than ending one.

2.3.1 Field Survey in Saudi Arabia 2013

The oldest department in King Abdul Al-Aziz University is its architecture department. It holds significant heritage value, which is why it attracts students from over the world. The researcher was able to conduct various discussions with the colleagues and students of this department, since he was a student as well as a teaching assistant during 2007-2008 in KSA. The field survey was facilitated through a general idea of the government's informative publications and the published works on the traditional architecture, although these were of a dispersed, scare and fragmentary character.

2.3.2 Definition of Geographical Region

Saudi Arabia is a vast nation which has been divided into six regions on the political map: the Central, Western, South-western, Eastern, Northern regions and the Empty Quarter or Al-Rub Al-Khali desert, which is in the southern part. The desert serves as barrier between the country and the neighbouring nations in the south, Oman and Yemen.

In this research, various regions were observed to understand their local characteristics in terms of earthen buildings. This also indicated the traditional building techniques and how they have evolved with time. The local context and its influence upon the earthen construction techniques were assessed. Furthermore, the final shape of the building by making use of the local building resources and the use of earth material in a distinct manner within each region is presented.

The geographical boundaries of the Najd are clear on the southern, eastern and western ends; however, it fades in an unclear manner towards the north. The northern boundary of Najd cannot be defined appropriately. Marco Albini indicates that certain scholars such as Grohmann have discussed this matter. The northern border of Najd is not precise in a geographical sense but through the efforts carried out by late King Abdul-Aziz Ibn Saud, the Saudi Arabian northern territories included the Imamate of Najd (Albini, 1990). At present, the northern Al-Jawf oasis is at times regarded as part of the Najd district even though at one point it was referred to as the Al-Nufud sand-sea south area.

The Al-Rub Al-Khali desert has not retained any communities, which is why it will not be included as part of the discussion. Al-Hejaz and Al-Hasa will also be excluded. Najd and Asir are the two geographical regions which are focused upon.

2.3.3 Selection of Settlements and Builders

Cities or towns that were quite old and retained a major population were chosen for the purpose of the research. Through this selection, the traditional master builders' knowledge and expertise which is fading can be recovered to an extent and this information can be documented. The area's remaining vernacular earthen architecture was analysed for essential characteristics and special attention was given to the methods and materials used for construction by the earlier generations.

Local museums and municipalities were approached to attain the names and addresses of master builders. The researcher is thankful to the officials, engineers and architects for their support. It was through their cooperation, assistance, guidance, responsiveness, hospitality and courteousness that such an extensive study was made possible.

2.3.4 The Interviews

A questionnaire could not be distributed amongst most of the master local builders since they were illiterate.

The interviews conducted with the first few builders were quite successful and showed that it was the best method to extract information. The building traditions of the locality could be written down while the builder spoke. The conversation was initiated from site preparation and continued until the building was finished. Such conversations proved vital in attaining the expertise and knowledge of these master builders. At the end of the interview, aspects which were not addressed earlier or required elaboration were inquired about.

During the interviews, it was observed that when the builders spoke about their skills and traditions they became quite excited. The traditional houses and its construction processes were analysed and it seemed to be quite interesting. In the beginning, the owner and the builder only had a verbal agreement and after the construction was complete a ceremony was also held by the owner. During this ceremony, a lamb was slaughtered, a scrumptious meal was offered to the master builder, neighbours and relatives.

There were two parts to the interview. The questions included in the first part of the questionnaire were designed to extract personal information like age, place, of birth, occupation, name, etc. In the second part, crucial questions were included which helped extract information regarding the area’s building traditions. The following points were included:

1. The basic building material types and sources
2. For the construction of traditional building materials, the tools used for making, cutting and shaping buildings and putting them in place
3. The size, dimensions and elements of the structure, which include roofs, floors, columns, walls and foundations
4. Traditional house building and the construction method used
5. Other trades and crafts related to vernacular building construction
6. Finishing and decorative elements of traditional earthen buildings that help develop a variety of features

2.3.5 Building Survey Visits

Various visits were conducted to the buildings, some accompanied by the architect and master builder of the area and some made alone to the ruins of the older settlements. To attain a complete and comprehensive picture of the entire research, a photographic survey was carried out during the visits. This helped gain knowledge regarding the construction and building materials that were used by the earlier generations. The causes of deterioration were also assessed through a visual inspection specifically for the mud buildings by taking earth products and soil samples. After thorough research, two distinct construction systems came forward. This analysis is discussed later.

2.4 Summary

Considering the traditional architecture of Saudi Arabia, it can be stated that the culture includes the interactions of the people with the environment. When the country became rich in oil and owing to its present developments, it completely ignored the traditional architecture. Modern methods, techniques and developments have been adopted.

A regional survey has been included in the research where two major regions from Saudi Arabia have emerged. These are the Asir and Najd regions. All regions have their own methods and techniques for using earth materials.

The cultural values and economics of the people within different regions are mostly similar. The distinct architectural languages are mainly due to the different climatic conditions and the local availability of building materials. The local communities and their degree of isolation is the main characteristic behind the origin of local architectural language. The distinct character of the region is based on the architectural styles that were developed upon the functionality, richness, simplicity and availability of local resources. In the next section, a detailed analysis of the construction methods used to develop these styles will be made.

CHAPTER THREE

EARTH CONSTRUCTION AND HISTORY

Valley (also referred as Wadi in the Arabic) clay, straw and water are mixed together and left. Over a large area, straw is spread out and the mixture is poured into a wooden mould. The mould is removed afterwards and this process is repeated nearly a hundred times in a vertical manner. It must be thoroughly dried and for this purpose it is left in the sun (Al-Junaid, 2014).

This recipe is easier than baking bread. The only cooker needed is the sun. There exists a domestic analogy which states that the Najd households must be able to perform the task. Najd is the traditional name used to refer to central Arabia. It is also expected that the entire process is a team effort where all neighbours work together to build a community. One of these neighbours is expected to possess unique skills which may be of woodwork, carving formal patterns using gypsum, plastering or then making the use of the appropriate mud mix (Costa, 1994). The help is provided for free as it is assumed that this favour will be returned at some point in time. Hasan Fathy, an Egyptian architect, stated that a house is built under communal production and it is not the job of a single individual. However, a hundred men can build hundred houses easily (Fathy, 1973). The builders must have some local knowledge to attain materials that are easily available from the valley bed gardens. Adhesive clay is present in the alluvial deposits of the Central Arabia valleys. If the appropriate amount of sand and silt is included, it is possible to attain shape and compression strength. Furthermore, cracking will not occur when it dries (Figure 17).

Figure 17. Valley Hanifa in Riyadh (ada.gov.sa, n.d.)

The unbaked earth material was considered as the ideal material since it could be used by the people and was traditionally available without cost. Specialist suppliers or architects would not be required to build a house. These building materials are considered as the easiest to use and most flexible of all. At one point in time, some life essentials came for free and could be used by the community at large; however, it is now paid for in the modern world. Earth building has been able to refrain from ownership since it has not been demanded by the community as a commodity.

Therefore, there is availability in such large quantities that the source of supply does not need to be controlled. Nearly three-quarters of the land on Earth is formed of adhesive soils and clays which are useful for building and construction. If this material is not available on an individual's land, it is quite possible that it will be present in the valley bed, where it can be used by all individuals.

3.1 History of Earth Building

Unbaked earth consists of wood and rough stone and these are mankind's oldest building materials. Sun-dried mud has been used for shelter since people have settled. A monolithic wall is formed using moist soil which is then left to dry, or the soil may be used to establish independent units like blocks and bricks. These bricks or blocks would be dried before being used to form the wall (Mosaibah, 2013).

In various parts of the world, earth-building techniques have developed in an independent manner. As people moved, the techniques became widespread. People in the early days were always moving around for hunting and gathering on patterns based on their surroundings. Natural features like caves were known to be the earliest shelters, followed by the earth buildings which became the extensions of natural features. For instance, at the cave entrance there would be mounds of earth or pits that would be dug into the ground (Bucci and Mollo, 2010).

The first permanent settlers were observed after there was development in settled agriculture. They could spend more time as well as effort on construction. In fertile river valleys, agricultural development started to take place, and this was where the clays and silt were also available that proved to be the best building materials in the case of earth construction (Al-Junaid, 2013). Wattle and daub was the first earthen building technique that was developed. In this process, the roof or façade is built using grasses or timber followed by a covering of earth (CRAterre, 2008). The rammed earth type technique was developed later, where the walls were made of timber and earth is placed between these walls. This helped form a thick wall which was compacted in its place. Later on, unit construction could be developed followed by units of cuboid blocks. These were constructed using frameworks. The materials could be separated from the building location since they could be transported after drying. For instance, a river valley which could be subjected to flooding may have earth that could be used for building construction at a higher level. This earth could now be transported. During the main cradle of civilization, earth building and agriculture construction developed in an independent manner (Facey, 1997).

The people started to gather together in towns after the agriculture system developed closer to the main rivers. The fertile river valley civilizations were able to provide the appropriate soil for construction purposes. Evidence suggests that earth building developed independently around the Yellow, Murghab, Jordan, Indus, Nile, Tigris and Euphrates rivers. Even though the towns had different cultures, their earth-building techniques were quite similar. Techniques improved and became refined as civilization and trade progressed. Earth-building techniques are impossible to chart since they vary across settlements as well as years. However, some patterns can be extracted. Near 5000BC, the transition from hand-moulded to cuboid blocks took place in Mesopotamia. Also, the Europeans introduced rammed earth to South America, where it was not present earlier (Mchenny, 1984).

People domesticated animals and plants to become farmers and this is when they actually settled permanently according to archaeologists. Considering this level of human affairs, this era may be referred to as the ‘Neolithic Revolution’, whose origins are in the Middle East. It took place nearly 10,000 years ago and can be specifically found in the Fertile Crescent, Iran and Turkey. When settlement started to take place, towns and villages started to develop, followed by cities. These areas contained specialists of crafts and trade which allowed for development. Hence, the concept of civilization emerged (Diamond, 2002).

In each continent over the world, human beings built their first houses using raw earth, which included crude huts and complex settlements. Unbaked earth was used for Neolithic towns like Catal Huyuk in Turkey and Jericho in Palestine, the 5,000 year old Dynastic cities and villages of ancient Egypt, great Bronze Age cities like Mohenjo-Daro and Harappa in Pakistan, Babylon in Iraq and Chan-Chan in Peru, and lastly religious monuments like the Iraqi ziggurats, Egyptian pyramids and other funerary monuments. Moreover, the core of the Great Wall of China is earthen: it is mostly made of unbaked earth and a few sections have been diced with stone to establish length (Oliver, 1997).

3.1.1 History of Saudi Arabia Earth Building

North of Riyadh city centre, only 15 kilometres away from it, ad-Dir'iyah is situated with its deep city walls and adobe houses. It is considered as a historic section of the great ancient valley. Further upstream, less than one kilometre towards the north, are the pinnacles and crumbling walls of al-Turaif. This is the old chief ad-Dir'iyah settlement and the old Saudi Arabian capital. There exists a strong sense of grandeur within its monumental parts and ruins. This life seems to be long gone and replaced with a modern city. The old and new Saudi Arabia can be clearly observed through ad-Dir'iyah: the traditional life of Saudi Arabia has been subjected to rapid transition and now the twentieth century seems different and advanced (Al-Saoud, 2011).

According to old and young Saudis, the tumble of stone and mud ruins is not only the fate of ad-Dir'iyah. It is referred to as the first Saudi state capital from 1745 to 1818. It stands as a symbol of nationhood as well as of the region where Islam was reformed. In the eighteenth century, it was this area from where the Saudis spread through Najd and later the Peninsula (Mcloughlin, 1993).

The historic importance of Valley Hanifah or Wadi Hanifah has been observed long before it was where Islam actually began. Usually, western people believe that Saudi Arabia was taken over by the nomadic Bedouin tribes. It is essential to realize that the nomads were never really in the majority and the major settlements have been taking place in the Kingdom for centuries. The

Arabians were usually settled cultivators with a few caravans and merchants who are now the major businessmen in the modern world.

Rule and order was maintained by an authority which was recognized by the majority. For settlements there were competing groups or a tribal warrior aristocracy. During the Neolithic period, the first settlement was observed and 5,000 years ago on the Gulf coast during Sumerian times the first urban centre was witnessed. The evolution of the date palm oases and desert camel herders took place 3,000 and 5,000 years ago. Since the beginning, the camel-herding tribes were dependent on settlements. Until recently, the tribes would include nomadic and settled sections with an exchange in the way of life of the individuals (Oliver, 1997).

Around the world, local knowledge of materials and building forms has evolved over hundreds of years or more. This is specifically the case for arid lands. Mud has been used for rural houses as well as grand architectural buildings for either religion or the display of power. Keeping in mind all materials, mud is the universal material that is used, and it is always available; however, its use has declined to a large extent. In the modern world, the influential visionaries include the French Industrial Revolution architect Francois Cointeraux, First World War architect Clough Williams-Ellis in Britain and the present-day Hasan Fathy. In early times, baked brick was used and now in the modern world the earth architecture has been replaced by steel, glass and concrete. Only poor or rural communities are using this earth building. Hadhramaut suggests that even though consists of nearly one-third of the population of Yemen, it is still considered as a backward region. Earth construction is considered as the last resort material and preference is given to shantytown packing cases and corrugated iron (Oliver, 1997).

Earth buildings and their techniques for development have lost their importance. These low-cost and simple techniques can be used to attain vast advantages. This aspect has been observed by Fathy, which is why he is involved in promoting the use of earth building in poverty-ridden areas as well as arid lands where house building is inefficient.

The arid zones present in the world have rural poor populations and this technique may prove to be useful. However, developed nations like Saudi Arabia that can afford the updated technologies would not make use of this out-dated technique (Fathy, 1973).

In a short period of time, Saudi Arabia has advanced a long way. Between 1902 and 1926, Abdul-Aziz bin Abdul-Rahman Al-Saud, known in the west as Ibn Saud, carried out various campaigns from Riyadh. The oil discoveries took place in the 1930s and the formal declaration of the Kingdom of Saudi Arabia took place in 1932.

Since the oil price rise and the Second World War, the progress of Saudi Arabia has advanced rapidly, something that has only happened for a few Gulf States (Figure 18)

Figure 18. King Abdul-Aziz (info.gov.sa, n.d)

Throughout the 1950s, the development of Riyadh experienced rapid growth since there were post-war revenues from oil. The expansion can be observed from Abdu al-Aziz's reign, which was the pre-war period. In the early 1920s, modernization was experienced when the wireless telegraphy and first motor vehicles were introduced. Riyadh city was limited by mud walls that enclosed the city for just a kilometre, but now it was expanding outside these walls. Through this expansion, the population grew and by 1936, the King stated that a new palace would be built in the north of the old city for the seat of government. Mud plaster and adobe were used in the walled complex, which was quite vast and known as Qasr Al-Murabba (Murabba Palace) (Figure 19). It was completed in 1938 and was considered an example of modern architecture that made use of mud plaster in the most efficient manner. The builders also stated this as they had built it with elegance and a vision. Since the glorious days of ad-Dir'iyah in the late eighteenth and early nineteenth centuries, such a building had not been observed in Najdi constructions. The Najdi architecture also considered it the swansong. The old building methods were downgraded to the developing nations or the countryside when the railway arrived in 1951 and the Second World War ended. Since this time, the earth architecture tradition has been considered a backward process (Mcloughlin, 1993).

Figure 19. Al-Murabba Palace (Al-Aidarous,2013)

Since the 1970s oil price rise, a transformation has taken place in Saudi Arabia. There has been a complete change from the past in terms of materials. Formal meals, the dress code and other aspects of art such as dancing and music are the only aspects which still remain; the rest have all been changed (Greene and Heidrich, 1986). The old way of life was difficult and a change was

Required, but it must be considered that if the older aspects were useful then they should not be made entirely obsolete.

Some cases, like family values and relationships, have survived the modernization process. The past has proved to be an anchor in this case. The Saudis consider this as a source of strength and pride, which is why they continue with these traditions. They consider hospitality, family sanctity, personal piety and their private lives, strengthened and managed with pride, as most important of all. These social welfare policies are implicitly based on the consideration that they are performed under Islamic obligations.

The old architecture has been rejected and there are various reasons for this. The Saudis believe that the construction in the past was done this way due to poverty, but now with all the wealth they are able to adopt the modern transition. Family values, religion and dress have no relation to this change. The modern generation has adopted materialism and the pleasure received is so great that they do not realize what may have been lost along the way. The architectural style was lost with the loss of the adobe. They did not consider experimenting with mud buildings to examine how these buildings could be modernized. The old style was also ignored and new materials were adopted. The Najdi houses were rebuilt to understanding the limitations and potentials related to the vernacular building tradition of Najd using traditional materials and architectural style.

3.2 Mud Construction in Saudi Arabia

Distinct variations are present for the various earth construction techniques. These variations are recognized all over the world and around 12 main construction techniques have brought forward (Houben et Guillaud, 1987, 1994). Three groups have been formed: load-bearing, masonry and monolithic structures. Five earth techniques are present within the monolithic group: rammed earth, direct shaping, dugout, poured earth and stacked earth. The masonry group consists of hand shaped adobe, mechanically moulded adobe, extruded earth, hand-moulded adobe, tamped blocks, pressed blocks, cut blocks and sod. Lastly, the load-bearing structure group includes earth sheltered space, fill-in, cob on posts, straw clay and daubed earth.

The state of the earth's hydration is the main difference between the three groups. For instance, dry or damp soil is required for monolithic construction, semi-solid paste or plastic soil is needed for masonry construction and lastly the combination of semi-soft paste and mud is needed for the load-bearing structure group. The soil variation is the reason behind the different raw earth applications and the different earth construction techniques. If cohesion is present, earth may be used as the only material. A balance must be maintained between the grain size fraction and soil components such as gravel, rock plus water, silt, clay, sand and others (Correia and Fernandes, 2006).

The balanced humidity condition is also an essential factor which affects the earthen material. The material will turn into powder if extremely dry conditions are present. If there is humidity, water can be added to the material and it can be turned into liquid. However, this would lose the cohesion level. Wattle, daub, cob, adobe, CEB and rammed earth are the widely used techniques in the modern world (Aslam, n, d).

In a climate which is desert-like, the houses are built using rammed earth, which is a compressed mixture of earth and aggregates, pressed between frameworks along with Compressed Earth Blocks (CEB) or adobe. Dry or humid soil is required for these techniques. Plastic soil materials are used for the sun-dried bricks or adobe construction. The earth would be used with wattle and daub, a structure of wood with earthen fill-in or cob, a mixture of earth with straw, or piled up to form walls, if the soil is soft (Correia and Fernandes, 2006). In the present research, the most appropriate conservation technique for cob and adobe materials was extracted since these are commonly used for Saudi Arabia earthen construction.

It has been observed that in the previous system, mud was used extensively for plastering or binding. This is considered an addition to the roof and floor construction, as this is the primary use of mud. In various part of Saudi Arabia like the north-west, the Najd, and the central and eastern parts of Asir North, these traditional systems have been used vastly (Akbarj, 1992).

Within the region, the main mud construction techniques are adobe, sun-dried block and cob, called Midmakh in Arabic. Until the last three or four decades, these were used widely (Al-Jawhari, 1996).

The present research focuses upon the use of earth as the building material. Hence, the two main techniques of mud construction, specifically adobe construction will be discussed in detail.

3.2.1 Adobe Construction

A. Origin and Importance

In the recent past, the common method used of construction in Najd, Saudi Arabia was the mud brick or adobe construction along with local variations. It is strongly related to the Arab culture which is why the Spanish word 'adobe' has been changed to the Arabic word 'Altob',(الطوب) meaning brick. From Spanish it passed through Arabic to North Africa then was converted to English for the southern United States and Mexico (Facey, 1997) (Figures 20, 21)

Figure 21. Compressed earth blocks in ad-Dir'iyah

Figure 20. Adobe material

In Najd, the courtyard houses were built using the adobe system. Internal micro-climatic conditions were established through these thick walled courtyard houses that give privacy, protection from sun, sandstorms and noise and security to the people. The United Nations housing expert, Hassan Fathy, who worked in Saudi Arabia, stated that in the Mediterranean basin and other arid regions, the courtyard system works as a socialization space as well as a thermal regulator. There is a broad use of local timber, stone and adobe bricks, as the flat roof structures are supported well. Hence, the natural environment resources and systems have been incorporated within the traditional construction.

B. Contract

Construction of the central Arabia adobe courtyard house was initiated after a verbal agreement takes place between the master builder and the owner. This master builder is the contractor, consultant, engineer and architect all at the same time. This agreement was not written and the rate of money was agreed upon beforehand, considering the payment to be made on a weekly or daily basis to cover the expenses and profit of the builder (Al-Saedi, 2013).

The owner at time would provide the material for the construction since he was carrying out the work on the construction of his own house or for neighbours or relatives.

C. Design

Prior to the commencement of the excavation for foundation, different rooms and spaces were marked on the ground using the builder’s foot or with the help of gypsum powder. The precision of various dimensions involved in the construction process was determined by the builders with the help of a small stick. This stick measures 50 cm in length, which is approximately the length spanning from the end of the fingers to the elbow. A stick typically belonging to a palm tree frond with all of the leaves was used for longer distances.

If large rooms could not be covered using the wooden beams available, the location of extra columns was additionally identified by the builder.

3.2.2 Limestone

There was an abundance of limestone in the Najd region because of geological conditions, and this was used in the construction process, particularly for foundations and columns. This limestone has natural fragmentation, in addition to well-defined layering of the stone which permits comparatively simple removal and moulding of the building material with the help of simple instruments.

There was extensive use of stone in Najdi buildings to create a foundation, at times rising a little over the ground. The stone courses served as a barrier to the elevating damp from the irrigated soil of the oasis and the frequently high water table inside towns. This was not unsurprising, since the salt-rich groundwater escalates into the mud and brings about significant damage to the base of adobe walls. Mud plaster covered these courses, like the mud-bring arrangement, which made them obscure most of the time. There was a lower degree of solid construction in the internal walls, which were normally constructed on the ground or an adobe base (Al-Ashiry, 1980).

Figure 22. Limestone foundation (Al-Aidarous,2013)

3.2.3 Tamarisk Trees

A significant source of timber is the tamarisk tree or athel. This typically grows in twiggy clumps, frequently up to a height of 3.6m. The wood was frequently employed in the past to construct wooden bowls and other utensils. In addition, because of its hard-grained nature, it is a vital material for construction purposes (Al-Jaded, 1994).

Athel trunks were utilized in the form of beams, door, lintels and window panels and frames, and also in the form of down-spouts. The main door frames were also constructed of tree trunks with a palm-tree in-fill panelling. Tamarisk tree was also used to make locks and keys.

Athel trees were normally cut during the winter season, when the sap was in the roots. Trunks were dragged to the building sites where the bark was occasionally detached and the timber was divided into pieces (Al-Jaded, 1994) (Figure 23).

Figure 23 Tamarisk trees (Al-Aidarous,2013)

3.2.4 Gypsum

Gypsum rocks were available extensively and were used in a kiln and fired with wood for some days, leading to the production of gypsum. Gypsum was considered a conventional material for building in the Najd area. It was occasionally created at the building site by following a similar technique. Here, the gypsum rocks were organized in a square shape on a pit which was dug in the ground and packed with wooden branches. The timber was burned for some days and after the fuel had been used up entirely and the material had cooled down, the processed material was crushed, sifted and kept in sacks (Figure 24) (Al-Ashiry, 1980).

Figure 24. Gypsum decoration in ad-Dir'iyah (Scth.gov.sa, 2010)

3.3 The Construction Process

The clays and sands of the region are especially suitable for producing adobe bricks and plaster. Adobe blocks, obtained from suppliers or created on site with the help of soil excavated from trenches, were utilized to create the foundations as well as limestone. Limestone was used for building foundations particularly beneath columns (Facey, 1997).

3.3.1 Excavation of Foundations and Making the Adobe Blocks

A continuous trench with a width of 80 to 90 cm and depth of 50 to 120 cm was excavated at the start of the construction work. These dimensions were dependent on the kind of soil and expertise of the master builders. A rectangular wooden framework was used to produce adobe blocks (known as Milban in Arabic), which was put on the level ground and filled with wet mud to generate adobe blocks that were dried in the sun prior to use (Figure 25) (Price, 1996).

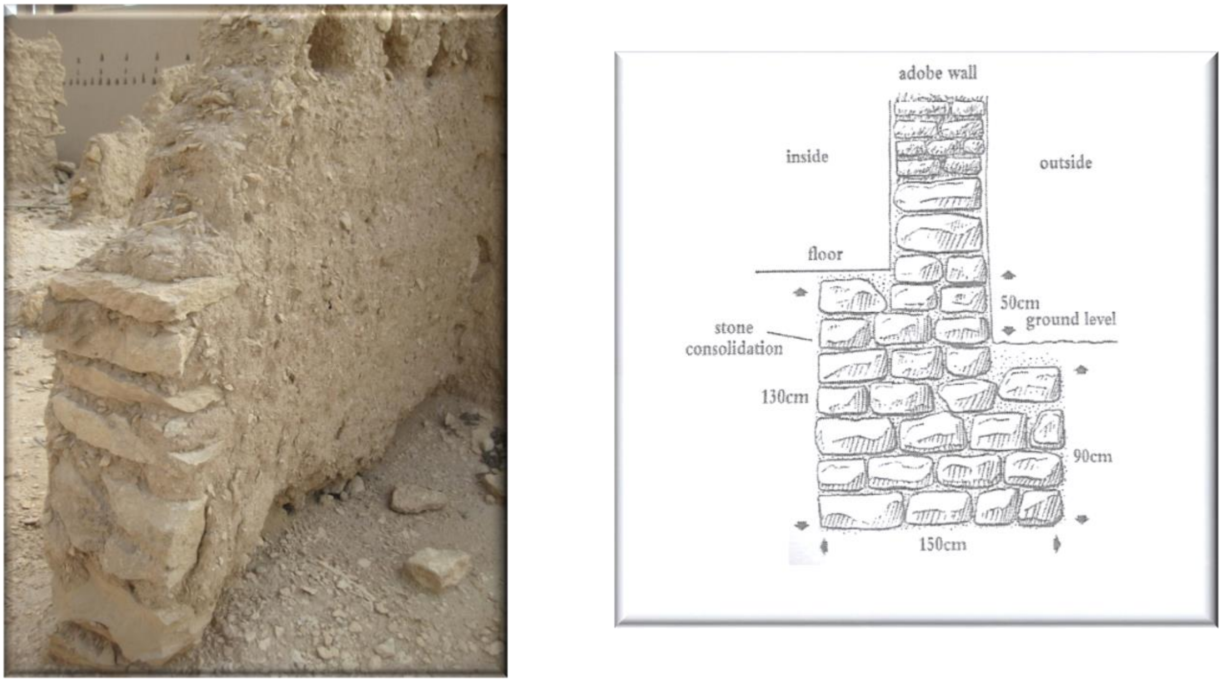


Figure 25. Limestone foundations (Al-Aidarous,2013)

3.3.2 Block Laying

The magnitude of the job and the speed of the builders determined the number of helpers employed by the master builder; however, two to seven workers were usually employed in the team. The helpers were supposed to provide adobe blocks and mud mortar to the builder who stood on the wall and added two to three courses of blocks in a single go. These courses were then allowed to dry for one or two days before the next set of courses was positioned. The construction work could be continued by the team until the required ceiling level was attained (Mosibah, 2013).

The construction of load-bearing walls involves very wide walls, so most of the time, their construction did not involve scaffolding and the builders carried on their job safely on top of the finished portions of the wall when building the upper portions of the wall. This process was continued till all portions were built. The construction of the floors continued in a vertical manner which allowed the use of intermediate floors for the storage and handling of materials required for building the walls of the topmost levels (Mosibah, 2013).

The thickness of the adobe walls is approximately 40 to 70 cm at the ground level, and tapers to around 20 cm at the parapet. The internal surface is normally vertical, which is why the external part of the wall appears to slant. The thick adobe walls function as heat sinks in the day and as heat sources at night, and this inhibits the diurnal fluctuation of temperature and raises the comfort of the residents. It has been suggested by Kaizer Talib that there is a considerable lag (more than 8-10 hours) in thick walls of adobe with small external openings and this does not allow heat to penetrate through during the day by means of direct or reflected radiation. In colder weather, the temperature balance is maintained by the walls by taking in heat during the day, which is then gradually re-radiated during the night (Facey, 1997).

Figure 26. Block laying in ad-Dir'iyah (Al-Aidarous,2013)

3.3.3 Columns

Columns and capitals were also constructed using stone. Limestone blocks were converted into drums that were put on top of one another, bedded on mud mortar; however, they were not dowelled together (Cantacuzino, 1985). The wooden beam was carried by the stone capital which allowed the doubling of the ceiling span of the room. The colonnades were also made from columns and these encircled the courtyard. Mud or white gypsum plaster was used to cover the completed column. A building with two or more floors would have a continuous arrangement of the columns to the entire height of the top storey's beams.

Stone columns are used by the master builder and his team to build deep arcades surrounding the courtyard and also in the centre of large rooms that could not be covered by tamarisk beams. These columns were made of unevenly cut cylindrical drums covered in gypsum mortar and mounted by rectangular capitals, providing support to the central athel trunks. At one end, the athel trunks are situated on the capitals, while on the other side, they are situated with abacuses situated beneath them to spread their weight in the adobe walls holding them. (Al-Jaded, 1994).

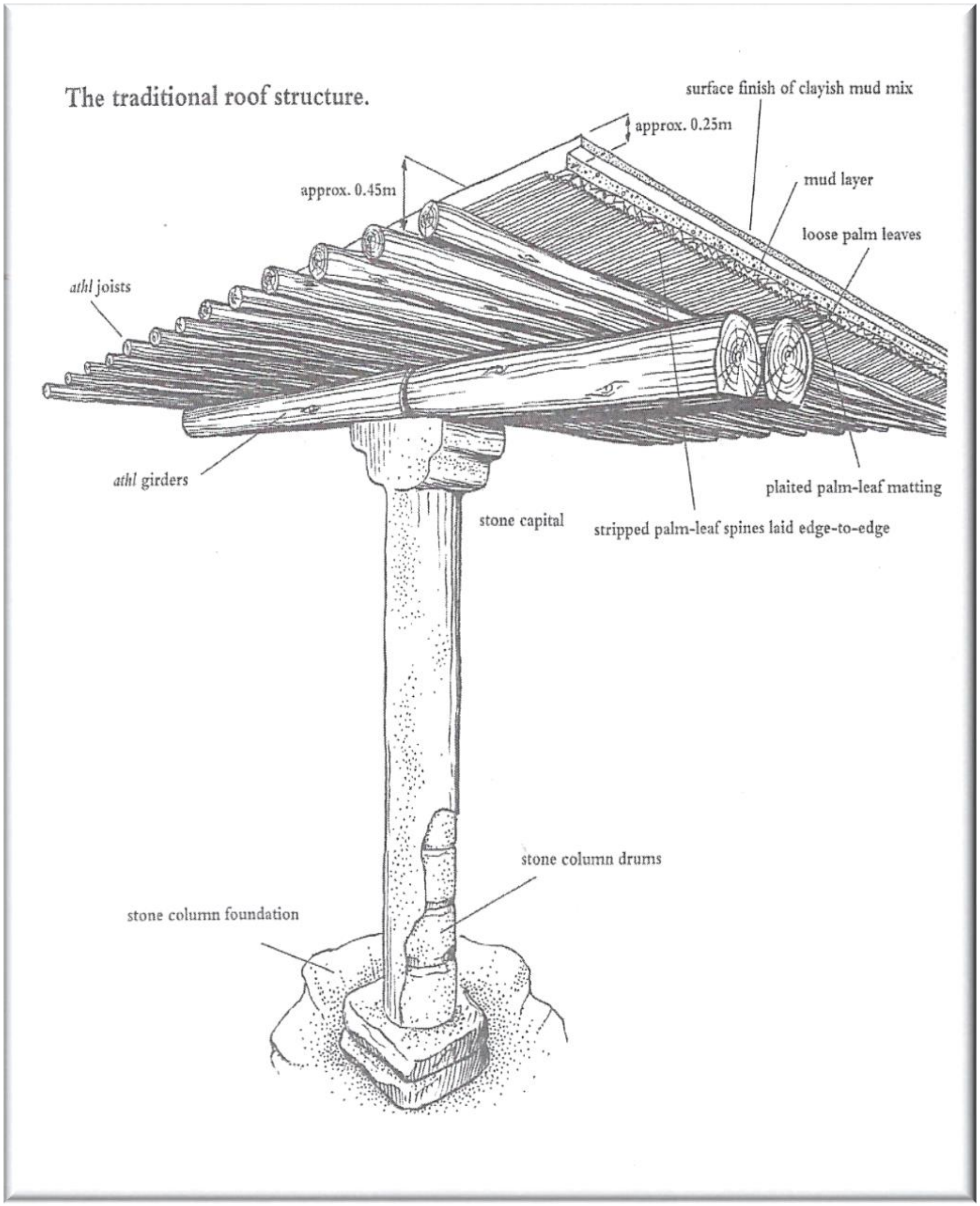


Figure 28. Traditional roof and column structure (Facey, 1997)

3.3.4 Floors and Roof

To construct ceilings and lintels, timber was employed structurally. Tamarisk was the most commonly used wood (athel); however, at times, palm trunks were also used for the primary bearer beams. Tamarisk is lightweight, durable and tensile. It does not break easily and branches and trunks grow sufficiently to be used for joists (Dethier, 1982). Joists would be placed in close proximity to each other to cover a room, or in a bigger room to cover a central column-supported beam. Typically, the largest span was no bigger than three and a half metres (Al-Saedi, 2014). Afterwards, stripped palm fronds were placed on the joists and a thick layer made of mud and rubble was placed over a scatter of loose palm leaves to create the floor on top of the roof. The same technique was used to build floors and roofs. There was an additional layer of mud on the roof, which was the sole distinction. This layer was there to provide more thickness and hence provide protection against rain and excessive heat. Athel logs were placed 15 to 20 cm away from each other and the leaves of the palm tree fronds were removed, after which they were placed on the athel logs alternatively in accordance with the shape of the frond. Palm tree leaves were then used to cover the entire framework, which was then overlaid with a mud layer. This was then levelled and smoothened with the help of clayey mortar topping (Sayigh, n.d.) (Figure 28).

Even though the roof is flat, it has certain precautions that curtail the accumulation of heat and the effect of radiation. Because of the varied heights of the spaces, which are in accordance with their functions and floor area dimensions, the roofs are at various levels. Parapets of around 60 cm height are used to encircle and separate each level on the roof, leading to the occurrence of shadows on the roof (Al-Jaded, 1994). The height of the parapet walls surrounding the roof was normally high enough to prevent invasion of privacy for the family and also for the neighbours. During the summer nights, the roofs provide an area for sleeping, while they provide an area for sunning beneath clear skies in the winters. In addition, they also facilitate the drying of dates and different agricultural crops (Figure 28) (Costa, 1994).

Down-spouts were used to manage the elimination of water. These were positioned around the perimeter of the exposed roof regions and were made of half hollowed tamarisk logs which were part of the roof construction. The sloping of the roofs was in the direction of these down-spouts, which were notched towards the outer end to throw the water far from the walls (Al-Saud, 2011).

3.3.5 Openings

The entrance door, the windows of the guest room located besides the entrance and a few small openings for ventilation close to the ceiling are the limited openings on the ground floor (see Figure 29). There are very limited external openings on the outer regions, and these are primarily situated on the topmost floors. There are several large openings in the interior portion facing towards the inner courtyard. The external doors and openings have been meticulously designed so as to ensure minimal interference with those of the neighbours. The other entrance is positioned such that there is no intentional or unintentional visual invasion into the courtyard, even when the door has been left open (Figures 10, 12) (AL-Zahrani, 2010).

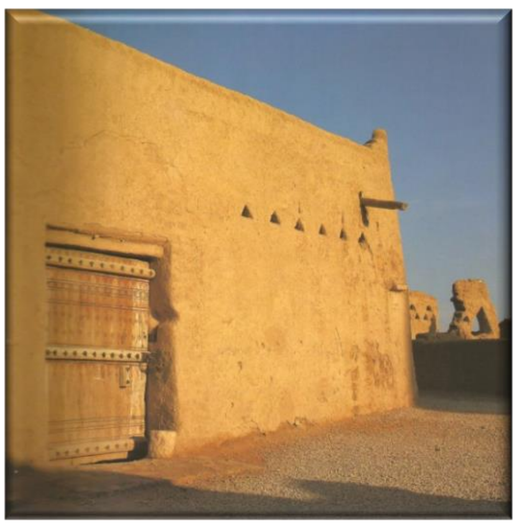


Figure 29. The small opening on the main elevation (Hyland, 1995)

At the upper parts of the exterior walls, the adobe houses of Najd depict various patterns of minor triangular openings. Since these openings were situated at a high position, hot air accumulates towards the top as the day heats up, while at night, cool ventilation air could be flushed into the room. Therefore, the microclimate of the interior spaces is regulated to a great extent by the ventilation openings. In addition, the openings allow for the management of the glare that occurs due to the exterior light's brightness, and also serve as a means of decoration and privacy (Figure 9) (AL-Zahrani, 2010).

A wall opening is constructed above the entrance, serving as a sort of window to look at the street without being noticed. It is occasionally constructed as a wooden box, or sometimes a bigger projecting bay that is given a decorative look on the wooden parts (Figure 10) (AL-Zahrani, 2010).

3.3.6 Finishes and Decoration

For a few weeks, the outer and inner walls were allowed to dry out, following which a special procedure was used to make the mud that would be used for plastering the walls. The majority of the houses had simple and similar exteriors, while the fervent decoration and adornment of the adobe houses was done inside the house. The reason for this was that very often that the poor and the rich were found to reside in the same locality. This ensured that the rich managed to provide a pleasant look to their interior portion without making the poorer neighbours feel bad (Daghostani, 2004) (Figure 30).

Figure 30. Elevation of adobe houses (Al-Junaid)

Sharaf existed in different sizes and shapes and were used on parapet walls, as well as on courtyard railings to offer an extensively pierced decorative screen on the topmost portions of the wall. In addition, it would give them additional durability to avoid erosion through rainwater (Figure 31).

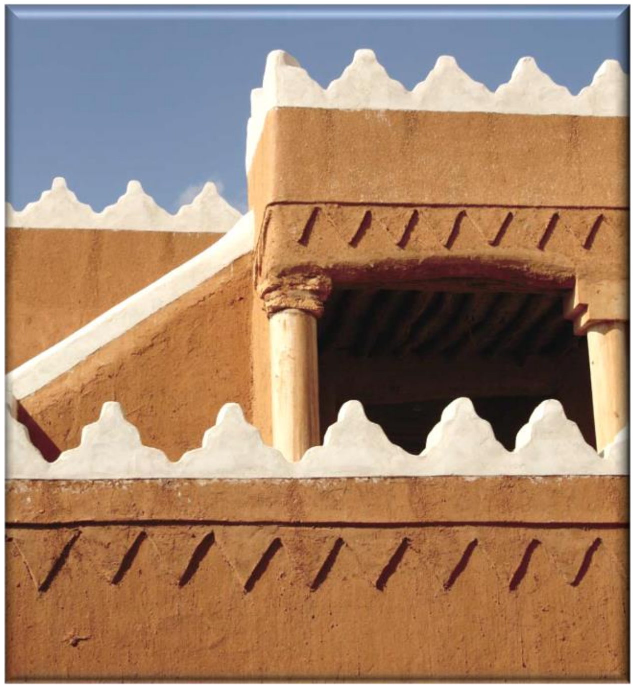


Figure 31. Decorative element for railing the roof (Hyland, 1995)

Gypsum was occasionally used for plastering adobe walls, particularly towards the lower ends of the walls, or in the form of an outlining accent surrounding the openings and wall niches that were used for holding oil lamps, or books and small things. Most of the interior decorations were carried out in the men’s reception room so as to signify the socio-economic status of the family. The builders decided the area of work after determining the complexity of the design and the capability of the workers to complete the task before the gypsum hardened. Extensive decoration was carried out in the walls of these rooms with the help of fine white gypsum plaster with incised flowers and geometric motifs. The casting of the plaster was done when it was still soft. The builder’s compass, drivers and other equipment were used to draw the incised designs in their precise location and these were then rapidly carved using a putty knife (Figure 32) (Al-Saedi, 2013).

Figure 32. Internal view (Hyland, 1995)

Geometric and stylish floral ornaments were typically used to adorn the interior doors, windows and lintels, as well as a few roof beams. Dyes or hot irons were used to burn the patterns into the timber. Dark blue, red, green and black colours were used in the design against the backdrop of light colours on bark-stripped wooden doors. This provides a powerful colour contrast.

3.4 Cob Construction

Different names are given to this system in different parts of the country. In Najd, it is known as Aroug, while in Asir it is called Midmak. There was extensive use of the cob mechanism in constructing castles and farm fences in the Najd region. However, in Hail, northern Najd and several areas of Asir such as Abha, Najran, Bishah and Al-Khurmah, it has been the main material used for construction purposes (Galea, 1987). There is similarity in the design and features of the Midmak or cob houses of northern Najd with those constructed with adobe in other parts of Najd. The sole difference is that the walls are made of mud layers instead of sun-baked blocks. Hence, as an example, consider the defensive tower like the house of Asir which is constructed on the basis of the cob system.

Figure 33. Model of Asir cob house in Najran (Murtadah)

The conventional mud house situated in Asir is considered to be one of the best examples across the globe of 'Architecture without Architects'. The traditional architecture of Asir was considered by David Wright, an architect from New Mexico in the south-western US as one of the best that he had ever seen all over the world (Al-Hussayne, n.d.).

In the cob houses of Asir, defence and security, apart from the climate and full use of local materials, are the key criteria for design and construction. It was suggested by Al-Hariri that because of the century's long history of foreign intrusions and conflicts, the Asiri population was worried about safety and security issues, following which they became skilled in building fortified structures and watchtowers, or Qasabat, to secure themselves from invaders (Al-Hariri, 1987).

Rifles and other firearms are still proudly put on display in the houses of most Asiri males, especially those from older generations. At the start of the construction of such defensive abodes, the ground plan was first established with lines of gypsum. A square plan was typically followed by these households, which have a three- to five-storey configuration. Drawings were not made on paper, as a builder typically made the design of the house, and may have discussed it verbally with the owner. In accordance with the marked plan, shallow foundations and trenches were dug and a continuous strip foundation of rubble stone that is partly made of mud mortar constructed (Al-Jaded, 1994) (Figure 34).

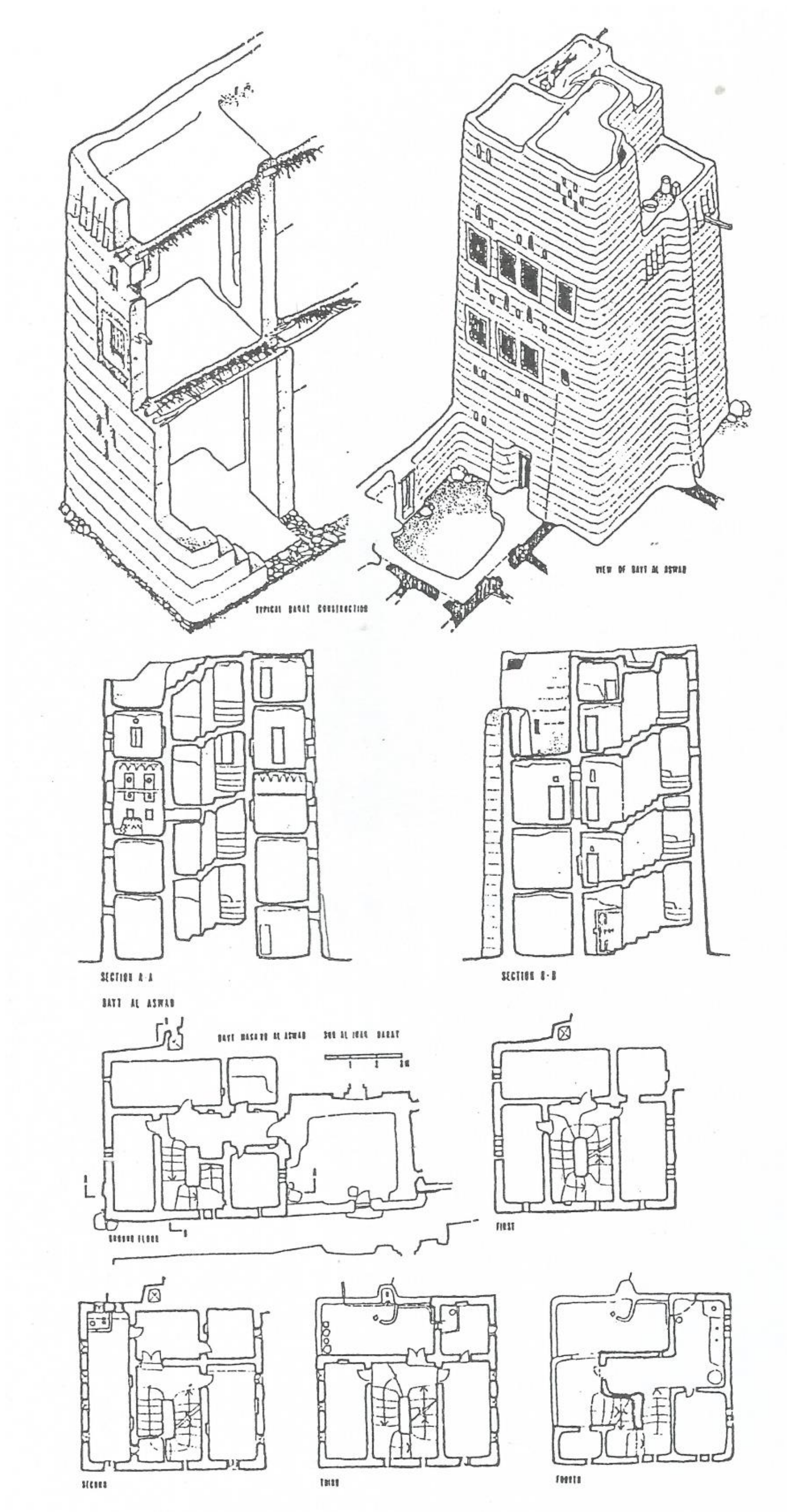


Figure 34. Model of an Asir house (Ragette, 2012)

Normally, earth could be excavated from the subsoil of the region or obtained from the surrounding area. It was then combined with water on the ground adjacent to the site. The mixture was kept that way for some days to allow it to ferment. The workers then trod it till it became of the required consistency. Straw was included in the midst of the process by means of scattering it in a series of thin layers, where each of the layers is positioned before turning the mixture. In this process, straw was used thoroughly to help in the drying out process and to spread out the shrinkage cracks all across the walls (Ragette, 2012). The mud was moulded in the shape of balls by tossing it from one hand to the other. These balls were handed over to the master builder who was positioned on the wall. The builder arranged the balls diagonally and used his feet to tread them down. At the same time, he walked backwards along the wall (AL-Hazmi, 2013).

Without the help of any framework, a continuous solid layer of mud of a height of around 30 to 45 cm was constructed one layer at a time. It was then kept this way for a few days to allow it to harden, after which the next layer was constructed. Elevation to some degree was given at the corners of each course or layer with the aim of improving the structure's stability (Al-Hamzi, 2013).

A flat wooden stick was used to pare down and beat the sides of each layer. This was done to make the inner surface smooth and to provide a small bulge to the outer surface to deflect the rain. During this period, the earth mix for the subsequent layers was prepared. The subsequent layers were constructed in sequence until the complete height of the wall was attained. A unique appearance is provided to the walls through this technique, where bands are indicative of each layer (Saxton, 1995).

The central region of Asir has frequent rainfall almost throughout the whole year. In this region, a distinct feature was formulated to avoid the erosion of mud walls. The construction process involved putting thin slices of slate side by side over each layer of cob. The horizontal bands of slab create a sequence of parallel parapets that protrude outwards by around 20 to 30 cm from the face of the wall and to some extent, slop outwards to discard the rain water which would, if left there, hasten the erosion of the walls and are used for maintenance (Al-Bini, 1990) (Figure 35).

Figure 35. Asiri cob house with horizontal bands of slabs (Murtadah)

The thickness of the exterior walls is around 70 to 80 cm, and these external walls taper as they go upwards until they become merely 20 cm thick on the upper floors. This structure then seems similar to the frustum of a pyramid and provides the structural benefits of an extensive and stable foundation, along with its aesthetic features. An internal staircase was constructed over a huge mud pier that spans the height of the house and functions as a significant structural member (Al-Bini, 1990).

The making of floors involved laying date palm trunks (split into halves or quarters) or stripped poles (like in Abha) directly on the wall head. In between the beams, smaller branches and twigs are positioned, and a layer of wet earth was pressed downwards over this wooden frame to create the level for the upper floor. Normally, mud plaster was applied on the tree trunk and branches employed to make ceiling and roof structures. Whitewashing of the mud plaster was also done most of the time. At times, however, gypsum plaster was smeared on top of the mud sub-surface (Galea, 1987).

The railings and parapets were shaped into sculptural forms along rooftops and terraces. There is a distinct projective crenulation on the external surface on the parapets and top floors on several plain mud houses of the region, particularly those in Najran. It was suggested by Jolyon Leslie that these components are minor defences that are backed by short lengths of timber that project around 15 cm from the wall's surface. These provide strength to the parapet and also offer protection from the rain to the mud wall beneath.

In Najran, several small openings are used, each of which offers a distinct function. The openings of the walls on the lower floors have small ventilation spots for security purposes. However, openings in the cob walls are created by simply making a gap in the mud course and smoothening the reveal with the hands. The shuttered windows close to the floor level of the living and reception rooms offer an overview while seated. There are arched openings with fixed glazing over these which offer background illumination to the inhabited areas when the windows are closed. Small rectangular openings in the middle of the top arches serve as a source of ventilation (Al-Jaded, 1994) (Figure 36).

Figure 36. Asiri small opening and painted house in bold patterns and colours (Sahaheri)

To curtail any kind of invasion, tough wood was used to construct the doors which were then covered seasonally with natural resin known as Qutran to secure them from white ants and other insects (AL-Hazmi, 2013). Bold coloured patterns are frequently used to paint the staircases, doors and windows and the areas surrounding them. Several colours of paint are offered by dyes created from local plants; however, the natural green obtained from the clover plant was the most preferred colour.

3.5 Modern Methods of House Construction

3.5.1 The Replacement Process

The construction industry of Saudi Arabia followed a traditional approach until the end of the 1950s when Portland cement and certain other contemporary building materials were imported from other countries and employed in different combinations. It was in 1959 that the first Portland cement factory started operating in the western region in Jeddah. An increase in demand for cement was observed in 1977, and the local production of cement from all factories was not enough to meet the local demands. Hence, over 6 million tons of cement were imported in 1977, a stark increase considering the fact that the figure was lower than 3 million tons in 1976 (Jadea, 2008).

There was extensive dependence on imported cement and other construction materials and this led to serious shortfalls, bringing about stark price increases. Several people seeking to build their homes could not pay the soaring cost of building materials. The Real Estate Development Fund (REDF) was set up by the government in 1975. The REDF offered an interest-free lending system which allowed individuals to obtain financial help for building their homes. This loan fulfils around 40% of the overall estimated cost of individual housing units, with the highest value of 300,000 S.R. = 70,000 Euro. This was later raised to 500,000 S.R. = 120,000 Euro (Housing.gov.sa, 2014).

The fund played an important role in fulfilling housing requirements; however, there continued to be an increase in the cost of building materials, land and labour. Reinforced concrete started being used on a wider scale in building private homes following the early exhibition values of contemporary reinforced concrete governmental buildings, along with the undocumented policies of the REDF and municipalities (Housing.gov.sa, 2014).

The newly constructed houses extensively utilized reinforced concrete because of its strength and durability. Nonetheless, due to the boom and conditions existing in the housing business, the quality of construction deteriorated. This is apparent from the poor installation of electrical and mechanical systems, poor quality of thermal insulation and lower strength of concrete (Med.gov.sa, 2014).

The 1970s and the early 1980s saw the emergence of an undocumented policy to discourage the utilization of conventional building materials that played a role in the rapid decline of construction through conventional means. Documented mud and building construction permits numbered around 1,500 in 1970; however, they declined swiftly in the early 1980s to merely 56. Currently, no new house is constructed from earth materials. Rather, reinforced concrete villas have taken the place of conventional houses made of stone, rubble, reed cob and adobe in various regions (Housing.gov.sa, 2014).

Some authors have reported that Saudi Arabia has actually gone backwards in the last 40 years, as the two kinds of housing that are ideal for the heat conditions of Saudi Arabia have been destroyed; that is the western province and the central province kind of house. It is expected that the experience obtained during thousands of years for constructing the houses could be salvaged and continued through the use of newer materials and methods of construction (Galipoli, Bruno and Perlot, 2014).

The REDF did not provide loans for construction that did not use reinforced concrete, and this played a major role in the rapid decrease in the use of earth and other conventional construction materials. In addition, the municipalities did not issue permits for adobe, stone and other conventional construction materials in the new residential localities (Housing.gov.sa, 2014).

Currently, nearly all reinforced concrete buildings constructed in the period of the construction boom are identical, not just in the materials used, but also in the methods used for the construction. The structural system is distinct from the majority of conventional systems in the sense that it is a non-wall bearing cast in situ reinforced concrete frame. Its constitution involves floor slabs, columns, beams, and foundations. Subsequently, the frame is filled with precast concrete blockwork or brickwork, following which cement stucco is used to plaster the entire structure externally and internally (Figure 37).

Figure 37. New construction of Ministry of Housing projects (Okaz)

3.5.2 Inappropriate Design

The architects creating the designs for the contemporary reinforced concrete villas and high-rise buildings frequently recommend the use of the most up-to-date technology without having sufficient knowledge regarding its overall performance. At times, these professionals are not fully aware about the local conditions. Keeping in view the warm climate of the region, villas that have reinforced concrete of international standards are exposed to the sun from all sides, as well as to dust and sandy storms. This shows that these building designs are quite impractical and result in a great deal of energy wastage. The majority of the buildings do not have any features to adapt to the harsh conditions except air conditioning units.

The fundamental climatic aspects were not taken into account in the new buildings. Air conditioning units are used most commonly in Saudi Arabia for the purpose of cooling the extremely warm environment. This practice is evident in nearly all modern residential places where air conditioners are used almost all year round. During the summer, air conditioning is sometimes used all day long. In addition, in some places, the units are substituted with bigger ones to make the internal environment tolerable. The cost of this solution has not been realized completely by the public because of the extremely high subsidization of energy costs. In the period 2008 to 2010, the domestic rate for electricity was 50 SR/KWH (1 Dollar = 3.75 SR). Users can understand the issue more with this rate compared to several years back when the subsidized rates were even higher (Agel, 2013).

The environmental, climatic and cultural issues have not been resolved adequately with the widespread use of new building materials, methods and equipment as a substitute for conventional building methods. For example, the street and adjacent open spaces use air conditioners to cool down the heat, in addition to motor vehicles and re-radiating paved spaces. On the other hand, the newly constructed modern buildings have given up their traditional identities and have turned into hybrids of exotic nature in their architectural design, key concepts, organization of spaces, elements and building methods used (Salem, 2006).

In these kinds of modern dwellings, privacy is another significant problem. It is imperative for individuals to adhere to the setback specifications given in the present urban laws, with open windows along the two metre sides and close setbacks. This meant that the windows of the top floors of each villa normally face each other, and this is not acceptable in certain parts of Saudi Arabia. In most parts of Saudi Arabia, it has been observed that the public is aware of the need to secure privacy, and rough and ugly solutions have been used to counter the issue (Mofti, 1984).

3.6 Summary

A survey was carried out in various parts of Saudi Arabia to examine the conventional building mechanisms. This survey examined the fading architectural legacy of the country to develop awareness amongst the public regarding these kinds of time-tested methods and their success. This part examines and elaborates on the mud techniques, one key aspect of which is the use of domestic building resources. These determine the ultimate shape of most buildings and offer a distinct aspect to each region.

In the past few decades, the conventional methods have been entirely disregarded and modern reinforced concrete villas have taken their place extensively in all regions. These modern dwellings have incorrect designs, which have brought about technical, social and aesthetic issues. This has an impact on people's awareness regarding whether such structures are appropriate under such conditions. In present times, an increasing number of people are seeking a suitable construction method that integrates the key elements of the traditional methods and the proficiency of the modern technology.

CHAPTER FOUR

THE FUNDAMENTAL BEHAVIOUR AND CHARACTERISTICS OF EARTHEN CONSTRUCTION MATERIALS

Much significance is awarded to the earthen construction in this age of sustainability as people look for eco-friendly ways of constructing houses. The effective solution for eco-friendly buildings is the adobe construction technique. In this method, soil is the chief material utilized. In this chapter, the way the soil functions in the adobe construction technique is examined. For this purpose, the geological context of Saudi Arabia is evaluated. The history of earth architecture is explained, with a focus on certain historical earthen architecture in the country. In this research, the technical characteristics of soil, for example, effective stress, relative humidity, unsaturated soil, Soil Water Retention Curve, compaction, impact of water on soil, etc. are examined. Soil testing and soil evaluation are critical aspects of adobe construction. Different tests are examined in greater detail, including laboratory and field tests. Finally, the research also highlights the rising awareness pertaining to adobe construction in the past few years. It explains the different activities performed by international firms to spread awareness with respect to adobe construction. Such activities involve research, development and training courses regarding earthen architecture. In addition, it seeks to generate awareness amongst individuals regarding the appropriateness of adobe construction.

4.1 Fundamentals of Soil Science and Adobe Construction

Soil is considered to be a natural component made up of organic compounds, minerals, living organisms and an interactive mix of water and air generated by physical and biological processes. It is vital to examine soil in the field of geology and civil engineering, as soil is a significant part of the material utilized for the construction of houses and other architecture. Soil has been closely related to the overall life of the humans from time immemorial. Adobe construction, which is also called earth construction, has been employed for a very long time. Soil is extremely crucial in adobe buildings. Hence, when constructing an adobe building it is vital to carry out a comprehensive study of soil. There are three significant layers in the soil: subsoil, topsoil and bedrock.

The topmost layer of the soil is found several feet deep within the Earth. It consists of a large amount of organic matter which is significant for the growth of plants and germination of seeds. It has rich nutritious value and moisture content. This is why the biological functions of the Earth occur in this soil. The topsoil provides the carbon and nitrogen molecules needed for these biological activities which are essential for the growth of the plant and functions as the habitat for the microbial population. When a large microbial population is present in the soil, it is considered to be suitable for the correct growth of plants, and this ensures that healthy crops are developed.

The topmost layer is a significant and important feature of agriculture and horticulture activities; however, it is not appropriate for construction and civil engineering. Since it contains organic components, it is not appropriate for any procedures that are part of construction activities.

The second layer of soil that is under the top layer is the subsoil. It has various colours, for example red and yellow, and it directly affects the movement of water. It is different from the top soil in the sense that it does not have any nutrients or organic substance.

The layer that is under the subsoil is the bedrock layer. This layer of rock does not consist of any organic or nutritious substance.

Soil is the most significant material in construction activities; hence, its performance must meet the standards. If this is not the case, the construction project may incur unwanted maintenance expenses, and at times, it is possible that the whole building may fail.

The bedrock layer is hard and available everywhere; deep within the Earth’s surface, and also on the Earth’s surface. Bedrock that is found on the surface level is known as outcrops. Out of the three soil layers present underneath the earth, the subsoil layer is used for construction activities.

An important aspect of civil engineering is the comprehensive study of soil. This is particularly significant when carrying out earthen construction. This is because soil has different properties in each region. When testing the soil, clay sedimentation is examined, as well as the organic element of the soil, in addition to other aspects. These tests are carried out to determine the strength of the soil, as well as its compaction, density and contamination.

Recommended construction projects are often deferred or cancelled simply because the soil at the construction site is not appropriate for the purpose of construction. Therefore, it is critical to examine the soil to find out if it is suitable for construction.

Hence, the geologist performs several tests to make sure that the soil is suitable for carrying out construction activities.

4.1.1 Soil Mechanisms

In any adobe construction project, it is vital to determine if the soil used for construction is appropriate for the purpose. Soil is the most important factor that determines the quality of the architecture. Soil is tested with the help of a method known as soil mechanism. This process is carried out to identify the quality of the soil that would possibly be used for construction purposes. The stiffness of the soil is determined through the soil mechanism procedure. The stability and security of the construction being carried out with this soil is the key factor considered when checking for the stiffness of the soil. Soil identification is another term used to signify the tests carried out for determining soil quality. This can be carried out with prior knowledge and training. The following methods can be used to determine the quality:

- Grain size distribution: this is employed to determine the quality of each grain size.
- Plasticity features: to determine the quality and of the soil.
- Compressibility: This is the test to determine the highest moisture content of the soil. It needs least minimum compaction energy for the highest density.
- Cohesion: to determine the capacity of the binder to bind the insert grain (Earthen Architecture for Sustainable Habitat and Compressed Stabilized Earth Block Technology, n.d.).

It has been mentioned previously that the topmost layer of the soil is not appropriate for construction as it consists of nutrients. Hence, this soil is not used for building purposes. In addition, the topsoil is not sturdy enough to meet the strength and durability required for construction activities. In civil engineering activities, like constructing houses, railways or tunnels, the topsoil is normally removed as it does not fulfil the specifications of density and compaction which are needed for construction activities (Strohmayer, 1999). It has a high degree of organic material, which is why it has weak aggregation. It is therefore, not possible to make foundations using topsoil.

It is vital to be aware of what soil actually is as it is the main component in building earthen houses. Soil is created from weathering rocks, which determine the type of the soil. It is the substance which collects mineral particles. In the soil determining process, the size of the particle is also vital. There are six varied sizes in which the soil particles are measured and these are given different names based on their sizes. Clay is the smallest particle, measuring just 0.002 mm. Silt is the second particle which has a slightly greater size than clay, measuring 0.06 mm. Sand comes next, measuring 2 mm, followed by gravel (6 mm), cobbles (20 mm) and boulders (over 20 mm). Soil should have the following parameters for being used in earth architecture:

Good soil = 15% Gravel + 50% Sand + 15% Slit + 20% Clay (Earthen Architecture for Sustainable Habitat and Compressed Stabilized Earth Block Technology, n.d.) If the soil utilized for earth architecture is used in the manner given above, then the earth architecture will be durable.

Certain factors play a role in the creation of soil, such as geology, climate and certain man-made activities. Saudi Arabia is a desert situated in the Middle East. There are three kinds of soil in the region: desert soil, valley region soil and the soil that is present in the mountain regions. The earthen construction uses the soil from the valley region.

4.1.2 Soil Strength

A key term used in soil mechanics is the strength of the soil, which is frictional material. Soil strength is used to determine the extent of soil strain that the soil can bear. The key factors that determine the strength of the soil include the density of particles, drainage conditions, the rate and the direction of the strain. The soil strength is a measure of the soil that deforms a constant volume and deforms without acquiring excess pore pressure.
The formula is used to find out the shear strength or oil strength:

In this formula, C signifies cohesion, while ϕ signifies friction angle. C and ϕ are usually not taken to be soil constants. The effective stress regulates the behaviour of the soil.

The formula signifies the criterion for soil failure:

Here, cu and ϕu are representative of the not drained strength.

It is not possible to apply this criterion everywhere and the parameters may differ as per the soil's moisture content. This undrained strength parameter is only applicable for clayey soils, which are not drained in the short term.

A significant soil property is the shear strength and is employed in soil mechanics to describe the extent of strength that can be endured by the soil. The size of the particles determines the soil strength, and also the presence of water within the soil. It has been discussed previously that there are different kinds of soil, depending on the size of the particles within the soil. Different names have been given to the particles as per their size, for example clay, sand, silt, gravel and boulders. Larger sized particles have larger capacities to preserve water, and it is this water that decides the strength of the soil. The construction process essentially needs to take into account the behaviour and strength of the soil. In addition, the development of the support system needs to consider the strength of the soil.

The strength of the soil is determined by the interaction between particles. It is when the particles glide over each other that shear failure occurs, and this happens because of extraordinary shear stress. Hence, it is critical to be aware of the behaviour of the soil and to evaluate its properties. In addition, soil stability should be determined. Knowing about soil strength is vital during the construction of earthen building, for the following reasons

- The soil strength decides the assessment of bearing ability
- The design of earth architecture is based on the knowledge of soil strength
- The shear strength of the soil is decided by the effective stress in the soil. The strength of the soil is mainly acquired by means of the interactions between the particles that can transfer normal and shear force.

Cohesive soil and frictional soil:

There are two main parts of the shear strength of the soil: cohesive soil and frictional soil.

$$\mathbf{S = c + \sigma \tan \phi}$$

In this equation, S signifies shear strength of the soil

C = signifies adhesion stress

σ = refers to normal stress

ϕ = refers to friction angle

In this equation, C and ϕ refer to the measures of strength. A greater value signifies larger shear strength.

Soil strength is examined in the laboratory using three different tests:

1. Undrained test
2. Consolidated or not drained test
3. Drained test.

4.1.3 Effective Stress

The soil mass is the stress that greatly affects the changes in volume and mobilizes the shear strength, which has been generated by the friction. The reason for the occurrence of stress is that all variations in the volume, shape or sharing resistance of the soil are solely because of variations in effective stress.

The term effective stress was devised by Karl Terzagi in 1925. Such stress is applicable in certain major changes like variations in volume and shape. It is because of effective stress that the particles inside the soil remain stiff. Effective stress takes into account the distribution of load within the soil across the region. The images given below explain overall stress and effective stress in terms of Terzagiri's explanation.

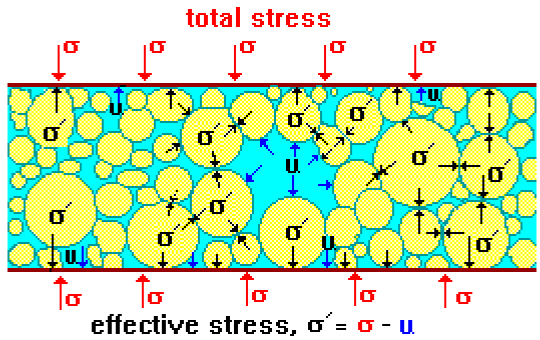


Figure 38. Vertical stress in the ground (Environment.uwe.ac.uk, n.d.)

In technical terms, effective stress describes calculated stress that moves soil successfully and displaces it. The following formula is used to determine effective stress:

Effective Stress = total stress – pore pressure.

$$\sigma' = \sigma - u$$

The preceding formula can be described in the following manner:

$$\sigma = H_{\text{soil}}\,\gamma_{\text{soil}}$$

$$u = H_{\text{w}}\,\gamma_{\text{w}}$$

A critical role is performed by effective stress in soil mechanics. This stress is considered to be the fundamental axiom as it plays a crucial role in the behaviour of the soil. Computations should differentiate between overall stress and effective stress.

The Mohr circle can be used to describe the effective stress as follows:

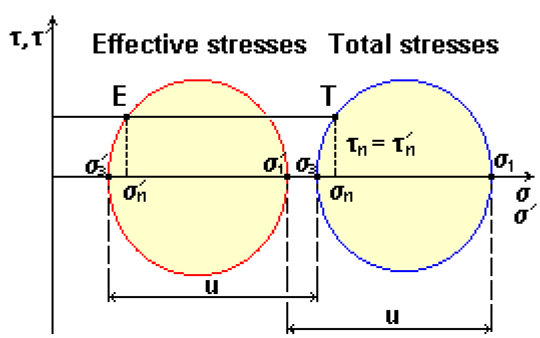


Figure 39. Mohr Circle

Two circles are shown in the above figure: the first circle describes the effective stress while the second circle explains the overall stress.

4.2 Unsaturated Soil Mechanics

The way in which the soil interacts with water gives rise to two statuses of soil, saturated soil and unsaturated soil. Two presumptions are made in soil mechanics, the soil is either saturated, or it is unsaturated. Solid particles are present in saturated soil along with water, while dry soil includes soil particles and air. The behaviour of unsaturated soil is determined by the link between suction or pressure and water content. There are three key constituents of unsaturated soil: which are solids, water and air (Fredlund and Rahardjo, 1993). When even a minor amount of air comes into the soil, it becomes unsaturated. Climate is the significant factor for determining the status of soil (saturated or unsaturated). Naturally, water leaves the soil because of evaporation, and then moves upwards. This process is referred to as upward flux of water, since water moves upwards from the soil. There is a reverse situation as well, called downward flux, where water enters the soil from the air as rainfall (Fredlund and Rahardjo, 1993), The pore water pressure condition of the soil is determined by these two opposing water contexts. It has been shown in several studies that mechanical and hydraulic behaviour plays a role in altering the water content of unsaturated expansive soils.

Conflicting outcomes are obtained in the two reverse procedures. The soil becomes dry and stiff due to upward flux, while it becomes saturated due to downward flux. One of the key issues of soil instauration is the negative pressure within the pore-water (Fredlund and Rahardjo, 1993). This leads to the swelling or expansion of the clays, which is quite dangerous. There are various instances where each year, the dwindling or the swelling of the soil brings about considerable damage to earthen construction. It is quite dangerous to construct buildings on expanded soil. The soil's expansive status is due to the increase in the negative pore-water pressure. The water's flux status has an effect on the unsaturated condition of the soil as it alters the volume of the soil and also its shear strength (Fredlund and Rahardjo, 1993). Safety issues are directly influenced by the shear strength. For unsaturated soil, the widespread boundary condition is a variation in flux. An important aspect for the unsaturated soil is the theory of consolidation. This theory also helps engineers to recognize the intricate systems and hence, offers a qualitative feel for the unsaturated soil's behaviour.

As has been asserted earlier, unsaturated soil is also known as soil with negative pore water pressure. The microclimate condition is a significant aspect for soil instauration. This kind of soil that has negative pore water pressure exists in any geological deposit. It can be residual or a lacustrine deposit, or a bedrock construction.

4.2.1 Relative Humidity

The amount of moisture in the air relative to the amount the air can hold is known as relative humidity. When air is unable to hold the moisture, condensation takes place, leading to the creation of excessive moisture in the form of dew. The following formula is used to represent relative humidity.

Relative Humidity (RH) = Actual Water Density x 100

Relative humidity determines the performance of the building. It can bring about growth of mould, mildew, staining, slip dangers, damage to equipment and corrosion. Eventually, it may cause decay and destruction of the earth building, while also impeding its insulation performance.

With respect to the ability to absorb relative humidity, earth construction is much more feasible compared to fired clay brick construction. Relative humidity can be well managed within earth buildings, as the earth construction can absorb 10 times more moisture content compared to fired clay bricks (Torgal and Jalali, 2011). Adobe houses function similarly to relative humidity flywheels by balancing the relative humidity of the external environment with that of the internal environment (the pores within the walls). People can comfortably live in any house that has the ability to balance or regulate relative humidity. Adobe construction maintains the relative humidity of the indoor air in the range of 40% to 60%, which is ideal for human health (Torgal and Jalali, 2011). When the relative humidity is lower than 40% or higher than 60%, it puts the human life at risk. Humans may suffer from asthma or allergy when the relative humidity is over 60%, while they may face drying of the respiratory tract, for example tonsillitis and bronchitis, when the relative humidity is lower than 40% (Torgal and Jalali, 2011). Therefore, it is vital to have earthen buildings as they maintain the balance of relative humidity.

4.2.2 Compaction of Soil for Earth Architecture

Air and water particles are part of the soil, and when these particles are present in the soil, it cannot be densified. Soil density is extremely important for its greater bearing potential. Hence, it is vital to decrease these particles in the soil, particularly when it is being used for construction purposes. This reduction in particles from the soil is known as compaction of soil. In this process, air and moisture are squeezed out to bring the soil particles closer, and when the soil becomes compacted, moisture cannot move. The following figure illustrates the distinction between compacted and non-compacted soil.

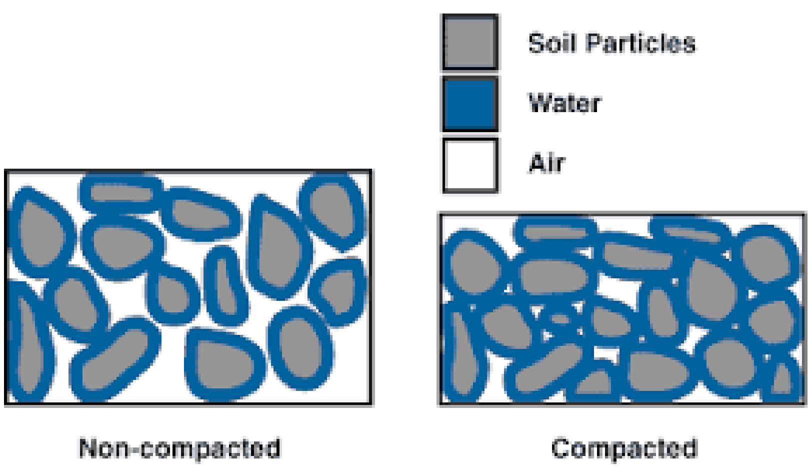


Figure 40. Soil compaction (Rediker,2012)

The image on the left shows that the particles are dispersed and there is a high amount of air and water, meaning that there is a lot of space between the particles. On the other hand, the image on the right shows that following the compaction process, the particles come close to each other and attach together. Because of the lower amount of space between the particles, the compacted soil becomes denser, while non-compacted soil remains sparse.

It is important to perform soil compaction so as to create a flat base and provide support during the construction of any kind of architectural structure. The reasons given below make it imperative to carry out compression:

- The compacted soil decreases the extent of settling
- There is an increase in soil capacity
- The building structure is prevented from any kind of damage
- Swelling and contraction is decreased.

One of the key advantages of soil compaction is that it provides high resistance and stability.
Soil is mainly of two kinds: the cohesive kind and the non-cohesive or granular kind. Another kind of soil also exists, which is the organic soil; but this kind of soil is cohesive and sticky in nature. The soil particles stick together in cohesive soil and it is quite soft in nature. Non-cohesive soil is not as soft and contains gravel and sand, and its particles do not stick to each other. It is important to eliminate air from any kind of soil because if this is not done then the earthen architecture may be prone to damage. Hence, if the soil is not compacted correctly, then it is possible that cracks may form and the building may fall down.
There are two ways in which soil compaction is carried out: intended compaction, and unintended compaction. Intended compaction is carried out deliberately and different tools are used for this purpose, such as compactors, rammers, rollers and vibratory plates. These are used commonly in the construction process and work towards decreasing the pores in the soil that are filled with air and water. Compaction equipment is chosen on the basis of the kind of soil, the objective of the soil and the extent of soil that is going to be compacted. No equipment or machines are required in the unintentional compaction process. Rather, different human activities are needed for compressing the soil, like construction vehicles or pedestrian

traffic. If the soil needs to be compacted for building purposes, intentional compaction needs to take place.

Soil compaction is an important component of earth architecture because it decreases the pore size and increases the soil's bulk density. The greater soil density enables the soil to carry a larger load. In addition, it provides support to the structure.

4.3 The Role of Clay

In constructing any architecture, clay is a sustainable material as it is available easily and preserves energy and emissions. It is a significant material, and is used in combination with straw, sand and water to construct earthen bricks that are used to construct walls. Clay also serves as an insulator, sound and heat proofer, and it is due to these features of insulation that the clay preserves the heat during the winters and keeps the temperature balanced during the summers.

Clay plays a significant role in earth construction and is a significant particle within the soil. Other particles within the soil get away from each other, but clay joins them together. Clay plays a significant role in attaching the larger particles of the soil to each other. Electrostatic forces provide strength to the clay. There are three kinds of clay: Kaolinites, Illites and Montmorillonites. Each kind of clay has different reaction to the addition and subtraction of water and has an impact on the binding abilities of the adobe material.

It is important to choose clay carefully as it is a vital component of adobe construction. It performs a key role in identifying the texture of the soil, its plasticity, cohesion and compatibility (Fao.org, n.d.). Clay is stiff, which is why it is used for plastering earthen buildings. Clay is the cohesive particle and is of a very fine nature. During the construction of earthen buildings, it attaches to the sand and straw. It is plastic when wet, which makes the plastering process easy. Clay has chemical and physical properties, yet, it is not easy to ascertain the properties of clay (Fao.org, n.d.). However, it is still represented in terms of plasticity. The pie chart given below explains the classification of the soil particles in the adobe building.

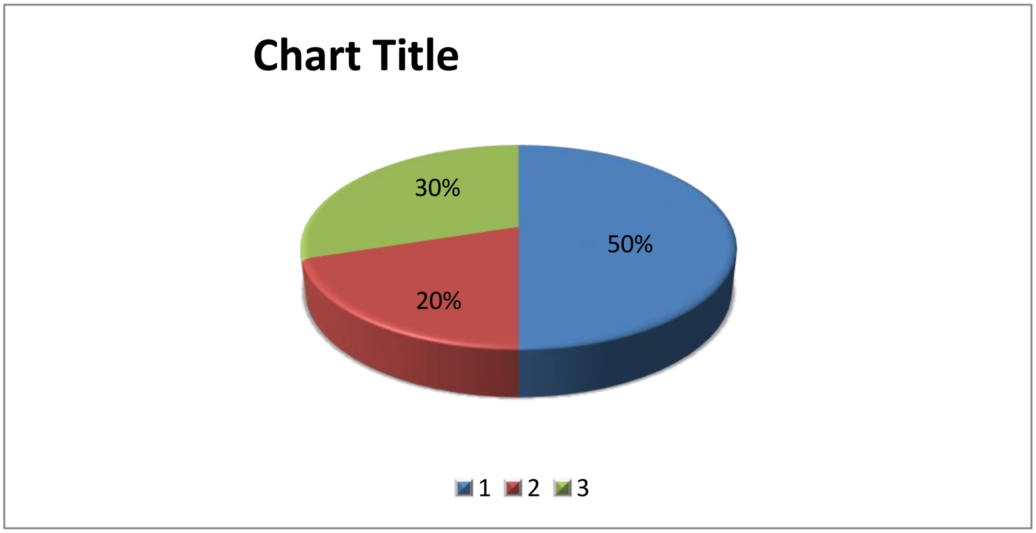


Figure 41. Classification of soil particles

The most commonly used material in adobe construction is sand, followed by clay. There should be lower than 30% of clay in the adobe building, as if it is higher, there are greater possibilities of swelling or shrinkage. Clay has a greater tendency to absorb moisture and this may create significant cracks or damages within the structure (Fao.org, n.d.). Clay also serves as a stabilizer in the earthen construction and plays an important role in enhancing soil grading.

There is an extreme climate in Saudi Arabia; therefore, the insulating feature of the clay ensures an average temperature inside houses in all seasons. Clay is also sustainable and environmentally friendly, which makes it a significant factor in adobe construction.

4.4 Role of Stabilizer

In adobe building construction, soil is the most important element. Soil consists of clay, and in its dry form, clay is hard, which provides it with the ability to hold up the earth wall. However, the clay becomes wet when the building comes directly into contact with rain. If there is leakage in the roof which exposes the clay walls to the water, the whole structure may become saturated and ultimately fall down. Therefore, it is vital to stabilize the clay so as to provide durability to the construction in the presence of water. This is where the stabilizer comes into action, as it makes the structure resistant to weather conditions. It is mixed in the soil to enhance its properties as a robust construction material. Various stabilizers are utilized in earth construction. These include:

- Stabilization with cement
- Stabilization with asphalt
- Stabilization with lime

When cement is used as a stabilizer in a building, it is important to use the appropriate quantity of cement as per the soil type. The following percentages of cement are used in the form of a stabilizer for earth construction:

- 5% to 10% for gravel
- 7% to 12% for sand
- 12% to 15% for silts
- 12% to 20% for clay

Cement is used along with other materials like lime, calcium chloride, sodium carbonate, fly ash and sodium sulphate, to function as a stabilizer.

Another significant material used as a stabilizer in the construction industry is lime. Lime has served the purpose of a stabilizer for a long time. When lime is used correctly and in the right quantity, it depicts impeccable strength. Traditionally, mainly earthen construction was used in building activities. The Pantheon temple that has been in existence for over 2000 years in Rome is an ideal example of construction that makes use of lime as a stabilizer. When lime is used in combination with Pozzolan, it turns quite robust, similar to cement. Such a stabilizer absorbs water to a high degree and works efficiently as plaster or coatings for the earth walls.

There is also widespread use of biopolymers for stabilizing adobe construction, which may be attained either naturally or artificially. The polymer may be obtained from animals, vegetables or mineral origin (Camões, Eires and Jalali, 2015). In ancient times, polymer was widely used in construction. Flours, gums, cactus, starches, oils and plant resins are examples of polymers used. At times, animal fats, egg whites, casein, blood, urine and excrement may also be used as stabilizers (Camões, Eires and Jalali, 2015). Waterproofing of the earth building is normally done with the help of oils and fats.

Asphalt is similar to lime in the sense that it is used extensively for the purpose of stabilization. Its most extensive use is in the construction of pavement. Asphalt provides cohesion and decreased water absorption, which is one of its key benefits (Mishra, 2014). There are four kinds of asphalt stabilizers:

- Asphalt stabilization for sand
- Asphalt stabilization for soil
- Mechanical stabilization that is water proofed
- Oiled earth (Mishra, 2014)

In Iran, a material known as sarooj is also used as a robust stabilizer.

A critical role is played by the stabilizer in ensuring the durability of the adobe construction. When a stabilizer is not used, it is not possible to construct a sustainable building. The stabilizer used depends on the climate and soil pattern prevalent in the region.

4.4.1 Effects of Water Content

Preparing the soil is a preliminary step in the earth construction procedure. During the preparation of soil, water is included to cover the particle surfaces with a thin layer of water. These films help the particles move over each other without any difficulty. Such a process works best in coarse-grained soil, since the water film is thinner than the grain diameter. In addition, the existence of water content takes the place of air in the voids.

Water content, also called moisture content, refers to the overall quantity of water that is included in the construction material, e.g. soil, ceramic, rock, etc. A critical role is played by water in building adobe construction, particularly while carrying out the compaction process. The quantity of water should be neither too low nor too high. Low water content makes the soil stiff ,which creates issues during soil compaction. An increase in water content allows the compaction process to occur swiftly as the water functions as a lubricant for the soil particles. An increase in water content reduces the durability and stiffness of the sample. When water is added, the soil starts functioning properly. The water content decreases the dry density of the soil. A constant volume is achieved by the air voids. The increase in water does not bring about a decrease in air voids and hence, the dry density decreases. An increase in water content makes it difficult to take out the air to further decrease the air voids.

The shear strength of the earth construction is also affected by the water content. Wu, Peng and Zhang (2011) performed a study in which it was shown that water content has a huge impact on the shear strength of earth buildings. The shear strength has a smaller value when there is high water content. An increase in water content leads to a decrease in the cohesion and internal friction angle of rammed earth. Low water content in the earth construction brings about variation in the cohesion by a small amount, while high water content decreases cohesion (Wu, Peng and Zhang, 2011).

With respect to the Najd in Saudi Arabia, brick construction is carried out by decreasing the amount of water included. This is possible by decreasing the percentage of clay in the mixture. This decreases the shrinkage and subsequent cracking in the drying process, while at the same time ensuring ample clay completely permeates the mixture with its adhesive solidity and compression strength. Including sand and silt in the mixture is called 'soil modification'. The effectiveness of soil modification was understood by Najdi builders; however, in present times, a more relevant method of obtaining the optimal mixture is linear shrinkage testing. In this test, a wet mixture sample is put in a shallow mould 60 cm in length. The overall shrinkage once dry can then be obtained.

The appropriate building material was normally determined by Najdi builders by choosing their source deposit carefully. An appropriate amount clay, silty soil and sand has been previously combined together in valley deposits. Lower amounts of water are absorbed by the silty soil compared to clay, and since the grains are impermeable, there is no expansion on wetting. Water is not absorbed by sand grains, and so these function as filler: they are stuck to each other by the sticky clay and provide compression strength to the brick when it is dry. Sand is included in certain regions of the world; however, it is not essential to do this in Najd as there is appropriate sand present naturally within the soil.

4.4.2 Performance of Stabilizer Earth Block

In the process of soil stabilization, the natural soil is altered in certain ways so that it can be used for the purpose of building. Enhancing soil with a stabilizer involves the load-bearing ability and hence provides strength to the construction. There is widespread use of earth blocks in earth architecture.

Compressed earth blocks are developed from damp soil that has been compressed under high pressure, which leads to the formation of the blocks. Portland cement plays the role of a chemical binder in compressed stabilized earth blocks. This process was employed recently in ad-Dir'iyah, Saudi Arabia.

Constructions that have been developed using stabilized earth blocks are eco-friendly. Such constructions are also widely present in the respective location and can be referred to as a sustainable construction. In addition, there is local availability of soil, hence it is not very costly to develop CSEB. These blocks are energy-preserving bricks, and unlike fired bricks, they do not create much pollution. Block performance can be improved by using stabilizers according to requirements. Cement is the ideal stabilizer for sandy oil, while lime stabilization is more appropriate for clayey soils.

When houses constructed using CSEB are properly designed, they can exhibit good performance in any weather, for example heavy rainfall, snowfall or frost. CSEB indisputably provides high durability to the houses and functions impeccably as a sustainable material. If the building collapses, the biochemicals in the upper layer of the soil will destroy the cement mixed in the soil in 10 to 20 years, making the CSEB become part of the earth in its original form.

CSEB consume around 5 to 15 times less energy compared to fired bricks. In addition, wood is not needed for the production of CSEB, meaning that the forests are preserved.

4.4.3 Soil Water Retention Curve

The soil retention curve refers to the relationship between water content and water potential or soil moisture suction. This was given the name the soil classification triangle or the ‘Soil Water Retention Curve’ by Edgar Buckingham. In addition, it is also known as ‘soil moisture characteristics’ and is a significant hydraulic property related to the size and interconnections of pore spaces. Hence, it is affected to a large extent by soil structure and soil texture, and also by organic matter.

The Soil Water Retention Curve (SWRC) determines the extent of storage of water and soil aggregate stability. There may be variations in the curve in accordance with the hysteric impact of water filling and the process of pore draining. The SWRC is non-linear in nature and hence accurate results are difficult to attain. The following figure shows Soil Water Retention Curve for soil that has varied textures, such as sand, clay and silt.

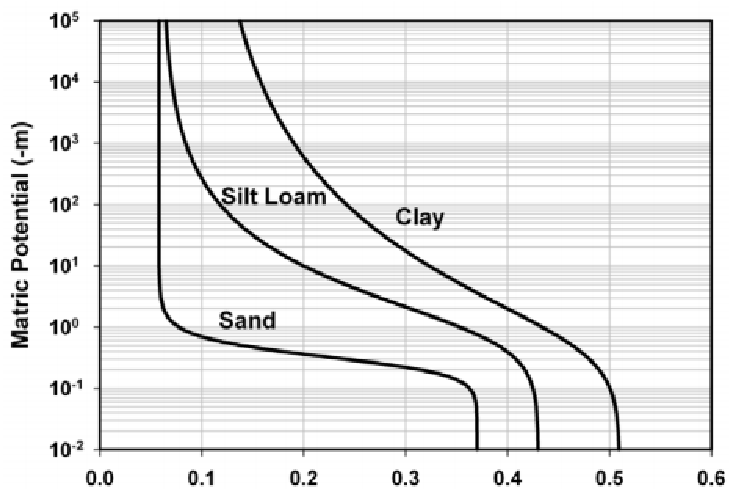


Figure 42. Soil Retention Curve (Jaquin, 2012)

To create a model of the water flux and solutes in the vadose zone or the unsaturated portion of the earth between the land surface and the upper part of the phreatic zone, the zone in which groundwater is at atmospheric pressure, it is vital to have correct information and details regarding the SWRC. In addition, it is also vital for ascertaining the spatial variability. The SWRC procedure is extensive, time-consuming and very costly.

Soil water retention is affected to a great degree by:

- The soil structure
- Soil organic matter
- Clay content

The formula for Soil Water Retention given below was prepared by Brook and Corey (1966):

$$\frac{\theta - \theta_r}{\theta_s - \theta_r} = \left(\frac{\psi_e}{\psi_m}\right)^{\lambda}$$

where,

- θ_r = residual volumetric water content (at high suction)

- θ_s = saturated volumetric water content

- ψ_e = air entry suction

- λ = pore size distribution index

Various models for the shape of WRC have been presented. The Genuchten model provided the following formula for WRC:

$$\theta(\psi) = \theta_r + \frac{\theta_s - \theta_r}{\left[1 + (\alpha|\psi|)^n\right]^{1-1/n}}$$

where,

$\theta(\psi)$ refers to the water retention curve

ψ = pressure

θ_s = saturated water content

θ_r = residual volumetric water content (at high suction)

α = inverse of the air entry pressure

n = measure of pro-size distribution

There is an abundance of natural expansive clay in Saudi Arabia, particularly in the Arabian coastal regions. Naturally, the clay is unsaturated which is why there are variations in its volume in accordance with the amount of water added. The Soil Water Retention Curve is the unsaturated soil parameter needed for modelling. The following figure explains the Soil Water Retention Curve of sand clay available in the coastal parts of Saudi Arabia. This kind of soil is available close to the Arabian Gulf and almost 400 km from Riyadh, Saudi Arabia's capital.

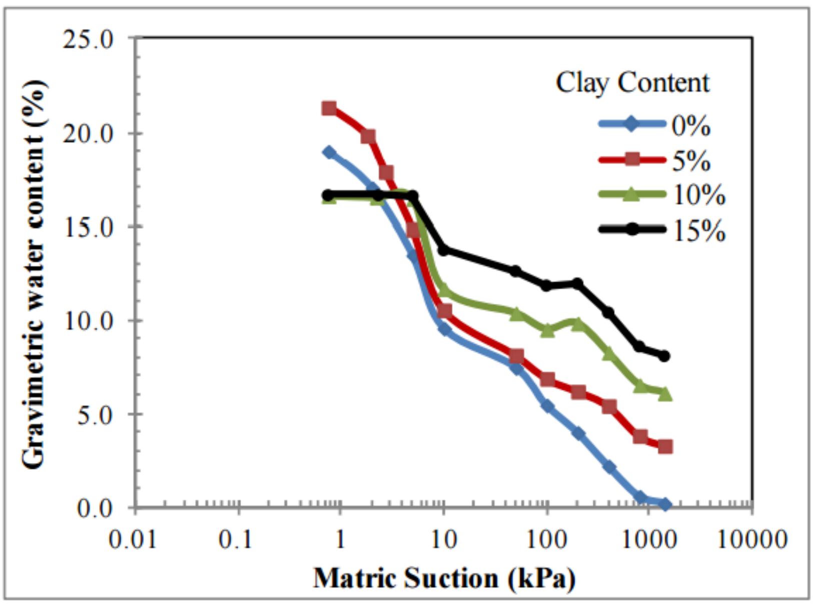


Figure 43. Soil Water Retention Curve of Sand. (Elkady, Dafalla, Al-Mahbashi and Al Shamrani, 2013)

The figure shows that an increase in clay content increases the residual water content. In addition, an increase in clay content also leads to an increase in air entry value. This brings a change in the shape of the Soil Water Retention Curve from a unimodal form to a bimodal form.

4.5 Dimensional Stability Test

The Dimensional Stability Test is mainly carried out to present uniformity concerning internal stress that is added during the process.

The sample dimensions are obtained at the reference markers for the test. Talc dusted paper is used to create a sandwich around the sample. The sandwich-shaped samples are put in an oven for a specified time, following which they are taken out of the oven and placed at room temperature for an hour for the purpose of reconditioning. The distances between the reference marks are measured and noted down (Intertek.com, n.d.).

4.5.1 Permeability Test

A Permeability Test is essentially carried out to determine the flow of water that passes through the soil. Water is made to pass through a particular soil sample with the help of a certain force. The rate of the water flow is identified using laboratory equipment such as the compaction hammer, Hobart soil mixer, levelling piston, scoop, moisture pan, timer or stopwatch, drying oven and depth gauge.

Water is added to a tank measuring 305 mm diameter up to the outlet level. Prior to the test, it needs to be made certain that the outlet reservoir is filled to the overflow point as this ensures that the excess water released from the reservoir during the test is the water that has passed through the sample soil. The perforated plate is put on the soil sample obtained and the mould is put on the sample over the U-shaped hanger. Nuts and three vertical studs are used to level the mould. On the top part of the sample, water is released. It is important to make use of the lower head when there is extremely high flow of water or when there are signs of piping or passing of fines from the sample while the test is being carried out. For some time, water is allowed to percolate to make certain of a high level of saturation and uniformity of the outcomes. Following this, water is permitted to pass through the reservoir somewhat faster than through the specimen. The extent of flow is found using the container or the quantity is measured. The temperature of the water is noted and the time taken for the quantity of flow is determined and noted down.

4.6 Summary

Adobe construction is becoming a sustainable and eco-friendly means of construction because of environmental degradation. A key factor that determines the quality and strength of earthen construction is the soil. Studies on earthen construction show that awareness regarding the earthen architecture is limited, and it is necessary to continue the research in this field so as to counter the shortcomings of adobe construction. Every field has played a role in sustainable development, and it is observed that the fields of architecture and civil engineering are also moving in the direction of sustainable development by utilizing adobe construction.

CHAPTER FIVE

BUILDING WITH EARTH AND SOIL TYPES IN SAUDI ARABIA

5.1 Soil Types

Soil is an extensively used term in the field of engineering and it encompasses all deposits in the earth's crust of loose fragmentary nature, typically admixtures of organic remains. Continuous and slow weathering of rocks through physical, biological and chemical processes makes soil. The key mechanism varies with the location, time and climate under which the weathering occurs; hence, if soils are to be used as a building material, it is important to be aware of their behaviour under various conditions that they will have to practically face.

The appropriateness of soil as a construction material is determined with the help of various standard tests. In this section, a few of these tests are explained and employed to study certain fundamental properties of soil samples obtained from earthen building sites all through Al-Dreivah and Najran, Saudi Arabia.

5.1.1 Lab Analysis

Testing the soil prior to its use in construction material is extremely important so that its suitability for the purpose can be ascertained. The pattern, structure, and overall behaviour of the soil affect the construction. For any building or structure, soil serves as the natural base. Testing the soil is vital to find out about its physical and chemical attributes. The bearing attributes of the soil may be affected by changes in climate, weather and overall site management. The building may collapse if its foundations are not laid properly. The soil tests allow the structural engineers to design the elements more accurately, and this makes it easy to identify the stabilization and the foundation depth of the soil. Furthermore, the lab analysis tests are not very costly, and even if the project is a low budget one, it is vital to perform soil analyses as the eventual security of people depends on the construction.

Various kinds of soil may be used for construction, for example peat, silt, gravel or sand. This is why soil testing is important, so that appropriate decisions can be taken for the safety and durability of the construction.

Different tests are carried out to find out the appropriateness of the soil for constructing blocks. There are two kinds of tests: field tests and laboratory tests. The simple field test is carried out in the following manner:

- Following mixing soil for block production, a little soil is taken and squeezed in the hand and made into a ball
- The ball is then thrown from a height of around one metre
- If the ball breaks, it suggests that the correct amount of moisture is not present in the ball
- If the ball gets squashed into a flattened ball or dish because of the hard surface, it appears that there is high water content in the soil
- If the ball disintegrates into lumps, it appears that the water content or the soil mixture is near the optimum moisture content (OMC).

Lab tests also need to be carried out in addition to the field tests to determine whether the soil utilized in earth architecture is appropriate for construction. Various steps are followed in the laboratory and are discussed below:

- When the soil sample is collected, it needs to be ascertained whether the sample signifies the soil. The most common and affordable means of obtaining the sample is collecting sub-samples from randomly chosen regions.
- A comprehensive evaluation of the soil sample is carried out from various angles. The chemical properties of the soil determine the method employed for analysing the soil.
- A comprehensive interpretation and a report regarding the quality and complete behaviour of the soil is presented.
- On the basis of the tests, the ultimate stage pertains to making recommendations and suggestions.

5.1.2 Lab Analysis of Compressive Strength of the Soil

The compressive strength of the soil is tested by using equipment such as unconfined compression apparatus, a proving ring with a capacity of 1kN, a dial gauge with a precision of 0.01 mm, a weighing balance, oven, sampling tube, stop watch, split mould with a diameter of

38 mm and length of 76 mm, knife, sample extractor, Vernier callipers, knife, and large mould. The following method is used to obtain the compressive strength of soil:

- The soil samples are placed in a large mould.
- The sample tube is inserted into the large mould after which the sample is taken out. The sample tube is inserted into the clay sample.
- The soil sample is saturated in the sampling tube.
- The split mould is covered with a thin layer of grease.
- The sample is removed from the sampling tube into the split mould using a knife.
- Both ends of the moulds are trimmed after which the weight of the mould is obtained.
- The specimen is taken from the split mould and the mould is divided into two parts.
- The diameter and length of the specimen are found using the Vernier calliper.
- The specimen is put on the bottom plate of the compression machine, following which the upper plate is modified.
- The values of the dial gauge and proving ring gauge are kept on zero.
- The compression load is put on, and the dial gauge reading is obtained. This reading may be obtained after every one minute for strain in the range of 6% to 12%, and 2 minutes or more for a strain of over 12%.
- The test is performed until surface failure has entirely developed.
- The angle between the horizontal and the failure surface is determined.
- A sample is obtained from the failure zone of the specimen, and the water content is measured.

5.1.3 General Properties of Soil

A. Particle Size

The composition of the soil determines to a large extent the suitability of soil for construction activities. A granular structure is present in majority of the soils, and this includes coarse particles, filled out and attached together with fine particles. Hence, the most fundamental classification of soils is with respect to particle size (Minke, 2012).

Various methods are used to distinguish soil into its constituents; however, the most well-known methods include sieving or sedimentation. The generally acknowledged categorization is presented in Table 1. The coarse fraction of soil includes gravel and sand. Gravel is considered to be that part of the soil sample which goes through a 6mm sieve, but is retained by a 2 mm sieve. Sand is that part of the soil sample which manages to go past the 2 mm sieve, but is retained by a 0.06 mm sieve (Minke, 2012).

Table 1. Classification of soil by particle size

Type	Name		Size range	B.S. Test sieve	Properties
Granular	Gravel		6 – 2 mm	Particles larger than 3/16 in	Particles visible to the naked eye. No cohesion when dry.
	Sand	Coarse Sand	2.0 – 0.6 mm	Most particles lie between No. 7 and No. 25 sieve	
		Medium Sand	0.6 – 0.2 mm	Most particles lie between No. 25 and No. 72 sieve	
		Fine Sand	0.2 – 0.06 mm	Most particles lie between No. 72 and No. 200 sieve	
Plastic	Silt	Coarse Silt	0.06 – 0.02 mm	Most particles smaller then No. 200	Particles barely visible to the naked eye. Gritty touch and slight cohesion when dry.
		Medium Silt	0.02 – 0.06 mm		
		Fine Silt	0.006 – 0.002 mm		
	Clay		Less than 0.002 mm		Smooth touch and plastic. Considerable cohesion when dry.

Further subdivision of the fine fraction is carried out to make silt and clay. Silt is that part of the soil sample that passes through the 0.06 mm sieve but is held by the 0.002 mm sieve. Clay is that part of the soil sample that moves through the 0.002 mm sieve. A very simple test can be used to differentiate between the coarse and the fine fraction. When a transparent glass bottle of 1 litre or more is filled up to one-third with a dried soil sample, one-third with clean water and then shaken briskly and allowed to settle, the soil particles are deposited in layers according to their density. The organic matter drifts to the top, and after almost five hours, the gravel and sand particles fall to the bottom, where the finer material is at the top in an easily discernible layer (Ingles and Metcalf, 1972). The coarse fraction consists of almost that part of the soil in which the particles can be differentiated directly by a person. The fine fraction is that layer which is placed over that layer where the individual particles of clay and silt are not discernible. Each layer's height can be determined from the side of the glass bottle and the percentage of each fraction is approximated (Hunt and Suhr, 2008).

It is recommended that a full laboratory assessment of the soil is carried out for all crucial earth construction projects as even though the test is easy to perform; however, its key drawback is that it is not possible to differentiate between the silt and the clay layers. This is possible by performing a mix of sieve analysis to differentiate between the coarser particles, as well as sedimentation analysis which differentiates fine particles as per the speed at which they settle from a uniform suspension in water (Minke, 2012).

However, in the majority of cases, natural soil is a mix of particles belonging to two or more different size groups. The texture of the soil, called its surface appearance, is affected by the size and percentage of the individual particles that are part of it. On the basis of the particle size distribution, various soil classification systems have been produced for different objectives. A shared means is offered by these systems to explain the typical features of soils. The triangular chart created by the United States Bureau of Public Roads is one such system (Figure 49) (Shan and Shroff, 2003).

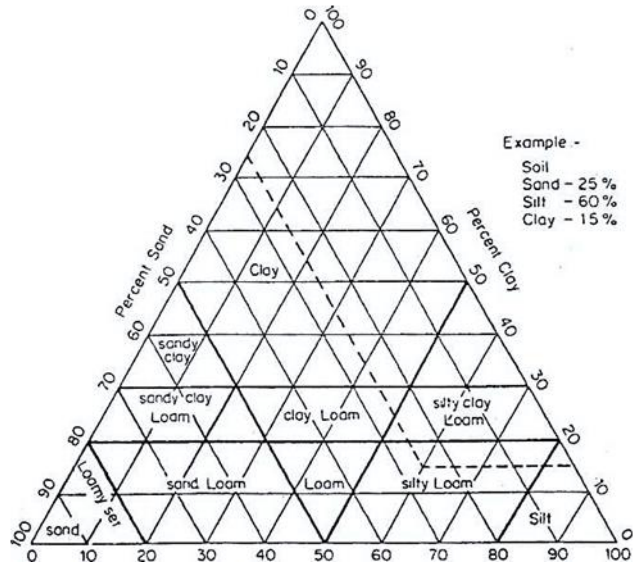


Figure 44. Textural classification chart for soils (Shan and Shroff, 2003)

Table 2. Soil classification system (US Bureau of Soil Systems)

Class	Sand	Silt	Clay
	%	%	%
Sand	80 – 100	0 – 20	0 – 20
Sandy loam	50 – 80	0 – 50	0 – 20
Loam	30 – 50	30 – 50	0 – 20
Silty loam	0 – 50	50 – 100	0 – 20
Sandy clay loam	50 – 80	0 – 30	20 – 30
Clay loam	20 – 50	20 – 50	20 – 30
Silty clay loam	0 – 30	50 – 80	20 – 30
Sandy clay	50 – 70	0 – 20	20 – 50
Silty clay	0 – 20	50 – 70	30 – 50
Clay	0 – 50	0 – 50	30 - 100

There are ten parts in this chart and clay is seen to take the top third position on the chart, while sand and silt are at the bottom, with 'loam' or sand-silt mixtures in the middle. In such a texture classification system, soils are given names with respect to their base components, for example sandy clay, silty clay, etc.

B. Consistency of Soil

The particle size analysis provides critical information, but is not adequate on its own to determine the soil behaviour of fine-grained soils. The reason for this is that a fine-grained soil's behaviour while water is present is dependent on the kind of clay mineral that is included in it and its quantity (Aslam, n.d.).

Fine-grained soil which includes clay grains can be remoulded without crumbling when some degree of moisture is present. It is the absorbed water around the clay particles that makes the soil cohesive. However, if the inclusion of more water makes the tiny film of water encompassing the clay grains too big, then the grains disintegrate and are no longer cohesive.

A technique was formulated by a Swedish scientist, Atterberg to explain the consistency of fine-grained soils that had different amounts of moisture content. When the moisture content is extremely low, soil functions similarly to a solid. An increase in the moisture content turns the clay body into plastic and by working on it, its shape can alter but still continue to be a solid. When the moisture content is further increased, the soil will turn into a viscous liquid that cannot maintain its shape when it is shaken. The 'plastic limit' is the term given to the percentage of moisture content at which the solid state of soil brings about the plastic state. On the other hand, the liquid limit is that percentage at which the plastic state of soil turns into the liquid state. This is explained better as follows:

- Liquid Limit (LL) refers to the moisture content at which the soil starts functioning as a liquid material and starts flowing (A fine-grained soil's liquid limit provides the moisture content on which the shear strength of the soil is around 2.5kN/m).

- Plastic Limit (PL) refers to the moisture content at which the soil starts functioning as a plastic.
- Shrinkage Limit (SL) refers to the moisture content at which no more shrinking is possible.

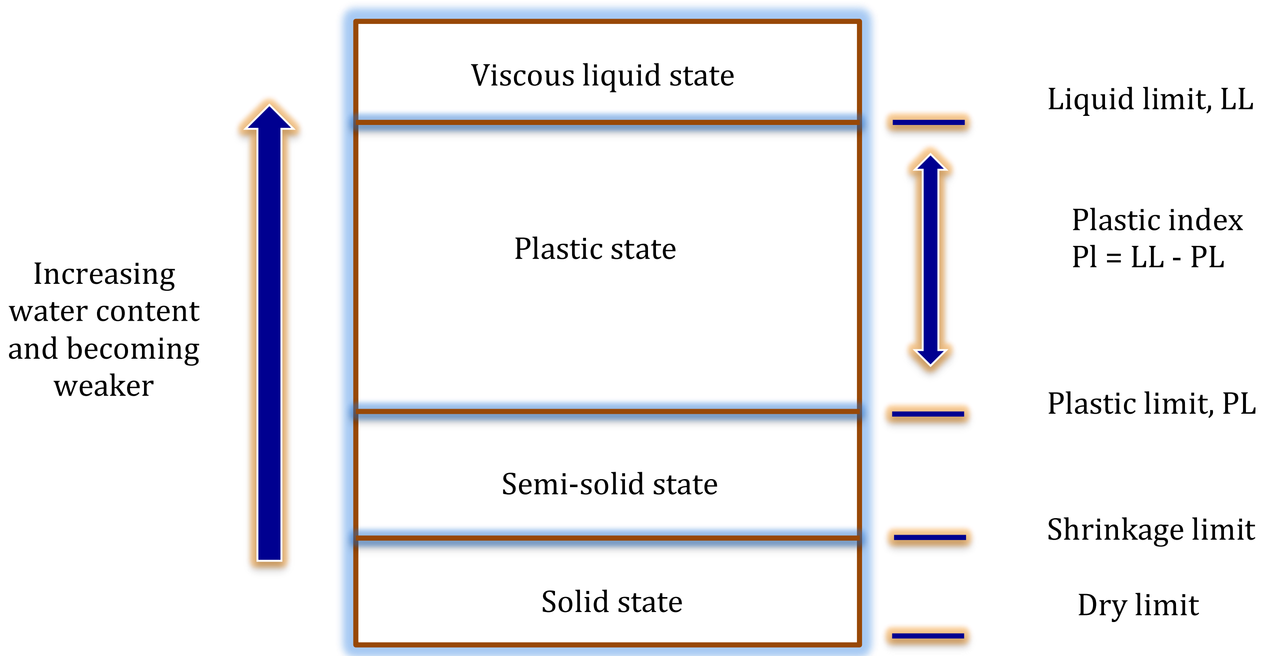


Figure 45. Changes in volume with an additional decrease in moisture content (SL refers to the quantity of water need to completely saturate the soil (100% saturation) (Jaquin, 2012)

Atterberg limits refer to the water content limits that explain soil behaviour. The Atterberg limits provide the consistency to soils (Shah and Shroff, 2003).

In addition, the plasticity index is the numerical distinction between the liquid limit and the plastic limit of a soil, and this index is used to identify the range of moisture content over which plastic characteristics are possessed by the soil. The liquid limit and plasticity index are influenced by the kind of clay mineral present and its quantity. Fine-grained soil that has a small plasticity has liquid limits lower than 35%. Such soils normally have a lower than 20% clay content. Those fine-grained soils which are of medium plasticity have been found to have liquid limits in the range of 35% to 50%. These soils normally have clay content in the range of 20% to 40%. Liquid limits of soils with greater plasticity are normally over 50%, while their clay content is generally over 40% (Shah and Shroff, 2003).

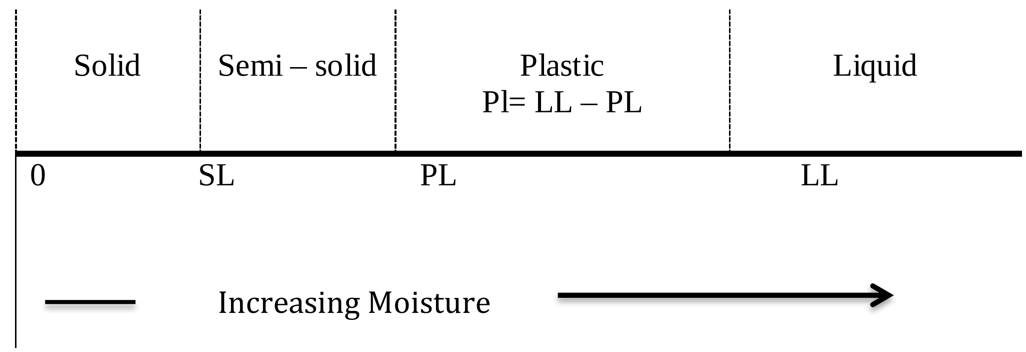


Figure 46. Atterberg Limits

The liquid limit of a soil is measured by putting the soil paste inside a standard brass cup that can be dropped on a hard rubber case by means of a cam functioning with the help of a crank. In the centre of the soil paste, a groove is slit from the centre with the help of a standard grooving tool. Following this, the crank-operated cam is used to bring the cup up and this is then dropped from a particular height that determines the moisture content at which the two halves flow together when a standard number of blows are imposed. The plastic limit can be found by rolling a thread of soil to a diameter of 3 mm. This can be done by rolling the thread between the hand and a glass plate. The moisture content at which the thread of soil starts cracking and crumbling when rolled to this diameter is known as its plastic limit (Shah and Shroff, 2003).

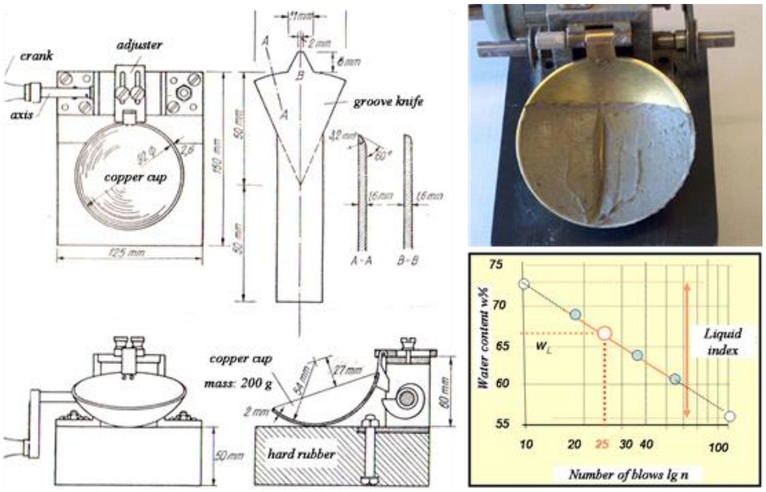


Figure 47. Liquid limit apparatus

C. Linear Shrinkage

Earth contracts due to water loss since moisture variations have a significant impact on it when it is considered as a building material. The nature and quantity of clay in the soil determines if a soil will shrink or not. To check the quality of soils, tests for linear shrinkage must always be carried out. Failure of smeared renderings, rain infiltration, and breaking of the wall are some of the problems that arise due to shrinkage (Maini, 2005).

A distinct semi-cylindrical brass mould and an oven for heating a soil sample at 110°C are used to perform the linear shrinkage test. The inside of the mould was lubricated to prevent the soil from sticking. This mould was then loaded with a consistent paste of the soil sample merged with water. First at room temperature and then in the oven, this paste was dried until shrinkage stopped. Calculation of the linear shrinkage of the soil was then done as a fraction of the primary size of the sample after the mould and soil had cooled and the mean length of the soil bar was calculated (Minke, 2012).

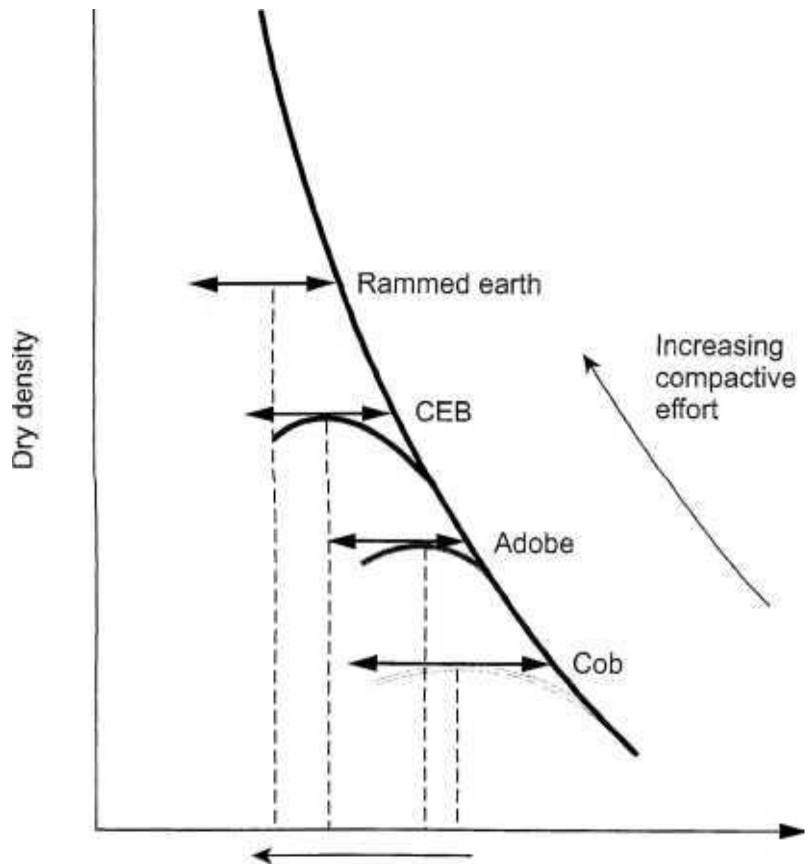
According to Houben and Guillaud (1989), alterations in the applied weight and variations in pressure in pore water lead to failure of effective stress factor saturated soils which hold water in the voids between the particles (pore water). Entire stress (the stress because of the applied loads), singular stress (effective stress) and pore water pressure collaborate to dictate soil behaviour according to the principle of effective stress states. Elevation in the effective stress is seen if any one of these deviates from normal. On the other hand, without any variation in applied loads, a failure occurs when pore water pressure is increased (namely, a decrease in effective stress). Rainfall-induced landslides and collapse because of a mounting water table are examples of such behaviour. Hence it is concluded that water significantly complicates the behaviour of soils.

D. Compaction

Mechanical force is employed to create rammed earth and compressed earth blocks from e soil mixtures because this increases the density of the construction materials taken from the earth and also reduces their volume. The strength of the material and creation of pore size distribution both rely on the degree of compaction (Jaquin and Augarde, 2012).

Since the air is eliminated, compaction increases the amount of saturation and density and ultimately decreases the volume of the soil. The original water content and the total energy provided determine the extent of compaction of a soil; this is calculated by its dry density (bulk of solids per unit volume of soil). There is optimum water content (OWC) for every soil, upon which maximum compaction can take place. The particles will not reorganize into a thicker material if the soil is not wet enough (Jaquin and Augarde, 2012). However, the density cannot be increased if the soil is too wet because the compaction will only endeavour to compress the water, which is not possible (Jaquin and Augarde, 2012).

The vibrating-hammer test or the standard or heavy Proctor tests are examples of tests that can be performed to check the OWC for compaction of a specimen. Depending upon the soil, each test employs a regular (but changed) compaction. The OWC for a clayey material will be evaluated by a Standard Proctor test, while a vibrating-hammer test will be performed for gravel, since larger moulds are required for huge particle soils. The Standard Proctor test is also employed for the OWC of modern rammed earth construction. The test outcomes are consistent and the OWC for a specific soil using the corresponding compaction technique is shown by the peak in the curve of compaction. Since the compaction process proceeds in layers for earth-building materials (e.g. rammed earth), the compaction process is complicated further. Equipment has recently been develop for the lab analysis of these procedures (Jaquin and Augarde, 2012).



Decreasing optimum Moisture content **Water Content**

Figure 48. Relationship between dry density and optimum moisture content. Ranges of moisture content and dry density for different earth building techniques (Jaquin, 2012)

5.2 Soils of Saudi Arabia

According to Atlas (2005), over 30% of the country is basically the Saudi desert. With particle sizes from medium to fine, this massive area of over 275,000 square miles is entirely covered by deep reddish orange sand dunes.

With enhanced percolation and little water-holding capability, the sand is mainly quartz, which is worn by the wind when dry. In valleys and oases, the soil is fertile due to natural streams from seasonal flow, and there is some clay. However, they are not suitable for agriculture. Production of clay brick and other fired clay goods cannot take place due to the shortage of natural clay amounts, according to Allison (Al-Jaded, 1994).

To check the different soils that were employed for construction in Saudi Arabia, numerous soil samples were taken from common building locations all over the country. The author questioned old-fashioned master builders using the field survey and they revealed that they normally used native soil for constructing houses. Hence, those native areas were used to pick the soil samples.

Spain and Egypt received these soils gathered from various regions of Saudi Arabia in closed plastic bags. Five samples from the central Najd and south-western (SWR) merely three soil samples were collected from three dissimilar areas in each region, since earth is widely employed as the chief walling material and also because of the huge zone of the central region, the Najd. A number of tests were run in the laboratory as all soils were moulded and employed in the examination of the soil qualities.

With liquid limit ranges between 24%-34%, plastic limits of 15%-21% and plasticity indexes of 9%-13%, all of the soil groups have a low degree of plasticity according to Table 3. The value of the linear shrinkage was seen to be directly proportional to the clay content, although 3.2%-6.1% is the range of the linear shrinkage of the different soil.

Table 3. Physical characteristics of the different soils used in building construction in Saudi Arabia (Saleh)

Region	% Sand	% Silt	% Clay	LL	PL	PI	Linear shrinkage
CR	76.98	19.69	3.32	24	15	9	3.2
SWR	54.36	27.9	17.75	34	21	13	6.1

5.2.1 Samples of Sun-Dried Earth

In various areas of the country, various specimens of adobe and cob were gathered from timeworn mud constructions, apart from the ones gathered during the investigation. As earlier, depending upon the earth type, such samples were separated into two groups. The thickness, strength and moisture content of the material in each sample were assessed.

Table 4. Moisture content, density and dry strength of sun-dried samples collected from the different region (Saleh)

Region		City or Town	Moisture content (MC)		Density (D)		Dry strength (S)	
			MC%	AYG.	D (kg/mA3)	AVG	S (MN/mT)	AVG.
		Al-Dariyah	1.67	1.73	1670	1770	1.88	1.84
Najd	CR	Riyadh	1.98		1690		2.02	
		Shaqra	1.53		1950		1.62	
		Najran1	2.19	2.39	1790	1750	2.72	2.18
Asir	SWR	Najran2	2.62		2020		2.58	
		Najran3	2.36		1440		1.24	

The outcomes of this study are recorded in Table 4. In different zones of the central region, 1.53%-1.98% is the range of the moisture content, while the south-western region (SWR) showed a 2.39% moisture content. With averages falling between 1750 kg/m^3-1770 kg/m^3, the samples in the different groups were revealed to be near to one another for dry density.

An Avery Denison machine was employed to check the dry strength of the samples. To confirm that the load applied by the machine at a deformation rate of 1mm/minute was evenly distributed, two 70 mm squares of fibreboard were employed, one over the sample and one below it.

The mean dry strength of specimens from the separate materials of the central area is in the range of 1.62-2.02 MN/m, as seen in Table 4. With 2.18 MN/m being their value, the uppermost mean dry strengths are in south-western region (SWR) due to the sandy soil fines that are rather significant. Clay and silt, as revealed previously, are abundant in the south-western region.

5.3 Need for Improvement

As revealed by Blake (1980), tradition has been pushed back a notch as Saudi Arabia embraced the modern era technologically, which kept advancing over the decades. Nevertheless, less than fitting buildings have been constructed on the basis of the advancement in the technical condition and betterment of the socio-economic system.

The handiness of cutting-edge technology replacements caused by abrupt financial changes led to the termination of construction employing local means and methods (Blake, 1980). Prohibition of local materials (particularly municipal protocols regarding adobe prohibition) has been encouraged by the modernization outlook, leading to a loss of the uniqueness of the architectural tradition of Saudi Arabia.

Under the chairmanship of HRH Prince Salman bin Abdul-Aziz along with associates from other involved organizations, an executive committee was recognized and a Royal verdict was delivered in 1998 favouring the improvement programme of historic ad-Dir'iyah (Renovation and Development), since ad-Dir'iyah happens to be a significant example of the earthen traditional urban fabric of the country (Ada.gov.sa, 2014). Focussed studies on ancient ad-Dir'iyah were undertaken by the High Commission for the Development of Riyadh, which laid out a concluding managerial plan in collaboration with the General Commission for Tourism and Antiquities for the refurbishment and restoration of ad-Dir'iyah, which was to be returned and reconditioned into its former state (Ada.gov.sa, 2014). ad-Dir'iyah was intended to become an epitome of cultural tourism for the area, since the improvement programme included several architectural, cultural, economic, and social plans. UNESCO funded a study of the location performed by the Egyptian Antiquities Organization as the Department of Antiquities and Museums developed an interest in saving the ruins of ad-Dir'iyah in 1974. Another study was performed in 1978. The ultimate goal of these studies was to pick constructions for conservation and repair, and suggest approaches for doing so.

Only some constructions were selected for repair by the Department of Antiquities. Since 1970, it has focussed on restoring the Palace of Nasr first, and then the Palace of Saa'd in Turayf in the late 1980s, according to the method suggested in the UNESCO files (SCTA, 2009).

Since sun-dried mud buildings logically suffer from heavy rain and necessitate continuous care, the assurance of their preservation comes with some tough choices. To attain the best outcomes regarding enhanced stability, there is no stabilizer created as yet which can be incorporated into a mud mix. Moreover, it was hard to point out the original part after restoration, and selecting the construction to be rebuilt or renovated was another problem itself (Al-Aidarous, 2012). The original look of the mud walls (excluding their arrangement), since they break down completely into shapeless forms, was hard to maintain, hence they have to be reconstructed again. This, according to Facey (1997) leads to those buildings looking like new buildings instead of 'restored' ones. Plenty of care is taken to make sure that the antiqueness is not lost completely and this is done by the employment of original materials for restoration. Structures in Turayf, like the Salwa Palaces, the Bait al-Mal, the Turayf Mosque and the Baths were decided to be reconstructed eventually. Nonetheless, to avoid them worsening, the task at hand is to secure several remains as they are. To reserve this famous spot for upcoming generations of Saudi Arabians, the Department is very determined about their work. The work done is remarkable and praised by not only Saudi Arabians but the rest of the world as well. Ad-Dir'iyah's endurance is guaranteed and it is likely to become an important icon of Saudi Arabian nationhood. Intense disapproval was shown by earth construction investigators on the fresh improvement and manner of building work at the visitor's centre of ad-Dir'iyah (Ada.gov.sa, n.d.). The outside of the walls and the load tolerating wall of the whole Al-Bejary Shopping Zone were hastily coated with mud and built with reinforced concrete and the fundamental brick assembly was uncovered and observable after rains wore off the mud plaster.

Indigenously obtainable mud mortar and limestone was employed to rebuild the city wall of ad-Dir'iyah since the 1980s when the Department of Antiquities was determined to rebuild its fortification. Suitable construction material and building methods were employed which is very obvious from the appearance and durability of the construction. In contrast to the old-fashioned mud brick structure, the construction of the shopping zone or other recently made buildings could be performed by adopting the stabilized earth construction process, providing it with remarkable strength and stability.

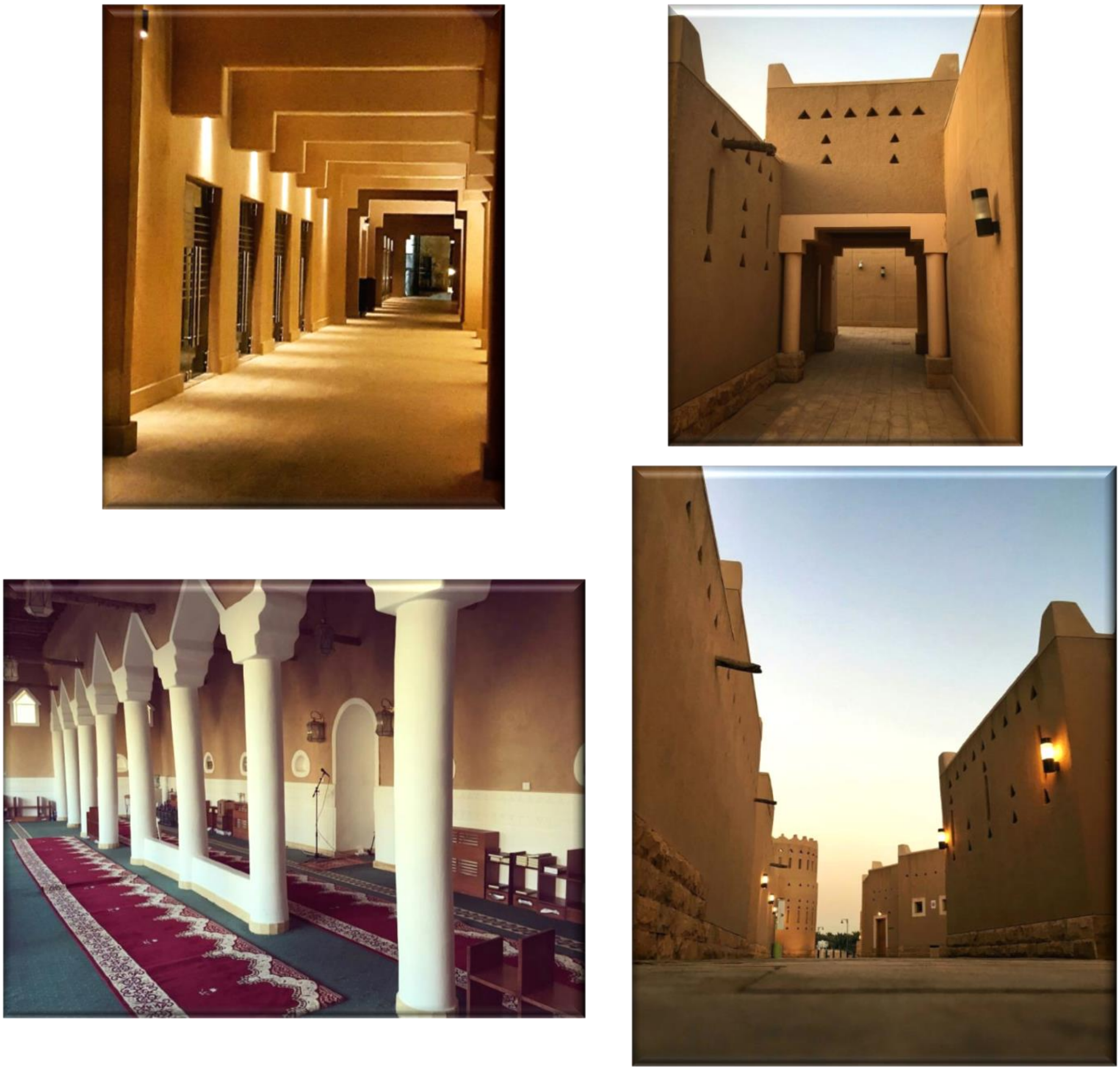


Figure 49. Al-Bjari District Heritage Commercial (Al-Aidarous,2013)

Figure 50. Map of ad-Dir'iyah (SCTA)

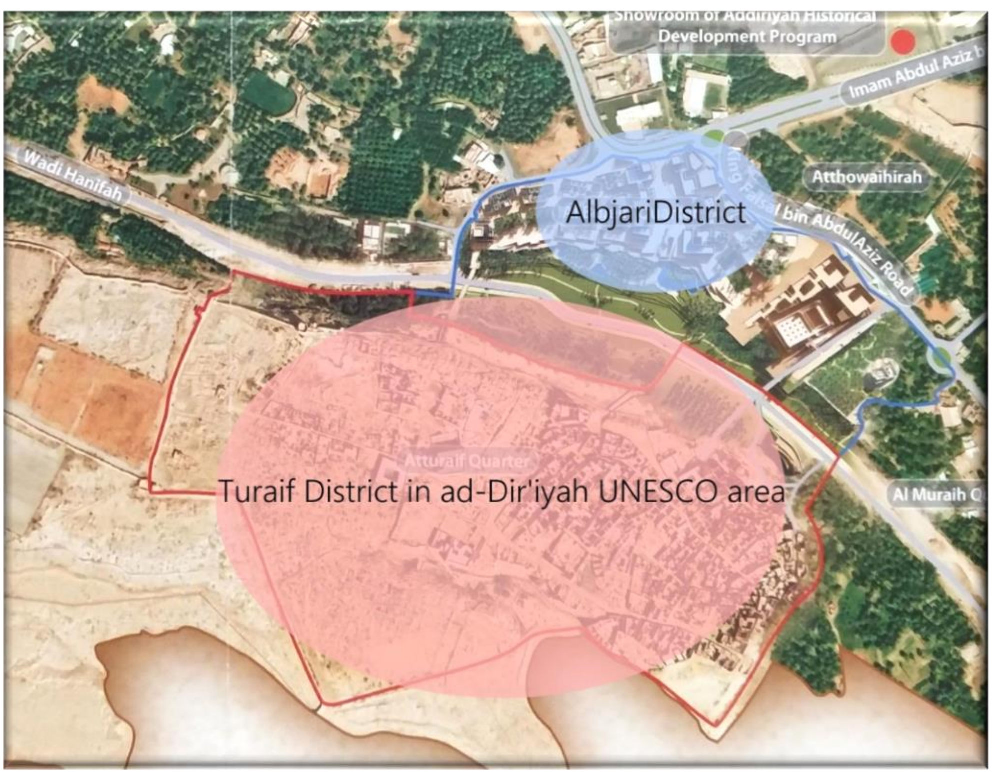


Figure 51. Area analysis of ad-Dir'iyah (SCTA)

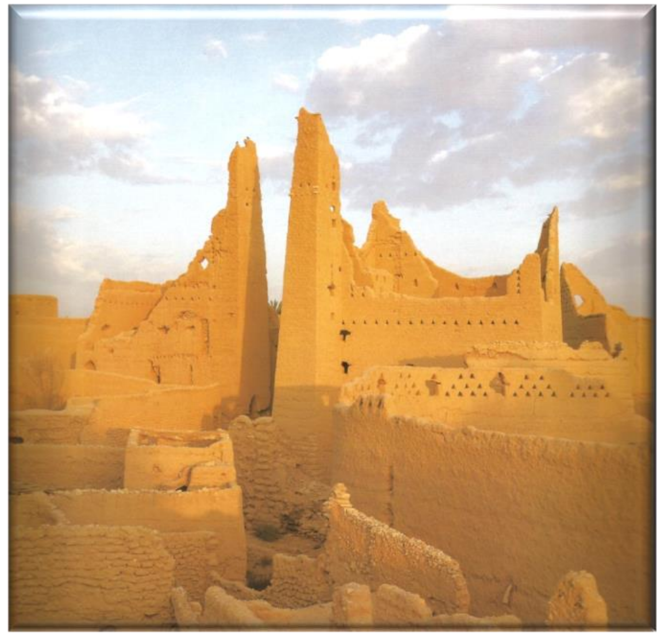
 

Figure 52. Turaif district UNESCO area (Al-Aidarous,2013)

5.4 Public Awareness

According to Al-Jaded (1994), several people nowadays believe that if pertinent, the past must always be used to take lessons from the blunders made and wrong decisions taken as this will greatly improve the present. Only public mindfulness regarding the appropriateness of the current reinforced concrete villas to the weather and cultural conditions of the area gives rise to these statements and beliefs because the more the public is concerned, the more chances there are of betterment. Such consciousness is improved by the capacities of local schemes that have been completely disregarded and substituted by western approaches that are frequently unsuitable for native situations and requirements. Grounding this type of awareness are lost character, concealment and heating issues. To stay clear of the trouble caused by this, approaches like paint, exterior and meticulous details and certain ornamental features of customary earthen constructions on novel reinforced concrete structures have been adopted by smart architects.

Certain models of complete support and reaction of most native architects to the architectural tradition of the country and the mindfulness of their customers happen to be mud plaster, stepped crenulations and triangular openings on modem era constructions, which can all be seen in the Najd area. However, if the construction is not entirely suitable for the requirements of the people, then the old-fashioned external look to an international project will be a huge ‘architectural lie’. Despite this fact, a number of marketable and promotional purposed constructions, primarily cafés, coffee shops and fast-food places with old-fashioned exteriors are sometimes built.

As Forsyth (2008) stated that some cities and other government organizations too have displayed a great amount of appropriate awareness regarding the conservancy and repair of traditional earthen constructions. Lately, via the organization of a yearly Janadriah Festival, the National Guard has taken its first step in contributing to reinforcing the Saudi Arabian heritage (Figure 53). The ultimate goal of this huge festival is a never-ending obligation to the heritage and cultural standards of Saudi Arabia. In this modern era, people have let go of their past, culture and heritage, not only in this aspect but in other aspects of life too. Reminding them of their roots, especially in the aspect of construction, is the topmost priority of this festival.

Figure 53. Al-Janadriah Festival (SCTA)

Special pavilions are arranged by numerous governmental organizations and private-sector establishments that finance this festival every year. The pavilion of the Royal Commission for Jubil and Yambu (RCJY) gave a streak of technology and traditional appearance, despite the fact that a lot of sites used for displays generally have a traditional look.

5.5 Absence of Adequate Research

According to Fathy (1986), to take care of the heating issues faced in reinforced concrete buildings in the area, a number of architects commenced research on adobe due to the vital detail that "Mud buildings are warm in winter and cool in summer". Studies like these focus on the assessment of the performance of adobe under thermal conditions and relate it to other modem building materials. Earth is a problem-solving construction material that is more than suitable for the issues related to weather resulting from the alteration to modem construction materials, and this point is encouraged by these studies. Nonetheless, this property of earth is not the one property that makes it a suitable and fine material for construction. Certain other rather significant properties make architects encourage the use of it. These side properties include strength, toughness, and durability (Mukerji, 1988).

To sum up the current knowledge of Saudi architects and engineers about earth building, Al Aqel circulated a feedback form among 60 architectural and engineering organizations and received 25 responses. According to the results of this survey, a huge amount of members of such organizations lack the requisite material on the subject of earth as a substitute construction material that can be employed for the construction of suitable buildings, although they are holders of B.Sc. degrees in architecture. Not only this, but all of the responses encouraged the employment of new building materials and openly discouraged the use of earth, suggesting banning of adobe construction by local building codes, seeming completely unaware of its importance.

We need to realize that traditions change with time and they must be continuously studied, assessed and improved so as to construct a strong bridge between past knowledge and information being discovered in the future. The bits and pieces of published work on construction with earth and the lack of sufficient information on earth construction in Saudi Arabia should not stop us at a point where we sentimentally look at old-fashioned adobe constructions, demanding that they can be implemented today without the least bit of alteration. Instead, change must be embraced with open arms.

Keeping in mind all of the aforementioned facts, since it is practically impossible for it to function positively anywhere ubiquitously, earth architecture must not be held up as the marvellous answer to all housing questions and issues. It holds great importance that the method used be not at all complex but still offer structural support and strength to create a better adobe arrangement for Saudi Arabia. If a better customary earth method is to be recognized and utilized all over the county without any hindrance, factors like economical budget and indigenous manufacture are also very essential. Therefore, to study construction and repair approaches that may be appropriate for Saudi earthen constructions, a number of field trips were taken by the author to places like M'Hamid El Ghizlane, Morocco and Hadhramaut, Yemen.

5.6 Building with Earth in Saudi Arabia

As stated by Maini (2005), many benefits are offered by earth exclusively for a hot-arid area such as North Africa, South America, and the Arabian Peninsula, and it could be a great asset in producing energy-saving, cost-effective residences. Like everything else, it too has visible drawbacks that cannot be overlooked when bringing back earth construction to the individuals of Arabia. This chapter enlists and discusses the chief advantages and disadvantages of picking earth as a construction material. A survey done by the author in 2013/2014 in which he collected soil specimens from Saudi Arabia and Yemen revealed the details of the nature of earth and factors responsible for its ruination in earth buildings. The requirement for better earth construction, particularly for the Najd region of Saudi Arabia and public mindfulness about the appropriateness of modem constructions is discussed at the end of this chapter.

5.6.1 Advantages and Disadvantages

To assist us to keep in view the better qualities and give us accurate and work wise comprehensive explanations for limitations, in this section, an overview of the positives and negatives of earth as a construction material are discussed, since there are quite a few advantages and shortcomings.

A. Advantages of Earth Construction

For a hot-arid county such as Saudi Arabia, the advantages that can be benefited from when selecting earth for building include:

- If not in every building location in the country, earth is the most economic and most easily obtainable construction material found at a maximum number of sites. Stones require a huge budget to mine while cements are highly costly to make, but when it comes to earth, it is practically the only local material easily obtainable to date with low-priced manufacture, as compared to other substitutes for example fired bricks that are not at all cost-effective during preparation.

- Inexperienced people who know little about construction can make use of earth without any issues and contribute to the construction of their own house, since earth construction does not require any costly tools, instruments or complex expert information, hence adding to the effortlessness and simplicity of construction. It is very user-friendly.

- According to Abanomi (2005), the utilization of costly energy in the manufacture of cements for moulded concrete blocks is not a problem when dealing with earth elements which can be shaped without the depletion of natural sources, for instance, wood which is very widely utilized for baking clay bricks in some areas of the country.

- Without any artificial heat required or power consumed, earth products can be easily shaped and manufactured, leading to no harm to the environment like contamination and devastation. Reprocessing of these products and recycling of their by-products is another great way to preserve the environment. The natural heat of the sun is used to dry earthen products (Zami, 2012).

- Several requirements can be more than satisfied considering the fact that earth is a tremendously adaptable substance. It permits structures to be constructed in a vast assortment of construction methods and styles. Earth can be employed with other materials like binding mortar for rubble stone walls, or as a filling and concluding material on wood frames. Trenched or earth-protected places to entire buildings of earth with walls and roofs in the form of curves, domes, and barrel vaults made of sun-dried blocks can make use of this material (Mosibah, 2013).

Figure 54. Arches at the Ba-A'alawy Mosque built in adobe (Al-Aidarous,2014)

- The idiosyncratic nature of every region, the procedures of building, indigenous building resources, along with the communal, financial, terrestrial and weather conditions can all be displayed by the use of earth (Maini, 2005).

- Thermal luxury stands to be the greatest advantage of earth since it has a high thermal insulation that works against the brutal temperatures of the outside. Basically it stabilizes and recovers indoor air moistness and temperature, which is ideal for hot countries like Saudi Arabia (Schroder, 2010).
- Apart from all of the above, the level of comfort keeps escalating as we deal with earth since it holds the ability to insulate sound. The use of earth also makes buildings fire resistant and hence safer and secure to live in.

B. Disadvantages of Earth Construction

Why the material is remains formally undesirable as a construction material in Saudi Arabia and other countries will be discussed under this heading. Its limitations, the absence of accurate knowledge on its manufacture and lack of awareness of the ways to employ them successfully, all stack up to make this list of drawbacks:

- Rain and capillary action from the foundations is not good for earth constructions because water infiltrates and compromises the building, making it susceptible to destruction (CRAterre, 2008).
- Weighty roofs of buildings with a large area cannot be supported with earth since it cannot bear that amount of weight. Beams and tops require power and support for their bending moments, and to rely on earth is not apt as it has little tensile strength. Roofing and walling methods that use earth elements in compaction, for example domes and vaults, however, can use earth suitably.
- Schroeder (2010) revealed that when dealing with clayey soils, obligation of earth products to volume alters. Hence these are usually inadequate due to the unnecessary shrinking and cracking and the flawed attachment between the plaster and the earth wall when they are subjected to changed climatic situations.

  Due to their low stability, repeated repairs and care are required because earth constructions are susceptible to surface wearing away, rain and wind-borne sand.
-

- Al-Junaid (2014) suggest that calamities like floods, earthquakes, pests, wind gusts and rodent damage cannot be tolerated by earth buildings and these ruin earth structures aggressively.

In modem structures, these weaknesses in earth buildings could be steered clear of. They are not only widespread in Saudi Arabia but in other developing nations too. Natural weather stresses, for example pouring rain and gusts of wind, especially in serious or uncommon conditions, are responsible for flaws in earth constructions. It is an undeniable fact that it is not only the weather that forms the circumstances for catastrophe: the main reasons behind this ruination are human factors, for example an inferior plan, improper choice of soil, carelessness, etc. Despite all of this, the part played by the environmental factors themselves in causing chemical, biological, mechanical and physical damage cannot be ignored totally.

To trigger flaws that arise from either the building itself, alterations in making of materials, or just in the earth construction, the chief human factors and the natural forces working from the outside may work individually or together.

5.7 Deterioration and Pathology of Earthen Architecture

Price (1996) revealed that the worsening of these constructions is a continuous headache for whoever is acquainted with earthen architecture. Earth is a rather defenceless building material, even though it is the most extensively used around the world. According to Clifford Price, "If we are to do anything to reduce or prevent this loss of our heritage, we must first be able to characterize the material. We need to be able to describe the decay, and to measure the extent and severity of decay. Only then can we hope to understand the causes and mechanisms of decay. Only then can we hope to understand the behaviour of any particular (material) in a given environment". The rapid deterioration of a massive amount of earthen constructions, comprising archaeological remnants, some modern constructions and other historic locations has resulted from inadequate knowledge about traditional building methods, poor use of resources and absence of habitual care in Saudi Arabia. Universal deductions concerning the complications and management of earthen constructions cannot be made due to the fact that the heterogeneity of earthen materials and building systems makes them hard to classify and makes it difficult to describe deterioration procedures. Earthen architectural heritage faces great jeopardy attributable to these factors.

The recognition and examination of weakening factors, the reasons behind corrosion, and the ordinary symptoms are all discussed in the following summary. To comprehend the cause of any issue and to successfully plan a reaction that solves the problem instead of only lessening the symptoms, we sometimes need to work in reverse, tracking it back to the root cause. We need to realize that evaluating corrosion is a circular interrogation in which the indications are normally the first noticeable indicator of deterioration and the start of consideration, and this summary intends to systematically examine the pathologies and factors responsible for deterioration.

5.7.1 Methodologies of Assessment

The problem of the 'restoration' and 'maintenance' of earthen buildings has been discussed by R. E. Hughes (1986). Chemical and mechanical factors were kept in view and a deterioration typology suggested. Hughes emphasized situations that consider the following factors:

1. The materials, on a big and small level.
2. The architectural history and its system.
3. The building method.
4. The structural organization.
5. The use and reuse, like predictable changes in the future.
6. The environment as a whole on a big and small scale.

Fruitful management basically depends on categorizing and methodically perceiving the procedures that result in active weakening and physical distortion, according to Hughes (1986). More damage than good is done when the noticeable indication of destruction is mended without recognizing the root cause of the decay. An approach for the preservation and repair of earthen buildings has been put forward by Van Balen (1990) and the relevant factors are listed below:

- Knowledge regarding the historical values.
- Assessment of the architectural typology.
- Architectural significance.
- Physical environment.
- State of the construction.

Van Balen (1990) highlighted the significance of studying the importance of the architectural object for preservation, and endeavoured to see past physical and merely mechanical concerns. Principally relevant for the preservation of earthen buildings, over the years this approach has also become more of a trend in the idea of preservation.

5.7.2 General Pathologies and Deterioration Phenomena

CRAterre and Doat (1983) explained in detail that destruction happens if water infiltrates or diffuses in, increasing moisture and salts from the ground that may travel into the bottom of the wall, or if the wall is unguarded by a suitable roof or shelter. The crown of the wall is normally affected by the general diseases of earthen architecture in Saudi earthen frameworks. The typical pathologies of earthen constructions and deterioration incidents have been discussed by several researchers. When exterior factors like wind, water and other background and environmental factors are involved, the deterioration is rendered extrinsic. The word intrinsic is used only if the causes are related to the type of building or composition of material.

Warren (1999) discussed failure and its recognition with an emphasis on ancient constructions. Although aiming at new buildings, Houben and Guillaud (1994) defined a number of common pathologies. The decline of earth in the framework of preservation was precisely discussed by Crosby (1983). A brief review of the most prevalent kinds of weakening and their main causes is given in this portion. Downfall, surface erosion, breaks and humps, basal erosion, shielding coating failure, and upper wall dislocation and inclining, according to Crosby (1983) are the most prevalent types of deterioration evident in adobe wrecks and constructions. According to him, the following water-associated issues lead to deterioration:

(1) Wet/dry cycles
(2) Freeze/thaw cycles
(3) Capillary rise
(4) Condensation

Most occurrences of erosion are openly associated with wind, human beings and rain, as explained in detail by Odul (1990). The connection between water and the destructive impacts of soluble salts was established by Vinuales (1981) and Chiari (1985) who held water responsible for most destruction. Infiltration of water, employment of resistant plasters and increased water table are the most frequent causes behind the decline of earth-building materials (Olivier and Mesbah, 1993). Dampness and heat, density relaxation, load reorganization, physical actions, and contraction and breaking, were stressed by Richard Hughes (1983) who saw past physical and ecological mechanisms. Frequently with a location-specific emphasis but occasionally with signs of common deterioration elements that greatly disturb earthen architecture, several case studies have also discussed deterioration. The multifaceted issues of deterioration by employing unsuitable supplies, wind erosion, biological etching and soluble salts in former repairs of the walls of Capo Soprano at Gela were addressed by Alessandrini and colleagues (1990). Noteworthy deterioration owing to changes in thermal expansion and the existence of salts has been caused by water, be it by run-off, capillary action or rain, and wind abrasion, thermal expansion and shrinkage and the employment of cement are the deterioration factors at the archaeological site of Taweq, ad-Dir'iyah, Saudi Arabia. Erosion at the top of the walls is a result of capillary rise and rain, while flooding is responsible for the deterioration at the base of the walls.

5.7.3 Causes of Deterioration

A. Human Factors

Poor Design

AL-jaded (1994) reported that earth buildings in Saudi Arabia have often been constructed by owners or local builders who lack the essential expertise required for the job and this results in poor judgement regarding the site conditions and precautionary measures. The ignorance shown when selecting the topographical location for construction of earth houses results in earth houses being washed away by floods because of their construction in valleys or areas that have a greater chance of being flooded. Inadequate drainage may also occur if proper designing of the topographical site is not done and may lead to accumulation of water at the base of earth walls. A frequent complication faced in earth buildings is base wall erosion resulting from water gathering due to faulty foundation plans, where earth walls run straight into the ground (Figure 55).

Figure 55. Decay caused by water and dampness (Al-Aidarous,2013)

It was reported in 2008 by CRAterre that the faulty foundation plans lacking substantial foundation, differential settlement of stone foundation, or building on expansive clay subsoil can cause significant issues like cracks and leaning walls. Wall cracking may also be seen in cases of architects providing inadequately spaced large openings where concentrated loads are not removed successfully (Figure 56).

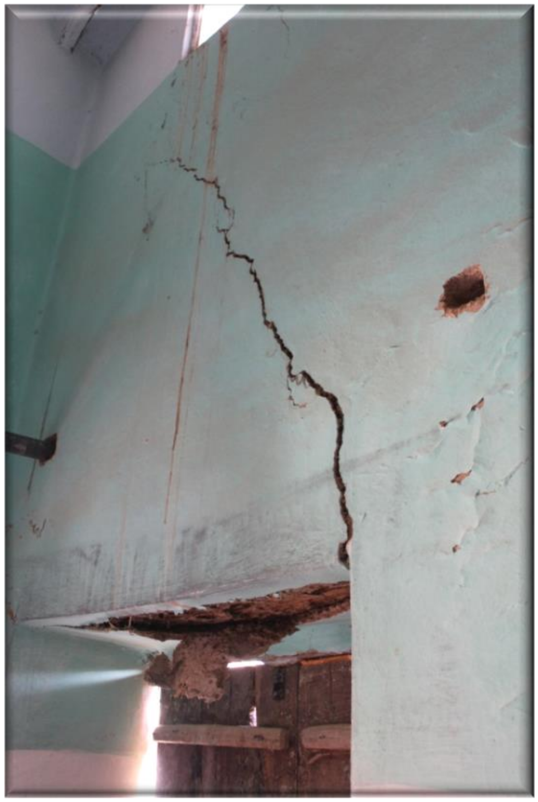


Figure 56. Cracks on adobe walls in Al-Junaid house in Hadhramaut (Al-Aidarous)

CRAterre (2008) reported that if proper considerations are not taken when laying out the architectural design, a building may be constructed near large trees or with landscaping close to earth walls. The growing roots will result in weakening of the building foundation, walls may collapse, sub-grade shrinkage may also occur as large quantities of water will be absorbed from the soil or the structure could also be damaged by moisture retention. CRAterre (2008) also reports that faulty designs and missing essential details in the construction design plan will give rise to complications like leaking roofs and unacceptable roof drainage, surface erosion, faulty gutters, breakdown of plaster or rendering, and flawed woodwork joints in doors and windows.

Incorrect Selection of Soil

It was reported in 2008 by Hunt and Suhr that earth buildings are seen to collapse rapidly when incorrect selection of soil is made. Cracks witnessed in earth buildings are due to the selected soil containing a high percentage of clay; these soils tend to have very high shrinkage/swelling ratios. Soils that have excessive sand in them tend to give reduced handling strength in green conditions, and the resulting product crumbles and erodes simply when dry.

Hunt and Suhr (2008) reported that topsoil is importance for growing crops rather than being used as a building material, because of the high content of organic material it contains. Employing topsoil to make earth products will result in attacks by termites and other insects. The changing weather conditions promote chemical reactions between the soluble inorganic salts, particularly sulphates, and the moisture, causing expansion and disarrangement of the soil product (Maini, 2005).

Negligence

It was reported in 2012 by Jaquin and Augarde that the survival of earth buildings is greatly reduced due to the lack of maintenance when otherwise their life may be prolonged with proper care. Ruination is mainly because of not attending to problems of cracking, sagging or bulging in earth walls and avoiding repair at the earliest possible stages of damage. Broken plumbing or roof gutters allow short-term water flows that cause harm to earth building in a very short time.

Destruction resulting from attack of vermin and other rodent infestation is because of the carelessness of occupants and their failure to fill cracks and hollow spaces. This is a standard that can be applied to all type buildings, including earth buildings (Jaquin and Augarde, 2012).

Some areas of the earth building are rapidly worn out while in others collapse may be witnessed due to improper care being taken of the external coatings and employing incorrect surface treatments. A waterproof, durable and decorative surface that offers a wide range of colours and textures is obtained by using cement stucco, which is an example of a plastering material commonly used on earth walls (CRAterre, 2008). There are still some problems associated with it, for example, firstly it increases the rate of deterioration of earth walls by trapping moisture and promoting the breakdown of surfaces, secondly due to a different co-efficient of expansion when it separates from the earth wall's surface it will hide water erosion occurring due to leaking roofs, broken plumbing and faulty gutters. This water erosion may not be visible but will harm the wall fabric and lead to serious structural problems that can result in a collapse.

B. Natural Factors

Mechanical Factors

Ruination of earth buildings is caused by the natural causes rain and wind. Mechanical destruction caused by both is witnessed on earth walls in both the dry and wet areas of the world. They both have their own limits regarding the severity of damage caused and how many other factors can contribute in each case.

Rain

Rain acts as a threat to all untreated earth elements, particularly those with high clay content (CRAterre, 2008). The clay binder completely washes away in torrential storms, allowing the other materials to be easily washed away and exposing the surface beneath to a new wetting cycle. Furrows, cracks, fissures and pitted surfaces that are seen in earth walls are because of the erosive action of rain that is followed by the drying out of earth walls (Hunt and Suhr, 2008).

The most usual destruction seen is in wall heads due to rain water penetration, insufficient drainage at the wall base and rain splash. Basal coving is the most frequent type of damage to unprotected earth walls. This is hollowing out of the wall just above ground level. This results firstly because of accumulated standing rain water at the foundation level and secondly due to rain splashes at the base of the wall. When rain rundown is seen in comparison to rain splashing, rain rundown runs deeper and wets the base of the earth wall while splashing causes mechanical erosion at the junction of the wall and the ground. This ruination process is further enhanced by the capillary action of moisture rising in the wall from ground water (Jaquin and Augarde, 2012) (Figure 57).

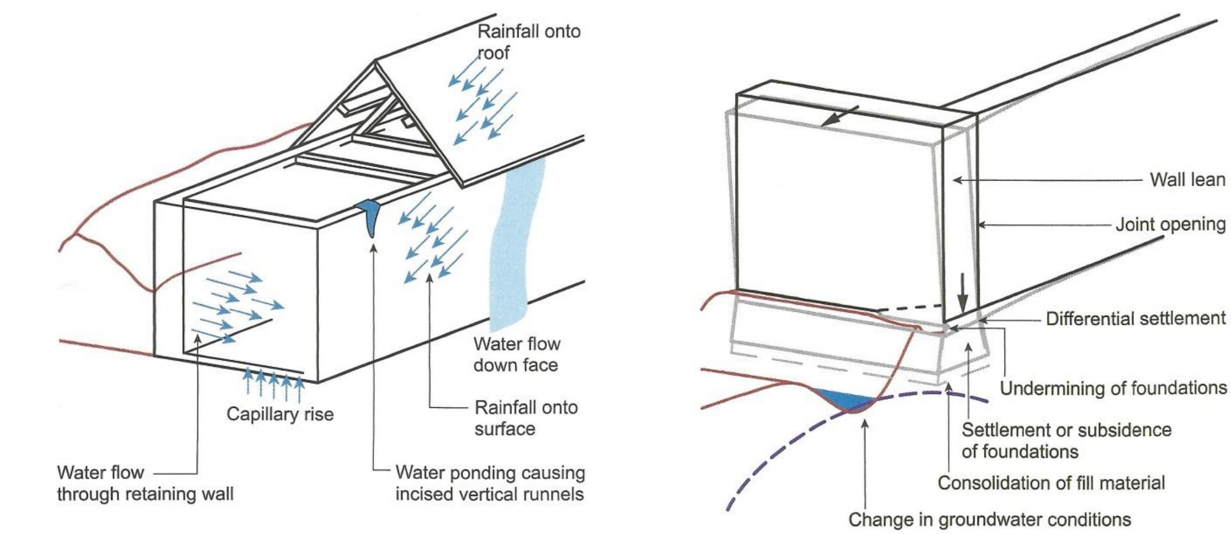


Figure 57. A general problem caused by dampness (Jaquin and Augarde, 2012)

Wind

Mosibah reported in 2013 that in the desert areas of Saudi Arabia, earth buildings get worn out by wind. Deterioration by wind is highly dependent on its velocity and ability to carry high contents of dust and larger particles of sand. Mechanical destruction results from the wind-borne sand and dust particles acting as a sand blast and causing abrasion of the surfaces of walls. In the dry regions and desert areas, symmetrical wear of exposed walls give good evidence of damage by wind. No such effect is found in the interior and protected walls of the area.

Erosion, wearing of surfaces, and washing-out of particles, leading to breakdown of soil constituents is mechanical destruction occurring because of wind-borne rain. It is difficult to point out the differences between rain and wind erosion as many effects are similar, yet abrasion caused by wind is more visible in the upper half of the wall and at the comers, while major damage resulting from rain and capillary action is visible in the lower third of the wall. Moisture present in the walls is dried by the action of the wind, while the damage occurring by capillary action increases.

Repeated changes in the weather conditions or chemical breakdowns cause a significant increase in the rate of weathering of earth walls by wind, especially when the elements have lost their surface hardness (Mosibah, 2013) (Figure 58).

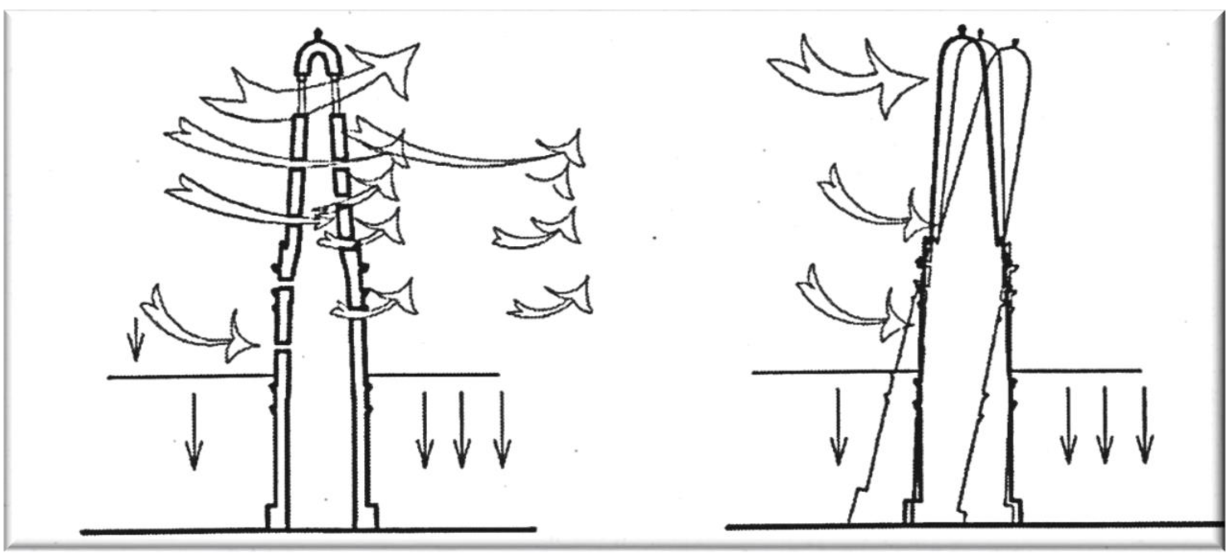


Figure 58. A study of wind effect earth building (Mosaibah, 2013)

C. Physical-Chemical Factors

Capillary Action

Capillary action occurs in porous materials that come into contact with any other material containing a high percentage of moisture. This is one of main reasons behind distress caused by ground water in the earth buildings of Saudi Arabia. Constructions like farmhouses, and earth structures constructed near rivers, lakes and ponds are particularly affected by capillary action (Figure 47).

Standing ground water gives rise to this natural phenomenon. Ground water may be present for a number of reasons like high water table, seasonal water fluctuations, improper sewage and drainage systems, excessive plant watering, or changes in grade on either side of the wall (CRAterre, 2008).

Trotman reported in 2006 that the porosity of the building material used in construction and the quantity of water present in the soil will determine the capillary action of ground water that rises up into the wall and causes the earth wall to erode, bulge, swell, and cave. This rising up of water due to capillary action from the ground into the base of the earth wall results in breakage of the bonds present in clay and the other particles of soil and ultimately results in a soft material that can easily be eroded by many deterioration factors. In addition, shrinkage cracks, loose sections of earth walls and mud plaster crumbling are seen because of the swelling and drying cycles happening because of ground water fluctuations. Hence, there is an overall decrease in the strength and durability of the earth building. Sometimes the wall fabric is fractured as a result of the dissolved salts present in the water subjected to capillary action that re-crystallize on drying, causing fractures.

Expansion and Contraction

Hardwick and Little, (2010) explained that over time continued expansion and contraction resulting from temperature fluctuations leads to the breakage of basic mechanical bonds. In countries like Saudi Arabia where a hot-dry climate is present in the summer time, it is seen that inconsiderable expansion and contraction of surfaces occurs due to the varying temperature of surfaces during the night time and daytime. These continuous cycles of expansion and contraction break up the different grains of soil, allowing wind, rain and other deterioration factor to erode the wall easily. A difference between the thermal expansion coefficients of soil and plaster causes cracking; this is also an added effect of the repeated cycles. Cracking in the plaster material also causes water and water vapour to penetrate the earth wall beneath; the plaster tries to stop the wall from drying to avoid these problems.

During the winter, particularly in cold climates when temperatures are significantly low, it is seen that ice crystals form within the earth products causing the mechanical bonds between the different soil components to break and resulting in structural damage.

Schroder reported in 2010 that earth products that contain a high percentage of clay are particularly affected by changing humidity and periodic surface wetting and drying cycles cause volume change. Exposed wall surfaces that experience rapid drying out are often seen to have shrinkage cracks as well as plaster failures.

Chemical Reactions

Ruination by soil erosion is possible because of the direct contact between the earth building and the local soil. Soil erosion involves the chemical composition of the local soil and the effective soil moisture. Evaporation is the leading cause of soil moisture rising, be it due to rainwater or ground water (Facey, 1997).

Most soils have soluble salts present as a major component. These salts travel up from the soil by capillary action as the moisture evaporates from surfaces, and get deposited on or near the surface of the wall. The stability of the earth structure is harmed in many ways by the increasing salt concentrations; for example the chemical devastation of the cohesive properties of the clay particles that ultimately results in the collapse of the earth structure.

On a hot dry day, a common issue faced is re-crystallization of dissolved salts that cause harm by shattering the wall fabric and peeling off soil particles at the evaporation line. Chemical reactions between sulphates and the clay fraction of the soil occur due to the presence of soluble inorganic salts, especially sulphates, in arid and semi-arid regions. Expansion and disruption of earth products is the common result of such chemical reactions. Areas with alkaline soil, high water tables, or improper sewage and drainage systems are a common source of such issues.

D. Biological Factors

Vegetation

Vegetation expedites the decay of earth structures. Seeds that are accumulated by wind, animals, birds ,and insects grow in the cracks of earth walls or roofs. These growths of roots break down elements and cause moisture collection, in turn contributing to the decay of the earth building (Al-Habshi, 2014).

Physical damage is a calamity that can also be caused by shrubs, trees, and other plants. The roots grow under the earth foundations, trapping moisture and transferring it to the structure. However, removal of these plants can halt the process (CRAterre, 2008).

Animals, Birds, and Insects

Certain animals and birds that are attracted to the soft structures of earth establish burrows and nests in roofs, walls and foundations. Other than that, insects that live in these cracks and hollow spaces can enter and depart without being noticed, and it is these insects that weaken the earth structure as well as damage the soundness of the building (Zami, 2012).

Straw is a component that is typically used in wood structures such as doors, windows, lintels, floorboards and roof members, as it can be used to improve the functioning of the structure. However, the presence of straw leads into further deterioration of the structure due to pests inhabiting the hollow places, making it an unhealthy environment for its occupants (Facey, 1997).

Nonetheless, there is no reason why these structures and houses cannot be deemed adequate enough to live in, and resist pest infection by simply giving more attention to detail and design while creating the structure. Another caution that can be taken is to avoid infestation through proper cleanliness by the occupants, as well as filling in cracks and hollow spaces and using insecticides.

5.8 Summary

In summary, it is noteworthy that the impediments in earth structures mentioned by various authors can be focused on as well as dealt with by various innovative solutions that have been established through proper research and modernization. Minimization of cracks, new ideas regarding water erosion, and upgrading the binding force, strength, and increasing insulation of the building structures can result in positive outcomes. Researchers such as Houben and Guillaud (1989), Minke (2006), Walker (2005) and Maini (2005) have come up with numerous innovative solutions in their published papers giving directions on how to stabilize earth structures so that they are longer-lasting, as well as covering the previous drawbacks of earth construction. These researchers have also stressed the urban housing crisis and how it can be resolved through durable constructions such as the use of rammed earth (RE) and compressed stabilized earth block (CSEB), stabilized adobe and other contemporary stabilized earth construction techniques.

A comparison of the advantages and disadvantages of earth-building material has also been taken into consideration, in order to help deduce the qualities of the material and provide a realistic picture of the shortcomings that are common but can be easily taken care of. The major causes of deterioration include special reference to Saudi Arabia, due to the fact that there is a lapse in information regarding the engineering properties of soil used in construction there, as a survey was done by the author in 2013/2014. During the research, substantially large samples of soil and sun-dried earth products taken and examined for their physical qualities showed that ‘Sandy Loam’ is the most suitable soil for improvement. Hence, the objective of this particular study is to incorporate traditional and modern expertise in order to create a form of soil stabilization that gives a durable and longer-lasting building material for hot-arid regions such as Saudi Arabia.

CHAPTER SIX

REVIEWING THE CONSTRUCTION TECHNIQUES OF HADRAMOUT, YEMEN AND M'HAMID El-GHIZLANE

Case study investigations are essential in this types of research. As indicated in the previous chapter, earth constructions are historical as well as current in many countries of the world. When it comes to the earth architecture of Saudi Arabia, a definite case study is required that has nearly the same architectural character, culture, building technique and use of adobe in particular.

It is very difficult to find any construction using the same earth material in recent times and in particular any with the same building character that is found in Saudi Arabia. M'Hamid El-Ghizlane in Morocco and Hadhramaut in Yemen were my finding after much investigation.

One city found closely resembling the architecture characters and culture of Saudi Arabia is the city of Hadhramaut. They had the pleasure to use the adobe recently which turned out to be a positive experience. In the past much research has been done on the earth architecture of Yemen. However, the focus of my research is on the areas of construction and conservation techniques.

M'Hamid El-Ghizlane is situated in the south-east of Morocco. Frequently used construction materials in the region are rammed earth and adobe. Historical constructions of rammed earth, adobe and both materials mixed makes this region of great value to understand the strength of rammed earth and the flexibility of adobe. This area is crowded with earth constructions; the writer made a visit to Yemen and Morocco between April and August 2014 to inspect and study the earthen architecture and construction techniques in both countries; however there are no research and teaching courses offered in English and Arabic.

The Terrachidia organization in Madrid was responsible for organizing the trip to Morocco. Mohamied along the years has conducted many courses. The field trip to Yemen to view the Hadhramaut heritage and organization was made with the help of Eng Abdul-Rahman Al-Junaid.

6.1 Hadhramaut: Yemen Architectures

In a fertile valley in the hinterland region of Yemen situated in Hadhramaut, the town is named after the hinterland as well. A strip of coastal towns on the Arabian Sea to the south and the strikingly precipitous (mountains). Saudi Arabia is bordered by the desert sands in the north. Since pre-Islamic times Hadhramaut has held importance for Yemen growth because the valley is situated in a very favourable geographical location, making it the largest and most fertile basin in the Arabian Peninsula. More than 200 km (125 miles) in extent, from both the southern and the northern side the valley is joined by many smaller subsidiary valleys, of which Dawan and al'Ayn hold most importance (Maxwell, 2000). From an administrative point of view districts or provinces make up the governorate, those are called after a wadi or main city name. These include al Mukalla, al Shihr and Hajr on the coast, and in the interior Dawan, Sayaun, al Qatin and the two desert outposts of al 'Abr and Thamud, to the north and east respectively. An area of over 155,400 sq. km (60,000 sq. miles) is covered by Hadhramaut, making it the largest governorate in the country, with more than a million inhabitants (Maxwell, 2000) (Figure 59).

Figure 59. Yemen map (Atlas)

Unspoiled beaches and stunning bays with coral reefs extend over 350 km (220 miles) of shoreline. The capital of the governorate is Mukalla and it lies 770 km (480 miles) from San'a'; Say'un is the capital of the interior.

Ramodah (2012) reported on Tarim and Shibam, two known important cities of the valley, as they provide the best display of mud brick architecture. Shibam, an old commercial centre with mud brick skyscrapers, has been a World Heritage Site since 1984 and Tarim is a town of saints, sadah, master builders, and learned men. The location of the region allows the architecture to be expanded. The division between the coast and interior is of major importance. Madar (Adobe) is used in many ingenious styles and forms unmatched in Arabia or the Middle East in the construction of towns of the valley, from the Daw'an valley across to the town of QabrNabl Allah Hud, in the interior region of Hadhramaut (Ramodah, 2012).

A range of building materials, techniques, styles and house layouts have been implemented in the architecture of the coastal strip. The mud brick architecture of Wadi Hadhramaut gives an excellent comparison to this urban fabric. For decades, mud brick construction in the Hadhramaut Valley has been an active regional industry and quite recently a series of public and private conservation and development imperatives at the local, regional, national, and international levels has affected it. It has remained a viable practice to date because of the many extrinsic and intrinsic institutional characteristics of the mud brick construction industry; this is also the focus of this study. At the national level, over the past decades Yemen has been seen as a traditional agricultural economy generating its revenue from oil production, infrastructure and business. (Mosaibah, 2012). Land in Yemen is not very suitable for arable and accounts for only 3% of it, yet in the last three centuries the inhabitants of Hadhramaut have put their energies into agriculture and built houses from locally available adobe materials.

Dating back to the seventh and ninth centuries BC (Al-Gelani, n.d.), Yemen was a site of ancient human civilizations. A vibrant past described of the nation, in particular of the Hadhramaut region, is that it was the land of the Queen of Saba, pre-Islamic temples were constructed of earthen architecture, and there were pre-modern international trade routes that spanned from India to Syria. Distinct class demarcations and living quarters have highly stratified

the social order in Yemen. In particular in Hadhramaut this fixed social system is followed in correspondence to strong sentiment towards international travel to gather wealth, as promulgated by ancient caravan trade routes through the region and the medieval intercontinental Indian Ocean trade, to Far East of Asia, Indonesia, semaphore, India and Africa (Damluji, 1993).
Over the millennium, it can be seen that a lineage of craftsmen and artisans have preserved the earthen architecture techniques. Particularly in the region of Hadhramaut, south-eastern Yemen, mud brick architectural traditions are continued to date by mud brick masters and masons.

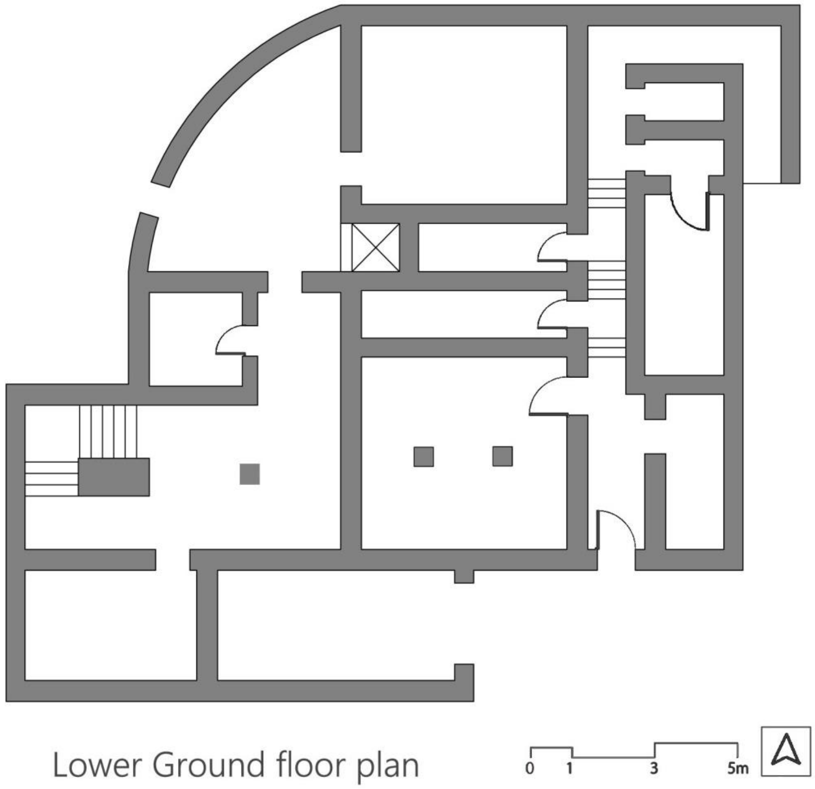
The former People's Democratic Republic of Yemen, now known as South Yemen, has three main cities, Tarim, Shibam and Seyoun in the Hadhramaut Valley. The valley has gained global admiration for the architecture of mud brick construction. The World Heritage List of 1982 includes the walled city of Shibam, due to which it has received an international spotlight and currently has the attention of a German technical aid programme sponsored by GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit) (Damluji, 2007). Another noteworthy town is al-Qatn, which lies by the crossroads to a tributary valley, Do'an. It was the land of Qu'aiti Sultans with Seyoun as the regional capital of the area subject to Kathiri Sultan's palace, which is a national symbol. The Museum of Hadhramaut as well as the local offices of the General Organization of Antiquities and Museums (GOAM) has to be the world's largest mud brick building after the recent construction (Damluji, 2007).

However, Tarim has remained an underdeveloped land, with little or no attention from the global preservation community (Al-Junaid, 2014). Even having a little name in the international community, Tarim is known as the religious hub of the valley. Every year hundreds of students from all over the world come here to acquire religious knowledge from the Shafa'i School of Islamic jurisprudence with a Sufi method. These cultural and religious factors are of great significance. The Hadrami people have an unchanged lifestyle and do not acknowledge any changes, particularly in a religious perspective. Tarim is of spiritual importance for Muslims around the world. It is known for the tallest minaret in Arabian Peninsula, Mihdhar, which is a 41-metre-tall mud brick minaret (Shihab, 2005). It is also known for its wide range of mud brick mansions which were built in the late nineteenth and early twentieth century. They belonged to the affluent merchant class and signify imported colonial designs such as, Neo-Classical, Mughal, Baroque, Rococo, Art Nouveau and Art Deco, made from the local load-bearing mud brick and lime plaster technology. These beautifully designed structures are the art of Tarimi masons, carpenters and lime craftsmen; even today in the Hadhramaut region the latter are known as the most talented.

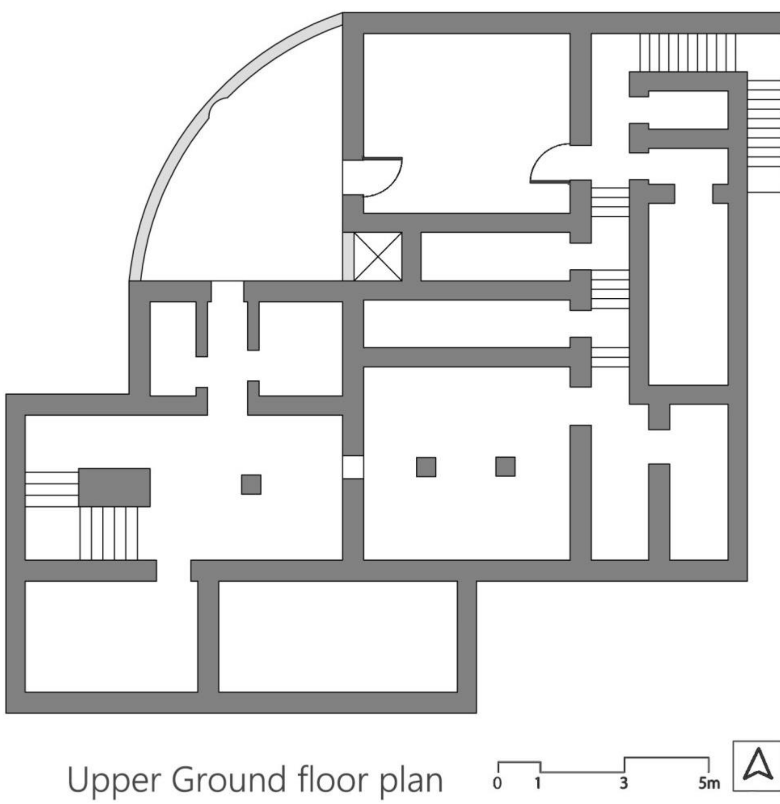
There is an abundance of earthen architecture-rich elements in Hadhramaut, however regarding the quality and method, the increasing speed of development in and around the old city has been unpredictable. It is apparent that there is negligence towards planning policies and a lack of knowledge about the protection of urban cultural heritage. The urban structure has worsened with the superimposition of roads and buildings which have brought about the end of the old quarters and their architecture.

6.1.1 Al-Junaid House

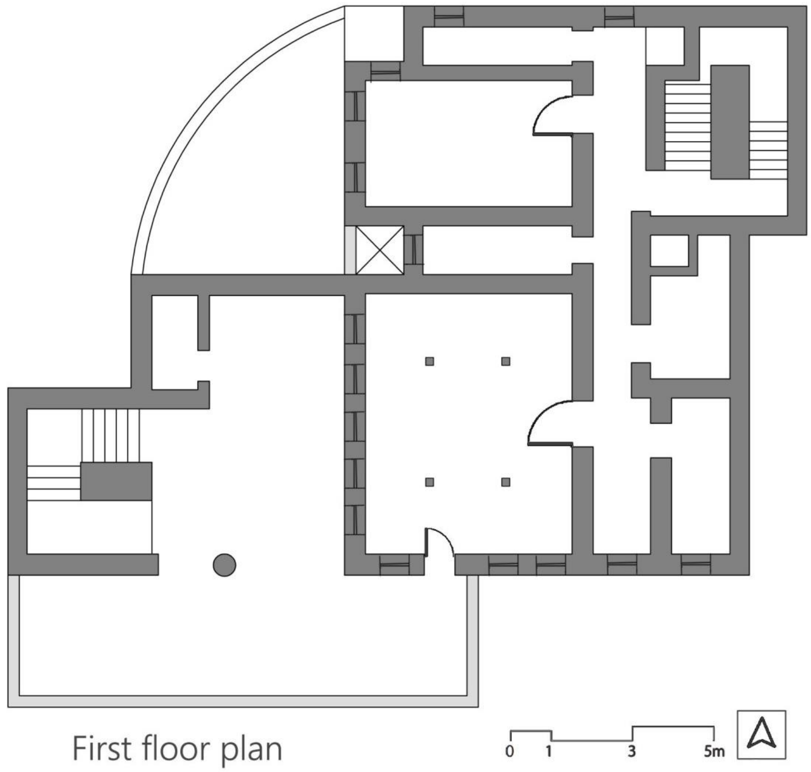
The Al-Junaid house is situated in the area of Abo Hawash in Tarim and is owned by the Al-Junaid family. The house was built in 1932 and a lot of renovation is required in this four-storey neglected building. In 2014, this house was chosen for renovation works, at that time not much could be investigated regarding the residents, however it can be said that since confiscation, the house has been left in this state. The building was last restored in 1970, covered in Nurah lime plastering, in spite of the fact that the residents did not come back to live there (Al-Junaid, 2014) (Figure 60).



Lower Ground floor plan



Upper Ground floor plan



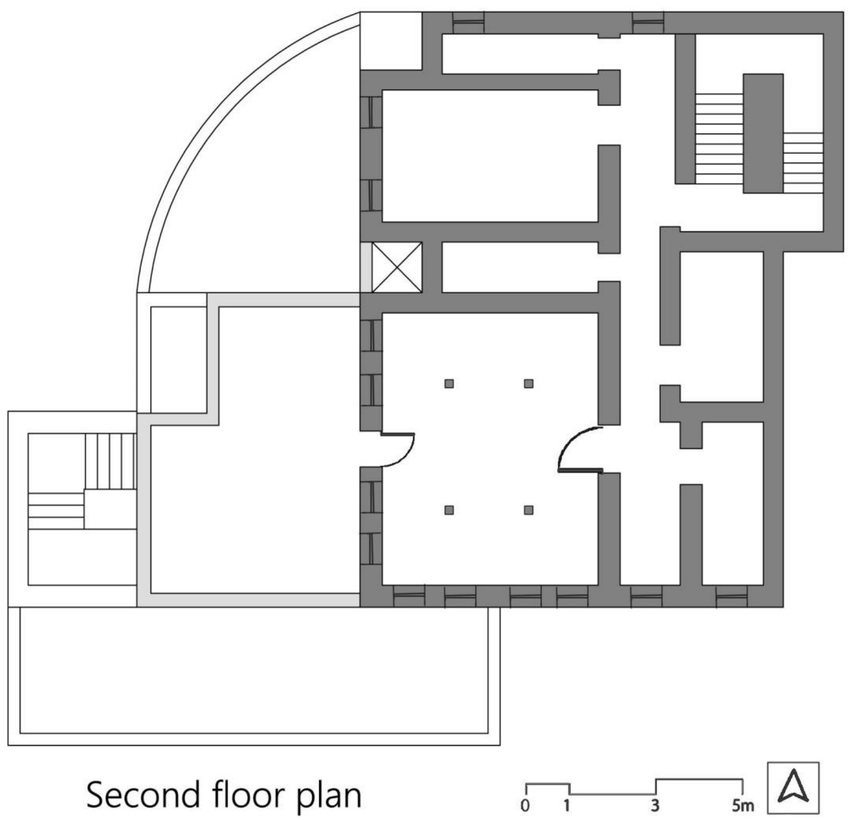


Figure 60. Plans of Al-Junaid House (Al-Aidarous)

The ground floor is the storage area and is called Ma'aqib. There is a long passageway that leads to the stairs. From the long corridor, five steps lead to the main entrance fronting south. There are several other entries from the back to the two walled courts in the exterior for livestock. It heads to the kitchen, from where a staircase leads to the enormous balcony on the first floor. There is a narrow west exit from the entrance at the north to the back storage, which also covers the south-facing wall. A storage room near the north entrance is utilized for animal food.

The designs of the first two floors are pretty much the same; they have the same number of rooms as well as the articulation of window screens at the main portico. During the survey, the rooms in the east were closed but the arrangement can be worked out from the second floor plan as both floors are of the same design. On the first floor, the main salon has a terrace or Mkharraj facing towards the main street. Riyum or the second floor initially had three enormous bedrooms with a terrace opening towards the main bedroom (Figure 61).

Figure 61. Al-Junaid house (AL-Aidarous)

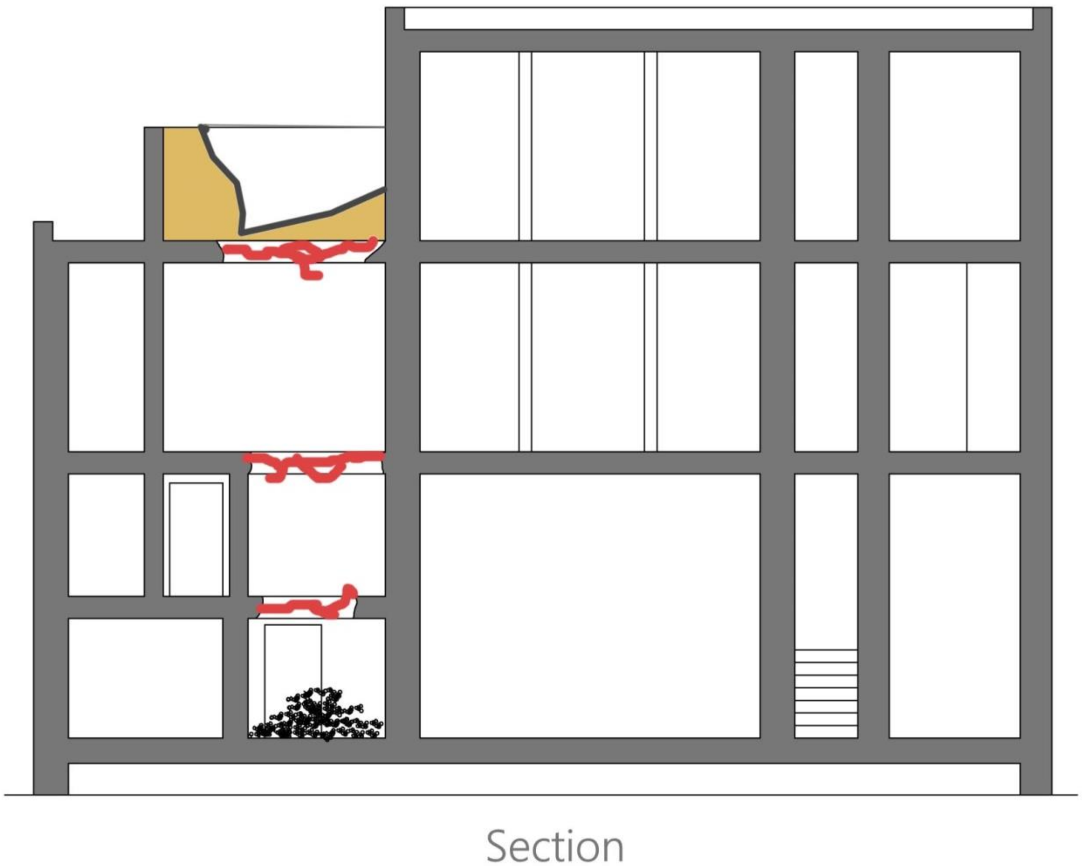


Figure 62. Section view showing subsidence of some floor slabs on three levels and demolished roof wall of Al-Junaid house (Al-Aidarous)

6.1.2 Mud Brick Construction in the Hadhramaut

The Hadrami economy is greatly dependent on the mud brick industry. More than 90% of construction in 2005 was mud-based. Moreover, highly experienced labour and craftsmen i.e. builders and master masons are easily available and in contrast with the construction of concrete houses, which requires steel reinforcement that increases their cost by 30%, making mud homes is relatively cheap (Bakraa, 2014).

Every month, a skilled craftsman earns around 100$ (Fagi, 2007). When given a building project, the craftsmen's teams sometimes also travel around the valley and farther to complete the task. Generally, the layout of the house is presented by the person who commissions the construction. The owner applies for a building licence to begin the construction from the local Ministry of Public Works, with the help from the estimation and floor plan provided by the master craftsman. The construction of houses that took more than five years to complete now only takes 5-8 months to finish (Conlon, Jerome and Al-Radi, 2002).

Mould dimensions were obtained from the mud brick masons. The ground, first and second floors are then built from Mador or adobe. The foundation of the building is made of 3.3-4 m high Mador wall. A 45m high and 30m wide ground wall made of Mador with a the complete thickness of 0.8 to 1.4 m at ground level then takes place. With each the floor the height of the floor is lessened i.e. the walls of the first floor in contrast with that of the ground floor will be less thick and high. On the second floor the adobe is orchestrated in stretcher coursing. There are four techniques to build an adobe wall in Hadhramaut and every technique is done in a specific way, as displayed in the pictures below (Borelli & Jerome, 1999) (Figure 63).

Figure 63. Foundation and thickness of walls (AL-Aidarous,2014)

The skills in these days are the same but it needs exceptionally dedicated skills, which are only obtained with time. Adaptive technology, like plumbing, electricity and other present-day facilities are readily used in homes today, where they are a symbol of skill and socialization.

6.1.3 Shibam Earthen Architecture

Shibam cradles the real local elements that are used in Hadrami construction. The structure and layout of this walled city has stood here since 1533. This however, is the date when the city was last renovated (Hadhramaut Heritage Centre, 2014).

Shibam, also known as the Manhattan of the Desert, stands on a rocky spur that flows out from the bed of the valley and contains almost 500 skyscrapers that are 82 feet high. The architecture of the buildings signifies the traditional mud brick style of the buildings of the Hadhramaut Valley.

For many years, Shibam has been a trading route for global traders and tribal caravans. The city's architecture is guarded by the walls and high rocky ground. Its intense urban design is the result of lack of level space for development, political circumstances (its area between two sultanates that were now and again in a state of war), serious daytime heat combined with sharp falls in evening temperatures as well as occasional flooding (Damluji, 1992). These houses were home to elites, whereas the artisans and the servicemen resided in the nearby quarters in makeshift housing. Shibam was a main focus of business and extensive markets. In 1982, with the award of World Heritage Site, the Old Walled City of Shibam was then identified by UNESCO for its urban planning.

Figure 64. Site view of Shibam (Yehya)

Today, in the Old Walled City of Shibam there are about 3,500 people living in the 400 mud brick residential towers (Leiermann, 2007). The tower has a single main entrance on the ground floor, other than that the ground floor is used as a storage place. A narrow staircase leads to every floor, containing three rooms on each floor. These houses are centuries old and are home to one family each. The oldest house as per the date on its door frame is of Bayt Abdullah Bafagh, 1609. Other than that, the majority of the houses date from 1880 to 1915 (Breton, 1986) (Figure 65).

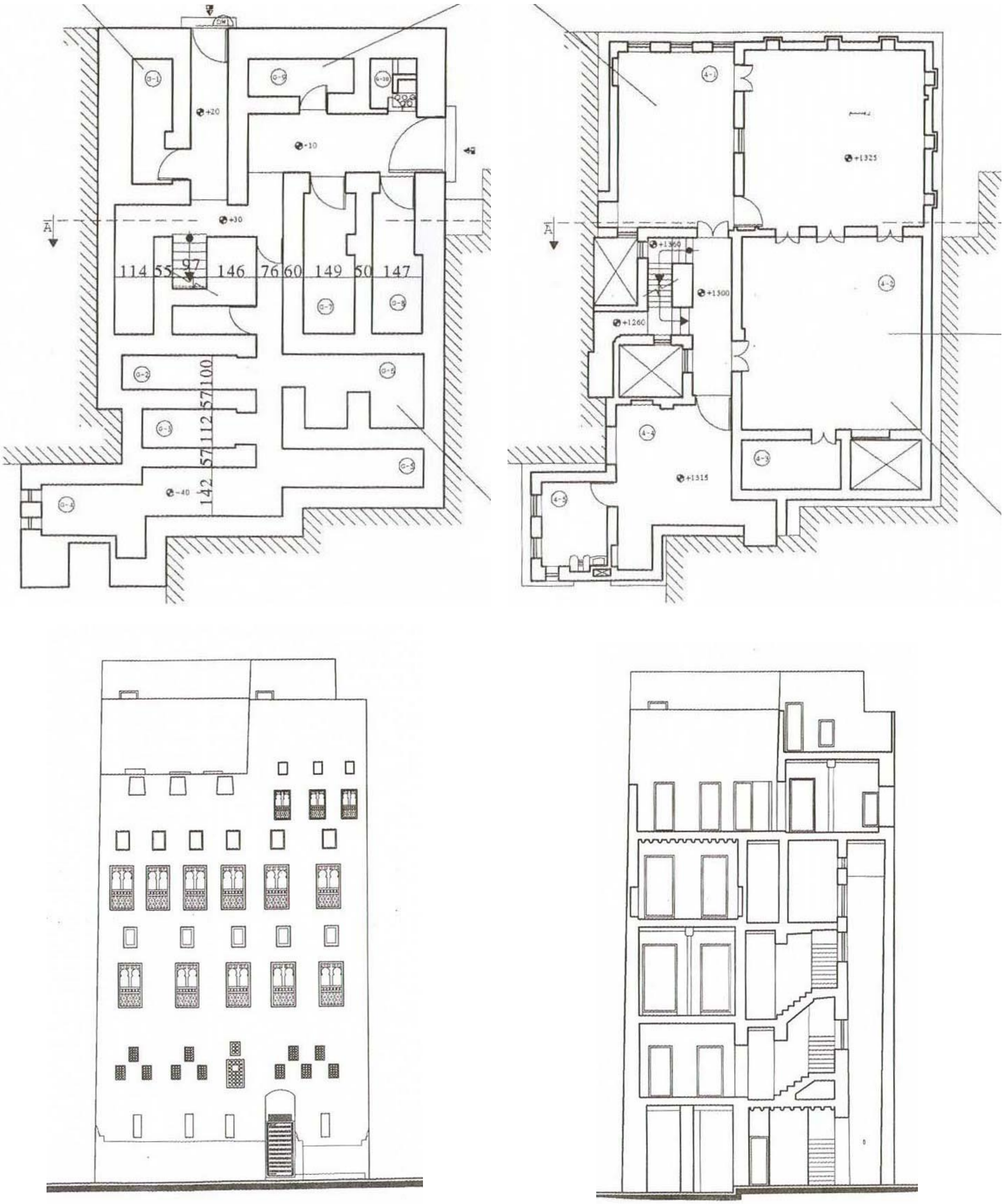


Figure 65. Bafagh house (Hadramout Heritage Centre, 2007)

Figure 66. Bafagh house (Al-Aidarous)

Among several reports, the one presented by Ronald Lewcock in 1986 was most outstanding in making a demand for Shibam to be the base of a coordinated regional socio-economic development programme that aims to reinstate the major buildings of the city of Shibam and Hadhramaut Valley as well as to resuscitate several economic and cultural areas (Lewcock, 1986).

However, until 2000 because of financial downturn and warfare, no development was made. In 2000, the Shibam Urban Development Project (SUDP) was initiated in association with Germany's main aid agency, GTZ. The Yemeni and German governments, through economic, technical, and social capacity development have originated a multisided approach to grow within the Old Walled City of Shibam

The outline of historical design that has structured Shibam for ages has been deliberately used to conserve the restricted space that guards the tall city because of environmental and security concerns. In any case, this, too, has been the after effect of an ancient area used for regulation that delineated "the quantity of floors based on the stature of the area of the houses"; this consistency in height regulations guaranteed that no housetop will shade the other (Boxberger, 2002). Another reason was to ensure the private life of families on the roofs. Depending on the profession of the residents, each structure had different features but had a comparable plan. Thus, it is incredible that even today the city has maintained its fundamental zoning policies.

During the restoration process, to maintain this original zoning regulation in each building, qualified architects, conservators, engineers, and local master builders work as a team. For each building the group scrutinise the wearying structure individually and deliver project approximations, records and strategies. This preliminary technical examination is funded. It has been determined that the proprietors of the Shibam buildings will get 35% of the building expenses in micro-assistance established on unit construction cost (Hadhramaut Centre of Heritage, n.d.).

Subsidies are greater for buildings that are of historical importance or require enhancement, such as windows and doors. If complete renovation of the building is needed, i.e. if the house is to be built from the ashes, the subsidies increase with every floor, as more money is needed for the reconstruction of higher floors. Individuals today have next to no motivation to modify the conventional stature, and without this sponsorship, Shibam in the long run would be left with just a few floors. Along these lines, various interested approaches have given rise to a coordinated method for the development of the local economy: the labour-based mud brick restorations subsidize the development of local small and medium craft enterprises that also preserve design strategies.

This procurement is comparative and more comprehensive as compared to the regulations made by the Hadhramaut government. Due to this legal order the mud brick construction will become more marketable. Its main objective is to preserve the conventional manufacturing trades that have characterized Hadhramaut for centuries. It is expected that with the draft law the active preferment of mud brick and other local technologies can help in establishing the security of this industry. A division of the draft law relates to the traditional craftsmen and their lifestyle.

It has been seen that the integrated conservation, reintegration, and craft-securing activities in Shibam are theoretically intact and economically practical. According to a survey conducted in 2005, employment in construction was increased by 127% and the whole city income of Shibam rose by 16% (von Rabenau, 2005). This rate of development can be applied only to the World Heritage City and not to the whole district.

6.1.4 Al-Mehdar Mosque

The main attraction of Hadrami architecture is the Al-Mehdar mosque that stands in the east of old city wall in the city of Tarim. The simple minarets define Tarim city and generally Hadhramaut. In 1410 the primary phase of the mosque was completed when it was built by Omar Al-Mihdar with adobe and coated with lime rendering. In 1321H the second phase took place followed by the third phase by a master builder called Awad Bin Afife bin 1331H (Mosaibah, 2013) (Figure 67).

Figure 67. Al-Mehdar Mosque (Al-Aidarous)

The builders of Hadhramaut play a main role in the building world for their adaptation of architectural elements and earth materials. Awad Bin Afife, a well-known architect played a significant role in earth construction. He was born in 1864 in Tarim. He designed and constructed numerous significant buildings in Hadhramaut, such as the Al-Mehdar, Riyadh and Al Taleb mosques and Al-Habshi tomb. He belonged to a family of earthen constructors and was the third generation dedicated to it (Mosaibah, 2013) (Figure 68).

Figure 68 . Al-Kaf Palace built by Bin-Afif (Al-Aidarous,2014)

The thickness of adobe wall relies upon the height of the building and wind erosion. There is a connection between the construction element and the decoration of the building, such as the decorative factors in the Al-Mehdar minaret. To lessen the load of the building, open decorative elements are used in these minarets. Several shapes of elements are also employed in Hadrami earthen architecture that is made from adobe: circular, square; rectangular and cylindrical. Moreover, the most difficult part in the construction of the minaret was building the 4.20m x 4.16m conical shape of Al-Mihdar mosque. The 10m deep limestone is used in it with the walls that are 1m thick (Ramodah, 2012).

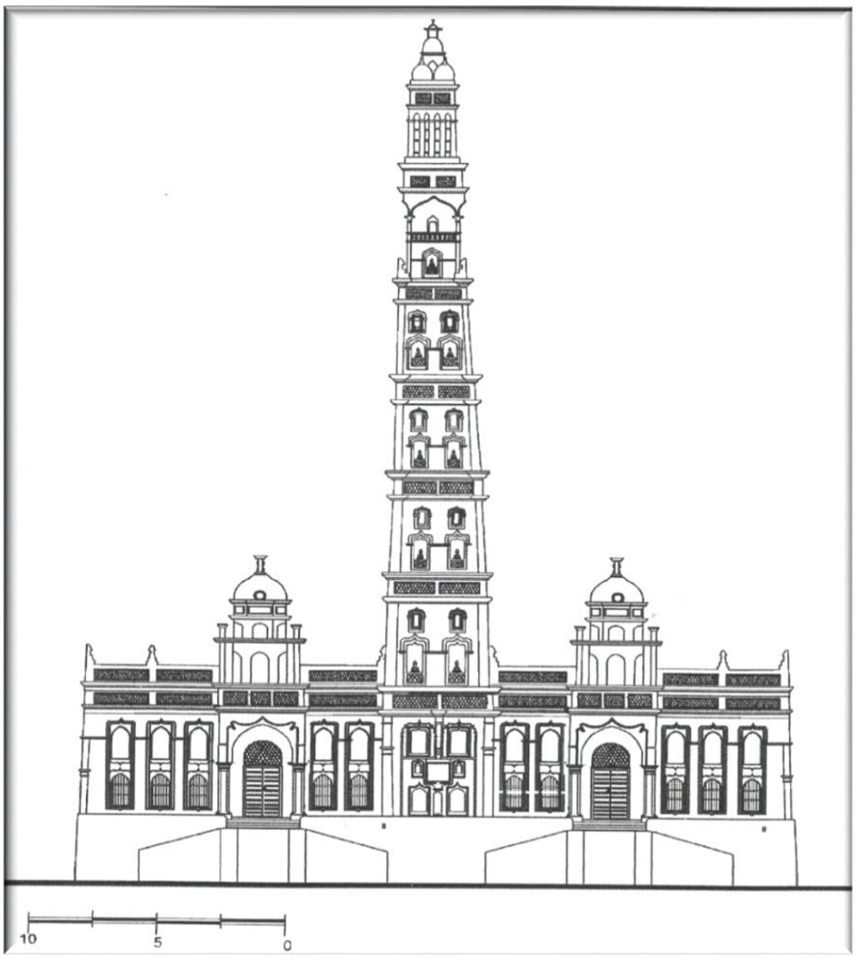
If we focus on the design of the Hadrami minaret, it encompasses various styles like circles, squares and a blend of both. Furthermore, the tower is separated into the following four parts:

- Minaret base
- Body
- Moazen room
- Roof of Moazen room

As per Ramodah (2012), the structure of minarets is designed and constructed in the ground for 10m to adjust a limestone such as a stone base mixed with earth mortar with ash. The top points of minarets provide easy access for repairing purposes and several other problems can be fixed there. Al-Mihdar is considered one of the largest mosques in Tarim. During the extension of this mosque, Awad Bin Afife observed the low slope of the hill. Therefore, he employed a great approach to solve the issue. The dimension of the low slope of the new extension was located down off the hill 4.5 m as compared to the old structure. Arch corridors of 12 m were designed by him to support the mosque courtyard. The corridor walls were 90 cm thick. The mosque wall and minaret would be affected if the builders put a solid load of limestones (Mosaibah, 2012) (Figure 69).

The position of minarets in mosques is determined keeping in view the following reasons:

- The activity of prayer calling should spread to the maximum range of the district.
- It should be safe from the influence of environmental and climate influences.
- It should also be positioned in such a way that it supports the entire mosque.



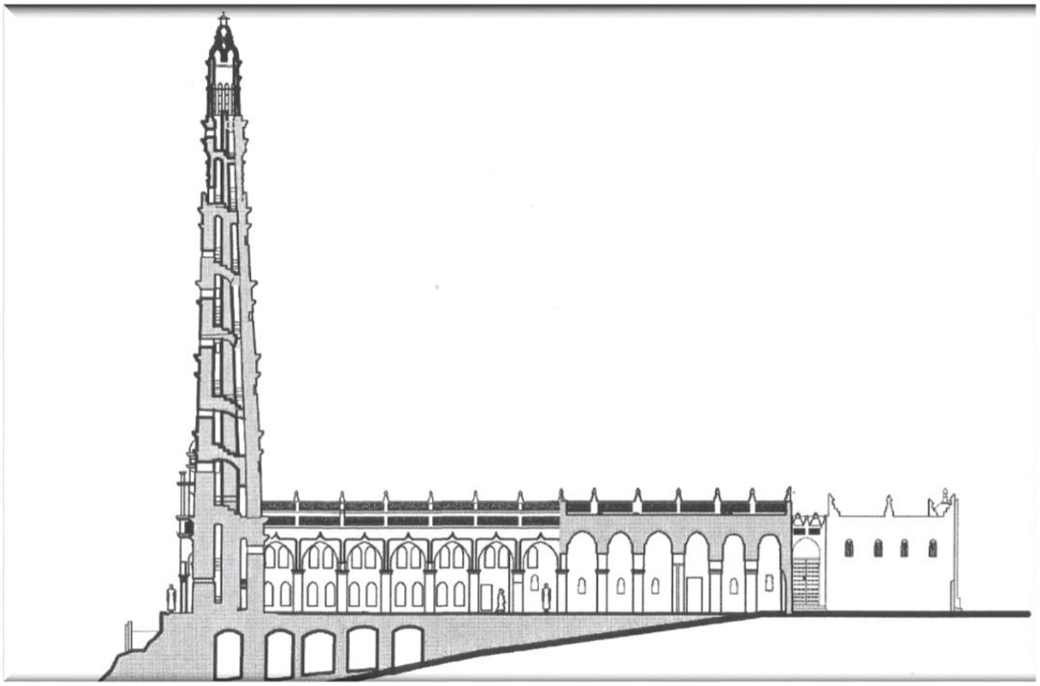


Figure 69. Elevation and section of Al-Mehdar Mosque (Mosaibah, 2012)

6.1.5 Building Notes

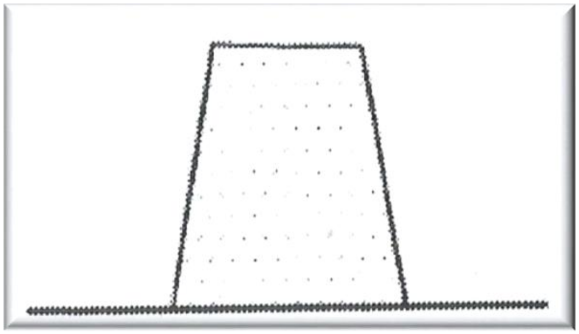
Like many countries, Yemen has a range of natural building materials in its several areas. In Northern Yemen, puddle earth is used for mud buildings, whereas in the Hadhramaut region, sun-dried mud bricks are generally used, which will be studied here (Damluji, 2009). A mud brick mainly consists of soil, chopped straw and water; these components are manually blended into a consistent mixture, and then using an open mould shaped into blocks of a standard size (Oates, 1990). The bricks are moulded in huge mud brick yards outside town, then are put out in the sun to dry for one week, after which they are ready to use. To set the beds, mud mortar is employed which is generally made of the same components. New blocks are of amazing quality, in spite of the fact that their imperviousness to crack decreases with the rotting straw, which goes about as both tough support and reduces compensation. Each floor is gradually built manually with these blocks. Sometimes, to make buildings more durable, lime is used on the inner and outer surfaces and a stone foundation is made as a damp course with limestone (Jerome et. al., 1999) (Figure 70). These bricks:

- Have better shielding qualities in contrast with baked bricks or concrete blocks
- Are easy to construct with
- Are tremendously long-lasting, provided that a consistent outer coating is maintained when required.

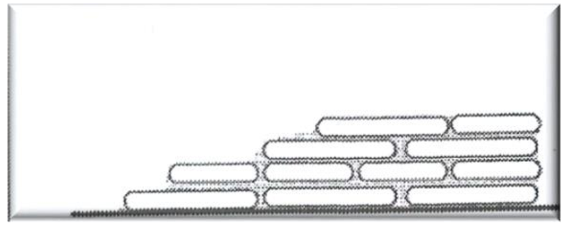
Figure 70. Process of making the adobe (Al-Aidarous,2014)

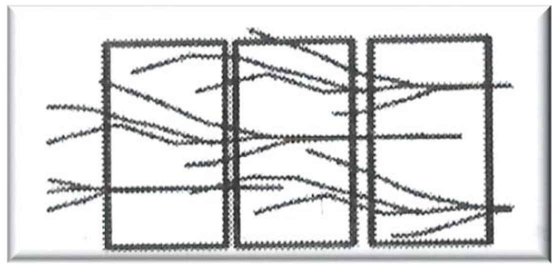
According to the master builder who reconstructed the Al-Junaid house, limestone is utilized and the actual stone is of one feet deep. All the builders dig the solid ground to make sure that the foundation is 1.52 or 1.82 m deep. Generally, 1.82 m of packed stones are employed. The depth of the foundation corresponds to the width of the limestone i.e. 30 x 30 cm.

All the floors of Al-Junaid house are of different heights. The ground floor, first floor and second floor are 4.6 m, 3 m and 2.5 m high respectively. The width of the walls from the ground to first floor is 0.8 m to 1.4 m and that of second to third is 0.8 m to 1m or maybe less. This is done to sidestep the compressive strength throughout the wall shape construction that appears from the diagonal wall. The walls of the ground level are thicker than those of the above floors; the width of the wall loses 30 cm in every 10m. Additionally, every fifth level of adobe in the construction uses Selvadora Prisca (Tephrosia Dora) to increase the tensile strength (Figure 71).



A section of diagonal wall





Laying the plants in the adobe every five levels

Selvadora Prisca

Figure 71. Increasing compressive and tensile strength (AL-Aidarous,2014)

The rooms on the ground floor had one or no opening but the top floors had some windows for cooling at night. The rooms on the top floor are family rooms, with either one or two wooden columns also known as Mirwsh, based on their size. According to Hasnen, the timber in the past was taken from the local agriculture. Around 150 years ago, Jawi wood was brought from Indonesia for construction. In fact, 400 years earlier a lot of trading was done by the Hadramis from Hadhramaut in South-East Asia and Africa. These trades also influenced the social culture of Hadhramaut. Besides this, it is evident that the architecture of the mosques in the cities of Tarim and Seyon was adopted from Africa and Asia. Specifically, Hadhramaut and Tarim had an embellished structure that was adopted from India Indonesia, Singapore and Africa. The element used for interior decoration is an earthen material manufactured out of Anabasis called Shinnan in Arabic (Figure 71).

Figure 72. A decoration element in Al-Kaf Palace with Anabasis plants (Al-Aidarous)

The builders described that it was not their duty to finish, whitewash and paint, render or decorate walls. Tarim builders divide themselves in three groups, each group completing a particular task.

Group 1- Construction

Group 2- Lime rendering and finishing also known as Hadrah

Group 3- Renovation

Architects and builders are familiar with the earth materials and Hadrah people (i.e. Tarim and Say'un) do the finishing. Mud lime is applied twice, first the base layer, a limited application that is precisely measured with little mud to complete the dividers of the floor (Al-Junaid, 2012). Then Nurah lime whitewash is applied to the bathrooms and mosque and then polished. The last task is carried out by the painters because it can be cleaned easily.

Figure 73. The process of making lime (Al-Aidarous,2014)

Fired clay from Shafaq is employed to make pottery, bread kilns and the decorative claustra screens on roof parapets. First mud is taken from date palm soils and made into a paste with animal droppings. It is then operated with several other items and fired. Today, the screens that are to be painted in white or green are cast in cement moulds and are not made from fired mud (Hasanen, 2014) (Figure 74).

Figure 74. Clay roof pattern (Al-Aidarous,2014)

6.2 The South of Morocco

One of the main gates to the Sahar desert is the oasis in the Drâa Valley (Morocco) that focuses mainly on earthen architecture. The Terrachidia organization in association with southern Morocco conducted a study in May 2014 to examine construction methods and campaigns during the evolution and main historical stages (Figure 75).

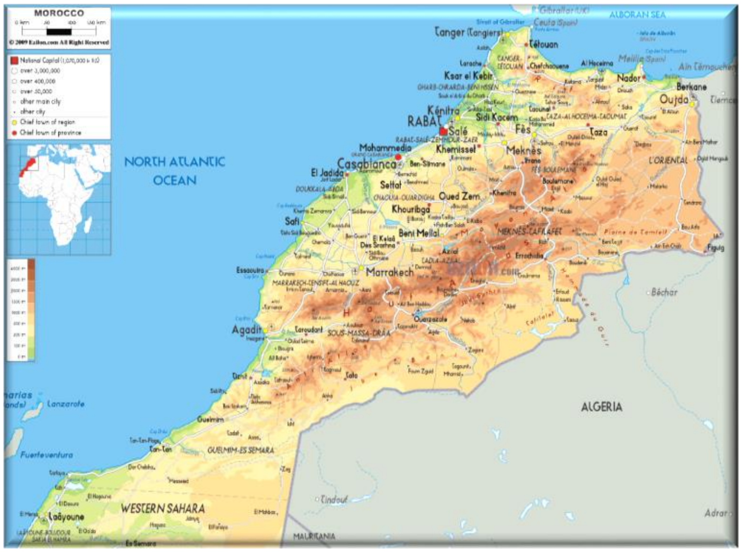


Figure 75. Morocco map (Atlas)

Local masters in workshops taught the participants about the traditional building techniques of the oasis. These local masters were hired to teach the participants along with their apprentices to help in the development of the region. The main source of economy for this region lies in tourism that mainly happens due to the Sahar Desert. However, to develop the tourism industry it is necessary to build a relationship with the local community to preserve its cultural heritage. Today, the tourism in these southern oases focuses mainly on desert and dunes tours (Figure 76).

Figure 76. Mhamid environmental characteristics and urban fabric: Talha Village (Al-Aidarous,2014)

6.2.1 Traditional Building

A. Techniques in the M'hamid Oasis

It is significant to know the architecture of the M'Hamid El-Ghizlane so as to grasp the importance and originality of the architectural characteristics. Until recently, the people of oasis assembled inside their braced Ksur, cautious settlements that were sufficient to shield their people not just from the roaming tribes which threatened them, but also from desert storms as well as the life-threatening temperatures of the zone (Martinez, Hermida and Adan, 2015). Usually Ksur architecture is made the same way from earth and wood from tamarisks and palms. Adobe bricks of rammed earth are used to build the walls for the top floors. The combination of two earth materials is ideal for earth architecture as it adds the characteristics of both materials to the mixture i.e. the strength of rammed earth and lightness of adobe, which is suitable for the higher level and embellishment of southern Moroccan buildings. Also, the lightness of adobe is apt for joints, horizontal structures and inner arches and piers (Baiche, 1992). Due to the lack of required wood the arch and domes are built from corbel arches or corbel vaults (Martínez, Hermida and Adán, 2015). Earth render is used to protect each building, however some solitary components, for example, domes, entrances, and a few inner spaces, particularly holy ones, used to be rendered with a mixed lime and earth mortar. The intensity of each structure determines the ratio of earth and lime in the mixture. Rammed earth is generally used to build the foundations of the buildings. Due to low humidity in the regional soil, this technique does not cause any major problems. Therefore, several mosques, palaces and other notable buildings have foundations of a stronger rammed earth, lime and stone mixture (Martínez, Hermida and Adán, 2015). Palm or tamarisk beams are coated with numerous layers for the horizontal structures. Woven palm leaves are crammed directly with earth so that the structure can bear the pressure from the load. These days, another layer of reeds in the middle of shafts and the palm leaves is applied, and sometimes waterproof plastic coating is used for rooftops. However, reeds generally belonged to more humid oases, like the Skoura Oasis (Martínez, Hermida and Adán, 2015) and were not used there in the past (Figure 76).

Figure 77 Adobe and rammed earth in M'Hamid El-Ghizlane South Morocco (Al-Aidarous)

B. Reflecting on Materials and Structure in the Local Building Tradition

Describing his art and techniques which has he had practised for over fifty years Abdul-Slam (2014) devised four categories:

1. An account of the characteristics and benefits of different kinds of soils suitable for particular tasks – such as making mortar, adobe, or rammed earth, or waterproofing – and the preparation of the mud.

a. Making of boards which is often referred as the wooden frameworks and the rammed earth wall.

2. Making of at-tub or adobe bricks, and manufacturing techniques.

3. The constructional framework of the house inside the Qsar and, in particular:

a. The pillars acting as foundations for the structural space within which the house will grow.

b. The wooden joists which join different elements of the structures, and develop connections between the ceiling and the floor of the upstairs.

4. The staircase, which is a raised, mounted structure interconnected with wood. It is considered as being among the permanent elements of the house, similar to the well and the bearing pillars, which are subjected to spatial modification but cannot be removed completely. At each of these places the owner performs the ritual slaughter of a sheep or, a cock, to mark them.

5. The correlation between the structure of the house and the structure of the Qsar, overlaying and integration into one another.

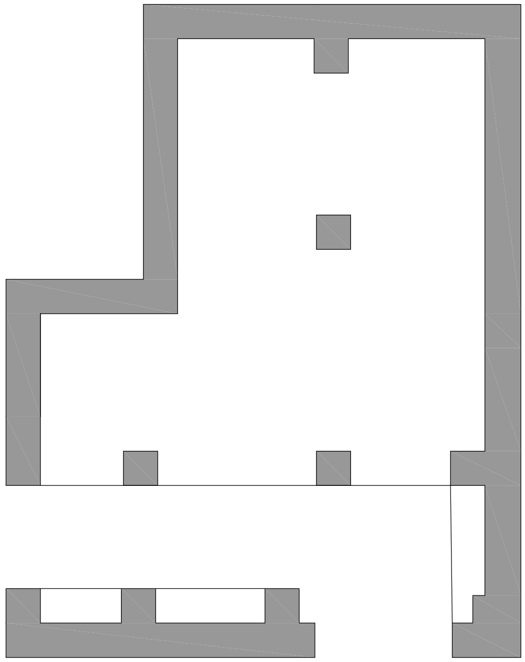
According to the master, the development strategy of the house relates to an auxiliary parallel or a similarity between the change of materials and the articulation of the structure. Both are associated with the origination of an inorganic prior condition i.e. the creation of the soul and breath as well as the articulation that creates movement and life. Such a mystical perception is essential for the understanding the building culture, and also for the rationale supporting its structural dynamics.

Fermentation or rotting is the main process behind the making of the earth dough which is used to prepare adobe. Adobe and rammed earth use different kinds of earth. Normally it is coarse and has a small amount of rocks that are removed by sifting or by hand. Comparatively, the earth employed for adobes is of good quality. The earth is dug from particular areas inside the gardens and palm groves and normally it has clay and sand in it. Customarily, the ration of clay to sand was worked out by touching it. In both situations, first a deep hole is dug and filled with water, afterwards the earth is added and is left to rest. Straw is added to enhance rotting in the process of adobe. The purpose of this process is to bring about swelling and 'transformation' in the primary material, which is now modified earth. With respect to chemical modification through fermenting or rotting, it is modified to form a shape. Swelling is identified with the formation of a soul or a fundamental principle.

The craftsman explained the technique of adobe constructed with rotten earth dough formed in a mould and then dried in the sun, in detail. Moreover, the technique of rammed earth boards, where the mould is in the boards, a wooden board inside which earth is pressed, was described as well. While the bricks lie in the sun to dry, the boards are pressed and compressed to shape them. The construction of adobe bricks is done independently while that of the rammed earth boards is collective or done as a group task. Historically, beginning with the construction in boards, Qsar of fasting age participated in collective works, such as construction tasks or clearing irrigation canals.

6.2.2 Restoration Work in Talha

Renovation at Talha Qser or the M'Hamid El-Ghizlane village was completed in April 2014. Originally the building was a commercial centre for the village, and during the workshop Terrachidia tried to restore the building (Figure 78).



Site plan of Talha central commercial

Central commercial building before restoration

Figure 78. Talha commercial centre (Al-Aidarous,2014)

The single-storey 28 m building welcomes visitors at the city gates. It is used as sitting place, called Dakkah in Arabic, and an entrance to the village. The building is built out of rammed earth coated with mud plaster and earth wash.

Structure-wise the building was fine, there were some cracks and a new roof was to be built for the commercial centre and re-adaptation of the exterior walls.

Additionally, some methods of moulded adobe rammed earth refurbishment techniques were presented to us by the local master builders (Figures 79-80).

Figure 79. Cracks in the rammed earth at Talha, Testing different methods of rendering (Al-Aidarous,2014)

Figure 80. View of Talha after restoration (Al-Aidarous,2014)

6.3 Laboratory Study on Mud Architecture Materials in Yemen by Ramodah

This laboratory research on the mud architecture of Yemen is highly useful since the declaration of Hadhramaut city's architecture mud as the best model in Yemen. This study helps in understanding the design of its buildings, their structure and the collection of samples of the materials used for construction.

In addition to the basic lime and ash as a plastering material, natural clay is used in the construction of residential and public buildings in the city of Hadhramaut. Moreover, the stone required to build the bases of various houses is utilized to hold the foundations of clay.

Now the question arises that how for this long these buildings have lasted. Buildings made of mud blended with straw and covered in just lime and ash highlights the brilliance of these buildings. This demonstrates that the local construction workers could understand these materials and their availability and managed to comprehend how to structure their building as a symbol of brilliance and exceptional engineering.

We selected some usual samples of mud and straw, lime and ash in affirmation of this perspective for laboratory tests.

6.3.1 Experiments on Clay

A. Properties of Pure Clay

Some properties of soil were determined from general mechanical soil tests conducted in the laboratory along with techniques and scientific steps to help us in this case. The results that were obtained from the lab were adequate to achieve the average readings. The following tables show the ranges of results obtained:

- General Properties of Soil

It should be mentioned before discussing the cause of disparity in clay properties that pure clay has a large amount of silicon and alumina, as portrayed by the model analysis:

Table 5. Properties of soil (Ramodah)

Feature	Value
Water content	6%
Plasticity limit	24%
Deflation limit	24%
Liquidity limit	35%
Specific weight	2,78
Hardening	3.06 x 10-4 cm/sec

Tables 5 and 6 show the assessment of the laboratory values of the physical and chemical measurements of the soil in Yemen. It should be noted that the values are rounded up to the neared decimal number.

Table 6. Typical analysis of clay used (Ramodah)

Number	Material	Percentage
1	Alumina	34%
2	Selica	50%
3	Lime + magnesium	6%
4	Iron Oxide	8%
5	Organic materials	2%
Total	100%	

Table 7. General physical specifications of the clay soil in Yemen (Ramodah)

Feature	Percentage
Water absorption	15 – 30%
Limit plasticity	25 – 40%
Specific weight	1.53 – 2.60%
Distance	37 – 43%

Table 8. General chemical specifications of the clay soil in Yemen (Ramodah)

Material	Percentage
Alumina	9.6 – 18%
Selica	33.8 – 46%
Lime + magnesium	1.4 – 22%
Iron Oxide	3.1 – 10.2%
Organic materials	5.7 – 18%

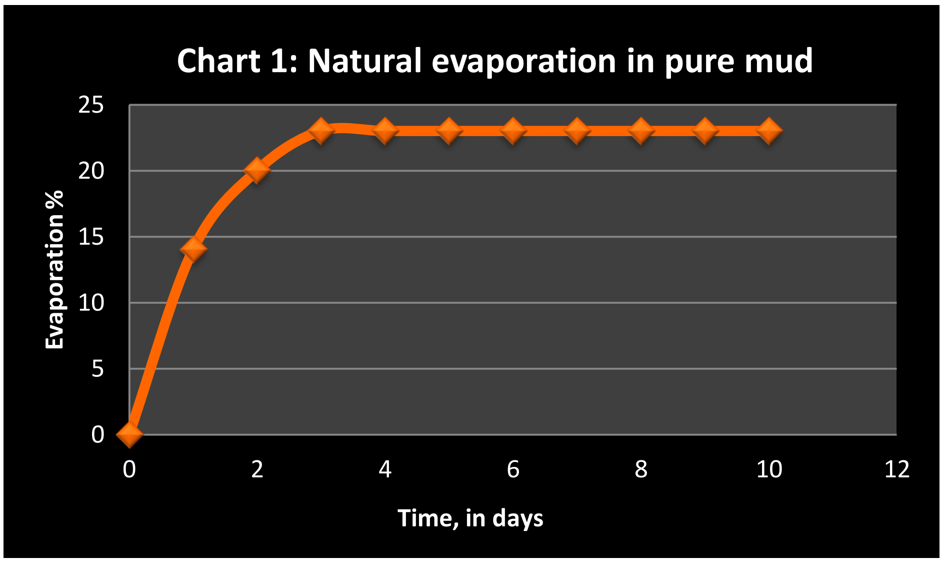
It is to be mentioned that the mud of Hadhramaut has a large amount of alumina and silica. The majority of these general factors in the properties of clay soil in Yemen have comparatively less organic material.

- Natural Evaporation

The aim of this experiment was to analyse the quantity of water that evaporates every day and how long will it take for the mud to completely dry. Due to this, the experiment was conducted in November when the weather is moderate. The compensation of water while preparing the soil samples was also examined during this experiment.

In this experiment, to determine the percentage of water evaporated each day, cubes of mud sample of 100 mm, water between flexibility limit and liquidity limit and natural conditioning and weights were taken as shown in Chart 1.

The chart clearly shows that the rate of evaporation in the first three days is high and is constant afterwards. This means that the clay dried completely after the third day in these samples but obviously it will take more time during construction with larger samples.



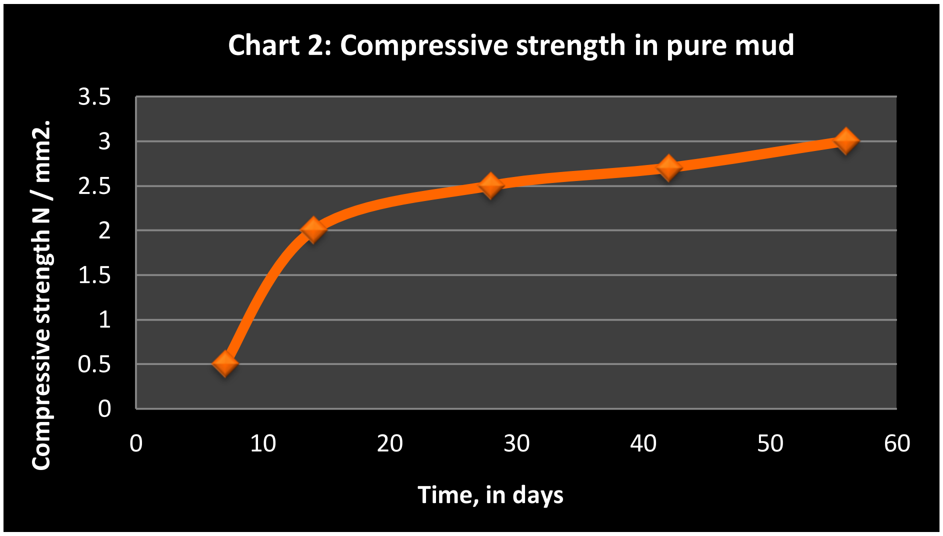
- Compressive Strength

Compressive strength can be observed by testing 100 mm mud cubes in a hydraulic piston after two, three, four and eight weeks of the casting process, which can be seen in Chart 2.

Cubes were also employed to determine:

- Linear shrinkage, shown in Chart 3.
- Specific weight, shown in Chart 4.

It is evident in the graph that the rate of compressive strength rises in the initial two weeks and then a very little increase is noticed in the fourth to eighth weeks. After four weeks the average compressive strength of the clay is 2.7 N / mm^2.



- Linear Deflation

Chart 3 shows the evolution of deflation over time and the graph shows that the deflation stabilized after the first week of the work of the same templates and the previous sizes.

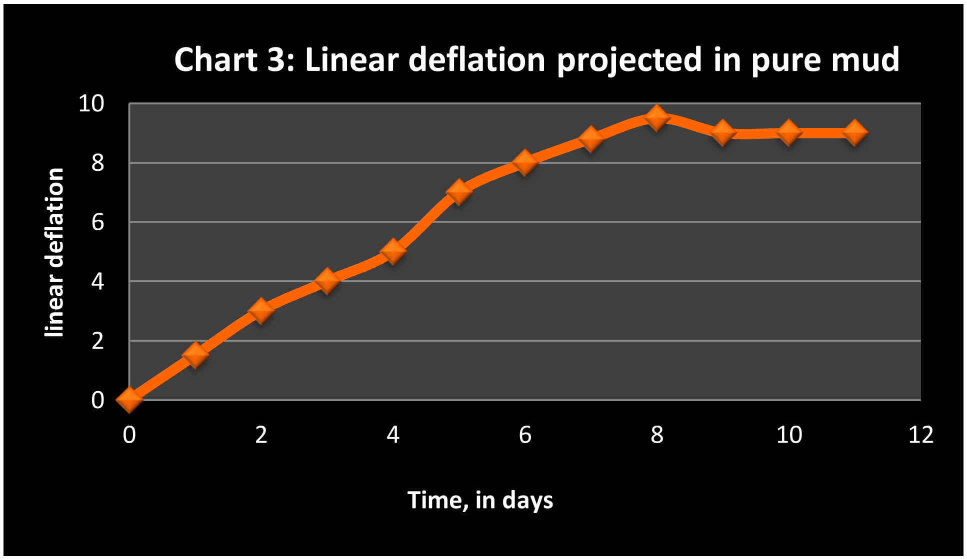
In the drying process the deflation folds in the mud show as cracks on the surface of the sample. Every morning the deflation values were measured and the percentage of the amount of linear deflation was calculated as follow:

$$\frac{X - Y}{X} \times 100$$

where,

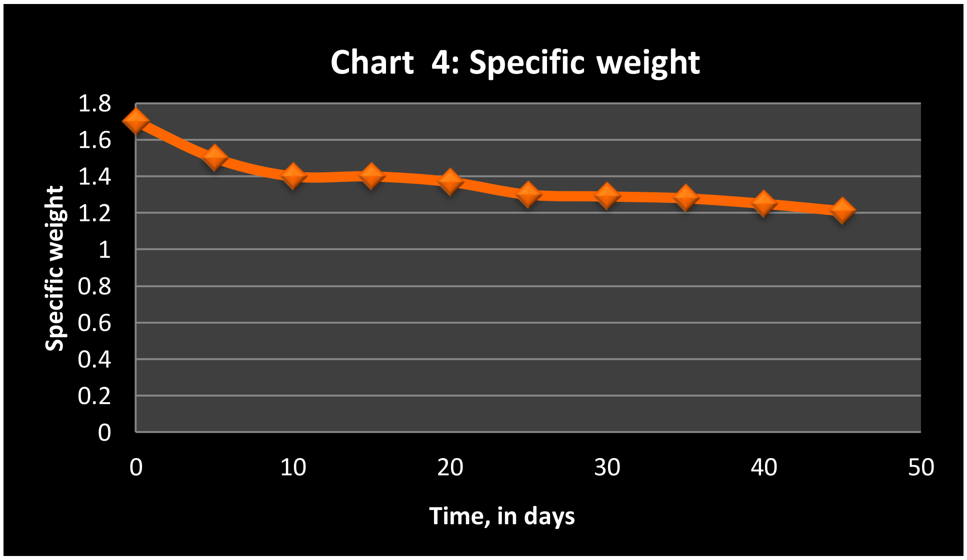
X is the original length

Y is the decrease in length every day



- Specific weight

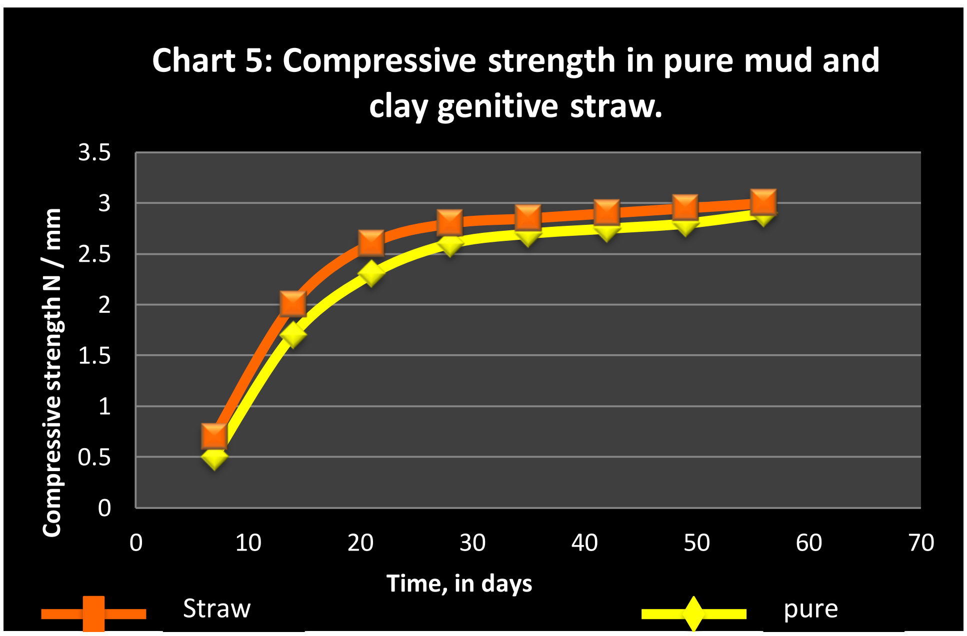
Before carrying out the test of compressive strength, clay moulds of 100x100x100 mm dimensions were used to determine the specific weight of the main samples. This was done by dividing the weight of the cube by the virtual size. Chart 4 shows the developments of specific weight with time. The first point explains the specific weight of the clay instantly after pouring. After three days, the specific weight lessens because the water from the mud evaporates leaving the dry mud behind.

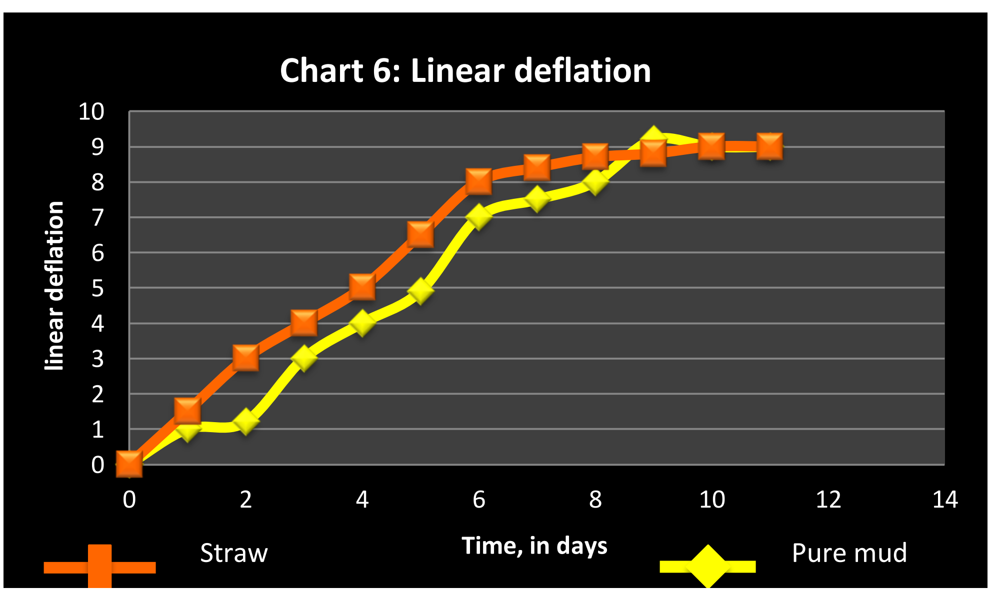


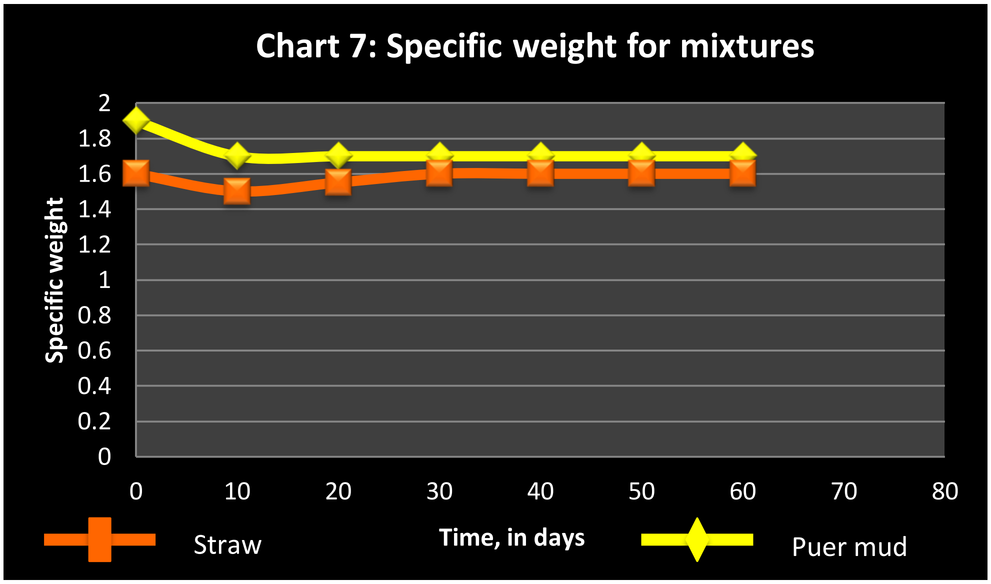
B. Mud Straw Installer

To prove that results obtained from the lab can be generalized, mud was then obtained from 30-35 cm below the surface of the Hadhramaut region. Straw was added to enhance the physical and chemical quality of the mud.

As can be seen in Charts 5, 6 and 7, there is prominent improvement in the physical and mechanical properties of the clay with time, in terms of compressive strength, linear shrinkage, and specific weight of the mixtures







C. Additional Experiments on Mud Architecture Materials

Initially to test the comprehensive strength I used a variety of mud cubes with a blended rate of 0.15% of straw of about 30-35mm in size. This concentration is used when mixing clay with straw for making mud bricks. Moreover, a few mud cubes were blended with 5% of ordinary Portland cement. Both set of cubes were put to dry for 28 days. The results of these tests are displayed in Table 5. It was found that due to the quantity of deflation in both samples, the volume of the mud noticeably lessens due to the evaporation of water.

Table 9. Comparison of mud and straw, and mud with cement is based on its resistance to pressure and the amount of deflation after 28 days (Ramodah_

Feature / Mud Type	Mud + 0.15% of Straw	Mud + 5% of Cement
Compressive strength.	1.32 N/mm^2	0.8 N/mm^2
Deflation	10%	6%

- Experiments Related to Textured Clay

The materials were subjected to examination, to analyse their properties and determine the amounts of stress they can withstand until its collapse. These experiments were usually conducted in extreme conditions. To study compressive strength, for example, force as provided in the given case, the shape of the models was in the form of cubes. The known range for the stress endured by bricks used in construction with respect to compression is between 0.6 Newton/mm^2 to 2.5 Newton/mm^2. Table 9 shows the results obtained in the case of bricks with straw. Positive results were obtained for the case for the mixture of clay with straw, also applicable in the cities of the valley tradition, which includes the city of Hadhramaut axis of this study as well. It is quite remarkable that the compressive strength of around 5% was not enhanced by substituting cement for straw, rather the compressive strength considerably decreased and reached 40%. This is because of mixing clay with straw but this process was adopted to improve the durability and concentration. However, as obtained from the table, owing to the relative amount of deflation in the mud and large addition of cement, this is not a common practice. Excessive water loss due to evaporation is the underlying factor giving rise to this phenomenon i.e. deflation increases with an increase in the amount of water. If the cement reacts with water and the reaction continues to occur, it is known as Bahamh cement. This shows that the slurry contains a significant amount of water which may be reduced due to evaporation causing deflation. As a result the slurry mixture with cement shows shrinkage effects as well. The currently prevailing ratio of deflation in the mud from all directions is 8-12%. Moreover, the mud used in this brick factory has certain acoustic and thermal insulation features in accordance with the nature and climate of this region.

D. Lime and Ash Tests

Primitive ovens are used to burn the limestone available in the Hadhramaut area, and it takes up to two days to complete the whole process of burning the stones in the oven. Afterwards, carbon dioxide is produced leaving free lime behind. As per this chemical composition, calcium oxide is produced which can be seen in the flowing equation:

Limestone ========➔ free lime + carbon dioxide

(Calcium carbonate)   (Calcium oxide)

After burning the free lime for the major part of the day, this mixture is then cooled with water that produces hydrated lime, which is a white powder. As per this chemical composition, calcium hydroxide is produced which can be seen in the flowing equation:

Free lime + water   =   Hydrated Lime

(Calcium oxide)   (Calcium hydroxide)

A large amount of heat is required for the formation of calcium oxide or free lime, i.e. 16.6 kcal, and around 32% of water is added to make the free lime crack and turn into a white powder, which is referred to as hydrated lime.

The output obtained from the burning process is not of similar quality to the ash obtained from the construction operations in Hadhramaut city. The difference in the quality is because the ashes are obtained from burning plastic and other waste materials, whereas there they use wood, waste residue and dry cattle feed to obtain ash. Moreover, the difference in the manufacturing and production process is another reason. Currently, much attention is given to the production of ash in order to obtain any potential advantage from it.

The common operational type has primarily been utilizing ash and lime. The use of mortar has been observed to fill in gaps and therefore prevent subsequent leaks while also reducing the presence of moisture within the construction. Multiple tests have contributed to judging the various physical properties associated with the materials used. Hence cubes of various combinations, including those of lime or ash and lime in the proportions 3:1 and 1:3 were used. Over a 28-day period, the cubes were dried at room temperature without exposing them to any additional external stimuli. Table 10 shows the various aspects which has been observed to change over a period of time, including aspects of the quality of the deflation and the related density. Nevertheless, in consideration of the limited availability of these exotic materials in relation to Hadhramaut,. This has contributed to our knowledge of being able to compare the associated properties with regard to the mortar used in relation to the hay, the mud and the cement present.

Table 10. Comparisons of the properties of mortar after drying for 28 days

Feature / Mortar Type	Net Lime	0.25% lime + 0.75% ash	0.75% lime + 0.25 ash
Deflation %	12	3	4
Specific gravity of (g/cm^3)	0.87	0.80	0.95
Compressive Strength (N / mm^2)	0.41	0.41	1.02

Table 11. Changes observed in the properties of the mortar over a four week period (Ramodah_

Feature	Mortar type	Age (days)			
		1	**3**	**14**	**28**
	Net lime	7	11	12	12
Deflation %	0.25% lime + 0.75% ash	1	1.4	2.9	2.9
	0.75% lime + 0.25 ash	0.5	1.4	4.3	4.3
	Net lime	1.50	1.14	0.86	0.87
Specific gravity of (g / cm^3)	0.25% lime + 0.75% ash	1.55	1.17	0.80	0.80
	0.75% lime + 0.25 ash	1.80	1.45	0.94	0.95

Table 11 shows the rate of changes observed in relation to the intensity and quality of the various types of mortar used.

E. Ash and Lime Applications

Considering the results derived from the experiments conducted with regard to the lime and the ash used, it is fairly evident that the mortar has not been forcefully applied since it has been primarily used underneath the tiles. Therefore, there is not much damage observed within the mud, particularly in relation to the mud combined with straw. To this end, it is perhaps relevant to explain that in consideration of the weight of the incomplete, the external stress factor is able to hold its own.

Should the changes in the properties conclude in deflation if the lime used is subsequently exposed? This is indicative of contraction in consideration of the drying process and would be expressed in terms of visible reductions in relation to the lime used. This could also be the result of the lesser measures of ash used.

Perhaps this explains and justifies the high volumes of lime added to the ash by the people in Hadhramaut. Laboratory tests also conclude that there is a lower permeability ratio in relation to the water within the mortar mix comprising lime and ash. This also enables the lime to withstand use over a 50-year period, with minor reconstructions of the tiles used after around 15 years.

A careful evaluation of the quality of the construction in the notes reveals that the overall mortar density has a lime component of around 25%. The ash process density stands at around 75%. The concluding density is considered to be lesser within the secondary mortar mix in comparison to the first, which could be attributed to the weight of the light ash. This is indicative of the drying process reflected in Tables 10 and 11. The second mix of mortar has a lime ash mix of one-third and this is reflective of it being improved in terms of quality, especially with regard to aspects of compressibility relative to the density and quality. It can therefore be summarized that the small percentage of ash impacts the mixture, despite its lighter weight, in consideration of the granules being softer in comparison to lime and having greater permeability.

This increases the overall weight of the material. The higher level of the density in relation to the amount of ash present overcomes the impact of the lighter weight of the material, which contributes to the reduced ratios within the second mortar at 25% of lime and 75% of ash.

While some of the material used in the construction carried out at Hadhramaut has been discussed in the current text, various other laboratory experiments were required to conduct a comprehensive review. Nevertheless, the type of construction material used has been overall concluded to be good and could be considered to have contributed towards the greatness observed.

6.3.2 Summary

There have been multiple laboratory examinations of the mud bricks used within the cities in the valley of Hadhramaut. The initiative intended to explore the superiority of the material used here in comparison to ordinary clay. Some of the benefits herein are therefore found to be:

- In adding straw to the mud, adding just 0.2% to the mix is the optimum ratio for providing good results.
- Adding 6% cement to the mud provides the best results in the mixture.
- The addition of ash to the clay contributes to its overall resistance and contributes to the overall quality of the slurry. This is reflective of the mortar grout almost throughout all the structures within the Hadhramaut valley.

CHAPTER SEVEN

MATERIALS AND CONSERVATION TECHNIQUES RESULTS AND DISCUSSION

7.1 Before Conservation

Generally, it is observed that traditional structures and buildings are more likely to use home-grown materials, as per the specific requirements of the geographical location wherever the project is being executed. In the early nineteenth century, William Smith, the modern-day Father of Geology explained that this is especially relevant since the various topographical regions have their own particular requirements. In more recent times, input by the likes of Sir Nikolaus Pevsner in the form of county architectural guides (Hunt and Suhr, 2008) has seemingly seconded this perspective. Hence, designers have initially worked with aspects of the overall landscape within the Earth, deciding upon whether to work with perhaps slate, or amongst a choice of granite, clay, sand or chalk, congruent to the illustrations representative of fields or hills. These are more likely to be in sync with the associated buildings towards defining the overall character of the locale. Needlessly expending upon materials imported from outside the realm could contribute to attempts towards replacing the local character of the region.

Workmen expending effort on restoring architectural masterpieces need to be aware of the basic differences in relation to traditional versus modern structures. This is important since present-day constructions are more concerned with the overall permeability and slimness of the structure, incorporating cavities within the walls which is considered the Rain Screen Principle in the United States. This is congruent to how capillaries function, wherein in the event of moisture being detected on the outer walls or upon the cladding, the air cavity functioning as insulation should be able to disrupt the capillary action and the associated surface tension observed in the water. The underlying gravitational pull would in turn drain out the accumulated water utilizing weep holes. The cavities are also utilized as thermal insulation within the structure, although steel and glass could be considered at the higher end in this regard (Forsyth, 2008).

On the other hand, traditional building methodologies involve diametric composites related to air inflows, heat dynamics and an aspect of flexibility and perhaps skin coatings in certain cases. The thick walls of the structures contribute towards regulating the air flowing through the structure and keep the building cool in the summer and warmer in the winter. The flooring and wall enable the moisture to pass through, which makes the air very breathable. In relation to the masonry, the lime mortar in the walls is more malleable and therefore compensates for periodic and gradual structural readjustments over a period of time without causing cracks to be visible. Lime mortar is also considered to be more porous than associated material since it facilitates the transition of air. With the availability of Portland cement from around a century, the stone floor has been recognized as being the primary conduit enabling evaporation which on the other hand contributed to leaching in relation to related salts and erosion in the material. The accumulation of water in the joints also contributes to corrosion related to the thawing of ice (Forsyth, 2008).

In the Yemeni context, buildings are often constructed incorporating the skin of sacrificial animals, processed through lime. Thus, after washing it with lime, earth applied to it provides colouring. The twentieth century has given rise to a tendency to hacking off the plaster in the interior towards reflecting the underlying construction, and this is often demonstrated in pubs and related interiors. This trend was in turn attributed to the Victorian era and ultimately seconded by William Morris in 1877 in the context of the Society for the Protection of Ancient Buildings (SPAB). This gave rise to the concepts associated with how scraped walls were more preferred in comparison to the un-scraped versions.

It is important that buildings and structures dating back a certain number of years are carefully restored. However, it is also clear that a greater proportion of old structures are allowed to fall into disuse and disrepair. The damage caused is primarily attributed to modern-day attempts to restore and renovate the structures, since adequate care is often not taken. Further, the use of Portland cement in this regard is also observed to be harmful.

Restoring old buildings can be an odious task at best and often the restorer has to decide on whether to undertake the task or simply let things run its course. This is aptly demonstrated in the National Trust's Upper structure in West Sussex which was repaired after a devastating blaze in

1989. In this regard, knowing the actual outline of the entire architecture was certainly a help. Indeed, it is always a challenge to restore structures to their original glory (Pearce, 2013). Sir Bernard Feilden considers seven degrees of intervention in this regard, including:

(1) Prevention of deterioration;
(2) Preservation of the existing state;
(3) Consolidation of the fabric;
(4) Restoration;
(5) Rehabilitation;
(6) Reproduction;
(7) Reconstruction.

Minimalist intervention options are always the preferred mode in this regard, along with the utilization of traditional implements to the greatest extent possible. Where the restorer tries to sort through destroyed structures, the impetus is to ensure that the structure is saved from further destruction to the extent possible, instead giving a tinge of 'picturesque decay' to the overall structure. Nevertheless, the traditional concepts of conservation may not always hold true at all times, which is aptly demonstrated in the case of Hadhramaut. Here, inserting steel supports to restore original woodwork would in turn give the repaired structure a look of continued originality instead of using like timber. Thus, the use of iron within the timber roof fortifies the structure for many more years to come. Therefore, the ‘conserve as found’ process may not reasonably hold true here, although the same principle applied in relation to the roof may not hold true in the context of the grouting on the stone walls, which is perhaps lost forever (Forsyth, 2008).

It is important to conduct a preview of the structure intended to be restored prior to initiating the task, which would help in understanding the current state of affairs. This would contribute towards a thorough perspective on the situation and insight on the shortcomings, besides providing an idea of the extent of repairs required. Thus, a thorough survey of the entire site enables the reviewer to identify external factors influencing the situation, besides correctly identifying the related structural issues within the building itself (Hunt and Suhr, 2008).

With regard to initiating reconstructive restorations in earthen structures, it is important to correctly perceive the factors impacting its deterioration and also explore the history of how it was initially constructed. This is in consideration of the fact that in the majority of situations, it has been commonly observed that repairing earthen structures is perhaps amongst the least challenging. This can be summarized in consideration of the fact that the majority of earthen structures do not necessarily require the heavy-duty and sophisticated machinery and complicated processes normally associated in erecting modern-day structures (Al-Junid, 2014).

To this end, it can perhaps never be emphasized enough just how important it is to protect the structures in the first place instead of undertaking all the hassles towards restoring the structures once they are damaged. This could include a degree of daily maintenance, like perhaps putting in a support against a weakened wall or proactively plugging a gap in a leaky roof. Besides, the restoration process could also include steps towards ensuring that the original fabric or the ornaments associated with the structure are not unduly moved. Should it be necessary to rearrange the structure, it would be perhaps more prudent to erect a new structure instead of needlessly tampering with the existing layout within the present structure. This would ensure that the pristine condition of the structure is retained over the millennia.

The process of adaptive reuse could be emphasized to a greater extent when considered in comparison to the processes associated with adaptive recycling. This is amongst the most basic requirements in relation to modern-day restorative projects and simultaneously also constitutes the SPAB philosophy. A related treatise available in this regard is the Repair of Ancient Buildings, authored by A.R. Powys. This architect was the Secretary of the SPAB prior to the First World War (Jaquin and Augarde, 2012). Important illustrations of major renovation and restorative projects within Saudi Arabia include the initiatives undertaken within ad-Dir'iyah, Old Jeddah and Riyadh.

In any event, the restoration processes adopted vary in different parts of the world. Hence, structures erected by the early colonialists originating from Europe who moved on to the present-day United States, New Zealand and Australia are often considered national monuments of historical importance. However, corresponding structures within mainland Europe dating back to the same period are hardly accorded the same importance. The European and western perspectives and processes in relation to restoration are perhaps considered more stringent in relation to similar practices elsewhere, since they are seemingly more concerned with ensuring the integrity of the associated cultural aspect. Hence, they are not just concerned with restoring the physical building and the structure. To this end, it is often prudent to allow for buildings of historical interest to be converted into museums. On the other hand, Asian and eastern cultures tend to focus more upon renewal. Such cultures seemingly emphasize buildings erected in the earlier centuries continuing to function in their originally intended use. In such cultures, the interchangeability of old and new structures is considered perfectly normal and the associated restorative processes employed are often a reflection of this trend (Jaquin and Augarde, 2012).

Internationally agreed upon treaties, including the ICOMOS Venice and Burra charters, define the general trends to be implemented in relation to how historical monuments are to be conserved (Marquis-Kyle and Walker, 1994). While the overall paradigms of such treaties are fairly broad and inclusive, they nevertheless do provide some guidelines on how to proceed with conserving buildings and allied structures.

To summarize the discussion, irrespective of the materials used and the processes employed, earthen structures considered in this context should be considered monumental or vernacular and should be protected and conserved to the greatest extent possible. It is also important that any restoration initiative undertaken in this regard acknowledges the advances made in present times. It is very important to observe the processes involved from a technical viewpoint in terms of the techniques involved, the structures used and the materials utilized. It is also important to consider the history of the building in trying to decide upon structural and construction flaws and weaknesses. In this regard, it is perhaps more relevant to align processes in consideration of modern-day advancements which would rationalize the processes adopted. Initiating restoration projects within such structures requires a team of experts within their individual fields, including architects, engineers and historians who will comprehensively understand the multiple parameters involved. The initiatives undertaken in this regard should be ideally reversible to a reasonable extent wherever possible.

7.2 Listing and Conservation Areas

Prior to undertaking a restoration project, it certainly helps to decide whether the structure is situated within a designated conservation area. If this is the case, it is summarized that there are multiple benefits to be accrued and associated responsibilities and limitations to be harvested. Listings enable the identification of structures relevant to our heritage, and include forts, places of religious worship and so forth. The majority of owners of such structures are only too pleased to have their locales designated so in consideration of the increase in associated value (Jaquin and Augarde, 2012).

It is important to legally check whether the structure is listed as being protected, with the planning authority within a particular location being a relevant source. The majority of listed buildings are listed in their entirety, irrespective of some areas of the structure being of perhaps greater importance than others. Irrespective of whether individual parts of the structure are explicitly designated to be protected, the entire structure is to be considered so. Thus, there is a possibility that structures such as garden walls, outbuildings and the like could also be listed separately as being protected in a different category (CRAterre, 2008).

Should it ever be perceived that there is a genuine requirement to alter the structure of a recognized and designated structure, it is important to have prior written approval to initiate and implement the changes. This could therefore include undertaking exercises related to applying a facelift to the premises, or even replacing worn out and broken window sills. Hence, prior to initiating any restoration or conservation work in this regard, it is prudent to check with the relevant authorities to pre-empt any criminal charges. Although the owners of protected buildings may be allowed to undertake repairs of their premises if it is deemed absolutely necessary, the extent allowed is minimal (Keefe, 2005).

The structural changes enacted within a building are reflective of the history of the structure. In implementing such changes over a period of time, it is possible that the heritage of the structure could be permanently altered. This could show in irreversible changes enacted in relation to the structure (Keefe, 2005). It is not possible to completely exclude the process of decay and damage in any structure over a period of time. Nevertheless, it is important to ensure that the changes and damage are minimal and if considered relevant, the processes undertaken in this regard should be reversible to the greatest extent possible. This is demonstrated in how an arched shelf within the Al-Junaid residence covered some three decades back has now cracked because of a weakened window beam (Figure 81).

Figure 81. Cracked arched shelf within the Al-Junaid residence (Al-Aidarous,2014)

A related concern is the utilization of recycled and disused material. Therefore, prior to setting out for the salvage yard to procure goods, it is important to consider the original source of the purchase. Recycling architectural structures from a different era is susceptible to being confusing for future generations. The trade of architectural goods encourages and gives impetus to related thievery even while it simultaneously ensures that the reference is properly utilized. Using recycled references in this regard could be done with genuine goodwill and often, old-world architecture juxtaposed with modern-day structures could be considered to be perfectly aligned with each other (Hunt and Suhr, 2008).

As the project is gradually worked through, it is important to keep the conservation officer in the loop on the progress so that the official cannot later accuse the conservationist of needlessly altering the structure. In the event of cost issues, this could be communicated while officials could often themselves make certain recommendations too (Warren, 1993).

Most buildings and structures designated for conservation request a 'Design and Access Statement' towards evaluating restoration applications. Normally, this constitutes the broad parameters of the initiative to be undertaken and how this would be reflected in the final outlook of the building. It enables the restorer to explicitly state the scope of the initiative, and provides them with the option of appealing against any rejections. For ordinary day-to-day repairs, perhaps a simple schedule of works alone will suffice, which could also list the cost to be incurred in the initiative. Correspondingly, a diagrammatic representation of the task being undertaken could be included, like the exact pathways of the drainage to be laid out (Ada.gov.sa, n.d.).

7.3 Rationale of the Documentation Process

To explain the Burra Charter (Marquis-Kyle and Walker 1994), the document helps understand restoration initiatives in the Saudi context. Thus, major conservation exercises try to replicate the existing material in the structure, trying to extract maximum value from using the original material. This therefore draws upon the use of technology, history, anthropology and scientific lines of enquiry, besides the use of architectural aids. The associated reports summarized are reflective of the intellectual perspectives which highlight the role of the various activities undertaken from a clinical perspective in relation to the likes of public policy, education, fund raising, community organizations, cultural performances, short-term construction initiatives and the like. Such a list helps to prioritize the various aspects involved. Through his initiatives undertaken in the context of Egypt, Mitchell (2002) contributed much towards helping us understand historical perspectives, which are being continued by modern-day professionals too. Polish conservationists have brought forth new perspectives on how major initiatives are to be concluded in Elblag, ensuring that the character and the spirit of the initiative is maintained (Johnson, 2000).

Although the Burra Charter is seemingly involved with summarizing the historical context of structures, it is nevertheless also important to understand various associated social aspects too (Marquis-Kyle and Walker 1994). This is amply demonstrated in the Nara Document on Authenticity, explaining the cultural context in the historical perspective. It recognizes that often it is difficult to quantify the precise value of authentic structures, which is why the cultural heritage of a location needs to be respected. Neville Agnew and Erica Avrami associated with the Getty Conservation Institute conducted a discussion with Hugo Houben, John Hurd, and Tony Crosby who are renowned specialists in restoring earthen structures. The experts emphasized the importance of documenting the scientific studies testing and evaluating various methodologies towards initiating restoration projects, since it is important to understand the local cultural context of whatever is planned (Agnew and Bridgland, 2003).

In trying to correctly perceive the heritage of a location, conservationists are therefore more open towards adjusting and accommodating their viewpoints. The field of study is therefore perhaps more receptive of input from the various stakeholders, with the processes being reflective of a fair amount of flexibility. Correspondingly, aspects of existing social practices are considered to include various prevailing aspects and parameters in consideration of ensuring the continuity of the existing parameters involved, instead of conducting the entire exercise in isolation (Keefe, 2005).

7.4 Earth Materials

7.4.1 Adobe Construction Technique

Adobe is made up of earthen blocks which are dried and moulded under sunlight. The manufacturing process requires the earth to be moulded without packing the paste, with the final dimensions of the blocks varying considerably with regard to their texture, colour, form and composition. The blocks are generally convenient to handle, which is why the weight factor is often focused upon.

The process is considered native to Najd, in consideration of local conditions which provide for simplistic designs and an overall ideal for the existing environment. Nevertheless, there are often issues with the durability of the final structure steps.

The processes involved therefore involve the utilization of alluvial soil, besides clay, which is also rich in mineral content and silt. These constituents are mixed together as a paste and later accordingly moulded. The homogeneous mix would therefore have resulted in soft earth, besides having components of vegetable fibres (Facey, 1997).

Once it is determined that the existing earth has certain shortcomings, it is possible to modify the mix, including the possibility of adding in chopped straw if the fibre content is not enough. This would reduce the propensity of the block to shrink when ultimately dried out in the sun and prevent cracks from appearing (Damluji, 2007). Furthermore, the process enhances the malleability of the structure, wherein the clay content results in being around 18%. However, a clay content of between 4-10% contributes to making the structure withstand repeated mechanical alterations to the structure. This entails removing the top soil to expose the earth lower down which is then transported to the actual production area before it is processed through a sieve (CRAterre, 2008) (Figure 82).

Figure 82. A mixture of earth with straw (Al-Aidarous)

It is very relevant to evaluate soil samples to predetermine whether it is necessary to add either sand or clay, by perhaps taking a small amount of the soil and soaking it in some water. It is recommended that the exercise be conducted in potable water to exclude the possibility of contamination by various impurities. Ideally, the process should be continued for quite some time prior to arranging for chopped straw to be incorporated within the mix. It should now be thoroughly mixed until the right consistency is obtained before starting the moulding process. Normally, the paste is applied using a shovel or a hoe before being kneaded with the feet of the person who is applying the paste. In modern terms, mechanized processes including the front of a loader perhaps attached to a tractor could expedite the entire process (Alvarenga, n.d.).

In this regard, such structures are always observed to be in need of some minor repairs, which particularly holds true after torrential rains and minor storms, since the structures erected are hardly considered to be water-resistant. The clay binding the structure is susceptible to being washed away by water. Alternatively, if too much water flows over the mud structures they are liable to swell up and thus damage the entire structure (Facey, 1997). To date there is no particular solution to the challenges encountered in this regard, although multiple studies are being regularly conducted towards deriving mud variants which could be considered to be resistant to the adverse effects of the environment, especially in consideration of uncontrolled water flows. In this regard, trials have been conducted with bitumen and the addition of chemical resins, but nothing has been successfully established and concluded. Ultimately, the application of ethyl silicate on the structural surface has been helpful to a certain degree, although it has nevertheless been observed to be not very successful in the case of very old buildings (Mchenny, 1984). M'Hamid El-Ghizlane buildings lists when cracks occur in earthen structures; most locals have been observed not to be too bothered. Instead, sand storms blowing through the area deposit silica and other materials in hard to reach spots which automatically solidify in the subsequent rainy season, and thus seemingly automatically repair the wall (Figure 83).

Figure 83. Rammed earth natural rendering (Al-Aidarous,2014)

As per research summarized by Facey, an optimum mix has been supposedly made by adding in 4-6% of cement to the mix before compressing it within a brick mould and allowing the portion to dry out in sunlight. The durability of the structure has been correspondingly repeatedly demonstrated in arid lands and the measure of this could be gauged by the fact that structures immersed in water for up to 5 years have subsequently been demonstrated to exhibit minimal damage. Therefore, there are multiple studies examining the effectiveness of adding cement to wall mixtures (CRAterre, 2008).

It is summarized that often, unsterilized sun-dried mud bricks have resulted in being more stable than other related options. There are indeed multiple factors involved, including the nature of the building materials used, the recipe utilized, and the quality of the mixture, and all such related factors have significantly impacted the final product rolled out. In this regard, the mud mix utilized within the context of the Najdi structures erected during the time al-Turaif came under brief occupation sometime in the 1960s demonstrated an inferior construction quality when compared to the related architecture erected during earlier times.

Clay forms a key constituent in mud brick structures and it is seemingly abundantly spread out in the Najd area within the ground water. Clay can therefore be naturally mined as a mineral and then utilized as an adhesive, although the stickiness of the material often makes it a challenge to work with. Clay has the inherent ability to absorb significant amounts of water and consequently expands. Later, once it dries out, it is also susceptible to shrinking. Thus, clay is liable to dry out and crack if it is allowed to completely dry (Al-Saedi, 2013) (Figure 84).

Ordinarily, the ideal clay and silt content is concluded to be between 20-30% within adobe, while the rest would be constituted by the other ingredients in the mix. The soil is considered to be fairly variable and it is therefore not possible to precisely quantify all the various ingredients. Furthermore, the mix is often observed to vary from location to location. Nevertheless, modern soil analysis and testing processes are known to provide fairly accurate measures in this regard.

A. Making Traditional Adobes in Saudi Arabia

Abdullah bin Hamid is considered to be a renowned master builder. Similar to medieval master masons in the European context, Arab societies constructing large mud structures concluded the projects utilizing the services of master builders. They had significant hands-on experience in successfully erecting structures and are somewhat considered the modern-day equivalent of architects in the locales they operated in. They were fairly well known almost all over Arabia, and were in high demand within the Najd area prior to the erection of modern-day steel and concrete behemoths. Thus, some two centuries back, ad-Dir'iyah used to boast about Ibn Hazam. In the 1920s and 1930s, the renowned Ibn Qabba held sway over multitudes of construction projects including the Murabba Palace in 1936-38 (Facey, 1997).

Today, Abdullah bin Hamid is a wizened 70-year-old veteran who has constructed adobe structures all his life. He took over the reins of the family business, following his father to Riyadh during the adobe construction boom in the city in the 1930s. However, with the advent of a new dawn with oil wealth, demand for their services gradually dried up since the majority of construction switched to steel and concrete structures. Ibn Hamid has nevertheless persevered and at present is primarily associated with multiple restoration projects. He has therefore worked upon restoring the Masmak Fortress and the Murabba Palace in the Riyadh area. Over the years he has found himself to be amongst a dying breed of craftsmen who are being phased out. He was well known to Prince Sultan since the latter utilized his services in restoring four wells within his personal farms (Al-Bini, 1990).

To start off the process, it is important to arrange for the related ingredients required. This involved arranging for the required grade of soil for the project. A corresponding location was identified within the Hanlfah valley by the ad-Dir'iyah populace in this regard. Considering that this source was located at some distance from the actual construction site, the soil had to be transported to the area where it was required. Thus, there was a minor cost incurred in procuring the soil. Thereafter, a considerable amount of straw was sourced and basic bricks were made utilizing almost a cubic metre of soil for around 50 bricks. Thirdly, it was important to decide on the correct grade of desert sand. Considering Professor Lamei's expertise in the Egyptian desert, a part of sand was mixed with three quarts of soil trucked in from the valley (Al-Zahranni, 2008).

The master builder, Ibn Hamid provided the correct recipe to be used herein. He therefore stated that it was not required to add any additional content of sand within the mix since the soil procured from the valley was already sufficient in this aspect. Some portions of sand were added to the initial trials conducted for the walls in 2006 which concluded in sand particles failing to adequately bond with the clay and were observed to fall off upon simply rubbing the walls. To confirm whether the mixture contained too much sand, associated chemical and sieve tests were conducted which proved exactly what Ibn Hamid had already predicted. It was therefore concluded that the clay transported in constituted some 35% sand, which was precisely as per the requirements in this regard (Facey, 1997).

A depression was drawn within the mixture, similar to making cement slurry, and 5% by weight of water was added, which was intended to aid in churning the mixture within the digger. Subsequently the mix was left to ferment for around 2-3 weeks, while being continuously sprayed with water to ensure its moistness. In the intervening period, the straw breaks down and chemically reacts in a minor way. The specifics still need to be correctly examined in this regard. At the result of the fermentation process, the mix turns a blackish-grey colour, something similar to manure. The mix now has a distinctive smell, and on applying it to the walls it hardens to a buff colour. Some 2-3 weeks go by and the mixture can now be applied upon the walls or can be processed for making bricks. For the latter, it is placed in moulds upon straw-strewn spaces where the mould is removed after which the brick dries off naturally. The brick is therefore initially placed in the shade so that the sun does not crack the fresh brick, and then it is dried off under the sun. Subsequently, the brick is stacked, allowing for clearer air-flows. It is important that a clean space be used to manufacture the adobe, since irregular surfaces could see the mud trickle down to the base. A common practice is to scatter some dry sand upon the entire surface of the manufacturing room, enabling the easy release of the bricks once they need to be turned over.

The adobes so constructed were subsequently dried under natural sunlight over a 2-3 day period in the hot summer months, or were exposed to the elements for 6-7 days under milder temperatures. During the cooler winter months, this exposure was extended to up to 2-4 weeks, although the frost factor certainly significantly decreased the incidence of producing adobes. The duration was also a function of the number of adobe bricks considered, since it was important that they were thoroughly dried under natural sunlight. The adobes could also be cleaned with a trowel if it was required; although that should be applied carefully on the moist surface if it is applied before the surface completely dries up (Minke, 2010).

To ensure the durability and resilience of the adobes under sustained rain, it was debated as to whether to add Protim 23 WR to the paste, although this option was subsequently discarded in favour of the more traditional processes (Ada.gov.sa, n.d.).

The protection of the adobe bricks from the natural elements, including the likes of frost, snow, rains, floods and the like is an important requirement in consideration of the need to ensure that the bricks did not get damaged before they were fully hardened (Mosaibah, 2013). This is in consideration of the fact that too strong winds could impact the surface of the adobe by creating minor depressions and craters upon the surface. Therefore, it is important to cover them with sheets. Nevertheless, once they have dried, the effort contributes to the tensile strength of the adobe. In the event that the adobes were not dried to the extent required, the process would continue even after applying the adobes, which would make the construction process difficult, since the adobes would be extraordinarily brittle. Under normal manufacturing conditions, the stacks of adobes can be covered with a tarpaulin to protect them from the extremities of the weather, although sealing them would be liable to interfere with their curing process. Nevertheless, once the adobes are properly dried, they can then be stored over long periods with minimal issues (Figure 84).

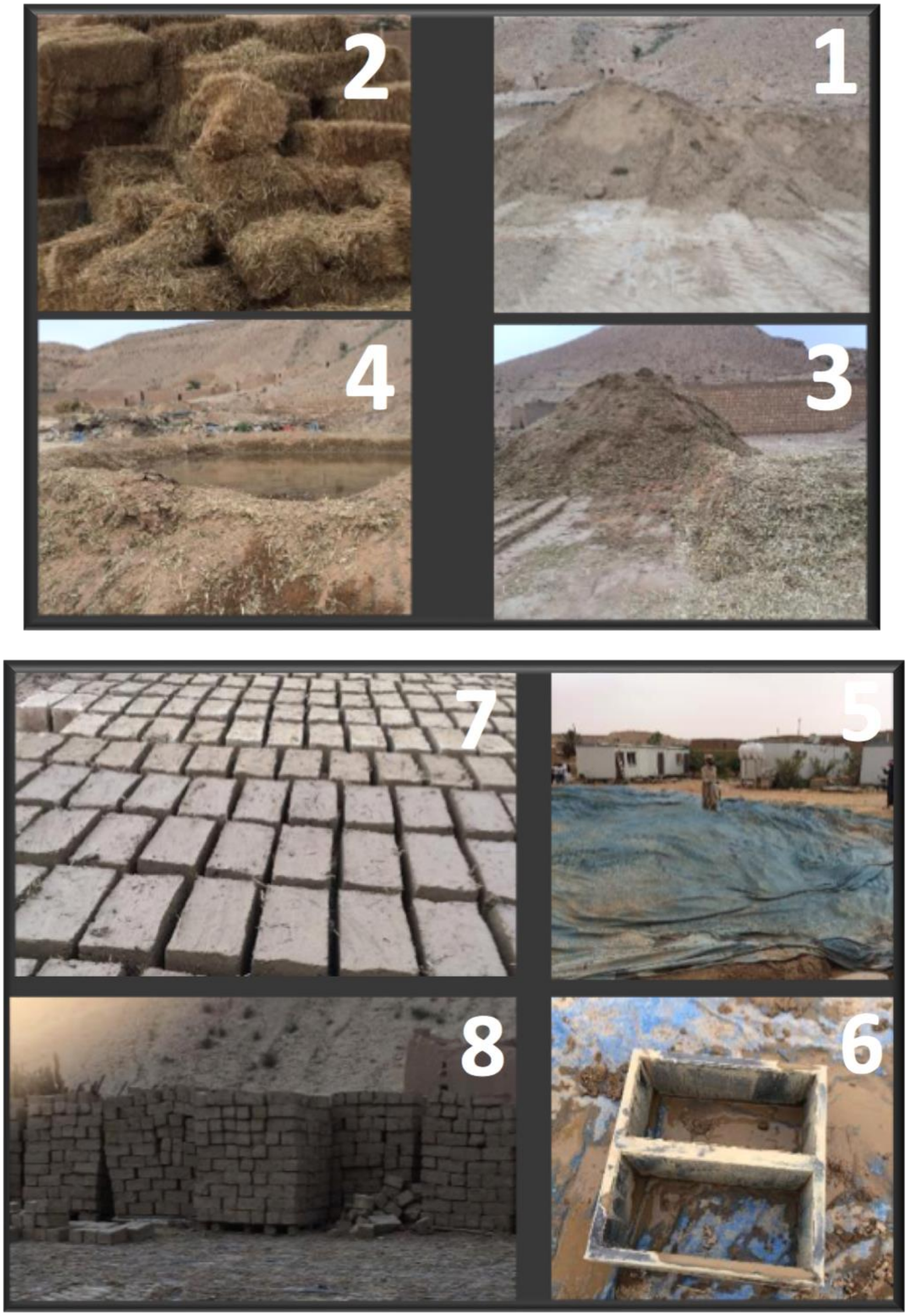


Figure 84. The process of making adobe in ad-Dirrya (Al-Aidarous,2013)

Figure 85. The resulting mixture used at ad-Dir'iyah for rendering and a mortar

B. Testing the Mud Bricks

To correctly conclude the durability of a brick, a basic overview can be gained by immersing it in water and noting the duration required to dissolve it, which should be at least 17 minutes. The fact that the ad-Dir'iyah bricks took almost 25 minutes was testament to their quality. It was interesting to observe how bricks with a minor cement content took almost the same time, raising questions on the utility of the additive incorporated in the formulation. Earlier studies have summarized that mechanically constructed blocks incorporating 4-6% of cement withstood almost 5 years of being immersed in pools of water. A related test evaluated the compressibility of the blocks, which was a bench test conducted within fully equipped laboratories. It normally involved measuring the amount of pressure applied in Newtons in squeezing a dried mud sample between two plates until it was crushed. Generally, this was read off in the range of 10 kg/cm^2.

Compression tests conducted upon the mud mix formulated in ad-Dir'iyah read off pressure readings of almost 4.89 Newtons per mm^2 under dry conditions. This was considered a reasonable reading relative to sun-dried bricks. The standard value summarized from the corresponding tests conducted earlier were 1.59 Newtons per mm^2 relative to bricks which have been hollowed out by termites and 2.05 Newtons per mm^2 for termite-free blocks. Perhaps the deciding factor in this regard relates to the care taken in the manufacturing process, which in turn is reflected in the durability of the structures erected utilizing the technology. Thus, despite the age of buildings within the general vicinity of the al-Turaif area, the structures in the ad-Dir'iyah are still very much habitable, despite the passage of 200 years. For comparative purposes, solid concrete test cubes have been registered to withstand around 30 to 40 Newtons per mm^2, which is almost 8 times the strength of the bricks used in the ad-Dir'iyah buildings. Notwithstanding this fact, there is hardly any need for such comparisons since it could also be summarized that should the adobe be strong enough, the concrete structure could be considered to be up to 8 times stronger than normal bricks (Ada.gov.sa, n.d.).

7.4.2 Cob

The alternative process in manufacturing earthen structures involves cob, which is still relevant and in practice. There are multiple structures in Devon in south-west England which have been constructed using walls in layers excluding shuttering. In this case, the mix should be moist and does not require ramming but instead it should be able to withstand its own weight when applied in layers. Chopped straw is added to strengthen the process. On erecting a wall, the uneven surfaces are sliced off to result in a smoothened wall. This methodology is still applied within constructions in the Hanifah valley for the walls of farms and in al-‘Udhaibat. Perhaps the construction process in Arabia differs from that in England in the context of the finishing in the latter area, which is perhaps of a better quality. The same methodology is applied to walls in ‘Asir and Yemen in encircling residential compounds. The process is also demonstrated within Asir and Bishah in Saudi Arabia, and in Sa‘dah, Yemen (Leslie, 1991).

7.4.3 CEB (Compressed Earth Block)

Current conservation initiatives used within Saudi Arabia are more likely to be drawn in the context of Compressed Earth Block (CEB) processes which are derived in consideration of compressing the soil with a die, either mechanically or manually to manufacture symmetrical blocks. The process was perfected in the twentieth century and enables the efficient mass production of bricks within both large scale-manufacturing units and smaller individual workshops. There are multiple variants of the presses available, and the system itself is now available fairly widely (Maini, 2005).

In the event of the soil being exceptionally sandy, compressed soil is utilized within the formulation, which should be sieved for gravel. Correspondingly, it is also important that the moisture content should equalize the earth being rammed. Initially, the earth is sieved by manual measures. Mechanical means can also be considered equally effective to ensure that the grains are uniformly spread. The use of stabilizers could conclude in ensuring the right level of moisture in the sandy soil.

Additives could be utilized to ensure consistency within the CEB readings and record values within 3-9%. In this regard, lime and cement are more commonly utilized to contribute to the mechanical resistance in relation to surface erosion for heavy walls and vaults (Al-Jaded, 1994).

Should the mixing processes be done correctly, it is then transported through a conveyer for compacting. To ensure the quality of the blocks, a measured quantity of earth should be added to the mix, with individual presses being filled in by a particular scoop size. The CEB block is then pressed and ultimately ejected from the mould utilizing a suitable press. There are options to either use simpler single compression variants or higher-end double compression systems.

Blocks ready to move to the warehouse need to be placed on pallets. Inside, they are wrapped in plastic sheeting to allow for deeper curing. After the blocks have stabilized, they are considered to be hard enough to be placed outside, dependent on the prevailing weather conditions (Schroder, 2010).

7.4.4 Straw

Chopped up barley or wheat straw can be added to the blocks, although the reason behind this is unclear. It has nevertheless been summarized that it is perhaps disadvantageous to add organic references within the mix, since it has been observed to conclude in termites attacking them and ultimately hollowing out the wall. Nevertheless, British studies have demonstrated that adding 1.5-2.0% by weight of chopped straw significantly contributes towards enhancing the compression ability and the related tensile strength of the mix. This could be attributed to the fact that the functioning, relative to a mechanized binding agent, provides for enabling wet mixes, resulting in lesser slump. At the same time it also safeguards against erosion should there be sudden rains after a dry spell, which could be attributed to the roots of the plants holding the soil together, preventing erosion (Facey, 1997) (Figures 84-85).

Leaving the bricks over an extended period of time prior to using them enables the organic matter in them to ferment, giving off lactic acid. This reduces their absorbency and sustains the brick over a longer period of time. Simultaneously, the straw produces colloids which enable a greater degree of adhesiveness within the bricks. Besides this, the straw also retains the moisture only on the surface of the bricks instead of allowing it to seep within the bricks, which increases the dryness of the mud within the inner walls and layers of the individual blocks. This reduces the incidence of the bricks cracking up. In this regard, animal dung is often added into the mix. The initiatives undertaken at ad-Dir'iyah included the use of Dusban 4TC (Facey, 1997). Certain structures in southern Morocco utilized animal dung which was concluded to be effective in this regard. If the paste was to be used as a wall plaster, an added amount of straw was used in consideration of the fact that once dry, it added to the hydrophobic properties of the walls and ensured their dryness (Binici, Aksogan and Shah, 2004). The paste was formulated in a shallow pit to conveniently add water to the mix since otherwise sand and silt would be collected in sediments at the bottom within the clay mix. It is also effective to trample upon the paste, since the movement of the feet enables a more uniform mix, perhaps similar to the tumbling effect within a cement mixer. Such a paste could be worked upon at the earliest stage, although it is nevertheless preferable to let the mixture ferment over a period of time to achieve optimum results (Figures 84- 85).

The final stage of the brick manufacturing process involves setting the paste within wooden moulds. Utilizing hand held moulds, the paste is plastered within clean, humid or powdered moulds. Spanish brick-makers are also known to use ash in this regard (CRATerre, 2008). The mould is filled to the top and the excess sticking out of the top is sheared off with a stick moved horizontally over the edges of the mould. To ensure that the corners of the brick are not jagged, the mould is shaken to ensure that the edges are loose enough. Prior to stacking them moulds, they are allowed to dry out. Normally, wooden moulds have been used over the ages, although metal versions are increasingly becoming more common. To ensure that it is easy to move the mould, handles are affixed to the sides of the moulds, which can vary in shape and size. In serialized mechanized processes, the moulds are filled through custom designed pressurized nozzles, adding to the overall efficiency of the entire process. It is therefore possible for individual workers to roll out between 200 to 500 bricks per day. On the average, around 3,000 of these bricks are required to successfully complete a small structure enclosing around 60 m^2 of space (Facey, 1997). Post construction, it is recommended that the bricks are left in the awning of a shaded structure for a day or two so that the surface does not crack and to avoid issues of shrinkage. Thereafter, the bricks are exposed to direct sunlight in rows. The bricks also need to be periodically rotated to ensure that all the sides are uniformly dried. When using the paste for covering a wall, it is considered important to allow it to undergo a degree of fermentation. Increasing the duration of the fermentation process is reflected in better-quality building products. Therefore, once the paste is applied to the wall, it is generally recommended that it be exposed to the elements for as long as reasonably possible. While restoring the ad-Dir'iyah structure, the Najdi master builder, Abdullah bin Hamid and his Egyptian consultant, Professor Lamei, recommended that the paste be fermented for over three weeks (Ada.gov.sa, n.d.).

7.4.5 Earthen and Mortar-Based Construction

It has been accepted that limestone-based mortars are just as well-suited to function in place of standard mortar and plasters within construction processes (Ashurst, 1990). Cement was invented in 1824 and since then has been extensively used in infrastructure projects. From around the turn of the twentieth century onwards, it has been regarded as a key product in constructing all residential and commercial facilities. Nevertheless, limestone-based mortars still have widespread utility within residential projects (Forsyth, 2008).

Initially, mortar was used in combination with sand and clay. This is still applicable where the wall incorporates lots of rubble since the mortar conveniently fills in empty spaces within the pieces used (Green low, 1976). Such clay and sand mixes are normally used in constructing the façade of structures in consideration of their ability to withstand the elements. To decide on the exact type of mortar to be used, a rule of thumb is to consider a small piece of the structure and mash it between the index and forefinger. If the piece squeezed crumbles easily, it is indicative of the mortar constituting of lime. On the other hand, if the piece within the finger remains intact despite repeated attempts to crush it, it is indicative that the mortar is cement based and is therefore able to withstand significant force (Holmes, 1997).

In the past few decades, there have been multiple incidences of unscrupulous builders constructing substandard structures within Saudi Arabia, utilizing questionable grades of grey Portland cement. This has adversely impacted the overall architecture displayed around the city. This is observed in consideration of the widespread use of hydraulic lime which undergoes extensive chemical treatment. The product is available in a powdered form but quickly solidifies once it comes into contact with water (Sami, 2011).

There are different grades of hydraulic lime available, including NHL 3.5 and NHL 5 which are classified in terms of the volume of clay and earth in the limestone uses. Lime mortars were commonly used within Saudi Arabia, and were normally exposed to the elements for around five days prior to application. The lime utilized was derived from local limestone and was traditionally used in the Hadhramaut area. The positive aspect was its higher calcium carbonate content. Modern-day processes involve utilizing lime drawn from limestone rocks in local quarries. Alternatively, a mix of lime, sand and clay could also be considered, which is generally mined from within the valley itself (Amm Mahfooz, 2011). Hence, the Shagra building within the Najd uses mortar made from a mix of sand, clay and lime which solidifies over a period of time, provided it is shaded from water spills. The present-day crumbling mortar generally observed within Najd could be attributed to the use of earthen mortars (Angawi, 1988). Therefore, structures in the Najd area commonly utilize a protective coating made from plaster made from whitewashed soil. Structures in Shagra make use of a mix of soil and lime which has proved effective in controlling erosion during the rainy season. Of the two, the plaster in the Najd area has a better finish, since it is manufactured by burning locally available limestone (Amm Saad, 2011).

Production of Traditional Lime Mortars

Primarily, quicklime is used to derive and produce lime. This is derived by heating limestone ($CaCO_3$) within a kiln to temperatures in the range of 800-900°C. Under normal circumstances, both quicklime (CaO) itself and limestone are sparkling white in colour. Correspondingly, clay-based limestone is a more dull white since it is shaded over by the presence of various metallic impurities. The major aspect differentiating limestone and quicklime is that the latter has a whiter shade which is taken advantage of when using it for plaster within Hadhramaut. Quicklime pebbles are also known to retain their shape over a considerable period of time. To this end, quicklime is initially heated in a kiln before being introduced to water. Considering the heat of the lime, the lime is dropped into the water to ensure the safety of the process by perhaps conducting the process within a simple depression in the ground. On being dissolved in the water, the solution turns to a viscous liquid, since the diluted quantity of the quicklime increases when the temperature brings the water to boiling. Normally, the paste is produced from three quarts of water and a single quart of quicklime. The quality of the mixture produced is normally a function of the duration of hydrating the quicklime. Generally, the mix is applied by a shovel or a trowel after hydrating the paste for up to four days. To ensure that the paste is smoothly applied, it is retained for up to two months, following which the paste is filtered to ensure its purity. This involves using wire-filter gauze and adequate hand protection since the lime is liable to burn through the skin on contact. It is also recommended to undertake adequate protection of the eyes and other parts of the body. On filtering the paste, it can be stored over long periods within cans or drums. While there is no expiration label, it is nevertheless recommended to ensure that the paste does not dry out completely, which also holds true for whitewash and mortars (Forsyth, 2008) (Figure 86)

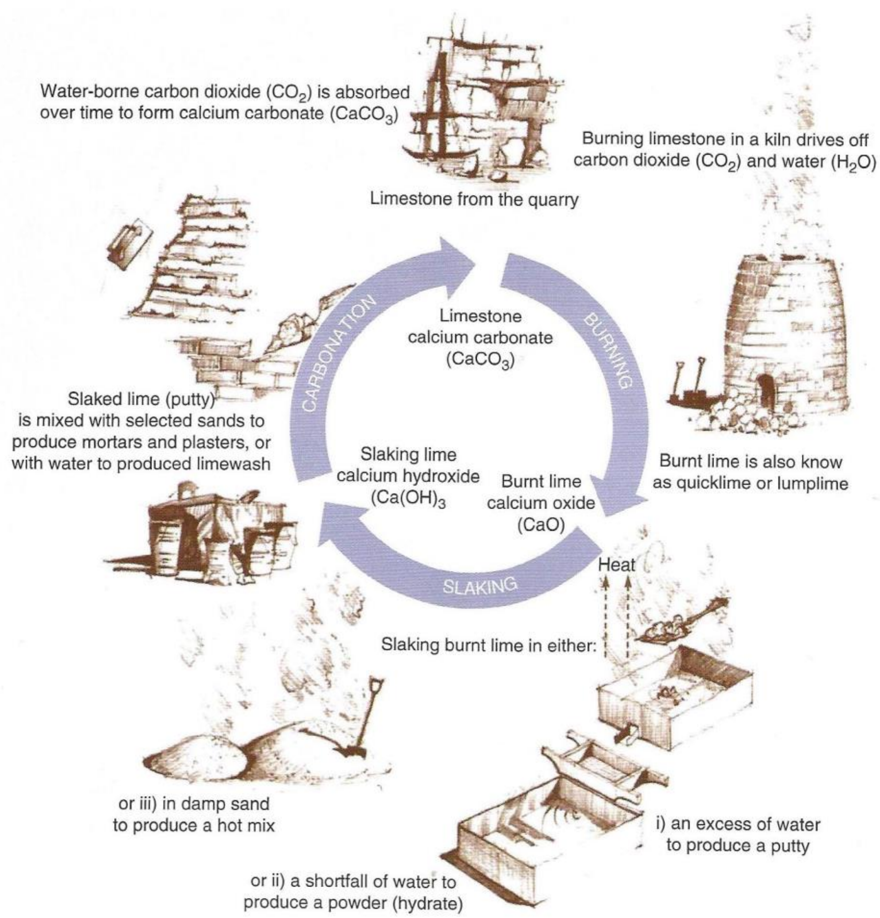


Figure 86. Lime life cycle (Forsyth, 2008)

The standard composition includes sand as an aggregate which is used together with a binding material which could include both lime and cement. Alternatively, at times additives in the form of various colouring agents and fibres can also be utilized. Finally, water is added into the formulation to activate the associated binders, resulting in the creation of a paste (CRAterre & basin, 1994).

Both adobe and CEB masonry are known to utilize natural earth mortar, and in ensuring its durability in relation to the natural elements, including wind and rain, exposed joints are protected by the use of pieces of tile, pebbles, cement and similar material. In considering and dealing with the propensity of retraction, the elements are also known to offer greater mechanical stability to the structure erected. It is important to review the extent of porosity within the walls, since should the walls be too porous, they would be liable to absorb greater amounts of humidity to the detriment of the safety of the structure. On the other hand, excessively reduced humidity could result in bonding issues within the masonry.

The hydrophobic properties of the mortar mix could be enhanced considerably to protect against the adverse effects of rain and frost by utilizing multiple products, including cement, bitumen, vegetable extracts, related natural extracts, lime and manure. They would contribute to providing a smoother finish in using the mortar. It is important to consider that alternative waterproofing and hydrophobic materials have also been considered along the lines of trying to hydrate lime in the presence of various grades of oil (CRAterre, 2008).

It is crucial that the strength of the mortar used is equal to the overall consistency of the adobe or the material comprising the CEB in consideration of the fact that both have to be incorporated within the structure of the masonry as unique elements.

7. 4. 6 Roof Timbers

To construct an adequate base, the proper grade of timber is required in consideration of the requirements associated with the joists and the related composite girders for the bearings. The athel tree is abundantly found within various Najd districts, although when constructing in large residential complex it is often a challenge to source a tree of the required dimensions. Hence, it is rightly summarized that the dimensions of the tree available has a direct impact on the sizes of rooms within residential compounds in the Najd area. The majority of houses therefore are observed to have rooms in the range of around 3.5 m in length or breadth. Indeed, during the building booms in the 1800s and in the 1920s and 1930s, there were severe shortages of local timber (Al-Ashiry, 1980).

In the modern times, many athel trees have been planted to overcome these shortcomings, and entire plantations and forests have been covered in this regard. It is also used a windbreaker and a dune stabilizer within the desert sands. There are therefore many farms in al-Muzahiiniyyah leading to Makkah and in the al-Kharj area south of Riyadh where the tree is now abundantly found (Momra.gov.sa, n.d.).

After gathering the required amount of timber, the next challenge is to make it ready for use by cutting it to the required size. This involves trimming it and chopping off loose bark. Thereafter, it is treated with Dnrsban 4TC as a precaution against termites before being finally coated in layers of bitumen. However, applying this layer has been observed to contribute to the presence of mould within the athel joints, attributable to the high level of humidity.

The erection of the actual roof involves initially positioning the girders in the centre of the room in consideration of the column capital or the wall. Normally, this is concluded by two girders using corresponding tamarisk beams having individual diameters of 25 cm^2, which are arranged adjacent to each other. Depending on the size of the room, up to three beams could also be considered with the undersides of individual beams being sliced through to form a flattened surface which seats the capitals of the columns involved for decoration. These are woven together (Sayigh, n.d.) (Figure 87).

Figure 87. Roof construction (Al-Aidarous,2013)

On laying the joists which are centred within 35-40 cm from each other upon stonework, they are placed upon a wall to balance out the loads involved and also work against termites. Subsequently, palm frond spines have their leaves peeled off for placement adjacent to each other across the joists. Nevertheless, it is a challenge to arrange them together. Nailing them to the joists is a valid solution although it is not recommended to use metallic nails within the structure. Instead, palm-leaf spines can be placed cross-sectionally within the joists, and arranged them to be knotted with the spines. This is supposed to provide a temporary scour, pending the completion of the roofing. However, since the input added to the beauty of the overall structure, it was decided not to dismantle it.

It was necessary to design corresponding plaited palm-leaf mats, which used to be fairly common amongst craftsmen in the country during the past, although it is now hard to find anyone proficient in this art. While it was being debated either to have a craftsman come over from Egypt, a certain Pakistani workman was discovered to be able to complete the task. The individual quickly taught the process to his colleagues, which helped to quickly complete and deliver in this regard.

Thereafter, a few palm leaves were placed upon the mats which form the base for a thicker layer of mud normally poured within depths of up to 15-17 cm. This mud is then mixed and pressed down upon the floor prior to being allowed to dry off for the next 3-4 days. While the precise utility of the loose palm leaves is perhaps unclear, it does seemingly add to the tensile strength of the layer of mud applied, in the event that the roof shifts slightly over a period of time. The process so executed contributes towards insulating the roof and adds to the convenience of those inside the structure, enabling them to breathe more easily (Contacuzino, 1985). In the context of Tarim at Hadhramaut, the process was completed with Salvadora Persica plants as a replacement for palm leaves since the former was slightly aromatic and this contributed to warding off termite attacks upon the wooden roof. Once the initial layer dried off, a secondary muddy screed was laid upon the first, with the coating being also utilized for subsequently plastering the walls. The entire process therefore almost doubled the amount of straw within the construction. A roller was run over the screed prior to it being allowed to dry off. Any cracks formed were sprinkled with clay dust and then smoothened to erase the cracks (Figure 88).

Figure 88. Palm leaves (Al-Aidarous,2013)

CHAPTER EIGHT

PROPOSALS FOR CONSERVATION

This chapter presents methods that can be adopted to prevent further damage from occurring, and to repair areas where damage has occurred. To this end, the chapter initially discusses conservation methodologies and how the principles could be applied in the scenario of restoring period buildings to their former glory. Therefore, structural issues are discussed including problems associated with building foundations. This is followed by how cracks can be repaired and how they could be proactively dealt with. Correspondingly, the dynamics of water damage are thereafter discussed, including how aquatic ingress could be effectively dealt with. In the summarizing sections, the text discusses the preservation of entire walls.

Moreover, the last chapter explains how irrespective of the materials and the processes used within existing earthen conservation, they should be considered to be monumental and vernacular, and should be conserved to the greatest extent possible. Therefore, it is important and relevant that any restoration works initiated should benefit from current advances in technology. The technicalities involved in undertaking the restoration of earthen structures should be carefully considered, especially with regard to the methodologies employed and the associated materials used. The overall history of the structure should also be taken into consideration when identifying its underlying structural flaws and weaknesses. Thus, employing technological advancements would contribute to enhancing the quality of the output and simultaneously rationalize the cost element. Prior to initiating restoration projects, a team of experts should be consulted which would ideally include architects, engineers and historians. They can provide necessary input on how the process should be executed so that there is minimal need for action at later stages, if at all required.

8.1 Maintenance and/or Repair Process for Superficial Cracks

In general, cracks are attributed to the tensile, or the related shearing, strength of the earth exceeding that of the surroundings, or due to structural elements and water issues. Water is known to easily collect within earthen structures and cracks which could cause the water to flow through the depression and thus ultimately widen the fissure. Further, termites are also known to take a heavy toll on structures in consideration of how they impact joists, columns and beams (Hunt and Suhr, 2008).

It is important to understand the basic reasons for cracks within a structure prior to initiating restoration efforts, since the crack is normally indicative of a deeper malaise. Therefore, this could include gathering relevant and information in relation to the foundation and the surroundings. The pattern of the crack observed is generally indicative of the associated structural movement and the repair efforts should be undertaken accordingly. It is important to monitor cracks over a period of time to conclude whether they are simply a recent phenomenon or are indicative of past issues. There are various associated and related proprietary devices available in this regard. The cracks could be periodically monitored on a weekly or a monthly basis to successfully conclude whether the structural movement is indeed permanent or is rather indicative of thermal expansion and contraction within the structure. The patterns of the cracks formed could help in determining the corresponding repair options available (Hunt and Suhr, 2008) (Figure 89).

Figure 89. Cracks in Al-Junaid house (Al-Aidarous,2014)

- Deep Cracks

Such cracks require following a structured process:

- Cleaning

- If required, the flaked parts around the cracks should be removed which could result in enlarging the damaged area.
- The joints of the bricks could be scratched and all the powder accumulated in the process should be cleaned up. Therefore, the joints and surfaces could be cleaned with a brush, with the nature of the brush dependent on the material of the effected region in terms of whether it is adobe, compacted earthen blocks, pise earth or cob (Ashurst, 1990).

- Preparing the Patching Material

- The patching material should be as close as possible in consistency to the original material used in constructing the structure.
- Necessary tests and reactions should all be considered in this regard.
- The mortar needs to be carefully formulated and should be as close as possible to the original material used.
- Columns and beams should be repaired with the same material as used in constructing the original structure.

It is recommended that the straw fibres mixed with the soil should be 12-15 cm long. However, fibres of smaller lengths could be used if the filling is on a smaller scale, or is being considered for a smoother surface. However, cellulose fermentation would require a corresponding time period.

In the context of CEB, earthen blocks and adobe, the earth should be mixed with sand to formulate a clay-based mortar, with the clay composition in the range of 10-15%. This would regulate the shrinkage of the mortar.

In undertaking the required processes towards removing the cracks, further structural movement should be restricted. Thereafter, the crack could be filled up. However, it is observed that if there is a possibility of further and additional structural movement or stress transfers, these need to be addressed first before initiating new repairs.

- Cracks in Structural Elements

Such cracks could cause serious deficiencies within the structure unless urgent corrective action is taken. They can be observed within columns, the roof, in the flooring, etc. (Bakraa, 2014).

In the context of the Al-Junaid house in Hadhramaut , a crack was observed in the ceiling in the first-floor bedroom. Since the roofing in the structure is made of wooden beams and joists covered with earth, they should be adequately addressed.

It was observed that they were seriously impacted by termites and humidity. To resolve the issue, it was decided to replace the beams supporting the joists. Since there is a seeming shortage of wood due to decreased agricultural productivity, steel beams were instead used (Al-Junaid, 2014).

8.1.1 Crack Filling

After the basic reasons contributing to the cracks were identified and properly addressed, it was observed that there was no further movement in the structure. Thereafter, the crack was filled up. There are two options in this regard. Cracks measuring less than 50 mm can be filled with earthen mortar which shrinks as it solidifies. Dried earthen bricks could also be placed within the mortar as per the column method, to pre-empt the shrinking of the earth within the crack. Smaller cracks in the wall should be filled by making mortar, utilizing material as close as possible in terms of consistency to the walls being repaired. Flaked and loose material should be brushed off with a paint brush and the cracks cleaned with water. The paste of the mortar should be soft so that it can be easily inserted in the crack with the tip of the trowel and can also be compacted. The cracks should be filled from the base, since the mortar will accordingly shrink and fill in the gaps as it moves upwards, and it should be filled with fresh mortar as the earlier applications dry off (Faria, 2015).

Larger cracks should be filled utilizing the column methodology. This would involve forcefully brushing off the cracked surface and widening it to expose a column. After measuring the dimensions of the column, fresh earthen blocks congruent to the size of the space could be placed there. Ideally, the consistency of the blocks should match the wall to ensure that matching measures related to the density of the material used are attained. The blocks should be dry. In affixing the blocks, the insides of the block should be sprayed with water and then placed on the earthen mortar within the column. The entire column should be similarly filled with the blocks and when the gap has been filled in, the surface should be adequately protected (CRAterre, 2008) (Figure 90).

1. Clean flaked parts

2. Remove all powdery material

3. Making the mortar

4. Fill all gaps

5. First level of rendering

6. Final Rendering

Figure 90. Crack filling process (Al-Aidarous,2014)

8.1.2 Crack Stitching

Two conditions indicate the need to stitch a crack. Firstly, a crack requires to be stitched when stress is expected to be transferred along the crack and the respective sections of wall are unable to withstand it. Secondly, crack stitching treatment is required when a 'belt and braces' approach is employed regardless of having taken proactive measures to avert any further damage. Thus, it is necessary to examine the stability of the structure to determine the extent of the forces being transferred across the crack. This will help to identify the number, size and position of the stitches to be applied.

Stitching refers to the process of roughly securing material across a crack. The stitching material may comprise of wooden stakes or stones. If the material employed is similar to that of the cracked wall, it may help to ensure structural stability owing to similar material properties such as extents of rigidity and thermal expansion. A horizontal trail is cut into the face of the damaged wall across the crack to begin with the stitching process. Following that, at each end of the trail, relatively deeper cuts are made into the wall to serve as hangers. It must be ensured that these sections are not cut too deeply into the wall and have sufficient support so that they do not affect the stability of the wall.

Next, the measurements of the trail are taken and the blocks assembled, which can be interleaved into the cracks by employing crack-filling techniques. The inner area of the trail is cleaned by brushing away the loose material and sopping it with water. Earth mortar is placed at the bottom of the trail, onto which the first layer of the blocks or other filling material such as wood stakes or stones, is assembled (Figure 91). After that, more layers are added. The filling material can also be inserted in the form of vertical alignment, if the stitch requires further support. On reaching the upper part of the trail, a final layer of mortar is filled in. The Al-Junaid house and the castle of Basgo in northern India have employed similar techniques for crack stitching (Jaquin and Augarde, 2012).

1. Replaced the structure element above the window (a steel stick)

2. Cutting a deeper section to provide hooks.

3. Filling the gap with wooden sticks.

4. Following the crack filling process.

5. Final crack stitching restoration

Figure 91. Crack stitching process (Al-Aidarous,2014)

8.2 Temporary Reinforcement of a Structural Element

A. State and Description

Stonework is more prone to humidity, developing cracks and other forms of structural defects. These pathologies may lead a wall to fall down or damage the whole building. Therefore, it is necessary to ensure temporary shoring before fixing the wall (SCTA, 2009).

B. Causes of the Pathology

Some major causes of this pathology are earthquakes and overloading, diverse base soils, differential and compacting reactions. These result in creating cracks, gaps and swelling in the walls at various places, such as bearing walls, connections of perpendicular walls, and building corners. Consequently, the structure of the building is damaged, which may lead to destruction of the wall and ultimately the building. Moreover, walls with a high ratio of humidity are more exposed to the risk of collapsing due to crack formation.

C. Description of the Repairs

It is suggested to start the shoring process under the building structure to provide support to its flawed sections or at the minimum curtail the damage and thus protect it from being damaged. The shoring setup must be self-supported and may not put stress over the wall.

An additional floor in the single-storey house is required by Tarim, Bin Sahl family. For this, a pillar can be constructed within the adobe wall which may not only support the new level but will also lessen the strain over the wall (Bakrraa, 2014).

Amendments like reconstructing an angle, a wall section or increasing wall thickness can be carried out using this system. This system helps to provide ample time to determine the cause of the occurring pathology on the basis of which a suitable technique can be selected for the repairs Conventional shoring techniques are quite similar to that of a temporary consolidation system. The latter involves mounting new material around the damaged sections. However, walls are provided with support through wooden boards or planks as this may help to save the structure from being crushed or overloaded. For this purpose wooden decking can also be employed. An example of this is the use of the Shibam support element in the outer ground level.

The installation of shoring along the sides of the wall is determined through the pertaining level of posed risk i.e. of destruction, deformation or dislocation of the wall. A triangular device (truss) placed firmly into the ground is employed to support these boards. However, if the building interior is not spacious, the device may also be installed against another wall in the street, keeping in view the structure of the building (Figure 92).

The shoring may be kept during the setting or drying period of mortar. However, in some cases it becomes necessary to take it away soon after completion of the reparation process i.e. after mounting all the constructional elements. However, it is required to provide temporary support to the structure in certain situations. It is much easier to remove the damaged portion, keeping the stable part and reconstructing it afterwards. In such cases costs are often overlooked. Shoring is employed when this procedure i.e. removal of damaged section cannot be undertaken or the building is at higher risk of falling down (SCTA, 2009).

Figure 92. Reinforcement of a structure in ad-Dir'iyah (Al-Aidarous,2013)

8.3 Foundation Issues

In the following section, two major factors leading to the deformation of buildings are discussed. Such issues occur when the foundational structure of the building is defective, calling out for the need for improvement. These can be prevented or resolved by improving the foundations and modifying the soil properties.

It is necessary to examine the movement caused due to deformation in the structure or development of cracks in a building. This will help to determine whether the movement is still present in the foundations or the ground, posing damage in the future. Thus, it is necessary to reduce the ground movement before taking any further steps, as in the presence of movement in the foundations of the building, none of the structural reparations will be of use. Therefore, foundation repairs or ground improvements must be undertaken regardless of their costs and material requirements, as they may cause severe damage to the structure of the building afterwards. These reparations must be planned efficiently and should involve professional engineers for their application (Minke, 2008).

Damage to foundations which requires repairing is caused by a number of reasons. However, as this damage does not depend upon the nature of building construction, this section discusses the foundation reparations briefly. Foundation repair is required when the following conditions arise:

- Change in the use of building
- Weak foundations
- Change in the soil properties

The process can be of two types:

- Repair
- Replacement (Keefe, 2005)

It is suggested to consult experts of the field to carry out foundation improvements. The process can be undertaken by enhancing the depth of the foundations, thus reaching a relatively stiffer layer of soil. Moreover, it can be achieved by widening the foundations, which will reduce stress per unit area by dispersing the building's load across a wider area. Moreover, certain factors should be taken into account, such as whether to repair the damaged foundations or to add new piles or mini-piles. A number of earth constructions built in the past have had brick foundations. If the foundations of these buildings are damaged or weakened, it is suggested to rebuild the structure in the same way as that of the original one. Care must be taken to protect the base of the earth walls from water which moves in through capillary action.

Compensation or jet grouting may be employed to improve the ground under the building. The method involves injecting a gel or mixture of cement and water into the ground. The injected material undergoes volume expansion once it is in the soil and elevates the upper surface of the ground after it is set. This forms the base of a strong foundation. However, this method is quite expensive and does not comply with the financial plan of every building (Jaquin and Augarde, 2012) (Figure 93).

The water pressure and the water content of the soil determine the soil's mechanical properties. Thus, changes in these factors may affect the properties of the soil upon which a structure is constructed. Variability in the distribution of groundwater around a structure may bring changes in these factors resulting in an impact on the stiffness and strength of the soil under it. Owing to the intricacy of the groundwater flow channel, it is necessary to understand them before initiating the undertaking of any intervening step. If reduction in the stiffness or strength of soil has caused a building or a part of it to fall down, it may be controlled by changing the groundwater profile. This can be done by establishing drain system, changing the direction of water flow or installing pumps to remove water (CRAterre, 2008) (Figure 93).

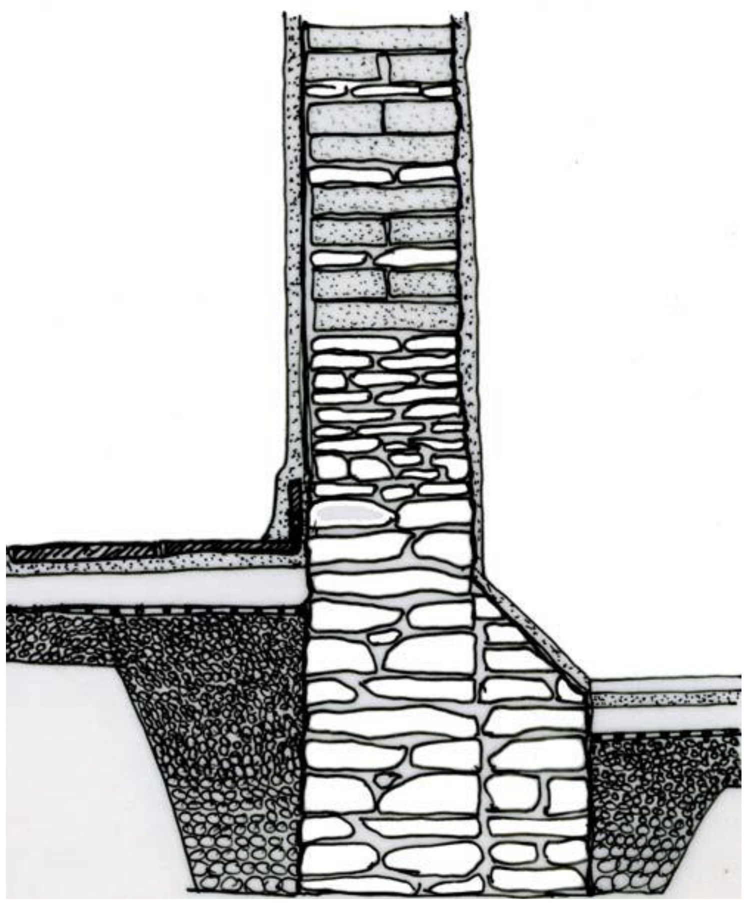


Figure 93. Foundation restoration (Al-Aidarous,2014)

8.4 Filling in Holes and Gaps

Gaps and holes are created in walls for a number of reasons:

- Scraping of wall caused by moisture
- Expanded cracks or unfilled holes
- Damage caused unintentionally by human activity such as shocks, animal activity or burrowing by rodents or insects
- Vegetation produced on the surface due to humidity which gives rise to moisture pathology and depositing efflorescent salts.

Craftsmen often find refilling of gaps a considerable problem which they overcome by using a framework of concrete or cement blocks to fill in the spaces. However, this practice is not recommended at all. Soil and concrete do not provide a significant level of strength to the wall. It not only deforms the stonework but also produces new defects in the structure caused by the reaction between the employed materials (Trotman, 2006).

A. Maintenance and/or Repairing Process

A mud wall is not easy to repair, as the material tends to contract while drying. However, this issue is addressed in the section discussing the reparation of cracks. Shrinkage must be accounted for significantly, as more filling material might be required for filling the gaps.

Shrinkage is of two major types, i.e.

1. Clay shrinkage caused due to water evaporation
2. Shrinkage by compaction caused due to overloading

The surface of the applied material shows swelling before evaporation takes place. The rate of water absorption on the surface of clay particles is quite high. In the same manner, the humidity of the clay and mud causes volume expansion of the material.

Moreover, improper application and poor quality of the employed material may cause shrinkage cracks to appear. With rammed soil, cracks appear vertically and in a uniform manner.

Thus, to rebuild the earthy structures it is necessary to control the shrinkage and resistance of the material. Unlike in cob or adobe which requires wet material to be filled in, a gap should not be injected with damp soil, as it will reduce in size and volume while drying out. Moreover, the sides or top of the repaired area will crack, which may give rise to new damage.

B. Reducing the Shrinkage Effects of the Material

Different techniques may be employed to make a mortar filling with minimal potential to shrink:

- Employing a lesser quantity of mortar: using dry blocks, adobe and clean materials to fill the gaps. This will allow the shrinkage to be limited to the mortar only which can be further controlled by testing prior to implementation.
- Decreasing the amount of clay in the mud being applied (poured mud): mud may be sifted to remove the thin particles of clay. The wet mixture used as filling for the gaps will contain only the rough part, comprising of sedimentary particles (gravel and rough sand), and a portion of the solid clay. The water content in the applied mud may be 16-20%. A concrete mixture may be used to make a plastic mixture. The thin mud removed earlier may be used for rendering or lime washing the wall to make it look smooth.
- Supplement with fibres: if the mud is too thin, the shrinkage effect can be reduced by adding long natural fibres to it. Instead of creating larger shrinkage cracks, it will form numerous micro-cracks. Usually, filling of gaps in shallow walls employ this method. Therefore, instead of filling cracks in the base with this technique, it is employed to fill gaps on the facing and top of the wall. However, material with fibres has relatively less mechanical resistance than earthen concrete or poured mud. The wall can be made stable by adding blocks, if the damage has occurred at the base or along the slope of the wall (for instance adobe).
- Make the mud stable: the shrinkage effect of mortar can be lessened by adding sand to it.

- The gaps may filled by sand during a sandstorm followed by rain, which may reduce the shrinkage.

In each case, before implementing any action to the wall, it must be tested. Samples of the mixture to be applied must be prepared and moulded (adobe moulds or smaller) to examine them prior to drying. The material which shows most significant strength and minimum shrinkage is the most suitable to be used (CRAterre, 2008).

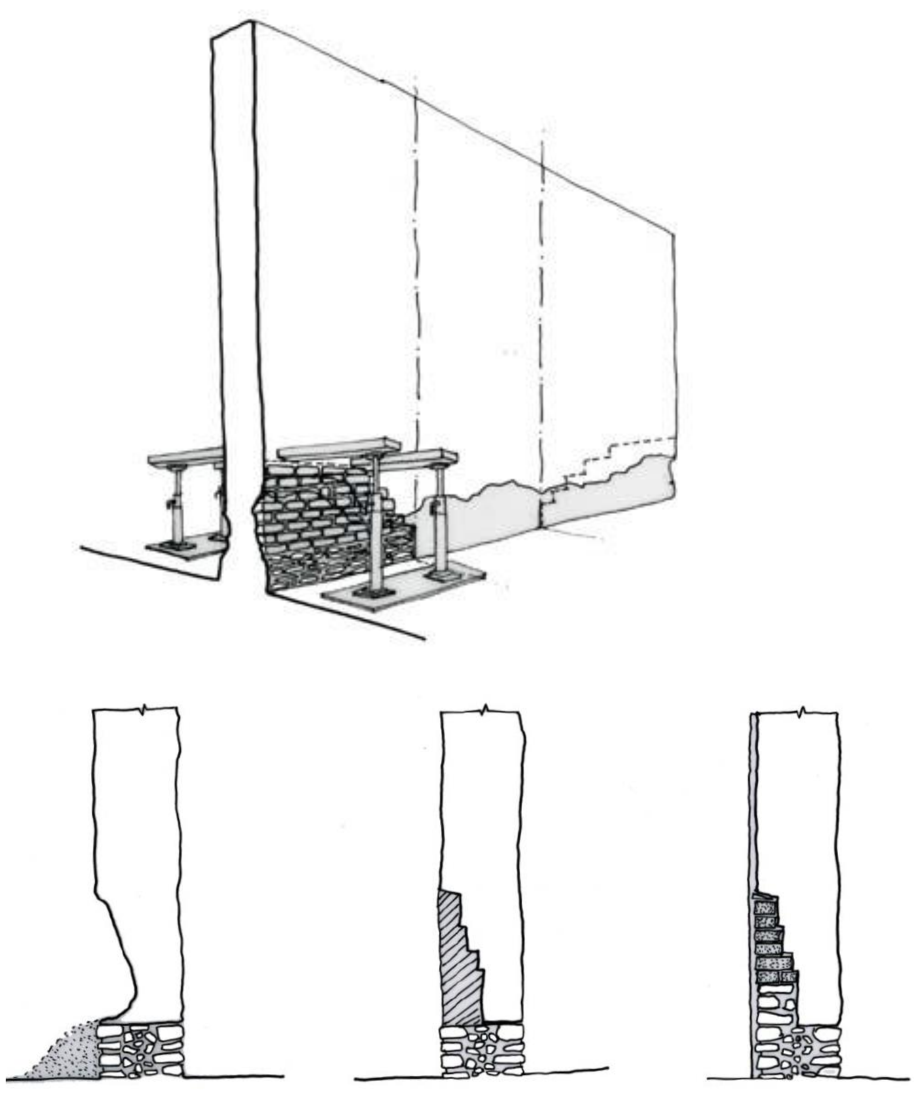


Figure 94. Filling in holes and gaps (SCTA, 2009)

8.5 Rebuilding a Collapsed Wall

Lack of solidity, holes, or large cracks or fallen off parts, may cause a number of pathologies to appear at the surface of walls. This may be owing to:

- Unsuitable materials: poor compacting properties, inconsistent mixture, etc.
- Defective application: coincident intersections, etc.
- Extreme humidity: lack of efficient evaporation allows the water to remain inside the wall causing the thin elements to detach from the compact material, impacting cohesion, and giving rise to efflorescence and microscopic mushrooms, resulting in cracks in the walls.
- Overloading.
- Destruction of adjoining constructions may cause imbalance, which may be further augmented by weather conditions.

However, the mentioned reasons may not be the only factors to damage the walls, rather a number of pathologies may combine to collapse a wall (Al-Junaid, 2014).

B. Maintenance and Repair Process

It is crucial to analyse the factors which may lead to the collapse of a wall before initiating the repair. The causes of the damage must be identified and treated to avoid any further impairment in the future. Moreover, the filling material used for gaps must be same as that of the original construction so as to avoid unexpected reactions.

C. Rebuilding Adobe Masonry

The following steps must be followed:

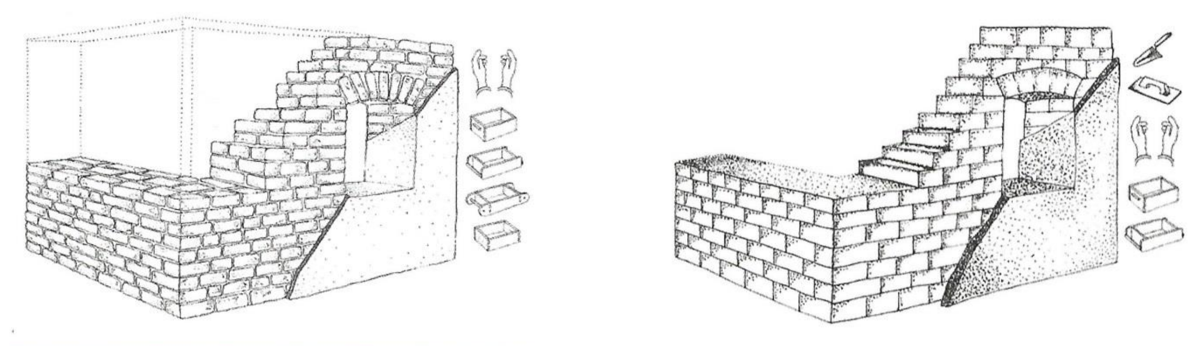
- Remove the damaged part or the whole wall. A hatchet or trowel may be used to cut down the adobe blocks.
- Clear off the rubble, saving the brick pieces to fill gaps. Find a material similar to that used for the construction of the wall. All elements may be cleaned with a brush to

attain workable surfaces.

- Moisten the areas over which new bricks will be laid. Bricks must also be dipped in water before use.
- Apply mortar to the area where bricks are to be placed. The quantity of mortar may depend upon the stability of the original material. Fibres, pieces of wood, steel rods or fiberglass, can be used to secure the horizontal joints.

The wall must be coated so that it may not look different from the other walls. This process is referred as 'rendering'. It is undertaken when the newly applied material dries off and the wall is not intended to be kept bare.

Before inserting bricks in the walls, the gaps as well as the bricks are dampened with the help of a brush. Following that, the bricks are placed over a thin layer of earth mortar, which is made with a material similar to that employed to construct the wall. The placement of bricks is helped with a stretcher bond. After laying down all bricks, the upper gap and any shrinkage is filled with mortar. The wall may be subjected to rendering if required (CRAterre, 2008; SCTA, 2009).



1.1. Adobe masonry wall

6. Earthen plaster for earthen walls

Figure 95. Adobe masonry wall and earthen plaster for earthen wall (CRAterre, 2008)

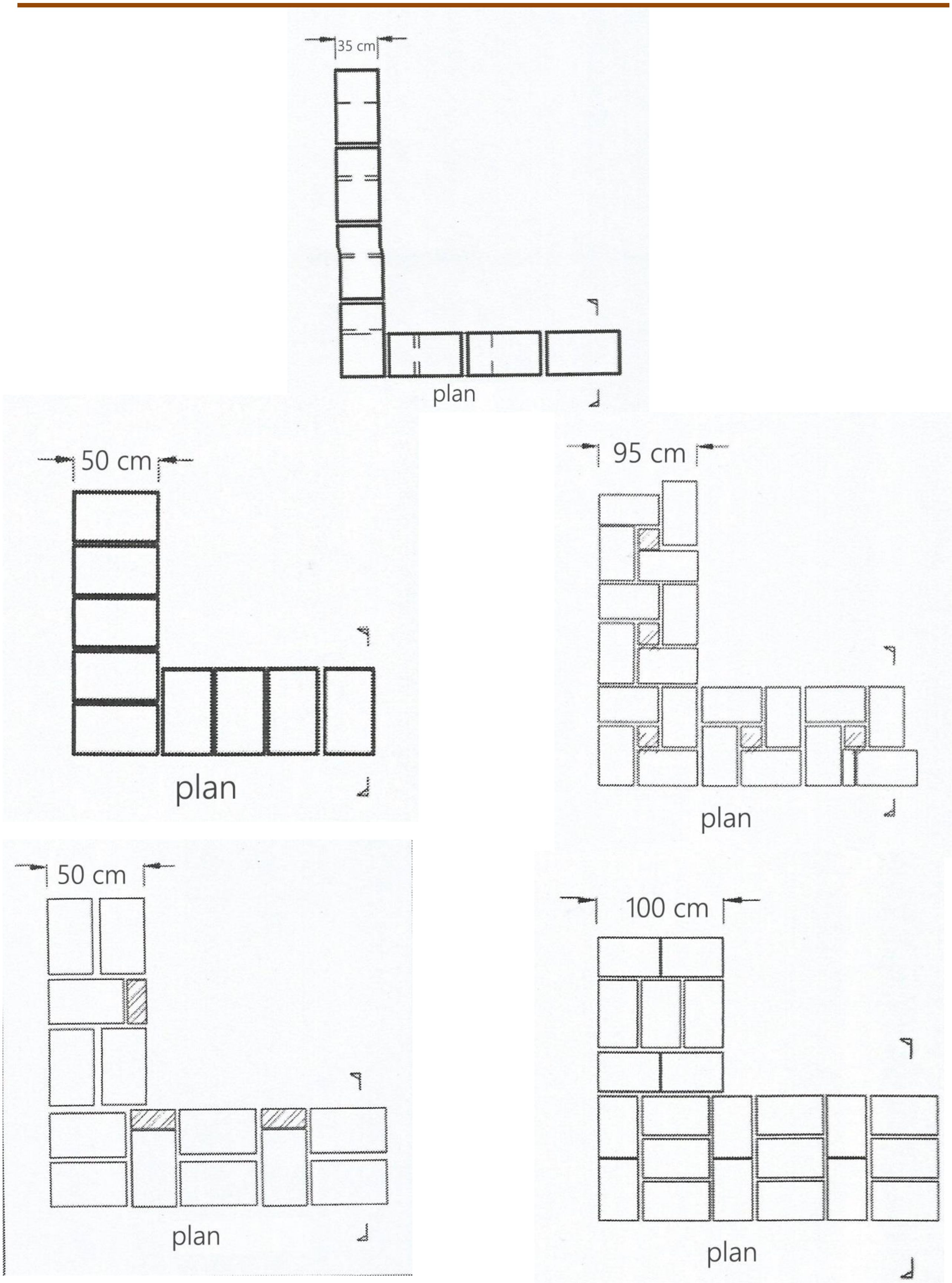


Figure 96. Building adobe wall systems in Hadhramaut (Mosaibah)

Figure 97. Before and after wall rebuild in al_Juniad house (Al-Aidarous,2014)

8.6 Water

When earthen floors and earth walls are dampened, considerable damage is caused due to the saturation of the construction material. This may lead to reducing the strength and rigidity, causing the wall to act as a frictional material or to remove material as slurry. In this section, reparation techniques to avoid the water damage caused to earthen walls along with the methods for fixing such damage are discussed (CRAterre, 2008).

A. Water at the Head of a Wall

One of the major issues posed to an earthen building is water pounding at the head of the wall. This stagnant water may inundate the soil. This causes the vertical capillaries to be eroded where water spills off, causing damage to the surface of the wall. Thus, preventing the puddling of water may reduce the erosion of earthen surfaces. In the following paragraphs various methods to avert the puddling of water at the head of the wall are discussed.

It is necessary to keep a cap to the wall water-resistant so that it may act as a barrier to the flow of water. It may be shaped as such to allow drainage of water and direct its flow over the surface of the wall. Hence, the head of the wall must be constructed at a particular angle so that it may direct the flow of water towards the edge and project out from the wall such that the water drops down vertically. In constructions where drain systems are not provided, the caps must allow the free flow of water from the edge by permitting the flow. The caps should not allow the water flow to erode the walls. Capping can be done through the following three techniques:

- Using a sacrificial material,
- Employing a permanent solution,
- Using an independent roof to cover the whole structure.

Sacrificial material is used for capping the walls if the respective construction site is already undergoing maintenance, but is able to withstand further repairs. Usually earthen material is used is this process. It may act as rendering or rebuild the adobe tiles. Regular replacements of the material may allow the surface of walls to resist damage, regardless of it being exposed to erosion over time.

A permanent solution to prevent erosion of the walls at the head can be found by using water-resistant materials or those which are not damaged by water. In Mediterranean countries, the use of interlocked semi-circular baked clay tiles or flat stone such as slates, on roofs and at the head of walls is a traditional practice which diverts the direction of water (Jaquin and Augarde, 2012).

In certain cases, either owing to the absence of a roof or an extremely damaged structure unable to support the roof, it is sometimes feasible to construct a roof over the whole of an existing earthen building. Regardless of the fact that carrying out construction over the whole site seems quite invasive, in the cases where the structure holds significant cultural value, this is quite a workable solution (Hunt and Suhr, 2008).

The construction of a steel roof over the adobe Casa Grande National Monument in New Mexico, USA, in 1932, is an appropriate example of such a case. Moreover, roofs can be constructed as temporary structures, set up over archaeological digs between seasons. Such constructions are undertaken to avoid the development of negative microclimate effects in the respective area.

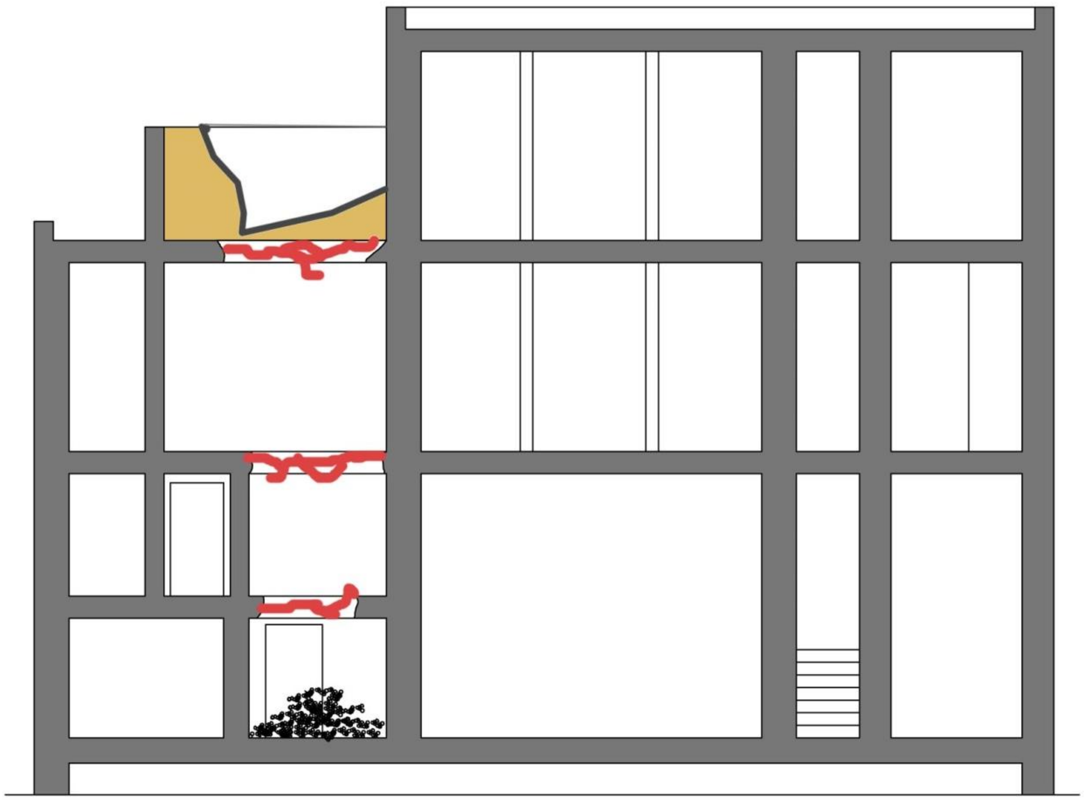
B. Preventing Water Damage at the Base of Walls

The foundations of earth walls are damaged due to an increase saturation level of the walls, which may be caused due to rainfall, ineffective drainage from roofs, direction of water flow towards the base of a wall or an increase in water level due to capillary action.

Various strategies can be employed to control or prevent damage caused by water. It is suggested to increase the size or efficiency of the eaves to protect walls from water coming from above such as in the form of rainfall. Their overhang can be extended to block the water flow towards the base of the wall (Keefe, 2005).

It is suggested to change the direction of water flow and provide the channels with effective drainage, if they are damaging the adjoining wall. Moreover, the base of the slope must be provided with effective channels for evaporation. Talus slopes are common blockades to evaporation, caused from erosion of the wall. In addition, water-resistant elements should be removed from the base of a wall, such as those used in concrete structures, as they tend to entrap water rising up through capillary action, consequently resulting in increasing the saturation level of the wall (Saleh, 2010)

In most earth building, roofs are kept flat. Such a construction is quite effective as they have fixed-in drains which project out from the walls. This allows the rain water to be drained efficiently, dropping away from the base of the wall. These drains become inactive when a building is out of order or requires reparation, causing the water to flow towards the surface of the wall, giving rise to saturation and removal of material. In the case of the Al-Junaid house, blockage of the drainage system caused the water to collect on the flat roof, causing it to undermine while the rubble fell from the second and first floor level to the ground level. The builders carrying out the reparation process are expert in the field. They reconstructed a floor slab of beams in the first floor roof and steel beams on the other floor. The construction was plastered with Salvadora Persica and 12 to 15 cm of earth mixture and was allowed to dry for 20 days. Following, that 5 cm of earth mixture with straw and then 10 cm of whit lime render mix with ash was applied. In this way they repaired the drainage system (Al-Junaid, 2012). The drains are advised to be subjected to timely reparations and relevant sections of wall must be protected to avoid potential damage. However, the methods described earlier may be employed to fix the damage.



Section

Step 1

Step 2

Step 3

Step 4

Step 5

Step 6

Step 7

Figure 98. Restoration process of Al-Junaid house roof slabs (Al-Aidarous,2014)

8.7 Facade Repair

Water can cause significant damage to earth walls if not provided with protection. Earthen constructions require reparation and renovation throughout, thus, ineffective maintenance may cause various problems. For instance, buildings are required to be maintained when they no longer are used or during a cultural change.

Weather changes or climatic effects such as rainfall or winds may cause minor damage to walls if they are not subjected to significant protection. However, absence or insufficient use of constructional elements may lead to major impairments. The facade of the walls can be repaired through the following two methods:

- Repairing specific areas which have undergone erosion or damage
- Rebuilding a protective surface (Damluji, 2007)

Conservation and repair rules indicate that repair approaches should be similar to a large extent to the original material and construction technique. It is preferred that earth walls should be restored by utilizing earthen wall techniques. The following repairing techniques are available in this regard:

- Re-rendering of the wall by providing a thin shielding layer and eliminating minor erosion
- Reconstruction procedures where larger extents of physical damage have happened.

Masonry has been used to repair historical buildings and modern approaches employing concrete have also been tried. Rendering is preferred in many cases as it avoids damage to the facade of a building. Renders to earth buildings can be entirely earth-based or comprised of substances that enhance water resistance. Furthermore, preservatives are also added, including lime, starch, bitumen and silicone.

Another factor that should be taken into account is the decay of renders after a certain period of time that leads to episodic re-rendering of a building, otherwise the walls of the building will be damaged. This turns out to be a regular maintenance plan for the building. As there is a whole variety of earthen materials that are utilized globally, it is not possible to define all the renders. So, we will not recommend render compositions or their application in this chapter. For this purpose, specialist local advice is required. Lime rendering only with gravels for 10 cm and render lime of 2 cm render final are used in Hadhramaut..

Figure 99. Lime rendering in Hadhramaut (Al-Aidarous,2014)

The major component used in the rendering process is similar to the original material used for the construction of the wall. Earth renders prefer soil that possesses the characteristics of the original material. Support is fitted into the body of the wall to back planks that permit masons to render the wall easily. A major example in this regard is that of the Al-Mehdar mosque in Tarim and male mosque.

- In the first step, the extra material on the wall is brushed away.
- Afterwards, the wall is soaked with water and render is applied to it.
- The render is then brushed onto the wall with the help of trowels.
- The render is coated smoothly and left for a certain time to dry.
- Meanwhile, if cracking occurs, it should be repaired and cleared up.

Water should be stopped from entering the wall as it damages the material. For this purpose, lime washing of earth structures was done previously. In fact, these strategies are still effective for modern repair. A 1:3 lime sand render should be coated onto a moistened wall surface in three coatings. Slurry will be formed once the first coat is finished. This takes the shape of a cracked wall as it dries out. To hide those cracks, two more coats are applied to the wall. This process is beneficial as it provides a solid colour (Mosaibah, 2013).

Grout Injection

Unprotected areas that must be filled with grout can be determined by sounding the entire surface. Grout is basically a liquid mortar that is inserted into the spaces of the brickwork (Mohsin, 2008).

The volume of mortar inserted into the gaps depends on the size of the gap: the larger the space, the greater will be the volume of liquid to be injected.

The coatings are glued onto the surface with the help of injected grout. It is made up of a large quantity of hydraulic binder, a light mortar, a preservative to aid the injection, and water to get a fluid substance. It should be noted here that most basic grout has the same amount of water and binder. Homogeneousness should be maintained and for this purpose, the grout should be mixed during the whole process.

Once the broken areas are determined, the grout is inserted in consecutive levels, restricted by pressure, almost 50 cm at a time. To avoid any sort of collapse, the surface of the broken rendering may be shored up. According to the laws of Blaise Pascal’s vase pressure experiment, pressure is relational to the height of the inserted liquid and not to the volume of material inserted. Syringes without needles are used for the injection process and their size must be altered keeping in view the volume of the liquid to be injected. Holes can be sealed using a piece of cotton wool.

Vibrations should be avoided and for this purpose, the broken surface is drilled without hammering. To check the filling of mortar after regular intervals, some holes are used as openings. In the initial stage, water is filled into the gaps. To inject the grout inside, the surface can be cracked to some extent during the injection of mortar. All openings must be blocked by the mortar when it is inserted inside the holes. Before repeating this action, it is necessary to allow the liquid inside the holes to dry. This process can be made easier by using ready to use industrial grouts, and their employment is highly recommended. A small broken area commonly does not compromise the full facing (Mohsin, 2008).

CHAPTER NINE

THE ACCEPTABILITY OF EARTH AND RECOMMENDATIONS

We have mentioned in the prior chapters that favourable conditions for construction are presented by earth when it is in a stabilized form and this can be easily done so as to construct strong buildings. Nevertheless, the flaws of raw earth signify simply one reason amongst a number of others that have added to its non-acceptance in Saudi Arabia as well as in most other countries.

Much effort is still required in developing and developed countries to achieve the full potential of earth as a building material, for a number of reasons. It should be noted here that a number of sessions of international professionals have suggested that more analysis should be conducted regarding the implementation of earth as a building material, but relevant concerns of planners, designers and research institutes cannot be ignored. On the other hand, restricted utilization of earth material by governments and private sector is also a significant factor. Nevertheless, many analysts have stated that earth as a building material will be used significantly in the near future.

Supporters of this material should concentrate on the fact that people's acceptance of earth as a building material cannot be overlooked. People have concerns about this material and once it is proved to be long-lasting, consistent and architecturally undamaged, its acceptability will increase. However, at the same time, the public should be provided with information that stabilized earth when used as a building material is a durable material that will give a structured building which would be equivalent to a modern building.

This section emphasizes the appropriateness of earth as a building material and earth maintenance. It not only takes factors that have lessened its significance in to account but its positive points are also summarized in this chapter.

9.1 Reasons for Non-Acceptance

Earth material has failed to gain importance and is officially unacceptable in a number of countries regardless of all the steps taken in the last three decades to enhance this material. The following points show the basic reasons why this material has failed to grasp the attention of constructors:

9.1.1 Low-Status Material

The major reason behind non-acceptance of earth in building construction works is status consciousness. Earth when used as a building material is considered more inferior, fragile, unhealthy and unattractive than modern building materials by decision-makers in some governments and common populations. It is evident from the policies of the current governments of many countries that cement is more favourable as compared to earth as it exhibits higher status (Ada.gov.sa, 2012).

The response of numerous government officials concerning the utilization of earth in their housing schemes has been explained by Jean Dethier, who is a well-known architect who worked in Africa for many years. According to him, when he questioned the relevant authorities regarding the ignorance shown in case of earthen building traditions, they would regularly answer: “Earth is a simple and out-dated material. It is evident from the prevailing cultures of industrialized countries that it is not much use, otherwise if it was so beneficial, they would have developed it and used it in their buildings”. Housing is not an essential need any more as it has turned in to a demonstration of standards and status. More emphasis is put on its display rather than its comfort.

Hadhramaut, Yemen is a poor society but if we focus on the techniques and substances utilized in the construction processes, they appear to be more advanced and expensive owing to the absence of alternatives that are used to demonstrate higher status (Hadhramaut Heritage Centre, 2012). People lacking those techniques and luxurious lives do not want to be classified as poor and remain with that title. In such societies, certain materials, schemes or techniques are designed for the whole society, keeping in view their standard, be it poor or rich. Poor people want facilities that are intended for wealthy people as they do not want to be assumed to be poor.

Earth houses are not given much preference in many developing countries as in their opinion, such houses represent low status. Rather than houses, they are considered as unclean, damaged, unsteady mud huts which have served as homes for a number of people in different areas around the globe. The aforementioned mentality has changed the perspective and has resulted in the increased demand for concrete houses. It has turned out to be a status symbol that people living in concrete houses are much higher in standard and their houses are modern and attractive.

The employment of cement and expensive imported substances in public buildings and elite houses has a negative impact on society as it has become a symbol to divide a society into various classes and has increased social issues.

As the demand for building materials like cement increases, owing to low supply, the following issues occur:

- Postponements
- Wastage
- Increasing prices
- Black markets

Because of these factors, the construction of many housing schemes has been delayed.

President Julius Nyerere (1922-1999) of the Republic of Tanzania opposed the predominant favour given to these 'fashion' materials. He expressed his opinion as: "The prevalent dependence on cement and tin roofs not less than psychological paralysis … People are not ready to construct their houses by using burnt bricks and tiles, rather they wait for a tin roof and European soil - cement. This sort of mental paralysis should be overcome if we want to progress in the future".

As a matter of fact, a number of international organizations plus individuals are putting in efforts to enhance the acceptability of earth material in areas where the tradition of its utilization has vanished. Moreover, this drive includes the promotion and utilization of this material in the regions where it has not been used so far. The efforts to promote and popularize earth as a building material have been based mostly on economics. Basically, this factor is significant enough when we take the third world housing in to account, it should not be overstated. The major preference should be to eradicate bias from the mentality of people regarding this material. Selection and utilization of any material is affected by the prevailing opinions of the local people and constructors, and this trend is common around the globe

A rapid increase in the popularity of earth buildings has been observed in Yemen Hadhramaut and these buildings are considered a status symbol there. In accordance with the opinion of Al-Junaid (2014), about 90 per cent of domestic construction in Tarim city and Shibam is being constructed in adobe and if we focus on the rules, they state that new buildings should utilize earth as building material to uphold the town's architectural atmosphere. If this trend of increased acceptability of earth in technologically advanced and developed countries prevails, within a short period of time, earth will manage to get more acceptability from various countries.

9.1.2 Weaknesses of Earth

It was mentioned earlier that many construction industries in developing and developed countries have overlooked earth as a building material. The basic reason behind ignoring it as a building material is the fact that it is difficult to restore, plus as it is considered inexpensive; it is not given much value.

The following reasons could be taken into account if the purpose is to understand the reason behind the deterioration of earth houses:

- Such buildings are made of inappropriate soil
- People residing in earth houses lack resources like time, money or experience to plan, construct and preserve them as they should be.

If soil is not treated at regular intervals, it starts to lack strength and stability. A concept has been developed in this regard that earth buildings are inferior to modern villas and demand high maintenance.

The concerns of designers, residents and decision-makers should be taken into account that hinder them in taking decisions regarding the acceptance of earth material to be used in construction procedures. These concerns involve inner distress, unwillingness and suspicions owing to the low strength, lack of dimensional stability, etc. The major criticism is regarding its low strength and the major question that is considered by people is about the strength of earth walls: whether they are capable enough of carrying the heaviest normal type of roof. The strength of a wall is not the only standard that is a major concern for the users, because other materials that are used in the construction process are weaker than materials .

Actually, if we focus on the benefits offered by earth as a walling material, these benefits prevail over the drawbacks of earth as a building material. It should also be kept in mind that by considering such statements, its drawbacks should not be avoided. Efforts are required in this regard to minimize the disadvantages of earth and make it more appropriate for creating inexpensive, energy-efficient, durable conservation techniques.

9.1.3 Lack of Knowledge

Unavailability of data regarding the performance characteristics of mud is one of the major reasons for which earth and other natural construction materials are superseded by modern elements. Regardless of considering the significance of the local building material, the area is given little importance. Even international organizations which deal with issues pertaining to housing and construction materials in developing countries also overlook this subject area. Most of the developing countries have rich heritage with respect to earth buildings. However, these technologies get very little acknowledgement, which may serve as a major solution to housing issues in these countries (Damluji, 2007). Some major examples of such constructions are the skyscrapers of Shibam, the city in Yemen often called the 'Manhattan of the Desert' due to its 500 buildings of which most rise up to eight stories and a height of 30 metres, the fortified villages of Morocco, the famous palace of Alhambra in Granada in Spain, the Great Mosque of Mopti in Mali, the domes of traditional Iranian architecture, and the beautiful forms of Nubian vaults in Egypt. These marvels of architecture gain much attention in travel literature, but the development of these traditional earthen structures lacks considerable research (Schroeder, Schwarz, Chakimov and Tulagaanor, 2005).

Previously, earth buildings used to have construction quality, attained by expert craftsmanship and knowledge based on experience regarding the suitability of soils and methods. This knowledge had passed on from one generation to another. However, the current era often overlooks this aspect. It is necessary to examine the engineering properties of soil based on scientific method, if it is intended to be used in construction. The research efforts carried out to study earth as a building material are quite minimal in comparison to those conducted for modem construction materials. Moreover, incomplete and sporadically published research on building with earth, as compared to the comprehensive research on modern building materials and techniques, shows the unattended utility of stabilized earth as a technical and economical resource for construction. Therefore, this calls out for the need to incentivize all types of research, especially experimental, in the field of stabilized earth, to construct a correlation between the efficiency, stability, and cost of the material and enhance its utility.

The comparison of earth products with modern and conventional building materials developed after significant experimental work is quite unjustifiable. Experimentation along with high quality control standards and very restrictive specifications during their production and construction processes tend to improve the properties of materials significantly. This can be signified through considering the considerable amount of money spent upon research regarding the use of cement. Moreover, the significance of research in this area can be understood by considering that at the present time less than one per cent of the research and development expenditure in the world addresses the issues of the developing countries. Lack of sufficient knowledge about the use of stabilized earth as a building material has hinder its introduction to the market. Currently, the subject of soil stabilization has been researched well; however, this is with respect to specific requirements of road, airfield, and dam construction. The use of soil stabilization principles with regards to building construction has been overlooked. Therefore, it is necessary to put some effort into conducting research and transferring extensive scientific knowledge in soil mechanics, keeping in view the needs of the builder in earth-building construction. It is suggested that the architecture schools in Saudi Arabia may attempt to provide education to their students about heritage techniques. The building material that we are discussing is one of the crucial elements of construction and has many aspects that are yet to be discovered. This proves that dissemination of information is as important as research, as with regard to this subject, the relevant information has not sufficiently reached the potential users.

9.1.4 Rarity of Experts

Some western technologists and experts without a significant interest in underdeveloped countries have conducted valuable research on mud as a constructional material. However, their education and experience in an industrialized environment tend to hinder their practices, although they may be able to utilize their skill provided that they learn to implement their knowledge and experience in a different economic framework, technical environment, lifestyle and cultural settings (Al-Hussayne, n.d.). Researchers have asserted that traditional building materials have not been given significant attention by housing planners and researchers. This ignorance is due to the reason that very few developing countries have locally trained architects and planners. There is a lack of educational facilities in these countries, which compels students to flee to developed countries, as a result of which their training is based on a different setting. Moreover, in countries with the relevant education provisions, western languages, curricula, and models of teaching are employed. As a result, such courses, whether they take place in developed or developing countries, have to deal with ideas and techniques that comply with the economic setting of rich countries. This makes the builder in developing countries think of their pertaining issues through the perspective of developed countries. Consequently the possibilities of improving the traditional building materials and systems have been ignored in most developing countries. They have been substituted by modern materials and western techniques which are unable to meet the needs in local settings (Al-Jaded, 1994). In the same manner, the need for the redirection of the education of designers in Saudi Arabia is called for. They may be provided with skills to employ local resources in construction process and to comply with the cultural values of the local population. Giving due consideration and respect to the cultural framework will allow them to attain a unique identity and gain strength.

9.1.5 Fear of Taking Risks and Suspicion

In developing countries, the reparation process of buildings employing earth or other local material is conducted either by the owner or under his observation. The owner is considered as responsible for all the potential risks regarding the expense. As a result, use of any new material such as stabilized earth blocks is expected to cause financial risks. In developing countries, the construction of a house is considered as a significant investment, considering people's income. Therefore, it is justified if they hesitate to invest money in new techniques or materials. It is a common practice in such countries to use the services of specialized professionals and qualified contractors who have significant liability in terms of law for designing and constructing a perfect product. However, regardless of this, the building owners are still hesitant about innovations.

In local communities, the owner of the house consults with his relatives and other community leaders. Among these, the most important opinion is considered as that of the local builder. However, the builder always suggests employing already tested solutions, as otherwise his reputation may be at risk. Moreover, stabilized earth is a relatively new concept in the market which demands more attention. One of the major reasons is the risk of variability in demands which may make the respective investment ineffective.

Moreover, suspicion is another issue faced in the development stabilized earth as well as many building materials and techniques in different social and cultural groups than those in which they are to be used. Suspicion is created when the material is to be bought, which may lead to refusal to use it. Foreigners who intend to introduce new materials or techniques in the construction market of developing countries are often looked upon with doubts or suspicions of them having personal economic interests in it. Local people may be apprehensive of the intention behind the insistence of foreigners that they use stabilized earth. They suspect them of having financial or other interests. This shows that psychological and sociological problems are more important to overcome than resolving technological issues.

9.1.6 Precise Knowledge

In the present times, the ability of earth as a walling material has been significantly underestimated. Thus, it is necessary to understand the restoration techniques and engineering properties of earth being employed as a construction material. This calls out for enhancing practical research by constructing model projects which may serve to indicate the cost effectiveness, thermal comfort, and quality and durability of its products.

Currently there is a propensity to integrate the advantages of traditional principles and modem expertise, so as to achieve the best possible results. The establishment of research centres may provide information in this regard by researching the properties and performance characteristics of earth to enable the formulation of standards, as a lack of significant standards will negatively impact the use of earth products, thus, reducing their production and marketing. These institutes can play a major role in the promotion of stabilized earth products appropriate for local needs. Research regarding features and performance is not enough and keeping in view such a situation, it is essential to conduct dynamic promotion programmes. The Indian Auroville Earth Institute is playing a significant role to facilitate effective research for builders or entrepreneurs and encourage them to implement the conducted studies through advertising, issuing simplified technical literature, and running training programmes, etc. Moreover, they aim to set up committees to gather researchers, suppliers, users and governments' organizations together to discuss the performance requirements. A number of workshops have been conducted in Spain by UPV and by Traecheida in Morocco, regarding this subject area.

The research objectives and programmes of international organizations seem to be quite similar to each other, which requires implementing significant measures to effectively coordinate them at the global level. This can be achieved by building information centres which may help to organize different activities and efforts in this regard by systemizing and communicating the respective information. In the future, the communication of information should be given more attention, as the results of research are not reaching the ultimate users effectively.

9.1.7 International Organizations Working on Earth Architecture

Owing to its eco-friendly structure, earth architecture is considered as the most sustainable architecture. In the present era, people prefer using eco-friendly things everywhere in their lives. Similarly in the near future, adobe construction will be a blessing in the era of cement concrete architecture, as it is not harmful to the environment as being energy-efficient and cost-effective. Various organizations have been working on earth architecture technology and have carried out significant research. The fields of research include the history of earthen architecture, the introduction and contribution of many modern architects in the field of earthen architecture such as Cointeraux, Gaudi, Schindler, Wright, Loss and many more. Moreover, they discuss various earth architecture types such as rammed earth, mud brick, compressed earth blocks and several earth-building technologies as well.

Various organizations have been taking significant measures to give recognition to earthen architecture. A number of schools, institutions and organizations have been established to provide knowledge about the process of earthen construction. Builders often have guests on the construction sites to demonstrate the implementation of advanced techniques in earth building. Moreover, various international organizations are providing education through workshops on the details of earthen architecture technique. The University of Grenoble in France is also offering a master’s degree in earthen architecture. The institute is serving as a major research centre.

All around the world, international conferences on vernacular heritage and earthen architecture have been organized in which research papers are presented related to earthen architecture. The UNESCO Chair of Earthen Architecture urges research and development projects in earthen architecture. It intends creating different training programmes in institutions for higher education in the field of earthen architecture. The first stage of this would be to make people aware of earthen architecture. Moreover, thorough courses for professionals are intended to be conducted on both a national and local level. UNESCO is taking part in conducting research on various areas such as on materials and technologies for earthen construction, production, building materials available at a local level, systematic knowledge of construction and environment-related issues related to earthen architecture. It also has support from governmental and international organizations and NGOs to promote research and development.

UNESCO has partners all over the globe which help it to achieve its goals. For the Middle East, the organization operates from Iran. Earthen architecture is experiencing new prospects which is enhancing people's interest in keeping up the traditional earthen culture and developing earth-building skills. It is necessary to develop earth-building information centres to gather data regarding the subject and communicate them along with recent research activities and results to various investigators and users. These centres would be aimed at:

- Determining research goals
- Offering affiliations and travel allowances
- Facilitating the exchange of academics and professionals
- Ensuring the education of designers and adequate training of labour
- Assisting with regional and international conferences
- Providing guides, audio-visual means and other training materials
- Developing planned projects and ensuring their maintenance

9.1.8 Proper Training

In the future, the use of earth as building material will be incentivized by a number of factors such as ease of availability which will enhance its utility at least in the developing countries. The skills and knowledge regarding traditional earth construction were transferred from one generation to another. However, in the current period it is facing a gradual decline in the majority of areas. One of the major reasons for this downfall is the modern technology-orientated training of designers which is causing these skills and expert craftsmanship to fade out in certain areas. It is suggested to rediscover these practices and make sure they are given due recognition and implemented by modern designers. Otherwise their survival in the market is quite at risk.

Young architects and engineers must be inspired to believe in the integration of past traditions and present technological opportunities for the conservation of constructions instead of annihilating one by the other. Giving an interview with Earthscan in 1980, the ex-Indian Prime Minister Mrs Indira Gandhi asserted that new constructions are based on an aim to preserve energy. Unlike old houses they are hot in summer and cold in winter. We should not only employ the new technology but should also consider aspects of the older one as well. There is a lot to learn from people concepts regarding make their settlements as such to comply with the climate, environment, and their way of living. We cannot adopt those techniques completely, as our ways of living are much different now, however, a few things can be adopted, making the new constructions as more efficient.

If we focus on the structure of construction projects, a number of participants are involved in its preparations. Different participants play a significant role in making the project successful and every participant has to perform his task in an appropriate manner. Consequently, participants should be active enough, particularly architects, engineers and planners, who are the ones to plan the structure of the building, take relevant decisions and decide the nature of the material to be used for the construction process.

It happens in several cases that when one plan fails, the architect has to look for a substitute. So, professional courses in architecture conservation can be a turning point at such moments as they offer numerous alternatives which take traditional and modem requirements into account. In a similar manner, building construction courses should start providing information about earth products and other traditional building materials and practices. In addition, technical data relevant to the aforementioned information should also be provided, and ways for their development. Moreover, these courses should be taught in the same manner as those on modern building materials.

In accordance with the opinion of Jean Dethier, who an architect and the director of an Earth exhibition at the Georges Pompidou Centre, France, “There exists an artificial obstacle between tradition and modernity and if the purpose is to overcome the present situation, it is significant to undo the actions of those who wanted to wipe out our past and drop us into an era of obliviousness and cultural bigotry half a century ago: actions of those people should be undone who inflicted their stereotyped schemes for 'progress at any price' on us making claims that they were appropriate for all the communities”. He added: “But if we focus on the solution in this regard, it is not to merely gaze sentimentally at traditions and adopt in the manner we get them. Like every other phenomenon, such traditions continue to flourish and they are continuously studied, re-explained and improved so as to make a dynamic connection between history and environment”.

9.2 Recommendations

The following points can be taken in to account by future analysts and will serve the purpose of recommendations:

- It is recommended that analysis to be conducted in future to evaluate and develop the strength and toughness features of various conventional construction systems like cob, rubble and coral stone. Moreover, emphasis should be put on the manufacturing of modem building products by means of date palm and tamarisk trees that have been overlooked. These materials would be productive enough, as a source of pollution will be controlled and fires in the fields will be managed properly.

- It is recommended that architectural conservation and building construction courses should be offered in colleges of architecture and engineering that involve knowledge about earth and other traditional building materials and methods. In addition, technical data regarding their performance and potential prospects for their development should also be provided. This should be done in the same manner as it is being done in the case of modern building structures and materials.

- Another major problem that should be dealt with is carelessness when it comes to hygiene and cleanliness. Research should be conducted in this regard and effort should be dedicated to develop earth houses but also provide knowledge about the benefits of cleanliness and maintenance to the local people.

- It is significant to develop durability tests for adobe to predict the lifespan of this building material, particularly in terms of the confrontation of wind-blown sand and water issues. The authentic durable performance of these blocks under different climatic circumstances can be assessed with the help of field trials.

- The following are the fundamental circumstances though which the fields of application of stabilized earth construction can be determined:

- Architectural maintenance knowledge
- Knowledge of ability of appropriate materials
- Appropriate climate
- Comprehensive economic considerations

This study has managed to provide information regarding the first three points for Saudi Arabia. As not much work has been done regarding comprehensive economic considerations, this point requires more analysis. It is recommended that accurate economic analysis should be conducted to examine the three basic cost factors, i.e., equipment, labour and tourism aspects. Moreover, stabilized earth blocks should also be compared with other alternative conventional building materials.

CHAPTER TEN

CONCLUSIONS

In terms of size, Saudi Arabia is a large country comprising different lands and different climates. This can be understood by the fact that more than one-third of the area comes under the category of deserts. As it is mostly covered with deserts, the old architectural structures are quite strong and manage to survive in various conditions like every sort of climate, culture, financial system and the existing building materials. At the moment, the new buildings under construction and those being established are built in accordance with western architecture. Following the western architectural ideas in this regard is not productive enough.

The basic objective of this study is to appeal to architects, various building professionals and the general public regarding the capacity of the long-established earthen systems of conservation technology and new construction. The information regarding the aforementioned factors will support the heritage material in Saudi Arabia. Moreover, this can lead to inspiring and encouraging the employment of conservation techniques through which the earthen fabric can be brought back. Another major advantage of adopting this strategy would be the reduction in the costs of the materials being used for construction purposes, as it plays a vital role in lessening housing unavailability owing to the reduction in costs.

The mentioned material should be developed in the local capability and should be employed to a maximum extent in local building materials owing to the limitation of experienced labour and high costs of imported materials. This will also facilitate local experienced labour to have an opportunity to play a significant role in the country's economy, tourism and so on.

It should be noticed here that appropriate employment of earth in a hot-dry land as a building material can be productive enough in giving proper shelters that fulfil the requirements for a building material. To bring earth conservation technology in the building industry into effect again in Saudi Arabia, following aims have been determined:

- To evaluate and articulate the vanishing regional styles of Saudi earthen architecture
- To inspect the fundamentals influencing factors of decline in earth buildings
- To examine the overall characteristics of the main soil types of the country and its study
- To cultivate the refurbishment technique by experimentation, keeping in view the Saudi earth construction by a field trip to Yemen and Morocco.

The following three basic and balancing strategies were taken into account to accomplish the purposes of this study:

- In June 2013, fieldwork was conducted by the author in Saudi Arabia.
- Laboratory methods were adopted and performed so as to gain a better interpretation of the influence of various factors pertinent to the soil mix and industrial procedure regarding the strength and quality of stabilized earth blocks.
- Some conservation technology also played a vital role in restoring earth building through the fieldtrips to Yemen, Hadhramaut .

10. 1 General Conclusions

The following results were obtained by keeping in view personal explanations, interviews with old constructors and the visual examination of earth buildings in various areas of Yemen and Morocco.

The Najd and Asir are two major geographical areas of Saudi Arabia and two different traditional architectural styles are recognized in these areas. Each style has its own characteristics and each shows the specific influence of its physical environment. Moreover, substantial contact with economic, cultural and social environments is exhibited by the aforementioned traditional architectural styles. The construction of earth houses, keeping in view the physical environment and interaction with other factors, has led to a sequence of architectural languages that were symbolized by productivity, effortlessness, functionality and the utilization of local building resources that verbalizes the final representation of the building and provides every region with its distinct character.

- An important thing to notice here is that the political boundaries never restricted the conventional architectural styles of Saudi Arabia. Therefore, the conventional Saudi architecture is influenced by the building materials, construction techniques and architectural characteristics of bordering countries that possess the same cultural and social values. The architectural concepts of the Najd were not affected by the culture and style of neighbouring countries. Nonetheless, the uniqueness and inventiveness of the vernacular architectural styles in the different regions basically rely on the extent of separation in which the local societies consider themselves. Physical obstacles, for instance, deserts and mountains, transportation and communication influenced the extent of the isolation.

- The aforementioned conventional architectural procedures of house construction in the various regions have been explained. The objective of each style was to fulfil all the needs of the local people by keeping in view the climatic circumstances plus other features of the local environments.

- Earth construction comprised the most important conventional structure of house construction in the Najd and the eastern parts of Asir in particular. In Saudi Arabia, the basic methodologies of earth construction were adobe and cob.

- In Saudi Arabia, recent times have observed the deterioration and demolishing of various buildings so as to construct buildings that were in accordance with the western style. The traditional construction systems were replaced by modern structures in the different regions of the country. Strengthened concrete structures made up of shaped concrete blocks were employed for their construction. As a matter of fact, adopting western architectural ideas in this regard is not productive enough and is considered ineffective.

- Many governmental agencies and individuals have now recognized the significance of traditional architectural structures and the experiences and understandings that have remained effective for centuries. They emphasize the importance of those experiences and have expressed their concerns in this regard. The major reason behind this concern is the failure of modern structures owing to the region's climatic and cultural conditions. Local people have also started complaining regarding the failure of such structures, as they are not capable of surviving all kinds of climatic changes. Currently, there is a high demand for an appropriate construction system by the people of Saudi Arabia that merges the qualities of the traditional procedures and the proficiency of modern technology.

In the aftermath of the progress attributed to mass industrialization efforts, developed societies are focusing more upon specialization and economies of scope instead of mass production. Simultaneously, they are laying a greater emphasis upon the environmental sustainability of projects. Mud brick structures seemingly offer multiple benefits which can be multiplied by the effective application of technical processes, subsidizing and encouraging firms towards investing in the processes. All this could ultimately contribute to significant development within Saudi Arabian society. Conservation undertaken in this regard would ensure the sustenance of the national cultural heritage which could increase tourism numbers. It would also ensure that the sector is sustainable in itself, utilizes significant amounts of labour, contributing towards creating more employment opportunities, and revitalizes the construction sector.

Considering how effective and efficient land utilization processes encourage the conservation of the local cultural heritage and the recycling of associated resources, the present locations can seemingly be safeguarded adequately. Thus, new mud brick constructions could contribute towards fostering harmony amongst different regional institutions, mud brick enterprises and construction industry professionals, all of which could contribute towards introducing new technical and financial input within the industry. Furthermore, households opting for mud brick structures could be encouraged to do so with subsidies which could go towards meeting conservation targets for constructing homes using this new method. This is aptly demonstrated within Shibam, Yemen. The need for effective conservation and to deal with the varied challenges in developing this sector could enhance the stature of the overall construction industry within Saudi Arabia, besides providing significant impetus to promoting the earthen heritage fabric within the country. It could therefore be a source of revenue for the state, since the mud brick industry could be considered to be an automatic extension of the nation's cultural heritage. The flexibility of the industry in this regard could be considered to contribute towards ensuring that the stakeholders fit in easily, and the expanding economies in the Najdi and Asir regions could provide significant opportunities for promoting earthen architecture. Indeed, the regions could significantly benefit by changing over to this construction mode, instead of solely depending upon concrete methodologies. Propagating mud brick constructions is not necessarily a novel idea. However, the novelty associated with this form of construction could perhaps be considered very much applicable in the Saudi context.

- Earth is considered a significant material as it provides numerous classy features for construction. The following factors enhance its significance:

    - Accessibility
    - Simplicity
    - Fire resistant features
    - Good thermal characteristics
    - Sound insulation features

  Nevertheless, the major drawbacks of using earth as a building material are mentioned below and owing to these factors, the local public have overlooked its significance:

    - Low resistance to moisture
    - Low load-bearing strength
    - Liability to volume changes
    - High water absorption
    - Low stability

- The deteriorations in earth buildings in Saudi Arabia cannot be overlooked but the reasons that cause that decay could be overcome by taking few considerations into account. For this purpose, modem earth construction techniques can be considered significant. The following are the major reasons behind the decay of earth houses in Saudi Arabia:

    - Poor design
    - Improper selection of soil
    - Inexperienced labour
    - Carelessness

In contrast, various mechanical factors like rain and wind, chemical reactions, biological factors like vegetation, animals, birds and insects and physical-chemical factors like capillary action, expansion and contraction are the fundamental natural reasons for the weakening of earth buildings.

10.2 Technical Conclusions

The literature review and various tests that were carried out gave the following results:

- In Saudi Arabia, sand and sandy soils are plentiful while clay rich soils can only be discovered near oases and valley beds. In fact, these are considered as a vital resource for agriculture. Samples were collected from different regions and it was found that the sand content was in the range of 54% to 84%. The highest sand content was found in Najd soils while the lowest content was found in Asir soils.

- As lime is quite cheap and low-priced, a number of construction industries in developing countries use it as a building material. Cementation and waterproofing are the techniques by means of which the performance of soil is enhanced.

- Stabilizers of soil, lime and straw are easily obtainable in Saudi Arabia and are being used in conservation regions at the moment. Lime is a conventional building material that is utilized generally as plasters and mortars.

- The following drawbacks of earth housing have played a significant role in affecting the living circumstances of people:

    - Low strength
    - Dimension uncertainty
    - High permeability
    - Poor stability

Rodent infestation occurs owing to carelessness when it comes to cleanliness by the residents. Vermin attack such places, and if earth buildings are not maintained, their stability is affected.

- If concentration is put on the strength, dimensional stability, permeability and durability features of earth as a building material, its performance can be understood quite easily and comprehensively. This study takes the aforementioned important characteristics in to account as processes of the performance of stabilized adobe prepared from synthetic soils, which replicate the sandy soils of Saudi Arabia.

- Nevertheless, the flaws of earth signify simply one reason amongst a number of others that have added to its non-acceptance in Saudi Arabia as well as in many other countries.

- To deal with wall cracking, collapse, decay etc., adobe and cob are used as they are considered as a special preservation method.

- Buildings constructed by means of earth are weaker as compared to other building materials. If such buildings are repaired, this does not sustain them for a long period due to low strength and relatively poor resistance to water damage. The study has defined the major science and engineering behind the performance of earthen construction materials.

To summarize, offering professional courses to architects detailing conservation options could contribute towards both architects and engineers understanding the options available in integrating traditional and modern engineering approaches. Besides this, associated building construction courses would also enable the stakeholders to be informed of the options available across the entire spectrum of construction materials. The process would therefore contribute to imbuing them with related technical knowledge and information regarding the materials. Thus, it is important that traditional building materials are explained, much like the attention normally focussed upon modern materials such as steel and reinforced concrete.

Historic earthen building materials in Saudi Arabia can survive for a long period of time if external dangers are eliminated. If the factor of erosion is reduced and evaporation is permitted, a historic earth structure can last for centuries, and this is evident from several old structures globally.

The buildings once built as vernacular are now referred to as cultural assets. As these are of great cultural value, a number of concerns are taken in to account before initiating the repair process. As the nature of repair is determined before initiating the process, it depends on the plan whether the building is to become a working building or a cultural memorial.

Although comprehending the conservation and repair of earth buildings has been a major function of master masons and experts, development has been observed in the scientific understanding of their behaviour. As a matter of fact, earth buildings cannot be considered better than conventional building materials, as they have certain issues that need to be addressed, but it is anticipated that a body of knowledge, available case histories and research will permit and manage to turn earth into an engineering material. Change has been observed after the treatment of the building material as an extremely unsaturated soil in case of earthen architecture and it is hoped that better understanding of the concept will be gained through it.

It is anticipated that this study will facilitate earthen architecture professionals to distinguish historic earth buildings, to identify their style and set them in their position in their historical background. Efforts should be put to identify weaknesses caused by individuals and after identification, they can be dealt with. Suggestions for restoration have been provided and as unsaturated nature of earth is now recognized, repair strategies will now be enhanced.

Furthermore, Saudi Arabia has important archaeological sites in the world since it has numerous heritage construction sites. However, the state of disrepair in the various sites requires urgent measures towards restoring the crumbling structures. Hence, it is important that proper measures are initiated at the earliest opportunity to arrest the decay. Previous chapters have detailed the various maintenance options available in this regard. The present methodologies employed ensure minimal human involvement in the exercises conducted to preserve the structures. Unfortunately, the pace of the work being executed is unsustainable and needs to be increased in order to materialize the official aim of conserving most of the historical areas. The problems being faced in this regard are further exacerbated by the shortage of skilled labour and manpower. Ideally, the renovation exercises being conducted need to keep in perspective the future use of the structures, besides making the workers aware of the importance of what they are doing. It is therefore very important that the initiatives undertaken in this regard are materialized at the earliest opportunity. There are positive indications of the possibility of genuine progress in this regard in consideration of the recently concluded agreements between the local government, the Saudi Ministry for Tourism and a team of experts in this field.

It is a genuine challenge to list all the restoration options available. Hence, it is necessary to undertake a detailed analysis of the situation to list the various challenges inherent in restoring earthen architecture. While it is important to utilize good-quality earth, it is equally relevant to use other materials, too, besides educating the workers involved in the process well before initiating the process.

This study intended to investigate the best methods for structural stabilization procedures for historical earthen building conservation in Saudi Arabia and to be helpful for Saudi earthen architecture professionals to be more aware of the various historical earthen buildings, identify their specific styles and judge their importance from a historical perspective. It is important to identify individual shortcomings in this regard, so that they can be resolved to ensure that the structures erected are preserved for future generations.

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INTERNATIONAL CENTRE FOR THE
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المركز الدولي لدراسة صون
وترميم الممتلكات الثقافية

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Conservation of Cultural Heritage in the Arab Region

(الحفاظ على التراث الثقافي في المنطقة العربية)

Glossary of Arabic Terms for the Conservation of Cultural Heritage

معجم المصطلحات العربية للحفاظ على التراث الثقافي

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آثار ATHAR

1

معجم المصطلحات
للحفاظ على التراث الثقافي
حسب الترتيب الهجائي العربي

العربية – الإنجليزية

Glossary of Terms for
the Conservation of Cultural Heritage
in Arabic Alphabetical Order

Arabic - English

معجم المصطلحات العربية للحفاظ على التراث الثقافي

حدود المعجم

الوضعية:	هذه وثيقة أولية أعدت للنشر من أجل مناقشتها والدعوة إلى إرسال التعليقات عليها. يجب عدم إعتبارها محاولة لفرض إستعمال هذه المصطلحات.
المحتوى:	المصطلحات النظرية (سيتم تناول المصطلحات التقنية في المرحلة التالية من هذا المشروع، بناء على المواضيع والمناطق الجغرافية)
اللغة:	العربية الفصحى الحديثة
الحدود الجغرافية:	جميع البلاد المتحدثة باللغة العربية
وسيلة النشر:	مستند رقمي للنشر على شبكة الإنترنت

المنهجية

احترم المؤلف توصيات مجمع اللغة العربية بالقاهرة فيما يخص المصطلحات التخصصية. وتشكل قائمة المصطلحات هذه نتيجة ثلاثة مداخل مختلفة:

1) <u>ترجمة المصطلحات الإنجليزية</u>
تُرجمت المصطلحات الإنجليزية المهمّة إلى العربية، بعد اختيارها من الأدبيات العالمية كالمواثيق والمعاهدات الدولية والكتب والمنشورات المهمة في مجال الحفاظ على التراث الثقافي.

2) <u>تبنّي مصطلحات عربية مع كتابتها بالحروف الإنجليزية وشرح معانيها لغير الناطقين بالعربية</u>
توصّل المؤلف إلى تسع مصطلحات عربية تعبّر عن قيم ومفاهيم خاصة بالثقافة العربية مما لا تحتمله الكلمات الإنجليزية. وعليه فإنه يقترح في هذا المعجم تبنّي هذه المصطلحات بصيغتها العربية وكتابتها بالحروف الإنجليزية وشرح معانيها لغير الناطقين بالعربية، وهي:

- أطلال *Atlaal*
- حَرَم *Haram*
- طاهر *Taher*
- عِبْرَة *'Ibra*
- عُرْف *'Urf*
- عَمَرَ *'Amara*
- فقه الحِفَاظ *Fiqh al Hifaaz*
- نَفْع *Naf'*
- وَقْف *Waqf*

3) <u>تعريب مصطلحات لاتينية</u>
حدَّدَ المؤلف ثلاثة مصطلحات لاتينية تُستخدم في أغلب اللغات الحديثة في مجال الحفاظ على التراث الثقافي بصيغتها اللاتينية، لذا فهو يقترح تعريبها, وهي:

- أناستيلوسيز *Anastylosis*
  تجميع وإنشاء القطع المتهدمة والمتناثرة بموقع أثري

- لاكونا *Lacunae*
الفجوة الناتجة عن فقد جزء من نسيج الأثر

- باتينا *Patina*
طبقة رقيقة متكونة على سطح الأثر نتيجة لمرور الزمن

ملاحظة: سيتم الشرح التفصيلي للمصطلحات المذكورة عاليه في مرحلة لاحقة من المعجم.

شكر

بدأت العمل في هذا المعجم في عام 2000، وأظن أنه سيستغرق الباقي من عمري. ولا يسعني إلا أن أتوجه بالشكر والعرفان لمؤسسة بركات، بجامعة أكسفورد لإعطائي منحتين في عامي 2005 و2006، مما مكنني من زيارة مكتبة إيكوموس في باريس، ومكتبة إكروم في روما. كما أنني أدين بالعرفان لمركز إكروم، والذي وفر لي مناخاً ممتازاً لإختبار الكثير من الأفكار والمبادئ من خلال برنامجه التدريبي المهم "آثار"، حيث تمكنت من فهم الكثير من الفروق في اللهجات العربية، والتناول المختلف للغة العربية في البلاد العربية المختلفة. كما منحني مركز إكروم زمالة لمدة ثلاثة شهور في عام 2007، مما أفادني كثيراً من خلال مناقشاتي مع الخبراء بالمركز واستخدامي للمكتبة الرائعة بالمركز. كما أنني أدين مرة أخرى لمركز إكروم وبرنامج "آثار" لنشرهما قائمة المصطلحات هذه على شبكة الإنترنت، وأخص بالشكر والعرفان زكي أصلان وروبرت كيليك. أما الأقارب والأصدقاء والزملاء الذين ساعدوني في المراحل المختلفة من هذا العمل، فلا أستطيع في هذا الحيّز الضيق أن أذكرهم بالاسم ولا أن أوفيهم حقهم من الشكر والعرفان. إلا أنني أبقى المسئول الوحيد عن أي خطأ أو تقصير حدث بهذا العمل.

دعوة للتعليق والمشاركة

يعدّ المؤلف مطبوعا عن الفكر والمنهجية المتبعين في المعجم مع شرح بالعربية للمصطلحات الواردة فيه. والمرجو إرسال التعليقات على محتوى هذه الوثيقة فيما يخص الأسئلة التالية بالذات:

1) هل ترى المصطلحات المقترحة مناسبة / كافية لبدء فهم وتشجيع المناظرة في مجال الحفاظ على التراث الثقافي بالمنطقة العربية؟

2) هل ترى المصطلحات العربية المقترحة مناسبة للتعبير عن المصطلحات الإنجليزية المقابلة؟

3) هل ترى المصطلحات العربية المقترحة مناسبة للتداول في بلدك فيما يخص التعليم، والتوعية، والممارسة المهنية، والبحث الأكاديمي في مجال الحفاظ على التراث الثقافي؟

نرجو إرسال التساؤلات والتعليقلت والأقتراحات على العنوان التالي:athar@iccrom.org.

List of Terms According to Arabic Alphabet	قائمة المصطلحات بالترتيب الهجائي العربي
English إنجليزي	**Arabic عربي**
Minimum intervention	التَدَخُّل الأدنى
Blue shield	الدرع الأزرق
Historical archaeology	آثار تاريخية
Urban archaeology	آثار عمرانية
Sampling	أخذ عَيِّنَة
Ethics of conservation	أخلاقيات الحفاظ
Authenticity	أصالة
Atlaal	***أطلال***
Curator	أمين متحف
Anastylosis	***أناستيلوسيز***
Ruins	أنقاض
Significance	أهمية
Heritage significance	أهمية تراثية
Cultural significance	أهمية ثقافية
Cosmic significance	أهمية كونية
Retention of authenticity	إبقاء الأصالة
Retention of associations	إبقاء الإرتباطات
Retention of meaning	إبقاء المعنى
Preventive measure	إجراء وقائي
Examination	إختبار
Disturbance	إختلال
Clearing	إخلاء
Management	إدارة
Heritage management	إدارة التراث
Risk management	إدارة التعرض للمخاطر
Visitor management	إدارة الزائرين
Resource management	إدارة الموارد
Site management	إدارة الموقع
Management of the archaeological site	إدارة الموقع الأثري
Associations	إرتباطات
Patrimony	إرث
Restitution	إرجاع لوضع سابق
Guidelines	إرشادات
Removal	إزالة
Replacement	إستبدال
Use	إستخدام
Sustainable use	إستخدام مستدام
Appropriate use	إستخدام مناسب
Maintenance strategy	إستراتيجية صيانة
Risk preparedness	إستعداد للتعرض للمخاطر
Emergency preparedness	إستعداد للطوارئ
Reproduction	إستنساخ
Repair	إصلاح
Addition	إضافة
Risk management framework	إطار إدارة التعرض للمخاطر

Revealing	إظهار
Reuse	إعادة استخدام
Adaptive reuse	إعادة استخدام تحويلي
Reconstruction	إعادة بناء
Rehabilitation	إعادة تأهيل
Reassemble	إعادة تجميع
Recycle	إعادة تدوير
Rearrangement	إعادة ترتيب
Reintegration	إعادة تكامل
Reburial	إعادة دفن
Refill	إعادة ردم
Repatriation	إعادة للوطن
Statement of significance	إعلان الأهمية
Statement of conservation policies	إعلان سياسات الحفاظ
Intrusive	إقتحامي
Acquisition	إقتناء
Access	إمكانية الوصول / الدخول
Public access	إمكانية الوصول / الدخول للجمهور
Reversibility	إمكانية إزالة التدخل
Detracted from	إنتقص من
Construction	إنشاء
Patina	***باتينا***
Propagation	بثّ
Interpretation program	برنامج تأويل
Presentation program	برنامج تقديم
Vestige of the past	بقايا الماضي
Archaeological remains	بقايا آثارية
Historic town	بلدة تاريخية
Infrastructure	بنية تحتية
Environment	بيئة
Historic environment	بيئة تاريخية
Physical environment	بيئة مادية
Built environment	بيئة مبنية
Interdisciplinary	بين-التخصصات
Intervention	تَدَخُّل
Historic	تاريخي
Impact	تأثير
Historical	تأريخي
Establish significance	تأصيل الأهمية
Interpretation	تأويل
Interpretation of authenticity	تأويل الأصالة
Stabilization	تثبيت الحالة
Periodical renewal	تجديد دوري
Risk avoidance	تجنب التعرض للمخاطر
Risk identification	تحديد التعرض للمخاطر
Provenance	تحديد مكان المَنْشَأ
Identification	تحديد هوية
Destruction	تحطيم
Accidental destruction	تحطيم غير مُتَعَمَد

Intentional destruction	تحطيم مُتَعَمّد
Investigations	تحقيقات
Intrusive investigations	تحقيقات اقتحامية
Archaeological investigations	تحقيقات آثارية
Control	تحكم
Development control	تحكم في التنمية
Alteration	تحوير
Vandalism	تخريب
Planning for management	تخطيط للإدارة
Planning for conservation	تخطيط للحفاظ
Surroundings	تخوم
Emergency intervention	تدخل طارئ
Curative intervention	تدخل علاجي
Preventive intervention	تدخل وقائي
Reinforcement	تدعيم
Decay	تدهور
Registration	تدوين
Heritage	تراث
Heritage of indigenous people	تراث السكان الأصليين
Archaeological heritage	تراث آثاري
Historic heritage	تراث تاريخي
Underwater heritage	تراث تحت الماء
Cultural heritage	تراث ثقافي
Movable cultural heritage	تراث ثقافي منقول
Living heritage	تراث حي
Industrial heritage	تراث صناعي
World Heritage	تراث عالمي
Material heritage	تراث مادي
Built heritage	تراث مبني
Built vernacular heritage	تراث مبني دارج
Sustainable heritage	تراث مستدام
Common heritage	تراث مشترك
Architectural heritage	تراث معماري
Submerged heritage	تراث مغمور
Cultural mapping	ترسيم خريطة ثقافية
Stratigraphy	تركيب الطبقات
Restoration	ترميم
Falsify evidence	تزوير دليل
Falsify historic evidence	تزوير دليل تاريخي
Falsify artistic evidence	تزوير دليل فني
Recording	تسجيل
Consultation	تشاور
Distorting the meaning	تشويه المعنى
Infill design	تصميم جديد لملء الفراغات بالنسيج العمراني
Evolution of cultural heritage	تطور التراث الثقافي
Modification	تعديل
Risk of damage	تعرّض لمخاطر التلف
Risk	تعرض للمخاطر
Enhancement	تعزيز

Displace	تغيير مكان
Change of function	تغيير وظيفة
Vernacular traditions	تقاليد دارجة
Significance evaluation	تقدير الأهمية
Risk evaluation	تقدير التعرض للمخاطر
Presentation	تقديم
Presentation of authenticity	تقديم الأصالة
Popular presentation	تقديم شعبي
Traditional	تقليدي
Risk mitigation/reduction	تقليل التعرض للمخاطر
Mitigate damage	تقليل الخراب
Intrusive technique	تقنية اقتحامية
Traditional technique	تقنية تقليدية
Modern technique	تقنية حديثة
Non-intrusive technique	تقنية غير اقتحامية
Consolidation	تقوية
Authenticity assessment	تقييم الأصالة
Impact assessment	تقييم التأثير
Risk assessment	تقييم التعرض للمخاطر
Site assessment	تقييم الموقع
Control assessment	تقييم فعالية التحكم
Assessment of vulnerability	تقييم قابلية التلف
Integration	تكامل
Harmonious integration	تكامل متوافق
Integrity	تكاملية
Integrity of heritage	تكاملية التراث
Ecological integrity	تكاملية إيكولوجية
Visual integrity	تكاملية بصرية
Historical integrity	تكاملية تاريخية
Cultural integrity	تكاملية ثقافية
Aesthetic integrity	تكاملية جمالية
Scientific integrity	تكاملية علمية
Physical integrity	تكاملية مادية
Adaptation	تكييف
Deterioration	تلف
Natural deterioration	تلف طبيعي
Excavation	تنقيب
Partial excavation	تنقيب جزئي
Retouching	تنقيح
Development	تنمية
Cultural development	تنمية ثقافية
Urban development	تنمية عمرانية
Sustainable development	تنمية مستدامة
Heritage diversity	تنوع تراثي
Cultural diversity	تنوع ثقافي
Threat	تهديد
Physical threat	تهديد مادي
Frequency	تواتر
Documentation	توثيق
Cultural	ثقافي

Inventorization	جرد
Integral part	جزء متكامل
Missing part	جزء مفقود
Condition	حالة
Condition of building	حالة المبنى
Physical condition	حالة مادية
Conjecture	حدس
Historic garden	حديقة تاريخية
Conservation crafts	حرف يدوية خاصة بالحفاظ
Haram	**حرم**
Degradation	حطّ من القيمة
Urban conservation	حفاظ عمراني
Conservation	حفاظ
Conservation-restoration	حفاظ-ترميم
Environmental conservation	حفاظ بيئي
Cultural conservation	حفاظ ثقافي
Permanent conservation	حفاظ دائم
Integrated conservation	حفاظ متكامل
Architectural conservation	حفاظ معماري
Preventive conservation	حفاظ وقائي
Preservation	حفظ
In situ preservation	حفظ بالموقع
Protection	حماية
Protect authenticity	حماية الأصالة
In-situ protection	حماية بالموقع
Permanent protection	حماية دائمة
Temporary protection	حماية مؤقتة
Integrated protection	حماية متكاملة
Environmental characteristic	خصيصة بيئية
Historic character	خصيصة تاريخية
Representative character	خصيصة تمثيلية
Physical characteristic	خصيصة مادية
Emergency preparedness plan	خطة استعداد للطوارئ
Management plan	خطة إدارة
Maintenance plan	خطة صيانة
Integrated management plan	خطة متكاملة للإدارة
Danger	خطر
Hazard	خطورة
Vernacular	دارج
Historic study	دراسة تاريخية
Historical study	دراسة تأريخية (دراسة التاريخ)
Risk analysis	دراسة تحليلية للتعرض للمخاطر
Degree of intervention	درجة التدخل
Archaeological evidence	دليل آثاري
Historic evidence	دليل تاريخي
Intangible evidence	دليل غير ملموس
Tangible evidence	دليل ملموس
Documentary evidence	دليل وثائقي

Collective memory	ذاكرة جماعية
Stakeholder	ذو صلة
Wall painting	رسم جداري
Safeguard	رعاية
Spirit of place	روح المكان
Record	سِجِلّ
Permanent record	سجل دائم
Shelter	سقيفة
Cultural tourism	سياحة ثقافية
Conservation policy	سياسة الحفاظ
Cultural policy	سياسة ثقافية
Context	سياق
Original context	سياق أصلي
Environmental context	سياق بيئي
Cultural context	سياق ثقافي
Natural context	سياق طبيعي
Traditional character	شخصية تقليدية
Deaccession	شطب من القائمة
Vernacular form	شكل دارج
Physical form	شكل مادي
Maintenance	صيانة
Active maintenance	صيانة فعّالة
Continuous maintenance	صيانة مستمرة
Preventive maintenance	صيانة وقائية
Damage	ضرر
Irreparable damage	ضرر غير قابل للإصلاح
Tahir	***طاهر***
Historical stratification	طبقات تاريخية
Superimposed	طبقة فوق أخرى
Style	طراز
Cultural route	طريق ثقافي
'Urf	***عُرْف***
Consequence	عاقبة
Ibra	***عبرة***
Display	عرض
Period	عصر
Treatment	علاج
Archaeology	علم الآثار
Amara	***عمر***
Urban	عمراني
Work of art	عمل فني
Risk management process	عملية إدارة التعرض للمخاطر
Elements of heritage	عناصر التراث
Curation	عناية متحفية
Architectural element	عنصر معماري
Agent of decay	عوامل تدهور
Agent of deterioration	عوامل تلف
Non-renewable	غير قابل للتجدد
Irreversible	غير قابل للعكس
Incompatible	غير متوافق

Incompatible with management	غير متوافق مع الإدارة
Incompatible with protection	غير متوافق مع الحماية
Intangible	غير ملموس
World Heritage in Danger List	قائمة التراث العالمي المعرّض للخطر
Inspection	فحص
Initial inspection	فحص أوّلي
Investigation team	فريق التحقيقات
Detach	فصل
Loss	فقد
Loss in value	فقد في القيمة
Fiqh al hifaaz	***فقه الحفاظ***
Understanding	فهم
Comprehensive understanding	فهم شمولي
World Heritage List	قائمة التراث العالمي
Inventory	قائمة الجرد
Renewable	قابل للتجديد
Recognizable	قابل للتعرف عليه
Replaceable	قابل للتعويض
Vulnerable	قابل للتلف
Distinguishable	قابل للتمييز
Reversible	قابل للعكس
Vulnerability	قابلية للتلف
Carrying capacity	قدرة الاستيعاب
Shared decision	قرار مشترك
Object	قطعة (فنية - تراثية - أثرية)
Listing	قيد بالقائمة
Conflicting values	قيم متعارضة
Value	قيمة
Economic value	قيمة اقتصادية
Rarity value	قيمة الندرة
Identity value	قيمة الهوية
Archaeological value	قيمة آثارية
Social value	قيمة إجتماعية
Human value	قيمة إنسانية
Historic value	قيمة تاريخية
Heritage value	قيمة تراثية
Cultural value	قيمة ثقافية
Outstanding cultural value	قيمة ثقافية متميزة
Aesthetic value	قيمة جمالية
Intrinsic value	قيمة جوهرية
Symbolic value	قيمة رمزية
Spiritual value	قيمة روحية
Universal value	قيمة عالمية
Outstanding universal value	قيمة عالمية متميزة
Artistic value	قيمة فنّية
Architectural value	قيمة معمارية
Attributed value	قيمة منسوبة

Documentary value	قيمة وثائقية
Disaster	كارثة
Irreplaceable	لا يعوّض
Lacunae	***لاكونا***
Monument	مَعْلم
Historic monument	مَعْلم تاريخي
Conservation laboratory	مُخْتبر الحفاظ
Historic property	مُمْتَلَك تاريخي
Cultural property	مُمْتَلَك ثقافي
Vernacular structure	مُنْشَأ دارج
Original material	مادة أصلية
Physical	مادي
Historic building	مبنى تاريخي
Heritage building	مبنى تراثي
Vernacular building	مبنى دارج
Site museum	متحف الموقع
Multidisciplinary	متعدد-التخصصات
Distinct	متميز
Compatible	متوافق
Collections	مجموعات
Groups of buildings	مجموعات المباني
Collections of heritage significance	مجموعات ذات أهمية تراثية
Cultural group	مجموعة ثقافية
Conservator	محافظ
Archaeological reserve	محمية آثارية
Setting	محيط
Traditional setting	محيط تقليدي
Conservation plan	مخطط الحفاظ
Conservation master plan	مخطط عام للحفاظ
Conservation approach	مدخل الحفاظ
Collections manager	مدير المجموعات
Site manager	مدير موقع
Historic city	مدينة تاريخية
Monitoring	مراقبة
World Heritage Centre	مركز التراث العالمي
Restorer	مرمم
Causes of deterioration	مسببات التدهور
Replica	مستَنْسَخ
Sustainable	مستدام
Level of significance	مستوى الأهمية
Survey	مسح
Condition survey	مسح الحالة
Archaeological survey	مسح آثاري
Ground survey	مسح أرضي
Aerial survey	مسح جوّي
General survey	مسح عام
Information source	مصدر معلومات
World Heritage Convention	معاهدة التراث العالمي
International convention	معاهدة دولية
Risk criteria	معايير التعرض للمخاطر

Endangered	معرّض للخطر
Conservation architect	معماري الحفاظ
Place	مكان
Historic place	مكان تاريخي
Heritage place	مكان تراثي
Place of heritage significance	مكان ذو أهمية تراثية
Spiritual place	مكان روحي
Architectural feature	ملمح معماري
Sculptural feature	ملمح نحتي
Practitioner	ممارس
Historic area	منطقة تاريخية
Conservation area	منطقة حفاظ
Urban area	منطقة عمرانية
Historic urban area	منطقة عمرانية تاريخية
Buffer zone	منطقة فاصلة للحماية
Protected area	منطقة محمية
Landscape	منظر عام
Cultural landscape	منظر عام للثقافة
Natural landscape	منظر عام للطبيعة
Regional organization	منظمة إقليمية
International organization	منظمة دولية
Prevention of decay	منع التدهور
Prevention of deterioration	منع التلف
Detached	منفصل
Archaeological method	منهج آثاري
Archaeological methodology	منهجية آثارية
Abandoned	مهجور
Threatened	مهدد
Resource	مورد
Archaeological resource	مورد آثاري
Cultural resource	مورد ثقافي
Non-renewable cultural source	مورد ثقافي غير متجدد
Spiritual resource	مورد روحي
Non-renewable source	مورد غير قابل للتجديد
Material resource	مورد مادي
Location	موضع
Site	موقع
Site of the monument	موقع المَعْلم
Archaeological site	موقع أثري
Historic site	موقع تاريخي
Significant site	موقع ذو أهمية
In-situ	موقعي (بالموقع)
International charter	ميثاق دولي
Nafe'	***نافع***
Sculpture	نحت
Fabric (of heritage)	نسيج (التراث)
Historic fabric	نسيج تاريخي
Physical fabric	نسيج مادي

Dissemination	نشر
Memorial	نصب تذكاري
Relocation	نقل لموقع آخر
Moving	نقل من الموقع
Urban pattern	نمط عمراني
Heritage typology	نوع التراث
Type of risk	نوع التعرض للمخاطر
Demolition	هدم
Identity	هوية
Indigenous identity	هوية السكان الأصليين
Regional identity	هوية إقليمية
Cultural identity	هوية ثقافية
Local identity	هوية محلّية
National identity	هوية وطنية
Original document	وثيقة أصلية
Authentic document	وثيقة أصيلة
Historic document	وثيقة تاريخية
Historical document	وثيقة تأريخية
Unity of the whole	وحدة الكلّ
State of conservation	وضع الحفاظ
State of preservation	وضع الحفظ
Existing state	وضع راهن
Underlying state	وضع ضمني
Function	وظيفة
Appropriate function	وظيفة مناسبة
Awareness	وعي
Waqf	***وقف***

2

معجم المصطلحات
للحفاظ على التراث الثقافي
حسب الترتيب الهجائي الإنجليزي

الإنجليزية - العربية

Glossary of Terms for
the Conservation of Cultural Heritage
in English Alphabetical Order

English - Arabic

ATHĀR Programme برنامج أثار
Conservation of Cultural Heritage in the Arab Region
الحفاظ على التراث الثقافي في المنطقة العربية

Glossary of Arabic Terms for the Conservation of Cultural Heritage

Scope

Status:	This is a preliminary document distributed to invite discussion and comments. It should not be seen as an attempt to impose a terminology.
Content:	Theoretical terms (technical terms will be addressed in a next phase according to themes and geographic regions).
Language:	Modern Classical Arabic
Geography:	All Arabic-speaking countries
Media:	Digital web publication

Methodology

The criteria for Arabic specialized terminology that were set by the Institute of Arabic language in Cairo were respected. The List of Terms is the result of three parallel approaches:

1) Translation of English terms

International charters, conventions and publications on the cultural heritage conservation were reviewed for key words, terms and concepts. An Arabic translation for each English term was chosen.

2) Adopting Arabic terms and transliterating them for non-Arabic-speakers

Arabic historical sources were reviewed for words that signify concepts and meanings that are specific to Arabic culture. Nine words are identified. They are represented in English by transliteration in order to keep their Arabic spirit:

- *Atlaal* أطلال
  Tangible and intangible aspects of ruins, including memories and feelings

- *Haram* حرم
  A protected place that includes a significant site, its associations, intangible aspects and its buffer

- *Taher* طاهر
  The Islamic concept of purity and cleanliness

- *'Ibra* عبرة
  Thoughts, feelings and lessons learnt from heritage, history and archaeology

- *'Urf* عرف
  Conventions, norms, traditions and rules inherited and applied by the community

- *'Amara* عمر
  Tangible and intangible aspects of living in a place, including physical, emotional, psychological and spiritual aspects

- *Fiqh al Hifaaz* فقه الحفاظ
  Theoretical and practical knowledge of Islamic views on the conservation of cultural heritage

- *Naf'* نفع
  Utility, use, function and the added value of an object, place, person or concept

- *Waqf* وقف
  A system of endowment that was developed in Muslim communities to secure the sustainable management and conservation of public institutions

A detailed explanation of each of the above terms and the rationale for selecting it to represent a unique Arabic concept or value will be published in a later version of this work.

3) Arabic transliteration of Latin terms
Three significant Latin words are adopted by most modern languages in the field of conservation for cultural heritage. These words are transliterated in Arabic:
- *Anastylosis* أناستيلوسيز
- *Lacunae* لاكونا
- *Patina* باتينا

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Call for Comments and Contributions

The author is preparing a publication on the rationale, methodology and explanations of the glossary. Comments on the content would be welcome, particularly when addressed to the following questions:

1) Are the proposed terms appropriate/sufficient to establish an up-to-date understanding of, and encourage a debate on, the conservation of cultural heritage in the Arab region?

For Arabic-speaking specialists:

2) Are the selected Arabic words appropriately equivalent to the English ones?

3) Are the proposed Arabic terms adequate for use in your country for education, raising awareness, professional and academic purposes?

Please send all questions, comments and suggestions to: athar@iccrom.org

List of Terms According to English Alphabet	قائمة المصطلحات بالترتيب الهجائي الإنجليزي
English إنجلـــيزي	**Arabic عـربي**
'Urf	***عُرْف***
Abandoned	مهجور
Access	إمكانية الوصول / الدخول
Accidental destruction	تحطيم غير مُتَعَمّد
Acquisition	إقتناء
Active maintenance	صيانة فعّالة
Adaptation	تكييف
Adaptive reuse	إعادة استخدام تحويلي
Addition	إضافة
Aerial survey	مسح جوّي
Aesthetic integrity	تكاملية جمالية
Aesthetic value	قيمة جمالية
Agent of decay	عوامل تدهور
Agent of deterioration	عوامل تلف
Alteration	تحوير
Amara	***عمر***
Anastylosis	***أناستيلوسيز***
Appropriate function	وظيفة مناسبة
Appropriate use	إستخدام مناسب
Archaeological evidence	دليل آثاري
Archaeological heritage	تراث آثاري
Archaeological investigations	تحقيقات آثارية
Archaeological method	منهج آثاري
Archaeological methodology	منهجية آثارية
Archaeological remains	بقايا آثارية
Archaeological reserve	محمية آثارية
Archaeological resource	مورد آثاري
Archaeological site	موقع أثري
Archaeological survey	مسح آثاري
Archaeological value	قيمة آثارية
Archaeology	علم الآثار
Architectural conservation	حفاظ معماري
Architectural element	عنصر معماري
Architectural feature	ملمح معماري
Architectural heritage	تراث معماري
Architectural value	قيمة معمارية
Artistic value	قيمة فنية
Assessment of vulnerability	تقييم قابلية التلف
Associations	إرتباطات
Atlaal	***أطلال***
Attributed value	قيمة منسوبة
Authentic document	وثيقة أصيلة
Authenticity	أصالة
Authenticity assessment	تقييم الأصالة
Awareness	وعي
Blue shield	الدرع الأزرق

Buffer zone	منطقة فاصلة للحماية
Built environment	بيئة مبنية
Built heritage	تراث مبني
Built vernacular heritage	تراث مبني دارج
Carrying capacity	قدرة الاستيعاب
Causes of deterioration	مسببات التدهور
Change of function	تغيير وظيفة
Clearing	إخلاء
Collections	مجموعات
Collections manager	مدير المجموعات
Collections of heritage significance	مجموعات ذات أهمية تراثية
Collective memory	ذاكرة جماعية
Common heritage	تراث مشترك
Compatible	متوافق
Comprehensive understanding	فهم شمولي
Condition	حالة
Condition of building	حالة المبنى
Condition survey	مسح الحالة
Conflicting values	قيم متعارضة
Conjecture	حدس
Consequence	عاقبة
Conservation	حفاظ
Conservation approach	مدخل الحفاظ
Conservation architect	معماري الحفاظ
Conservation area	منطقة حفاظ
Conservation crafts	حرف يدوية خاصة بالحفاظ
Conservation laboratory	مُختَبر الحفاظ
Conservation master plan	مخطط عام للحفاظ
Conservation plan	مخطط الحفاظ
Conservation policy	سياسة الحفاظ
Conservator	محافظ
Conservation-restoration	حفاظ-ترميم
Consolidation	تقوية
Construction	إنشاء
Consultation	تشاور
Context	سياق
Continuous maintenance	صيانة مستمرة
Control	تحكم
Control assessment	تقييم فعالية التحكم
Cosmic significance	أهمية كونية
Cultural	ثقافي
Cultural conservation	حفاظ ثقافي
cultural context	سياق ثقافي
Cultural development	تنمية ثقافية
Cultural diversity	تنوع ثقافي
Cultural group	مجموعة ثقافية
Cultural heritage	تراث ثقافي
Cultural identity	هوية ثقافية
Cultural integrity	تكاملية ثقافية

Cultural landscape	منظر عام للثقافة
Cultural mapping	ترسيم خريطة ثقافية
Cultural policy	سياسة ثقافية
Cultural property	مُمْتَلَك ثقافي
Cultural resource	مورد ثقافي
Cultural route	طريق ثقافي
Cultural significance	أهمية ثقافية
Cultural tourism	سياحة ثقافية
Cultural value	قيمة ثقافية
Curation	عناية متحفية
Curative intervention	تدخل علاجي
Curator	أمين متحف
Damage	ضرر
Danger	خطر
De-accession	شطب من القائمة
Decay	تدهور
Degradation	حطّ من القيمة
Degree of intervention	درجة التدخل
Demolition	هدم
Destruction	تحطيم
Detach	فصل
Detached	منفصل
Deterioration	تلف
Detracted from	إنتقص من
Development	تنمية
Development control	تحكم في التنمية
Disaster	كارثة
Displace	تغيير مكان
Display	عرض
Dissemination	نشر
Distinct	متميز
Distinguishable	قابل للتمييز
Distorting the meaning	تشويه المعنى
Disturbance	إختلال
Documentary evidence	دليل وثائقي
Documentary value	قيمة وثائقية
Documentation	توثيق
Ecological integrity	تكاملية إيكولوجية
Economic value	قيمة اقتصادية
Elements of heritage	عناصر التراث
Emergency intervention	تدخل طارئ
Emergency preparedness	إستعداد للطوارئ
Emergency preparedness plan	خطة استعداد للطوارئ
Endangered	معرّض للخطر
Enhancement	تعزيز
Environment	بيئة
Environmental characteristic	خصيصة بيئية
Environmental conservation	حفاظ بيئي
Environmental context	سياق بيئي
Establish significance	تأصيل الأهمية

Ethics of conservation	أخلاقيات الحفاظ
Evolution of cultural heritage	تطور التراث الثقافي
Examination	إختبار
Excavation	تنقيب
Existing state	وضع راهن
Fabric (of heritage)	نسيج (التراث)
Falsify artistic evidence	تزوير دليل فنّي
Falsify evidence	تزوير دليل
Falsify historic evidence	تزوير دليل تاريخي
Fiqh al hifaaz	***فقه الحفاظ***
Frequency	تواتر
Function	وظيفة
General survey	مسح عام
Ground survey	مسح أرضي
Groups of buildings	مجموعات المباني
Guidelines	إرشادات
Haram	***حرم***
Harmonious integration	تكامل متوافق
Hazard	خطورة
Heritage	تراث
Heritage building	مبنى تراثي
Heritage diversity	تنوع تراثي
Heritage management	إدارة التراث
Heritage of indigenous people	تراث السكان الأصليين
Heritage place	مكان تراثي
Heritage significance	أهمية تراثية
Heritage typology	نوع التراث
Heritage value	قيمة تراثية
Historic	تاريخي
Historic area	منطقة تاريخية
Historic building	مبنى تاريخي
Historic character	خصيصة تاريخية
Historic city	مدينة تاريخية
Historic document	وثيقة تاريخية
Historic environment	بيئة تاريخية
Historic evidence	دليل تاريخي
Historic fabric	نسيج تاريخي
Historic garden	حديقة تاريخية
Historic heritage	تراث تاريخي
Historic monument	مَعْلم تاريخي
Historic place	مكان تاريخي
Historic property	مُمْتَلك تاريخي
Historic site	موقع تاريخي
Historic study	دراسة تاريخية
Historic town	بلدة تاريخية
Historic urban area	منطقة عمرانية تاريخية
Historic value	قيمة تاريخية
Historical	تأريخي
Historical archaeology	آثار تاريخية
Historical document	وثيقة تأريخية

Historical integrity	تكاملية تاريخية
Historical stratification	طبقات تاريخية
Historical study	دراسة تأريخية (دراسة التاريخ)
Human value	قيمة إنسانية
Ibra	***عبرة***
Identification	تحديد هوية
Identity	هوية
Identity value	قيمة الهوية
Impact	تأثير
Impact assessment	تقييم التأثير
Incompatible	غير متوافق
Incompatible with management	غير متوافق مع الإدارة
Incompatible with protection	غير متوافق مع الحماية
Indigenous identity	هوية السكان الأصليين
Industrial heritage	تراث صناعي
Infill design	تصميم جديد لملء الفراغات بالنسيج العمراني
Information source	مصدر معلومات
Infrastructure	بنية تحتية
Initial inspection	فحص أوَّلي
In situ	موقعي (بالموقع)
in-situ preservation	حفظ بالموقع
In-situ protection	حماية بالموقع
Inspection	فحص
Intangible	غير ملموس
Intangible evidence	دليل غير ملموس
Integral part	جزء متكامل
Integrated conservation	حفاظ متكامل
Integrated management plan	خطة متكاملة للإدارة
Integrated protection	حماية متكاملة
Integration	تكامل
Integrity	تكاملية
Integrity of heritage	تكاملية التراث
Intentional destruction	تحطيم مُتَعَمَد
Interdisciplinary	بين-التخصصات
International charter	ميثاق دولي
International convention	معاهدة دولية
International organization	منظمة دولية
Interpretation	تأويل
Interpretation of authenticity	تأويل الأصالة
Interpretation program	برنامج تأويل
Intervention	تَدَخُل
Intrinsic value	قيمة جوهرية
Intrusive	إقتحامي
Intrusive investigations	تحقيقات اقتحامية
Intrusive technique	تقنية اقتحامية
Inventorization	جرد
Inventory	قائمة الجرد
Investigation team	فريق التحقيقات
Investigations	تحقيقات

Irreparable damage	ضرر غير قابل للإصلاح
Irreplaceable	لا يعوّض
Irreversible	غير قابل للعكس
Lacunae	***لاكونا***
Landscape	منظر عام
Level of significance	مستوى الأهمية
Listing	قيد بالقائمة
Living heritage	تراث حي
Local identity	هوية محلية
Location	موضع
Loss	فقد
Loss in value	فقد في القيمة
Maintenance	صيانة
Maintenance plan	خطة صيانة
Maintenance strategy	إستراتيجية صيانة
Management	إدارة
Management of the archaeological site	إدارة الموقع الأثري
Management plan	خطة إدارة
Material heritage	تراث مادي
Material resource	مورد مادي
Memorial	نصب تذكاري
Minimum intervention	التَدَخُّل الأدنى
Missing part	جزء مفقود
Mitigate damage	تقليل الخراب
Modern technique	تقنية حديثة
Modification	تعديل
Monitoring	مراقبة
Monument	مَعْلم
Movable cultural heritage	تراث ثقافي منقول
Moving	نقل من الموقع
Multidisciplinary	متعدد-التخصصات
Nafe'	***نافع***
National identity	هوية وطنية
Natural context	سياق طبيعي
Natural deterioration	تلف طبيعي
Natural landscape	منظر عام للطبيعة
Non-intrusive technique	تقنية غير اقتحامية
Non-renewable	غير قابل للتجدد
Non-renewable cultural source	مورد ثقافي غير متجدد
Non-renewable source	مورد غير قابل للتجديد
Object	قطعة (فنية - تراثية - أثرية)
Original context	سياق أصلي
Original document	وثيقة أصلية
Original material	مادة أصلية
Outstanding cultural value	قيمة ثقافية متميزة
Outstanding universal value	قيمة عالمية متميزة
Partial excavation	تنقيب جزئي
Patina	***باتينا***
Patrimony	إرث
Period	عصر

Periodical renewal	تجديد دوري
Permanent conservation	حفاظ دائم
Permanent protection	حماية دائمة
Permanent record	سجل دائم
Physical	مادي
Physical characteristic	خصيصة مادية
Physical condition	حالة مادية
Physical environment	بيئة مادية
Physical fabric	نسيج مادي
Physical form	شكل مادي
Physical integrity	تكاملية مادية
Physical threat	تهديد مادي
Place	مكان
Place of heritage significance	مكان ذو أهمية تراثية
Planning for conservation	تخطيط للحفاظ
Planning for management	تخطيط للإدارة
Popular presentation	تقديم شعبي
Practitioner	ممارس
Presentation	تقديم
Presentation of authenticity	تقديم الأصالة
Presentation program	برنامج تقديم
Preservation	حفظ
Prevention of decay	منع التدهور
Prevention of deterioration	منع التلف
Preventive conservation	حفاظ وقائي
Preventive intervention	تدخل وقائي
Preventive maintenance	صيانة وقائية
Preventive measure	إجراء وقائي
Propagation	بثّ
Protect authenticity	حماية الأصالة
Protected area	منطقة محمية
Protection	حماية
Provenance	تحديد مكان المَنْشَأ
Public access	إمكانية الوصول / الدخول للجمهور
Rarity value	قيمة الندرة
Rearrangement	إعادة ترتيب
Reassemble	إعادة تجميع
Reburial	إعادة دفن
Recognizable	قابل للتعرف عليه
Reconstruction	إعادة بناء
Record	سجلّ
Recording	تسجيل
Recycle	إعادة تدوير
Refill	إعادة ردم
Regional identity	هوية إقليمية
Regional organization	منظمة إقليمية
Registration	تدوين
Rehabilitation	إعادة تأهيل
Reinforcement	تدعيم

Reintegration	إعادة تكامل
Relocation	نقل لموقع آخر
Removal	إزالة
Renewable	قابل للتجديد
Repair	إصلاح
Repatriation	إعادة للوطن
Replaceable	قابل للتعويض
Replacement	إستبدال
Replica	مستَنْسَخ
Representative character	خصيصة تمثيلية
Reproduction	إستنساخ
Resource	مورد
Resource management	إدارة الموارد
Restitution	إرجاع لوضع سابق
Restoration	ترميم
Restorer	مرمم
Retention of associations	إبقاء الإرتباطات
Retention of authenticity	إبقاء الأصالة
Retention of meaning	إبقاء المعنى
Retouching	تنقيح
Reuse	إعادة استخدام
Revealing	إظهار
Reversibility	إمكانية إزالة التدخل
Reversible	قابل للعكس
Risk	تعرض للمخاطر
Risk analysis	دراسة تحليلية للتعرض للمخاطر
Risk assessment	تقييم التعرض للمخاطر
Risk avoidance	تجنب التعرض للمخاطر
Risk criteria	معايير التعرض للمخاطر
Risk evaluation	تقدير التعرض للمخاطر
Risk identification	تحديد التعرض للمخاطر
Risk management	إدارة التعرض للمخاطر
Risk management framework	إطار إدارة التعرض للمخاطر
Risk management process	عملية إدارة التعرض للمخاطر
Risk mitigation/ reduction	تقليل التعرض للمخاطر
Risk of damage	تعرّض لمخاطر التلف
Risk preparedness	إستعداد للتعرض للمخاطر
Ruins	أنقاض
Safeguard	رعاية
Sampling	أخذ عَيِّنَة
Scientific integrity	تكاملية علمية
Sculptural feature	ملمح نحتي
Sculpture	نحت
Setting	محيط
Shared decision	قرار مشترك
Shelter	سقيفة
Significance	أهمية
Significance evaluation	تقدير الأهمية

Significant site	موقع ذو أهمية
Site	موقع
Site assessment	تقييم الموقع
Site management	إدارة الموقع
Site Manager	مدير موقع
Site museum	متحف الموقع
Site of the monument	موقع المَعْلَم
Social value	قيمة إجتماعية
Spirit of place	روح المكان
Spiritual place	مكان روحي
Spiritual resource	مورد روحي
Spiritual value	قيمة روحية
Stabilization	تثبيت الحالة
Stakeholder	ذو صلة
State of conservation	وضع الحفاظ
State of preservation	وضع الحفظ
Statement of conservation policies	إعلان سياسات الحفاظ
Statement of significance	إعلان الأهمية
Stratigraphy	تركيب الطبقات
Style	طراز
Submerged heritage	تراث مغمور
Superimposed	طبقة فوق أخرى
Surroundings	تخوم
Survey	مسح
Sustainable	مستدام
Sustainable development	تنمية مستدامة
Sustainable heritage	تراث مستدام
Sustainable use	إستخدام مستدام
Symbolic value	قيمة رمزية
Tahir	***طاهر***
Tangible evidence	دليل ملموس
Temporary protection	حماية مؤقتة
Threat	تهديد
Threatened	مهدد
Traditional	تقليدي
Traditional character	شخصية تقليدية
Traditional setting	محيط تقليدي
Traditional technique	تقنية تقليدية
Treatment	علاج
Type of risk	نوع التعرض للمخاطر
Underlying state	وضع ضمني
Understanding	فهم
Underwater heritage	تراث تحت الماء
Unity of the whole	وحدة الكلّ
Universal value	قيمة عالمية
Urban	عمراني
Urban archaeology	آثار عمرانية
Urban area	منطقة عمرانية
Urban conservation	حفاظ عمراني
Urban development	تنمية عمرانية

Urban pattern	نمط عمراني
Use	إستخدام
Value	قيمة
Vandalism	تخريب
Vernacular	دارج
Vernacular building	مبنى دارج
Vernacular form	شكل دارج
Vernacular structure	مُنشأ دارج
Vernacular traditions	تقاليد دارجة
Vestige of the past	بقايا الماضي
Visitor management	إدارة الزائرين
Visual integrity	تكاملية بصرية
Vulnerability	قابلية للتلف
Vulnerable	قابل للتلف
Wall painting	رسم جداري
Waqf	***وقف***
Work of art	عمل فني
World Heritage in Danger List	قائمة التراث العالمي المعرّض للخطر
World Heritage List	قائمة التراث العالمي
World Heritage	تراث عالمي
World Heritage Centre	مركز التراث العالمي
World Heritage Convention	معاهدة التراث العالمي