Investigation of the Binding Materials Properties and Assessment of Durability Issue in Fasil Ghibbi Palace in Gondar

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Practical Fulfillments of the Requirements of the Degree of Master of Science in Civil Engineering

(Construction Technology and Management)

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Abstract

Historical monuments are the precious signs of our past. They are non-replaceable fragments of our cultural heritage and their future depends on our attitudes and actions towards preserving them. Attitudes are undoubtedly changing in the ways we view our cultural heritage and people are becoming more conscious of the unity of human values and regard ancient monuments as a common heritage.

Conservation of ancient monuments is a process which will lead to the prolongation of the life of cultural property for its utilization now and in the future. But, before practicing conservation, one must have a broad understanding of the field itself. This is of course to ensure that any action carried out during the conservation work is properly performed and is in accord, not only with the building requirements, but is within the scope of contemporary knowledge of the subject.

The appropriate selection of the binding materials during the construction of stone bridges, palaces, churches, cathedrals restoration, and conservation of historical monuments is essential at the time of intervention.

Today, these historical structures are in different physical state, some are in relatively good condition, while many are in a deplorable state.

The purpose of this study is to identify the method of construction and analyze the construction materials which were used in Royal palace construction in order to define their characteristic properties, durability and to consider the properties of original materials, thus enlightening the usability of them in repair of such buildings. For this purpose, samples of the construction materials like binding mortar, which were used in Fasil Ghibe Palace construction, were taken and Extracted in Ethiopian Geological Survey Laboratory.

The type of binding material which was used during the construction of the Fasil Ghibbi palace is identified as Lime (CaO) or by its local name Nora. And also the method of construction was by stone masonry.

The major cause of deterioration of the Royal Palace is due to various reasons, some of which are long life, lack of periodic maintenance, unchecked growth of trees, grass, algae & mechanical impact on the wall surface by Visitors.

Key Words: Durability, Gondar, Heritage, Lime, Royal Palace

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List of Abbreviations

UNESCO: - United Nation Economic, Social and Cultural Organization

M.sq:- Meter Square

AAS: - Atomic Absorption Spectroscopy

HF: - Hydrofluoric

OPC:-Ordinary Portland cement

PPC: -Pozzolana Portland cement

0C: - Degree Centigrade

T: - Temperature

RH: - Relative Humidity

Amp: - Ampere

Chapter One

1.1 Introduction

For the period of several centuries, the influence of several distinct cultures produced rich and diverse cultural heritage that we see today in East Africa countries. The most tangible remains of these heritages are stone built buildings and structures including, palaces, mosques, residential houses and tombs. At present, these heritages are in different physical state, some are in relatively good condition while many are in an appalling condition. The presence of these historical monuments has benefited these countries economically and culturally therefore, it is essential to ensure that these monuments continue to exist.

Ethiopia, one of culturally rich countries in the world with oldest civilizations and unique geographical features, is situated to the Horn of Africa. Recent studies witnessed that ancestor of the modern human used to live in Ethiopia over three million years ago. Hence the nation has been a cross roads of civilizations and peoples for thousands of years.

Through this long process of civilization and history, quite a number of towns and cities had flourished. Of these, Gondar is a medieval royal city which was ascribed by UNESCO as the" World Heritage Site" in 1978.

The origins of the Royal palace can be found in the old tradition of the Ethiopian emperors to travel around their possessions, living off the produce of the peasants and dwelling in tents. Reflecting this connection, this precinct was frequently referred to as a *katama* ("camp" or "fortified settlement") or *makkababya*, the name applied to the imperial camp in the *Royal Chronicle* of *Baeda Maryam* (Wikipedia 2014). Gondar is positioned in Northwestern part of Ethiopia, at about 740 and 175 kilometers away from Addis Ababa and Bahir Dar respectively. Its altitude is 2200 meters above sea level.

Founded by emperor Fasiladas in 1636, the city of Gondar had been the seat of the Ethiopian state for about 250 years. The foundation of this Imperial city witnessed a period of optimism and renaissance of the golden days of *Aksum* and *Lalibela*.

Architecture, literature, education, music, painting commerce that had been perished after the fall of ancient *Aksum*, rose to prominence (Bureau 2011).

The Royal compound lying within 70,000 m.sq, it encompasses six lofty castles and many different purposed buildings like the royal archive, house of the musicians, the lion cage, the horse zoo, the sauna bath, house of the spinners etc. The earliest and grandest of all edifices is that of Emperor Fasiladas, which is 32 meters high and with battlemented square tower (Bureau 2011). Today, these historical structures are in different physical state, some are in relatively good condition, while many are in a deplorable state (see figure 1 and figure 2).

Moreover, due to the existence of these historical structures, this township has become tourist attraction. Due to that, this township and the country as the whole have benefited by promoting their culture and by emerging economical growth. In view of the above benefits, it is essential to ensure that these historical structures continue to exist. Pursuant to this, there is a need to establish the actual conditions of these historical structures with a main purpose of evaluating the possibility of conserving this cultural heritage, which has great historical value and is a potential tourist attraction.

Heritage structures and historical monuments have a central cultural place in any society; old stone bridges, palaces, churches, cathedrals, monuments, etc., nevertheless, degradation processes generated by natural or human actions lead to deterioration, damaging or even loss of these inestimable treasures. Thus, regular maintenance and remedial works are unavoidable (BrankoGlisic 2007).

Figure 1: Buildings in good condition

Figure 2: Buildings in deplorable state

Building binding materials have a long history, and the date 1824, traditionally taken as the origin of Portland cement, is in fact only the date of a patent (I) granted to Joseph Aspdin (1778-1855) of Leeds, England. Who may not at that time have made Portland cement at all. Today cement is the successor to a line of materials with a history reaching hack to the ancient world; it has a chemistry of perhaps unsurpassed complexity amongst major inorganic industrial materials and is still the subject of intense study. At some point in the second quarter of the 19th century, about 150 years ago, the cement as we know it now was first produced (Stephan Kröner 2007).

Throughout history, cementing materials have played a vital role. They were used widely in the ancient world. The Egyptians used calcined gypsum as cement. The Greeks and Romans used lime made by heating limestone and added sand to make mortar, with coarser stones for concrete (Stephan Kröner 2007).

The Romans found that cement could be made which set under water and this was used for the construction of harbors. The cement was made by adding crushed volcanic ash to lime and was later called ’’pozzolanic’’ cement, named after the village of Pozzuoli near Vesuvius (A.M.Neville 1986).

1.2 Statement of the Problem

Historical monuments are the precious signs of our past. They are non-replaceable fragments of our cultural heritage and their future depends on our attitudes and actions towards preserving them. Attitudes are undoubtedly changing in the ways we view our cultural heritage and people are becoming more conscious of the unity of human values and regard ancient monuments as a common heritage. Responsibility for conserving these monuments, and the appreciation of mental and physical skill applied to their erection is thus recognized.

Conservation of ancient monuments is a process which will lead to the prolongation of the life of cultural property for its utilization now and in the future. But, before practicing conservation, one must have a broad understanding of the field itself. This is of course to ensure that any action carried out during the conservation work is properly performed and is in accord, not only with the building requirements, but is within the scope of contemporary knowledge of the subject.

The appropriate selection of the binding materials in the ambit of stone bridges, palaces, churches, cathedrals restoration and conservation of historical monuments is essential at the time of intervention. The physical and chemical properties of binding materials should match as close as possible to those of the unaltered original binding materials. This could be considered as a fundamental requirement in order to avoid incompatibilities of the replacement binding materials.

In order to have a sustained programme for maintenance and conservation of Fasil Ghibe palace we need to identify the physical and chemical properties of the binding materials, address the question of durability of the construction materials used at the time of construction and restoration and prevent further erosion of the integrity of the Fasil Ghibe palace. Additionally, means to address the existing conflicts to balance the conservation of the historic value of the Fasil Ghibe palace with the need to improve the traditional liturgical functions have yet to be implemented.

Like many other countries in which monument conservation seems to be a fairly new practice, Ethiopia faces several problems in dealing with the issues of historical monuments. First, there is no suitable system for discovering and recording historical monument in the country. The systems are quite important in monument conservation, particularly among other things, to locate the monument location, function and owner, to classify the monument into their functions, to assist the authority in keeping a record of the monument for future research and funding and to measure monument defects and suggest remedial measures. Secondly, there is lack of technical knowledge in repairing and maintaining historical monuments. This is a major problem because almost all conservation works, which involve both repair and maintenance stages require an understanding and analysis of monument defect diagnoses.

1.3 Purpose of the Research

The following paragraph summarized some of the advantages of this research for both individuals and communities.

Identifying the binding material and assessing the durability of construction materials which was used during the construction of Fasil Ghibe Palace is vital for rehabilitation and adaptive reuse of a heritage building not only preserves cultural values, it can be a profitable investment. Heritage conservation is also an effective catalyst for stimulating local and regional economies. Studies show that rehabilitating heritage buildings has a greater economic impact than new construction. As an added benefit, the promotion of historic places as tourist attractions helps local residents develop a greater understanding and appreciation of their own culture and heritage.

However, till now peoples did not have the exact information about the method of construction and type of binding material which is used during the construction of Fasil Ghibe palace. Some of them say, they are done using egg and fresh leather byproduct as a binding material and others says lime. So, the outcome of this research will address the above question.

1.4 Objectives

The objectives of this research are:

a) To identify the binding material used at the time of construction.
b) To characterize and asses the durability of binding materials.
c) To study the construction method used at the time of construction.

1.5 Scope and Limitations of the Research

The scope of the study is focused on only on identification of binding materials and durability problems in the Royal Compound which encompasses six lordly castles and many different purposed buildings like the royal archive, house of the musicians, the lion cage, the horse zone, the sauna bath, house of the spinner etc. due to time and financial constraints other historical buildings which are found in Gondar are not included.

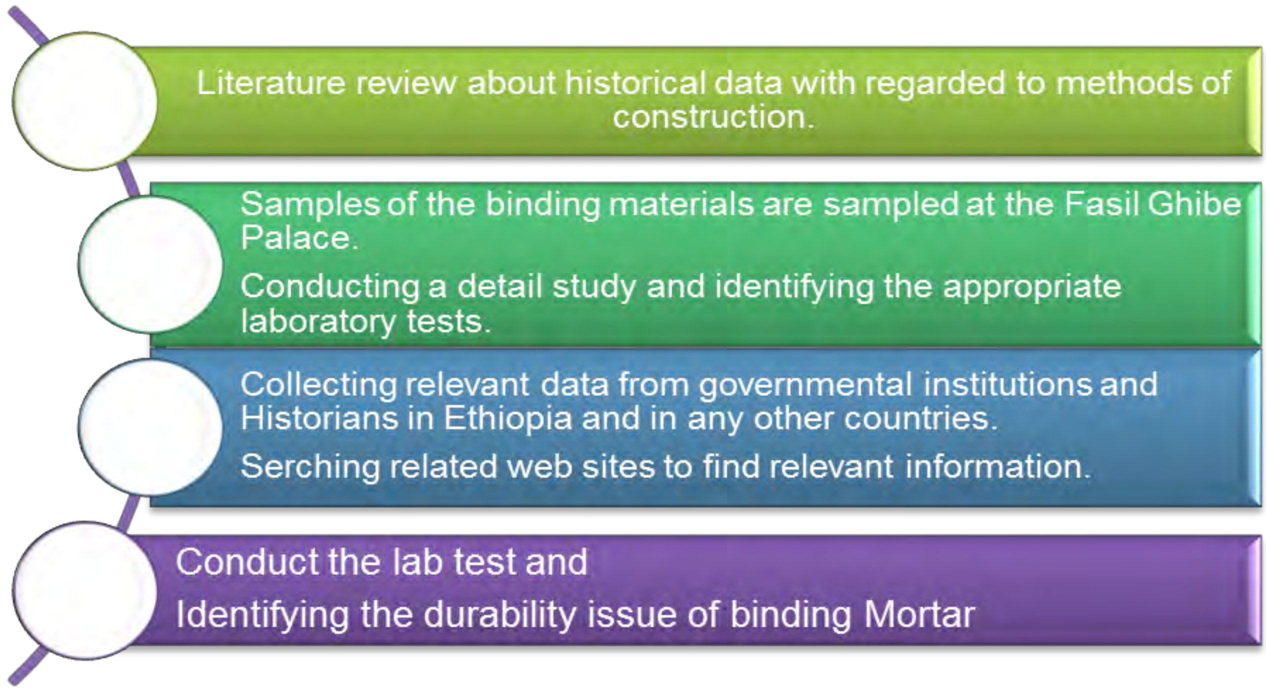
1.6 Methodology

To gather useful information of the important historic buildings in Gondar, Ethiopia; this study is based on literature review and experimental study approach. To tackle this complex challenge, much effort was directed to a comprehensive review of existing literature, on site examination of the Royal Palace, extensive photographic documentation of the material features and condition of the Palace and landscape features of the property, in-depth archival research to reveal the history of the Royal Palace and informant interviews and written narrative, and laboratory tests. The literature review was mostly acquired from published books, research papers, seminar papers and journals mainly from the archival records of the Addis Ababa University, Center of Ethiopian Studies and from the web. The literature review was supplemented with the in depth physical investigation of the Palace in question to go on with the Royal Palace history. The in depth physical observations were carried out through site survey where data was obtained from a visual inspection of defects at its exact location or based on building elements.

Laboratory experimental tests included: General Silicate Analysis, it includes: $LIBO_2$ FUSION, HF Attack, Gravimetric and AAS; and Mineralogical Analysis.

Binding materials' sample specimens were taken from sections of interior walls of the buildings in accordance with obtained permit from the Royal Palace Administration and tested in the laboratories at the Geological Survey of Ethiopia, Central Geological Laboratory for chemical Analysis properties. The Sample specimens were taken from the walls by using a hand cutting Tool but the sample specimens from the restoration site where taken simply by hand.

The major steps to be followed while conducting the research are presented in the following flow chart:



After identifying the durability of the construction materials; the question of safety will be addressed. Based on the above methodology the objectives of this research will be addressed.

Chapter Two

2. International Practices on Policies of Protection and Conservation of Historical Heritages

2.1 Cultural Conservation Policy on International Level

Most of the brief discussions made here under are based on international charters, conventions and recommendations but at the end of this topic a detailed analysis at some national and/or regional charters is also made to focus the content of the discussion on the national level.

The international practices on the conservation of cultural heritages show that there are a number of charters, conventions, and recommendations concerning the development of cultural policy over the last century developed by different international institutions and organized societies who have great interest and concern about conservation of cultural heritages.

The following brief description of charters, conventions, and recommendations represent the chronological development of cultural policy. Documents described are international, regional and/or national in their scope.

Though not a comprehensive list of all national cultural policies and legislations, these documents identify key issues and represent key policies in the development of contemporary thinking about the conservation of cultural property.

To mention some of the earlier international documents prepared concerning conservation of heritages it can be said that the first manifesto produced to set up the ideal of restoration of ancient buildings as" protecting our ancient buildings, and handing them down instructive and venerable to those that come after us." prepared by the Principal of the Society for the Protection of Ancient Buildings (SPAB) to be the earliest initiatives(http://www.getty.edu/conservation/reserch_resources/charters/charter00.html) 1877).

The contents of the manifesto is devoted to attacking thoughtless and destructive efforts of restoration that leave the building a ‘’ feeble and lifeless forgery.’’ The manifesto recommends protection rather than restoration as well as resisting tempering with the fabric or ornament of the building as it stands, advocating ’’staving off decay by daily care.’’

The second notable international consensus concerning the conservation of heritages would be the recommendations of the sixth International congress of Architects at Madrid, 1904. “The recommendations emphasize the importance of minimal intervention in dealing with ruined structures and of finding a functional use for historic buildings. The document sets forth the principle of unity of style, which encourages restoration according to a single stylistic expression”.

(http://www.getty.edu/coservation/research_resources/chartes/charter01.html)

The Athens Charter for the restoration of historic monuments which was adopted at the first international congress of Architects and Technicians of Historic Monuments, Athens 1931, could be cited as the other notable international initiative taken to safeguard the characters and historical values of ancient structures.

The Athens charter emphasized the importance of setting out an agreed international guiding principle for the preservation and restoration of ancient building of public importance, with each country being responsible for applying the plan within the framework of its own culture and tradition.

As International Council on Monuments and Sites marked at the congress in Athens the following seven main resolutions were made and called ‘Carta del Restauro”.

1. International organizations for restoration on operational and advisory levels are to be established.
2. Proposed Restoration projects are to be subjected to knowledgeable criticism to prevent mistakes which will cause loss of character and historical values to the structures.

3. Problems of preservation of historic sites are to be solved by legislation at national level for all countries.
4. Excavated sites which are not subject to immediate restoration should be reburied for protection.
5. Modern techniques and materials may be used in restoration work.
6. Historical sites are to be given strict custodial protection.
7. Attention should be given to the protection of areas surrounding historic sites.

Apart from the above resolutions made by the conference in Athens there were some key issues approved regarding the general principles, administrative and legislative measures as well as restoration and the techniques of conservation of cultural heritages.

The Summarized General Conclusion of the Athens Conference is a follows:

I. Doctrines. General Principles.

- The conference noted that there predominates a general tendency to abandon restorations in by initiating a system of regular and permanent maintenance calculated to ensure the preservation of the buildings.
- When, as a result of decay and destruction, restoration appears to be indispensable, it recommends that the historic and artistic work of the past should be respected, without excluding the style of any given period.
- The conference recommends that the occupation of buildings, which ensures the continuity of their life, should be maintained but that they should be used for purposes which respect their historic or artistic character.

II. Administrative and Legislative Measures regarding Historic Monuments

- The conference unanimously approved the general tendency to recognize a certain right of the community in regard to private ownership.

- Recognizing the difficulty of reconciling public law with the rights of individuals, the conference had in the opinion that they should be in keeping with local circumstances and with the trend of public opinion, so that the least possible opposition may be encountered.
- It recommends that the public authorities in each country be empowered to take conservatory measures in cases of emergency.

III. Aesthetic Enhancement of ancient monuments.

- The conference recommends that, new constructions of buildings, in the neighborhood of ancient monuments, the character and external aspect of the cities in which they are to be erected should be respected. Even certain groupings and certain particularly picturesque treatment should be preserved.
- A study should also be made of the ornamental vegetation most suited to certain monuments or group of monuments from the point of preserving their ancient character.
- It specially recommends the suppression of all forms of publicity, of the erection of unsightly telegraph poles etc…

IV. Restoration of Monuments.

- The conference approved the judicious use of all the resources at the disposal of modern technique and more especially of reinforced concrete.
- They specified that this work of consolidation should whenever possible be covered in order that the aspect and character of the restored monument may be preserved.
- They stressed that the adoption of modern material to be applied particularly in cases where use makes it possible to avoid the dangers of dismantling and reinstating the portion to be preserved.

V. The Deterioration of Ancient Monuments.

- Concerning determining the methods of conservation of specific cases, the conference recommends the architects and curators should work in close collaboration with specialists in the physical, chemical and natural sciences.

VI. The Techniques of Conservation.

- The conference is gratified to note that the principles and technical considerations set forth in the different detailed communications are inspired by the same idea, namely:

In the case of skeletons, scrupulous conservation is necessary, and steps should be taken to reinstate any original fragments that may be recovered, whenever this is possible; the new material used for this purpose should in all case be recognizable. When the preservation of skeletons brought to light in the course of excavations is found to be impossible, the conference recommends that they be buried, accurate records being of course taken before filling in operations are taken.

Even though there are number of other conferences, the next notable international convention was the Hague convention, 1954, for the protection of cultural property in the event of armed conflict.

The convention seeks to ensure that cultural property, both moveable and immovable, is safeguarded and respected as the common heritage of mankind. The convention encourages parties to prevent theft and vandalism of cultural property and proposes a distinctive blue and white shield shaped emblem to identify protected cultural property. (http://www.getty.edu/conservation/research_resources/charters/charter06.html)

Along with these substantial global changes of critical thinking about the concept of conservation and conservation principles to strengthen the policies, conventions and enforcement mechanisms, there were other developments which have direct impact on the international and national policy measures of conservation of cultural heritages.

One of the main developments which have great impact on the conservation of cultural heritages is the foundation of the United National Educational, Scientific and cultural

Organization (UNESCO) on 16th of November 1945. Among the fundamental and diversified target issues that this organization (UNESCO) is founded to address, cultural heritage conservation stood being the focus ‘to create conditions for genuine dialogue based upon respect for shared values and the dignity of each civilization and culture.’ (http://portal.unesco.org/en/ev.php-URL_ID=DO=DO_TOPIC@URL_SE...)

Based on the basic principles set out by Athens charter the other probably the most important development concerning the conservation and restoration of historic heritages was the Venice charter, 1964. This international charter for the conservation and restoration of monuments and sites was established with the intention of a thorough study of the principles involved and to enlarge its scope during the 2nd International Congress of Architects and Technicians of Historic Monuments which met in Venice from May 25th to 31st 1964.

In general the Venice charter codifies internationally accepted standards of conserving practice relating to architectural elements and sites with all the settings of the traditional layouts. It sets forth principles of conservation based on the concepts of authenticity and the importance of maintaining the historical and physical context of a site or building. Since then the Venice charter continues to be the most influential international conservation document. The Venice charter states that monuments are to be conserved not only as works of art but also as historical evidence.

Among the most important issues forwarded to be considered concerning the conservation and restoration of historic monuments on the Venice charter, only few which are relevant to this research are highlighted as follows:

DEFINITIONS:

ARTICLE 1: The concept of an historic monument embraces not only the single architectural work but also the urban or rural setting in which is found the evidence of a particular civilization, a significant development or an historic event. This applies not only to great works of art but also to more modest works of the past which have acquired cultural significance with the passing of time.

ARTICLE 2: The conservation and restoration of monuments must have recourse to all the sciences and techniques which can contribute to the study and safeguarding of the architectural heritage.

CONSERVATION

ARTICLE 5: The conservation of monuments is always facilitated by making use of them for some socially useful purpose. Such use is therefore desirable but it must not change the lay out or decoration of the building. It is within these limits only that modifications demanded by change of function should be envisaged and may be permitted.

ARTICLE 6: The conservation of monuments implies preserving a setting which is not out of scale. Wherever the traditional setting exists, it must be kept. No new construction, demolition or modification which would alter the relations of mass and color must be allowed.

ARTICLE 7: The monument is inseparable from the history to which it bears witness and from the setting it occurs. The moving of all or part of a monument cannot be allowed except where the safeguarding of that monument demands it or where it is justified by national and international interest of paramount importance.

RESTORATION

ARTICLE 9: The process of restoration is a highly specialized operation. Its aim is to preserve and reveal the aesthetic and historic value of the monument and is based on respect for original material and authentic documents. It must stop at the point where conjecture begins, and in this case moreover any extra work which is indispensable must be distinct from the architectural composition and must bear a contemporary stamp. The restoration in any case must be preceded and followed by an archeological and historical study of the monument.

ARTICLE 10: Where traditional techniques prove inadequate, the consolidation of a monument can be achieved by the use of any modern technique for conservation and construction, the efficacy has been shown by scientific data and proved by experience.

ARTICLE 13: Additions cannot be allowed except in so far as they do not detract from the interesting parts of the building, its traditional setting, the balance of its composition and its relation with its surroundings.

HISTORIC SITES

ARTICLE 14: The sites of monuments must be the object of special care in order to safeguard their integrity and ensure that they are cleared and presented in a seemly manner. (http:/www.icomos.org/Venice_charter.html)

United Nations Educational, Scientific and Cultural Organization (UNESCO) seeks to ensure the cultural property both moveable and immovable in a number of ways by recommending every member country to recognize the importance of protection and conservation of their own heritages for the sake of their citizens as well as for all humanity. The recommendations made by UNESCO include suggestions to formulate, develop, and apply policies for protection, conservation, and presentation of their cultural and natural heritages.

These recommendations stress on the increased financial resources for the safeguarding and preservation of cultural and natural heritage and suggest scientific and technical, administrative, legal, financial, education, and public involvement measures to be taken.

Many nations around the world have accepted and responded to the recommendations of protection and conservation of architectural heritages in different ways but most often it was adaptive reuse of old structure which was a common activity of utilizing the functional aspects of historic structures without losing its historic significance.

Adaptive reuse of heritage buildings often calls for modification of the interior spaces up to the level of demolishing the whole internal partition works so that the building could have a new internal layout without affecting the shell or exterior appearance of the old building to give room for the new function that of the modern society is in need of.

There were many controversies about the applicability of conservation in the manner of adaptive reuse of historic structures considering the vitality of the interior spaces as much as the exterior façade of the building. Up until today, there are different school of thoughts concerning conservation of cultural heritages but all give due credit to the charters and recommendations forwarded by UNESCO.

Recently, UNESCO's recommendations and suggestions was further tuned to architectural works of historic significance in the charter ratified by the International Council on Monuments and Sites (ICOMOS) by establishing principles for the analysis, conservation and structural restoration of architectural heritages on the 14th General assembly which was held in Victoria falls, Zimbabwe, on October 2003.

These sets of recommendations by ICOMOS charter are presented in the form of principles and guidelines: where principles set the basic concepts of conservation while the guidelines present the rules and methodologies that a designer should follow in the protection and conservation activities.

Among the principles, as general criteria, which have the status of approved\ratified ICOMOS document, the following seems to be of paramount importance to the protection and conservation of architectural heritages in response to the attitude developed with regard to adaptive re-use. The under stated principle by ICOMOS sets a clear and precise policy measure as a criteria for the activities of responsible authorities with regard to remodeling and utilization of interior spaces.

Principles

1. General Criteria

1.2 The value of architectural heritage is not only in its appearance, but also in its integrity of all its components as a unique product of the specific building technology of its time. In particular the removal of the inner structures maintaining only the facades does not fit the conservation criteria.

1.3 When any change of use or function is proposed, all the conservation requirements and safety conditions have to be carefully taken into account.

The principle is justified considering that each item of cultural heritage is unique and that the disappearance of any one item partially or the whole constitutes a definite loss and an irreversible impoverishment of that heritage with its entire historic message that should be transferred to the next generation.

This recently formulated principle of conservation and revitalization of architectural heritages is adopted as a policy in many countries as a national and regional charter of protection and conservation while some countries do not accept it as criteria because of the magnitude of the redevelopment pressure prevailing in respective countries.

2.2 Historical Heritage Policy on a National / Regional Level

Experiences of different countries around the world show that conservation methodologies for cultural heritages are devised in a general guideline of principles of conservation works. According to analysis made on some heritage conservation policies and enforcement mechanism of countries which I selected, like that of Government New Zealand, Government of Australia, Government of china, two issues stood out clearly as being, in my opinion, the most important in ensuring successful and meaningful heritage preservation. One is community involvement and awareness creation; the other one is making a clear government policy and policy enforcement strategies.

These countries have policies that have adopted the Venice charter of 1964, which is the international charter for the conservation and restoration of monuments and sites, by contextualizing the content of the charter to suite their own pressing and importantly addressable issues.

This fact of adopting the international charter is usually accentuated by developing and clarifying the details of implementation strategies of the policy on regional level by respective regional authorities as the experiences other nations like the government of

Christchurch city in New Zealand and the Western Australian city government of Australia.

The reviewed policy documents of these city governments clearly show the importance of clear and explicitly detailed framework of protection and conservation of cultural heritages of a city in a way that could form a positive impact on creating supportive attitude of the residents of the city.

2.2.1 Policies With Regard to Conservation Principles

The city of Christchurch Heritage conservation policy document clearly states that the internationally accepted conservation principle, the commonly known as the Venice charter, is adopted on the national level as ICOMOS New Zealand charter and the Christchurch shares this adopted principles with the rest of New Zealand to safeguard its heritages.

2.2.2 Policies With Regard to Heritage Research

Research forms the foundation of all conservation work. It provides the information needed to assess heritage value, to make sound conservation decisions and to raise awareness of heritages.

Most nations have heritage conservation policies which encourages and agitates responsible authorities both governmental and non-governmental organization to perform a detailed research on identifying heritage buildings, places and objects for listing and study on the preparation of conservation plans for listed buildings to facilitate the activities of proper conservation in a manner that has little or no negative impact on the heritage building.

2.2.3 Policies With Regard to Heritage Identification and Listing

According to the reviewed conservation policy documents of different countries, identification and listing of heritages is given due emphasis along with the research and documentation processes. In fact the identification and listing of heritages activity is an ongoing process in which the list of heritages will only reflect the current state of knowledge about the heritages of a nation or region at that specific period.

The number of heritages in the list could grow and of course minimize if loss of heritages happen due mainly to unavoidable accident like earth quick or flooding.

The usual trend of establishment of heritage list is the local government shall initiate the inventory activity, once the inventory is completed the local government may elect to include all of those heritages in its list, or may include a smaller sub-set of those listed in the inventory list.

The inclusion or exclusion of heritages from the list should be based on their degree of historic heritage significance, supported by the findings in the inventory, irrespective of whether they are privately or publicly owned.

A heritage should always be designated on the basis of a clear statement of significance, which shall be cross analyzed with assessment criteria and other guidelines which shall be established by the responsible authority in protection and conservation.

According to (Awaj, February, 2008) the criteria used to list a building, place or object in the city varies from country to country but the commonly used criteria to categorizing and listing are summarized as follows:

Historical and Social Significance

For its historic value or significance in terms of a notable figure, event, phase or activity and whether it is important reflection of social pattern of its time.

Cultural and spiritual Significance

For its contribution to the distinctive characteristics of a way of life, philosophy, religion or other belief and/or the esteem in which it is held by a particular group or community.

Architectural and Artistic Significance

For its significance in terms of a design of a particular style, period or designer and whether it has significant artistic value.

Group and setting Significance

For its unity in terms of scale, form, materials, texture and color in relationship to its setting and/or surrounding buildings.

Technological and Craftsmanship Significance

The heritage item's importance for the nature and use of materials, finishes and constructional methods which were innovative for the period or of noteworthy quality.

2.2.4 Policies With Regard to Heritage Protection

Rules and regulations concerning protection of heritages are the necessary components of heritage conservation policy but this shall be known with the fact that regulation does not by itself protect heritages however it gives framework and guidelines within which protection can be achieved and is an expression of a community's commitment to conservation.

The heritage protection policy can be of different in content and details of scope in which the listed heritages of a community can be protected but the usual trend with regard to how this can be achieved can be learned from experiences of other nations in the world. Many countries try to achieve the protection of heritages by giving emphasis to working in collaboration with owners and developers as well as other stake holders like non-governmental organizations who are actively participating in the same intention.

Community awareness creation has been taken as the best means to achieve the goal of protecting the heritages because the very fact that a community who does not have any value related to the heritage is always against the protection mechanisms of heritages.

Therefore, in this protection policy with regard to listed heritages the main points which shall be addressed are:

• To provide legal protection against demolition and alteration initiatives,

• To create awareness in the community and the users, if any,

• To promote heritage conservation schemes

2.2.5 Policies With Regard to Conservation Plans and Re-Use of Heritage Buildings

The policy with regard to conservation plan and re-use of heritage buildings is the guiding principle as to the future use and rehabilitation mechanisms concerning the listed heritages. This policy document sets out what is significant about the heritage and therefore show what is possible to be done without affecting its historic or artistic or anything related to its significance.

This policy document shall set a plan of action which varies in scope from a do it your self-plan for simpler structures to a professionally prepared plan of action. This policy is believed to help developers and current users of the heritages the limitations and possible activities that could be implemented on the heritage to make it better fit for their functional demand that they may have.

Some city governments even went to a level where the government staff assigned in the protection and conservation of heritage structures to devote their time in producing a number of alternative schemes in which the heritage can be protected while having functional usage for the owners and present users of the heritage structures.

This is mainly because of the fact that the conservation is dependent on finding compatible new uses with the best scenario of addressing the economic interest of those who are using it while preventing demolition, or to confine the extent of alteration.

2.2.6 Policies With Regard to Conservation Incentives

Effective public policy regarding conservation of heritages must acknowledge the additional responsibility and costs of maintenance and preservation of older, heritage properties can impose, and provision of adequate financial and technical support and assistance is necessary to help owners conserve their property.

Grants must be made available from the government as an incentive to be allocated for the purpose of conservation up on request from owner or building users and assistance shall be allocated with specific criteria such as:

• The relative value of the heritage,

• The contribution the proposed plan of action in the conservation of the heritage,

• The timing and urgency of the work, and

• The availability of fund and technical staff needed for technical assistance etc…

2.3 Contextual Background Information on the City Of Gondar

Ethiopia is one of the few countries in the world who has manmade and natural heritages recognized and registered by UNESCO as heritages of the world.

Apart from these historic world heritages the country has a lot more national and regional level heritages which need proper care and utilization exist throughout the country, among these one could mention the built up historic heritages of the city of Gondar which are living testimonies of the level of technology and the indigenous architectural style in the times of the foundation era of the city.

Presently, these precious elements of the city are experiencing a seriously critical condition due to so many factors among which lack of proper conservation and preservation practice is the main one.

2.3.1 Brief History of Gondar and Fasil Ghibbi Palace

Founded in 1636 as Ethiopia's capital city by emperor Fasiledes, Gondar is a city of Castles. The first named after Fasil himself, was built around 1640 by an Indian mason and Ethiopian Builders and Craftsmen. Fasil progeny continued building castles, the last one being that of Empress Mentwab built in 1750 A.D. set as a walled enclosure of 900 meters in perimeter Fasil Ghibbi host a variety of buildings, including seven castles built by five kings and one queen (Mentwab) beside, there are smaller castle like structures, such as the Wosheba gimb (Sauna House) Shemanewoch Gimb (Weaver house) Duqet bet (Granary house) and Anbesa bet (Lions Cage) many of the latter and severely damaged. There are also three churches inside the imperial compounds. Twelve gates served as entrance to Fasil Ghibbi, while there were four overpass bridges that linked the compound to the outside. Overall, a period of some one hundred years of building castles, bridges, and other structures testifies to a Gondar era in Ethiopian history marked by relative prosperity and stability, and durable set of values by which the ruling dynasty abided.

Gondar also served as the capital of Ethiopia during the Gondar period (1636-1769) and is one of the most important historical cities in the country. Central Gondar still houses the castles of the Fasiladas Palace, which was constructed during the Gondar period, historical Ethiopian Orthodox churches, traditional circular houses, and buildings constructed by the Italians during their World War II-era occupation. This mix of history and culture creates a unique urban space that is unlike any other in Ethiopia. Today citizens of Gondar recognize the buildings as historically significant, and protection programs have been implemented. The Fasiladas Palace, for example, has been restored by UNESCO, in cooperation with various European countries, since becoming a registered UNESCO World Heritage site. Church members and local crafts people have also worked to protect historical Ethiopian Orthodox churches. However, no periodic historical preservation programs have yet targeted the historical buildings in Gondar.

Thus, many of these buildings in Central Gondar have been lost due to age or change in lifestyle. Land shortages have accelerated the destruction of these historic buildings. Rapid population expansion has increased the density of housing and residents in Gondar.

The development of the restoration materials and method should be based on an understanding of the performance requirements of the materials, taking into account, nature and current condition of the existing materials, functions of new materials and the degree of exposure of the Historical Heritages (ICOMOS 2003).

Mankind has used many types of binders throughout history: from mud in vernacular earthen architecture to current high performance cement. However, gypsum, clay and lime have been by far the most common and important binders in historical buildings. Their use expands several millennia and is represented in the architectural feats of all kind of civilizations. Lime based mortars have been also used in building construction for thousands of years.

In the 1800s, the development of natural and Portland cements provided architects and contractors a range of new properties with which to work (Tate March , 2005).

2.4 Mortar

By definition, a mortar is agglomerate composed of grain of sand joined together by a binder. It has a plastic consistency and is traditionally used as a building material (Ngoma, Characterisation and Consolidation of Historical Lime Mortars in Cultural Heritage Buildings November 2009). Mitchell, July 2007 also states that a mortar is a material in a plastic state which can be trowelled into place and sets insitu. It consists of;

- ✓ A binder (lime, Ordinary Portland Cement (OPC)
- ✓ An aggregate (sand or gravel)
- ✓ Water

2.4.1 History of Mortar

The most ancient mortar discovered to date is in Galilee, Israel near *Yiftah'el* and is reputed to be 10,000 years old (Mortar 2014). Mortars produced before the end of the 19th century, when the Portland cement first appeared in building constructions are also termed as historical or ancient mortars (Ngoma, Characterisation and Consolidation of Historical Lime Mortars in Cultural Heritage Buildings November 2009).

Mortars with different binder types have been used since ancient times for different applications; masonry mortars between bricks or stones, mortars as wall finishing materials internally (plaster) or externally (render), mortars as foundations for flooring, rubble mortars for the infillings of walls, mortars as casings of water conduits or jointing compounds from terracotta pipes, decoration mortars, etc. The compositional variation in historic mortars is surprisingly large with great differences both geographically and during different time periods. Mud, gypsum and lime had traditionally been the three most common binder types during the construction history of mankind until about two centuries ago, when their use was replaced gradually by different natural cement types and later by Portland cement, which is nowadays the dominant binder type in the construction industry. Mud is probably the oldest binder type in mortars (J.Elsen December, 2005).

Old time mortars were used in masonry construction not as glue, but as a seal or separator between the individual masonry units. The purpose of this gasket (just like in an automobile engine) was to absorb small amounts of movement yet keep the pieces together. It is important to note that, while the mortar and masonry unit are not fused together, there is a bond between them and this bond has helped masonry walls to resist expansion and contraction, wind shear, and seismic as well as gravity loads (Bates 2014).

2.4.2 Composition of Historical Mortar

The vast majority of historical mortars were prepared from the lime based binder, and silicate, carbonate or, dolomite sand. To improve workability, adhesion, strength and durability some additives such as, finely ground brick, volcanic pozzolana, hay and, horse, camel or goat hairs were added. Beyond main components of mortar (binder, aggregate and additives) in the structure of historical mortars exist other materials as well, which are characterized as inclusions, as they participate in small percentage. These materials are pieces of shells, charcoal particles, lime lumps and chips of wood or straw. These materials are met in structural mortars (which helps to crate bondage between the individual masonry unites) as well as in renderings and they are observed in different historical period (Ngoma, Characterisation and Consolidation of Historical Lime Mortars in Cultural Heritage Buildings November 2009). With the purpose of modifying and/or improving some of the properties of the mortars, traditionally they have been mixed (together with the basic components), with some different products or additional constituents. These products have evolved along the time. At the beginning the admixtures were composed of natural substances (blood, egg, fig juice, pig grease, manure, etc.). The current admixtures are generally industrial byproducts, like fly ashes or blast furnace slags , or other more elaborated products, like organic polymers, acrylic resins, epoxy resins, etc (ÇİZER July, 2004).

According to Alick & Hughes (2002), their role in the behavior of historical mortars as well as their origin is not always clear but Palomo et al. (2003); relate their presence with the intention of modifying and/or improving some of the properties of the historical mortars. Their systematic presence in different historical period indicates that their existence is neither accidental nor meaningless.

2.4.3 Types of Mortar

The most common difference between mortar types is the nature of the binder. This research will focus on lime, clay, Gypsum and cement. Various combinations of binder types, production methods and relative quantities affect the qualities and purpose of the mortar that is produced. This flexibility can be used to create mortars for specific situations (Mitchell July 2007). Mortar can be classified according to its particular function. Functional requirements of mortar can be configured in two categories. Those intended to protect the masonries against climatic or environmental actions (render and plaster), and those whose primary aim is to contribute to the structural stability of the masonry (joint bedding and re pointing). Mortar can also be classified according to the binder used; mortar made with lime based binder (lime mortar) and mortar made with cement based binder (cement mortar) (Ngoma, Characterisation and Consolidation of Historical Lime Mortars in Cultural Heritage Buildings November 2009).

The binder affects the physical and chemical properties of the mortar, its strength, how quickly it hardens or sets, and its reaction with surrounding materials (Mitchell July 2007).

2.4.3.1 Lime Mortar

The term lime refers both to calcium oxide (CaO) or quicklime, the product of the calcination of calcium carbonate (calcite or aragonite: $CaCO_3$), and to the compound obtained after the hydration of the oxide, i.e. calcium hydroxide ($Ca(OH)_2$), the mineral portlandite, also known as slaked lime or hydrated lime. This term also applies to the products of the hydration of Ca and Mg oxides formed after the calcinations of magnesium limestone and, in particular, dolomite ($CaMg(CO_3)_2$).

Calcitic lime is commonly known as fat lime, while dolomitic or magnesia limes are commonly called magre limes (C. Rodríguez-Navarro 2002).

It was discovered that when limestone was burnt and then combined with water, it produce a plastic material that would dry and then harden with age. The lime mortar used before the 20th century was simply an aggregate and a binder. The binder was lime, obtained by burning limestone or sea shells. The aggregate was sand or earth. As a binder in masonry construction, lime is generally considered inferior to Portland cement based mortars, though lime stone (calcium carbonate) is a raw material for both. (Bates 2014)

Lime mortar was used to lay brick work, building stone and to point roof tiles. The main ‘ingredients’ were lime and sand but additives such as eggs, casein, keratin (from boiled hooves), tallow, blood, bees wax or bitumen are used to increase water resistance. Crushed brick or tile was often added to mortar to improve setting times, and other additions might be used for their aesthetic qualities (Band 09/04/2004).

Lime may be weaker, take longer time to set, set in a different way, and require a higher level of skill or understanding to use properly, but it has distinct long term advantages. These include: greater compatibility with soft materials, good workability, increased initial adhesion, flexibility, greater porosity (breathability) and better weathering properties. The mortar lets moisture out as well as in. Cement mortars lock the moisture in so that the only way it can escape is through the brick or stone, deteriorating it in the process (Bates 2014).

Lime mortar is self-healing. Movement in masonry structures may result in large individual cracks where hard cement mortars are used, but lime mortar will develop multiple fine cracks. The lime mortar possesses a unique capability known as autogenously healing, the process whereby free lime in the mortar combines with water and CO_2 from the atmosphere and through carbonization it is transformed into calcium carbonate which seals the minute fissures that occur as the mortar flexes (Bates 2014).

2.4.3.1.1 History of Lime

The earliest archaeological evidence for lime burning is a kiln from Mesopotamia dating ca.2450 BC. Archaeological evidences show that lime was used in the construction of some of the floors and paving of the ruins excavated in Çatalhüyück (Turkey) , dated between 10000 and 5000 BC . These archaeological findings, along with the remains of 4500 years old lime kilns found in Khafaje, Mesopotamia, confirm that lime was a common building material in the Levant during the Neolithic. Lime mortar has been also used for flooring fishermen's huts excavated at Livinski Vir in Serbia - Montenegro dated at about 5600 BC. (J.Elsen December, 2005)

The Egyptians also used lime as a binder. Some coatings of lime in different pyramids have been dated ca. 4000 BC (Boynton 1980). However this is challenged by Lucas and Harris (1982) and Ghorab et al. (1986) who indicate that the Egyptians did not use lime in construction (they used gypsum) until Roman times. Other ancient civilizations, like India, China and the different cultures of pre Columbian America (e.g., Mayans and Aztecs) systematically used lime as a building material (C. Rodríguez-Navarro 2002).

The Greeks used the so called "Santorini earth", a tuff, as a pozzolanic additive mixed with lime for the manufacture of hydraulic lime mortars as those found in Thera (Santorini, Greece) . The Greeks also used a technique called "polishing" consisting in the application of coatings made of lime and crushed limestone mixed with pozzolana . The Romans used lime in construction since the last two centuries of the Republic. In addition to air lime, they routinely used lime mixed with either natural (pozzolana.) or artificial (brick powder) pozzolanic materials, thus obtaining the well-known composition of cementitous and the cocciopes as described by Vitruvius (30 BC) (C. Rodríguez-Navarro 2002).

Roman lime kilns have also found in Britain but in the post Roman period there is very little evidence for lime burning. Lime was used throughout the world by the ancient civilizations as a binding agent for brick and stone. The concept was brought to Britain in the first century AD by the Romans, who used the material to produce lime mortar.

Outside Britain, the Romans frequently mixed lime with volcanic ashes, such as pozzolana from Pozzuoli in Italy, to convert a non-hydraulic lime into hydraulic cement suitable for use in constructing aqueducts, baths and other buildings. However, in Britain, lime was usually mixed with artificial pozzolanas, for example crushed burnt clay products such as pottery, brick and tile. In the eighteenth century, a so called Roman cement was manufactured by the burning of cement stone (argillaceous or clayey limestone), collected from the coast around Sheppey and Essex (Lyons Third edition 2007).

After the fall of the Roman Empire, natural and artificial hydraulic limes, including Roman cement, together with traditional air lime were the most common binders in construction since Byzantine time, though the Middle ages, Renaissance and Baroque, until the discovery of Portland cement in the early 19th century by Aspdin (C. Rodríguez-Navarro 2002). Lime mortars were used until the middle of the 20th century. Portland cement was invented in 1824 but it was expensive and too strong for many building applications; cement based mortars didn't fully take over until after the Second World War with changes in building methods and materials. Lime was, and still is retained as a minor ingredient to improve workability (Band 09/04/2004).

2.4.3.1.2 Formation of Limestone

Limestone is a sedimentary rock composed mainly of calcium and magnesium carbonate. It is formed by the deposition either of the skeletons of small creatures and/or plants (organic lime stones), or by chemical precipitation, or by deposition of fragments of limestone rock, on the beds of seas and lakes. Limestones are contaminated to a greater or lesser extent by the deposition of sand or clay which is the source of the impurities found in them. Usually there is a difference in quality in a deposit from one layer to the next. The purest carbonates and the most suitable from the production point of view tend to be the thick bedded type. Carbonate deposits may be found in horizontal layers as deposited, or at an angle from the horizontal due to earth movements. They will vary in density, hardness and chemical purity (Spiropoulos 1985).

Since pure limestone is rarely found in nature, limestone always contains some impurities in small or large quantities such as magnesium oxide (MgO), silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3), sulphur and alkalies. Therefore, lime stones are generally classified according to the contents of the calcium carbonate and the impurities as high calcium lime stones, magnesium lime stones and dolomitic lime stones (Spiropoulos 1985).

Limestone's containing 90 % and more of calcium carbonate are called high calcium lime stones, the ones containing 10 % and more of magnesium carbonates are magnesium lime stones and those containing magnesium carbonate over 25 % are called dolomitic lime stones (ÇİZER July, 2004).

2.4.3.1.3 Production of Lime

The production of calcium oxide from limestone is one of the oldest chemical transformations produced by man. Its use predates recorded history. Most ancient languages have a word for calcium oxide. In Latin it is calx, from which the name of the element calcium is taken. In old English, its name is lim, which is the origin of the modern commercial name for calcium oxide, namely lime. The abundance of limestone in the Earth's crust and the ease of its transformation to calcium oxide do not alone explain why the lime is one of the oldest products of chemistry. Lime has many properties that make it quite valuable (Shakhashiri 2014).

Lime is manufactured by calcining natural calcium carbonate, typically hard rock carboniferous lime stone (Lyons Third edition 2007). The first step of lime production required finding a suitable raw material. This process involved, primarily, discovering calcium carbonate based stones (i.e. limestone or marble) or seashells. Quarrying techniques had become well advanced during construction of the great Egyptian pyramids and further advanced during the Roman building era. Ability to determine the types of stone containing an adequate amount of calcium carbonate involved trial and error, as well as ages of experimental attempts. Once workable quarries and materials were located, workmen acquired skills for identifying and extracting suitable calcium carbonate raw materials (Krumnacher February 5, 2001). The mineral is then quarried, crushed, ground, washed and screened to the required size range. The limestone is burnt at approximately 950°C in either horizontal rotary kilns or vertical shaft kilns which drive off the carbon dioxide to produce quicklime or lump lime (calcium oxide). Quick limes include calcium limes (CL) and dolomitic limes (DL), depending upon the composition of the starting mineral (Lyons Third edition 2007).

$$\underset{\text{Calcium Carbonates}}{CaCO_3} \xrightarrow{950\ ^0C} \underset{\text{Lime}}{CaO} + \underset{\text{Carbon Dioxide}}{CO_2} \quad \text{……………………(Equation 2.1)}$$

Limestone quarries are usually developed in a number of benches or lifts. For primary blasting of the limestone, holes are made by drills operated by compressed air. The excavated limestone is transferred for crushing and grinding. There are several types of crushing and grinding machines to produce limestone of sizes suitable for several designs of kilns (Kuenen 2009).

During the kiln operations the limestone reaches temperatures as high as 950 °C, and carbon dioxide is driven off limestone to leave so called quicklime. The quicklime descends through the cooling zone and is discharged at the base of the kiln. Obviously, various air pollutants are generated during combustion of fuels in the kiln. (Kuenen 2009)

2.4.3.1.4The Lime Cycle

According to (C. Rodríguez-Navarro 2002) the lime cycle consists of three stages (Figure 3):

- ✓ Calcinations;
- ✓ Hydration or slaking and
- ✓ Carbonation (or air setting).

Figure 3: The lime cycle: Electron microscopy images show reactant and products of the different stages of the cycle.

Description of each stage in this cycle is presented below.

Calcinations:-

Limestone is a naturally occurring mineral as such, its chemical composition and physical characteristics vary not only from area to area but within veins of limestone in the same area. This variation in raw material results in variation of quality of the end product. In order to convert the calcium carbonate raw material into lime, it is necessary to heat the mass of stone.

This practice dubbed calcining serve to derive out the water and carbon dioxide from within the stone. Calcining of carbonate stones takes place in kiln (Ngoma, Characterisation and Consolidation of Historical Lime Mortars in Cultural Heritage Buildings November 2009).

Figure 4: Calcining of carbonated stone in Uganda traditional vertical shaft kiln

The first stage of the lime cycle involves the calcinations of limestone at a sufficiently high temperature as to cause the decomposition of calcite according to the reaction:

$CaCO_3 \longrightarrow CaO + CO_2$ ……………………………………………..Equation 2.2)

This reaction is strongly endothermic, so the production of calcium oxide requires high energy consumption and the use of suitable kilns. Traditional lime kilns involved the firing of wood or coal along with limestone blocks, resulting in lime mortars with a high content of ash. Kilns used since the industrial revolution placed the fuel and the limestone in separate compartments. Thus, the resulting limes do not present any ashes and have homogeneous characteristics, something difficult to achieve through the use of traditional kilns (C. Rodríguez-Navarro 2002).

The temperature of dissociation of $CaCO_3$ is 898°C at pCO_2 = 1 atm. This temperature is reduced the lower the pCO_2 is, and increases as pCO_2 increases (Boynton 1980). CO_2 released by carbonate decomposition (plus CO_2 generated by the combustion of wood or coal in traditional kilns) must be evacuated to avoid the re-carbonation of CaO, or to hinder carbonate de-carbonation.

The presence of other gases, e.g. water vapor released during the combustion of wood in traditional lime kilns, may speed up the decomposition process and reduce calcinations temperature (D. V. Beruto 2003). The characteristics of the oxide product are strongly dependent on temperature and duration of the calcinations process (Boynton 1980).

CaO crystals formed a low temperature, and/or after a relatively short period of calcinations, are nano sized, show a very porous structure and are highly reactive.

An adequate knowledge of the mechanism of $CaCO_3$ calcination is crucial to optimize this process and to obtain oxides with desired properties. Despite many studies, there is no consensus on how such a reaction occurs (Ngoma, Characterisation and Consolidation of Historical Lime Mortars in Cultural Heritage Buildings November 2009).

Hydration or Slaking:-

Quicklime needs to be slaked or hydrated in order to yield workable lime. Hydration involves the introduction of water or moisture to activate the quicklime, having been deprived of water and carbon dioxide following calcining. When exposed to water, regardless of form, liquid, steam, vapour, or ice, quicklime exhibits a strong affinity for moisture, adsorbing it into its pores. As the water penetrates into the surface pores, heat of hydration is triggered (Ngoma, Characterisation and Consolidation of Historical Lime Mortars in Cultural Heritage Buildings November 2009).

Alternatively, it can be made by stirring hydrated lime into water, followed by conditioning for at least 24 hours. However, the traditional direct slaking of quicklime produces finer particle sizes in the slurry; the best lime putty is produced by maturing it for at least six months (Lyons Third edition 2007).

$$CaO + H_2O \longrightarrow Ca(OH)_2 + Heat$$ ……………………………………..(Equation 2.3)

The above reaction is highly exothermic. Thus, safety precautions have to be taken during traditional lime slaking, both due to possible burns and to the corrosive effect of splashes (pH 12.4). If the hydration occurs with the stoichiometric amount of water, a dry powdered precipitate is formed.

In the case of lime putties, there is a range of phenomena that occur after slaking if the paste is kept underwater during long periods of time (months or years). This is the so-called “ageing”, which was used since Roman times to improve the properties of slaked lime. Pliny indicates that there was a law in ancient Rome which established that lime putties should be "aged" for at least three years prior to their application (C. Rodríguez-Navarro 2002).

This tradition, based on empirical observations, has survived to our day. However, until relatively recently, there were doubts about whether or not ageing produced any improvement in the properties of lime paste, and if this was the case, it was not known which was the cause and/or mechanism of such improvement. (C. H. Rodríguez-Navarro 1998), also showed that after ageing of lime pastes for 2 to 10 months, there were a reduction in the size of portlandite crystals and an increase in their surface area.

However, (Ruiz-Agudo 2010) indicates that depending on the characteristics of the oxide (hard vs. soft burnt lime), the rheological evolution of slaked lime putties was different, although in all studied cases a general improvement was observed after long periods (several months) of ageing.

McKee outlines the basic procedures involving the slaking of quicklime as follows:

Before making mortar, quicklime was slaked (more correctly, hydrated) by the controlled addition of water. One of the three methods was followed: (1) sprinkling or “drowning”; ideally, water equal in weight to 1/3 of the quicklime was sprinkled over it.

Heat was given off, the material cracked open and became a powder, and increased in volume. This method was considered the best. (2) Immersion: the quicklime, placed in a basket, was lowered into the water for the proper length of time, and drawn up to complete the slaking. The handling was tricky, at best, and demanded considerable skill. (3) air-slaking: the quicklime was simply left exposed, to pick up moisture from the air. Most authorities agreed that this method was not recommended. Lime from different sources varied in its capacity to take up water in slaking. Some called fat, took up ½ of their volume, and produced a dry powder 3 ½ times the volume of the original quicklime.

Others called “meager”, might take up only 1/3 their volume of water and produce a dry powder only a little greater than the original volume. Masons preferred the fat limes, although in reality they were no better, and might not even be so good. The fat limes did produce a larger quantity of mortar, from a given quantity of quicklime, than the others (Mckee 1971).

Carbonation (or air setting):-

Lime hardens by the absorption of carbon dioxide from the air, which gradually reconverts the calcium oxide back to calcium carbonate (Lyons Third edition 2007).

$$CaO + CO_2 \xrightarrow{Slow} CaCO_3$$

Lime ***Carbon Dioxide*** ***Calcium Carbonate*** …………………………..(Equation 2.4)

The carbonation process is slow, being controlled by the diffusion of carbon dioxide into the bulk of the material. When sand or stone dust aggregate is added to the lime putty to form a mortar or render, the increased porosity allows greater access of carbon dioxide and a speedier carbonation process. The maximum size of aggregate mixed into lime mortars should not exceed half the mortar joint width. Typical lime mortar mixes are within the range 1: 2½ and 1: 3, lime putty: aggregate ratio. Because of the slow carbonation process, masonry lifts are limited, and the mortar must be allowed some setting time to prevent its expulsion from the joints (Lyons Third edition 2007).

The setting of air lime mortars and plasters begins with an initial period of drying and shrinkage and is followed by the carbonation reaction. The reaction interface advances through the porous system from the surface towards the unreacted core. This process consists of several steps:

- ✓ Diffusion of CO_2 (gas) through the open pores,
- ✓ Dissolution of $Ca(OH)_2$ in the pore water,
- ✓ Absorption and dissolution of CO_2 in the alkaline pore water forming carbonic acid H_2CO_3;
- ✓ Its immediate dissociation into bicarbonate and carbonate ions,
- ✓ Reaction between Ca^{2+} and CO_3^{2-} ions forming $CaCO_3$ through nucleation and growth.

All these processes are interrelated and altering the kinetics of one process influences the others (C. Rodríguez-Navarro 2002).

The volume, geometry and size of the pores, as well as the water content, play an important role in the progress of carbonation. This is primarily due to the fact that water largely controls the rate of CO_2 diffusion, which along with CO_2 dissolution (forming carbonic acid) is a rate determining step for carbonation. As water evaporates during drying, an effect which is promoted by the exothermic nature of carbonation (Moorehead 1986) and the less hydrophilic character of newly formed $CaCO_3$ if compared with Ca $(OH)_2$ (D. a. Beruto 2000), pores tend to stay open. This accelerates CO_2 diffusion towards the interior of the material which is carbonating.

The textural characteristics of $CaCO_3$, as well as the cementing structure formed after carbonation, appear to depend on the properties and characteristics of precursor portlandite crystals and on the conditions of carbonation (i.e., water content, T and RH, pCO_2, pH, and ionic activity). There are studies on the effects of the size, surface area, and habit of portlandite crystal on the kinetics of carbonation. In general, the smaller the portlandite crystals are, the higher their reactivity during carbonation is (Van Balen 2005). In turn, the textural features of the portlandite precursor and the kinetics of carbonation determine the physical and mechanical properties of lime based materials (Cizer 2012).

For instance, mortars prepared with aged lime putties show faster carbonation and a higher mechanical strength than mortars prepared with fresh lime putties or with dry hydrate (Cazalla 2000). (C. Rodríguez-Navarro 2002) Show that mortars prepared using aged lime putty (16 years old) display a carbonated structure which resembles Liesegang patterns, which is also observed in historical buildings (Figure 8). The authors linked the formation of the Liesegang pattern with the micro textural characteristics of aged portlandite crystals

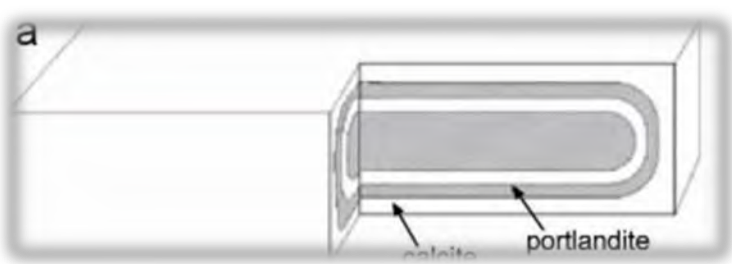


Figure 5: Scheme of a mortar prism

Figure 6: Section of the prism after 1 year carbonation following phenolphthalein impregnation. The red rings correspond to uncarbonated parts, while the whiter rings are fully carbonated (from Rodríguez-Navarro et al., 2002).

Figure 7: Example of Liesegang pattern following differentia weathering in lime plasters in a historical building (Saint Maria Church, Utrera, Spain) (from Hansen et al., 2008).

2.4.3.1.5 Properties of Natural Lime Mortar

Building limes, both air limes and natural hydraulic limes, have certain qualities that make them perfectly suited for use on traditionally constructed masonry or timber buildings (Torney February 2014):

Vapour Permeability:

The relatively high vapour permeability of lime allows moisture to move through it. The absorption and evaporation of moisture from the material helps regulate humidity within a building and diffuse penetrating water, subsequently protecting the structure from moisture associated damage (Torney February 2014).

Vapour permeability of lime generally decreases as compressive strength increases, although this may be altered using additives (Torney February 2014).

Flexibility

The 'flexible' nature of lime enables it to absorb minor structural movement associated with the expansion and contraction stresses that a building undergoes due to changes in temperature and humidity. This means it is less vulnerable to crazing and cracking than are many cement based products. Flexibility typically decreases as compressive strength increases (Torney February 2014).

Environmentally Friendly

Lime contains no volatile organic compounds, petrochemicals, lead or other contaminants (unless included as additives to modify the material properties). Lime based products allow water vapour to be dissipated, preventing the buildup of condensation. In addition, the alkalinity of lime helps to inhibit the growth of mould and other pathogens. These factors contribute to a healthier internal environment (Torney February 2014).

Aesthetically Pleasing

Lime finishes complement the appearance and visual qualities of natural stone and brick. Lime finishes show up slight variations in texture and color. Due to the light scattering properties of the calcium carbonate crystals in lime, it has a surface luster which is pleasing to the eye. In contrast, cement based finishes tend to appear flat and dull (Torney February 2014).

Compatibility Criteria

It is the physical properties and associated performance characteristics of lime mortars that dictate their compatibility with traditional building materials. When used together with stone, brick and timber and specified correctly, lime mortars act sacrificially to prevent the adjacent material from deteriorating (Torney February 2014).

The relatively high vapour permeability of lime enables the diffusion of moisture through it; it allows the building to 'breathe'. Inappropriate repair of historic structures using less vapour permeable materials, such as cement based products, can inhibit the movement of moisture through a building resulting in problems such as internal damp, rotting timbers and exterior deterioration of masonry.

2.4.3.2 Clay Mortar

Clays are the main binders of earth and are made up of very small mineral particles (<2 microns), leached out during erosion of rock. The molecular structure of clays consists of sheets of silicate and aluminates ions. Electrostatic forces set up within such structures produce binding properties (practicalaction.org n.d.).

Clay mortar solidifies through drying rather than setting (as is the case with cement or hydraulic limes) and this therefore takes a longer period of time. After application clay mortar should be protected from rain. Equally, in very dry conditions it may be necessary to put damp hessian over the work to avoid too rapid drying (Jenkins 2011).

Clays have also a variety of uses, especially for ceramics, but it is their use as binding materials in the unfired state; although they have the limitation that they soften when wetted, they are also undoubtedly the cheapest binders, with very low energy consumption, and are deeply embedded in traditional building cultures in many parts of the world (practicalaction.org n.d.).

2.4.3.2.1 History of Clay

Clay is one of the oldest, most sustainable and healthiest building materials on earth. Its history goes back to pre-history and has been used by indigenous peoples for millennia all across the globe.

Throughout history clay has been the most widely used binder in the world, not just for vernacular building but also for castles, public and religious buildings, and monuments such as from the 35 meter high minaret of *Tarim* in Yemen ,the thousands of kilometers long great wall of China, the walls of Jericho, The Ziggurats of ancient Babylon, the Coliseum, the Minarets of Islam to sophisticated modern structures the world over clay has been and continues to be the building material of choice for much of the world's population (practicalaction.org n.d.).

As recently as 100 years ago, building with clay and clay components was one of the most broadly used construction techniques in Central Europe and the American Southwest. And today clay remains the major construction material in many countries in Asia, Africa and South America.

The world's earthen architectural heritage is rich and diverse, with a wide variety of techniques providing a fabulous wealth of know how in an extremely wide range of natural, historic, cultural and socio-economic environments. There is hardly an inhabited country which has not developed a tradition in earth, and all the great civilizations in the past built with it (practicalaction.org n.d.).

2.4.3.2.2 Formation of Clay

Clay is a kind of sedimentary rock, granulated (not compact), cloddy, included in the phyllosilicate group, with a microscopic laminar structure (H.Auch-Schwelk 2013).

It is fundamentally composed by clay minerals, so by hydrated aluminum silicates. Their generic formula is: Al_2O_3 .mSiO_2 .nH_2O. (On 0.3>m>8 y 0.5> n >19)

The chemical composition and the laminar structure are the basis of its most important properties. Clay minerals (phyllosilicate group) are formed by SiO_4 tetrahedrons joined by their vertexes, forming layers. They can be linked with cations forming charged layers, and those can be joined by water molecules (H.Auch-Schwelk 2013).

Clay minerals can be classified in Clay minerals of two sheets and Clay minerals of three sheets (H.Auch-Schwelk 2013):

I. <u>Clay minerals of two sheets</u>:

A. KAOLINITE Al_2O_3 . 2 SiO_2 . 2 H_2O (Kaolin)

- White color.
- White porcelain (china) is made with it.
- Soft Pearl shine, Greasy touch.
- Plastics.

Figure 8: Kaolinite

II. Clay minerals of three sheets:

B. MONTMORILLONITES

- Grey or green color.
- Soft, Greasy touch.
- Low plasticity.
- Great water absorption, with high increases of volume.

Figure 9: Montmorillonites

C. ILITES

- The majority group.
- Raw material of the most commonly ceramic materials used in construction.
- Good water absorption capacity.
- Good plasticity.

2.4.3.3 Gypsum ($CaSO_4$)

Gypsum is a naturally occurring mineral that is made up of calcium sulfate and water ($CaSO_4+2H_2O$) that is sometimes called hydrous calcium sulfate. It is the mineral calcium sulfate with two water molecules attached. By weight it is 79% calcium sulfate and 21% water. Gypsum has 23% calcium and 18% sulfur and its solubility is 150 times that of limestone, hence it is a natural source of plant nutrients. Gypsum naturally occurs in sedimentary deposits from ancient sea beds. Gypsum is mined and made into many products like drywall used in construction, agriculture and industry. It is also a by-product of many industrial processes (www.natureswayresources.com).

Gypsum is also used as a generic name for many types of sheet products made of a non-combustible core with a paper surfacing that adds strength. These include drywall, ceiling tiles, partitions, etc. whose strength is directly related to its thickness and a few trace materials.

Gypsum is a rock that, like limestone, occurs naturally in many parts of the world. And, like limestone, in an absolutely pure form, it is white. However, the usual presence of darker impurities produces rock in varying shades of gray, brown, and even black. Since it normally is found close to the surface, gypsum can be mined or quarried easily. According to (Wallace, 1995) the hero who first discovered the peculiar property that makes gypsum so valuable remains unsung. But mankind owes him a huge debt. Because gypsum can be ground up and “boiled” or calcined at a comparatively low temperature until three quarters of its moisture content has evaporated. When that happens, the rock becomes a fine powder, commonly known as plaster of Paris. Our unknown friend discovered that, by returning the water to the powder, he could make a mortar or pliable mass that could be formed into any shape and hardened. When this great secret of nature became common gossip, it didn’t take long for man’s ingenuity to put it to work. How well it has served us through the centuries is apparent from a listing of a few of the ways in which gypsum is seen during an average day.

2.5 Traditional Lime Production Process in Ethiopia: Case study in Ambo, Senkale

Ambo (also known as Hagere Hiwot) is a spa town and separate *woreda* in central Ethiopia. Located in the West Shewa Zone of the Oromia Region, west of Addis Ababa, this town has a latitude and longitude of 8°59′N 37°51′E and an elevation of 2101 meters (Wikimedia, 2015).

There is a long history of production and use of lime in Ethiopia specifically in Ambo, Senkale since the Italian colonialism. Its main use has been as a cementing agent and as a decorative whitewash in the building industry. In recent years the demand for lime has increased. It is now also used for water treatment, in the sugar industry, for agricultural purposes and in other miscellaneous applications such as road stabilization. However, traditional methods of lime production are still very much in evidence and few attempts have been made to improve upon these methods, for example by improving the kiln design and the process of production.

The overall production process of lime involves quarrying, crushing and screening of limestone and the burning of the sized stone in kilns of which there are several types.

2.5.1 Lime Production Process

2.5.1.1 Raw Materials and Quarrying Techniques

The quarrying of limestone has been practiced since the earliest days and we have evidence of the methods used for the recapture of large blocks of stone from the selected quarry sites which is located in the west outreach of Ambo City for different construction purpose.

As it is shown in the (figure 11) they drill holes with sophisticated tools, break the stone away with powerful explosives and remove it in large capacity transport vehicles.

Figure 10: Quarry Site Near to the Plant

A method still used today for cutting and transporting limestone ornamental purposes. For ornamental purposes it is necessary that the stone should not be subjected to shock or strain that might cause cracks to develop.

2.5.1.2 Crushing and Screening

Crushing and screening plants to prepare the limestone for either burning or direct shipment are provided, primary crushers being designed to receive the size of stone loaded by the loader on the production site.

2.5.1.3 Lime burning

From a chemical point of view the lime burning process is, of course, fairly elementary. The reaction $CaCO_3 = CaO + CO_2$, which denotes the driving off of carbon dioxide from a carbonate rock by the application of heat to produce calcium oxide (commonly known as unslaked lime or quicklime) is probably one of the most fundamental of all chemical reactions.

The conditions occurring inside lime kilns further complicate the process. Lime burning depends on heat transfer from burning fuel and combustion gases to solids. Too high or too low temperature or too long or too short retention period adversely affect the quality of the lime. Design for optimum utilization of heat is of great importance as fuel is the largest single factor in the cost of producing lime.

In Senkale Lime production Factory the source of energy is Furness fuel and the calcination process will takes three days in the kin but they don't have a noted data to know the exact burring time and temperature.(See the Figure below)

Figure 11: Limestone burning kin (Ambo Senkale Lime Factory)

However, because limestone contains a number of other constituents and no two are similar in physical or chemical characteristics and because we are dealing with a practical situation where large tonnages must be treated, there are many complexities in the process.

In recent years lime producers have experienced very great difficulties in obtaining suitable fuel for burning in their kilns. The state has imposed a series of rules and regulations on the importing of fuel due to the increasing rate of fuel consumption. The scarcity of fuel and calcareous raw materials (coral and shell) has resulted in considerable increases in the price of lime.

2.5.1.4 Hydration

A further process in lime manufacture is the hydration or slaking of lime with water to produce calcium hydroxide ($CaO + H_2O = Ca(OH)_2$) which is commonly termed hydrated lime or slaked lime. Technically the terms hydration' and 'slaking' are synonymous but based on popular connotation hydration involves adding only enough water to yield a dry powder whereas slaking involves the use of excess water to yield a putty, slurry, or milk of lime.

Two of the most widely used of these machines today are the Knibbs and the Kritzer hydrators. The former consists of a single large vessel in which the lime and water are mixed by means of revolving paddles. The Kritzer type is used in the hydration process of Senkale Lime Factory.

In order to remove the grit impurities and if necessary to classify the hydrated lime into different size fractions, the product is then treated in an air-separation system of which there are various types. In a finished hydrated lime the particles are normally all minus 200 meshes but a super refined quality containing all minus 375 meshes can be separated for special purposes. As it is shown in the figure below the remaining anhydrates limestone impurities will be discharged.

Hydrated lime is normally packed in paper bags for transportation to the customer although bulk tank cars are used for some of the larger consumers. (See figure 13)

Figure 12: Finished product of Lime

Chapter Three

3. Characterization of Historical Mortar in Fasil Ghibbi Palace

A mortar is a material resulting of the intimate mixture of sand grains, a binder (lime, cement, etc.) and water. The properties and characteristic of the mortars mainly depend on the nature of the binder component. That is the reason for which, its evolution with time has been much related to the development of artificial cementitous materials. So, with the consolidation of the Roman civilization the use of lime mortars was generalized and extended. Since the XVIIIth century, hydraulic binders begun to partially replace the lime. These new materials hardened more quickly and developed higher mechanical strengths. In the XIXth century, the invention of Portland cement revolutionized the world of building materials, completely displacing the use of lime in all type of civil and military constructions (A. Palomo n.d.).

In older masonry structures, the mortar properties need to be compatible with the existing mortars and be “sacrificial” to the masonry during any kind of intervention. Inappropriate re-pointing materials and execution practices can result in permanent damage to older masonry assemblies, affecting their aesthetic qualities, historical value, performance, and service life.

In this research work the attention will be focused on identifying the binding material which was used during the construction of the Gondar Royal Palace and the binding material which is currently used for the restoration activity.

3.1 Selecting Appropriate Technique for Analysis

With the availability of a variety of atomic spectroscopy techniques, laboratory managers must decide which of these is best suited to their particular analytical requirements. Unfortunately, because the techniques complement each other so well, it may not always be clear that, which the optimum solution for a particular application is.

Selecting appropriate technique requires considering important criteria, including:

- ✓ Detection limits
- ✓ Analytical working range
- ✓ Data quality

- ✓ Cost
- ✓ Interferences
- ✓ Ease of use
- ✓ Availability of proven methodology

By taking in to consideration the above listed criteria; ancient mortars from the Royal Palace and Mortar which is used for the restoration purpose were characterized by optical microscopy, scanning electron microscopy, AAS (Atomic Absorption Spectrometry), and Gravimetric, HF- Attack, $LIBO_2$ Fusion and Mineralogical analyses. The analysis is carried out in Geological Survey of Ethiopia, Central Geological Laboratory, Addis Ababa, Ethiopia.

3.2 Sampling

As (Ngoma, Characterisation and Consolidation of Historical Lime Mortars in Cultural Heritage Buildings November 2009) quoted from Hughes and Callebaut, 1999; Sampling is a crucial part of the practical, analytical procedure that is applied in all forms of historical binding materials investigations. Sampling takes place through stages which include:

1. Establishment and clarification of the objectives of an investigation
2. Visual analysis and documentation of the entire structures and then its materials including, building phases, decay form and mechanisms
3. Formation of hypotheses that require testing by sampling and further analysis of materials
4. Choice of analytical method for analyzing the materials
5. Sampling with associated information recording

3.2.1 Establishment and Clarification of the Objective

Characterization of historical binding materials in a historical building or monument is carried out broadly for two reasons:

1. Conservation and repair related investigations, aimed at the determination of the cause of evident problems in the deterioration of a historical structures and/or the

characterization of existing materials in order to allow the practical selection of replacement materials.

2. Academic studies, looking to clarify the architectural, chemical and physical performance of historic mortars for the long term development of replacement materials or the archaeological study of building technology and its associated social implications.

In both approaches, binding materials can be studied using a range of investigative techniques selected depending upon the information sought. The clarification of objectives relating to damage diagnosis or academic study, ties in closely with detailed knowledge of the entire structure and its materials.

3.2.2 Visual Analysis and Documentation

The first analysis to be carried out is the visual study and documentation of the entire structure, with the focus falling secondly on the details of the materials. In the onsite inspection, details of materials used and the methods and date of construction should be obtained from the historical documents (Ngoma, Characterisation and Consolidation of Historical Lime Mortars in Cultural Heritage Buildings November 2009). But in the case of “Fasil Castle Palace” the details of binding materials used at the time of construction has not been identified. Study of similar structures or other structures in the local area constructed of similar materials can be helpful in providing case study evidence, particularly, if these other structures vary in age from the one under investigation. Account must also be taken of climatic and other external environment factors at the location, since factors such as relative humidity may be of considerable importance when assessing the causes of deterioration. An assessment may also need to be made of the particular environment conditions to which each part of the structure has been exposed. In particular, the wetting and drying frequency and temperature variation, that an element is subjected too, should be recorded because these factors influence various mechanisms of deterioration (Ngoma, Characterisation and Consolidation of Historical Lime Mortars in Cultural Heritage Buildings November 2009).

In theory, samples should be taken from the most representative area, but, due to the minimum invasiveness requested, they are generally collected from pre-existing cracks, lacunas or edges.

However, carefully paying attention to the conditions in which they have been collected, these samples can give interesting information which can be validated by further analyses.

As mentioned above, the accuracy of the investigation depends not only from a representative sampling but also from an adequate preparation of the sample for the analysis (Michelle 2009).

Once a profound visual analysis and documentation are executed, one knows the diversity of the materials present, the degree and mechanisms of damage and based on the information obtained, hypotheses about decay mechanisms and materials compositions that require testing by sampling and further analysis of materials can be formed.

3.2.3 Formation of Hypotheses

Based on the information obtained from visual analysis and documentation, hypothesis about binding materials composition and decay mechanisms, which required testing by sampling and further analysis of binding materials were formulated. According to (Hughes & Callebaut, 1999) this approach aims to reduce cost and effort, but is also fully consistent with mainstream conservation philosophies of minimum intervention and damage to historical buildings. Therefore, following hypotheses were formulated about binding materials composition and decay mechanisms:

1. Binding materials of the superstructure walls system of the historical buildings in ‘Royal Palace’ castle is made with lime mixed with sand and/or special type of soil.
2. Binding materials composition is a major factor that influences the deterioration of binding materials of the superstructure wall system of the historical buildings in ‘Royal Palace’.

3.2.4 Choice of Analytical Method

Hypotheses are tested by analyses of the materials. As yet, no standard analytical procedure exists to characterize historical mortars, different approaches and analytical techniques are recommended. The analytical procedure used for characterization of historical mortars is based on Van Balen et al. (1999) proposed approach, which combines several analytical methods currently employed for characterization of historical lime mortars. (Figure 14)

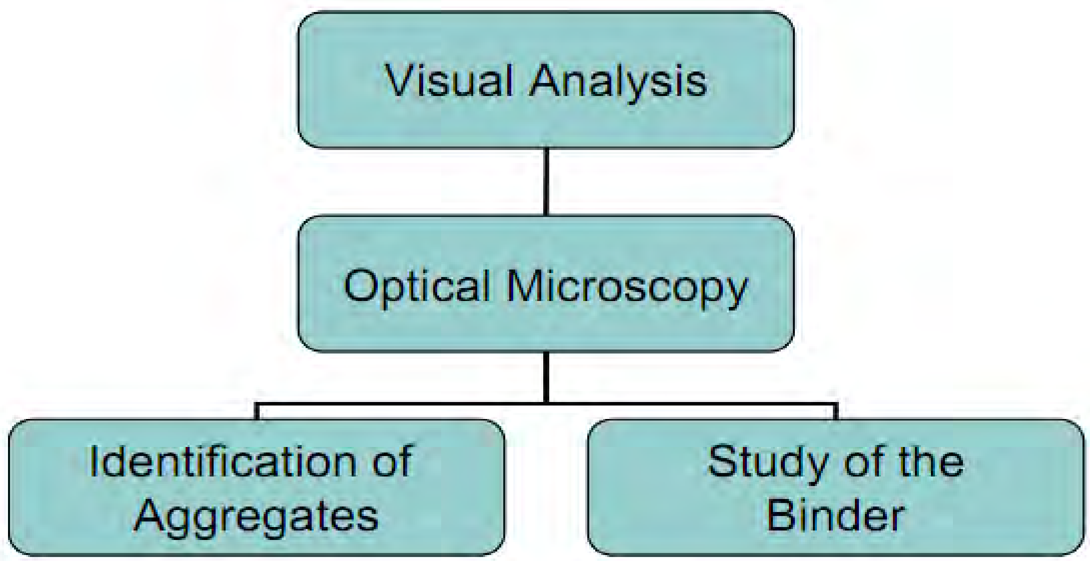


Figure 13: Analytical Procedure; Van Balen et al. (1999)

3.2.5 Sampling with Associated Information Recording

Appropriate sampling of historical binding materials can be very difficult due to culturally precious nature of the materials. However, it is always necessary to collect samples for analysis, which will be representative of the material under investigation and also provide enough material for all the laboratory tests analysis.

Therefore, binding materials' samples specimens were taken from sections of interior walls of the buildings in accordance with obtained permit from the Royal Palace Administration and tested in the laboratories at the Geological Survey of Ethiopia, Central Geological Laboratory for chemical analysis properties respectively. The Sample specimens were taken from the walls by using a hand cutting tool but since it's not in a harden state the sample specimens from the restoration site where taken simply by hand. The aim of sampling was to get a complete representation of mortar variations regarding materials composition and physical condition from different ages. As such, sampling was performed considering the different construction periods and physical conditions.

<u>Description and pictures of the samples collected:</u>

Description: Internal Wall

Weight (gm.): 9.95

Sample Label: G_1

Picture:

Figure 14: Sample taken from the internal wall

Description: Restoration Site

Weight (gm.): 10

Sample Label: R_2

Picture:

Figure 15: Sample taken from the restoration site

- G_1 represent for sample which is taken from the internal wall of the palace, R_1 represent sample which is taken from the restoration sites.
- Samples are processed using different characterization method and analyzed individually.

3.3 Experimental and Procedural Conditions

By considering the nature of two samples; It was decided the type of specific laboratory test for sample characterization. Therefore the analytical method used for characterizing the binding material which is taken from the original palace internal face of the wall were done by using the General Silicate Analysis, it includes: $LIBO_2$ FUSION, HF Attack, Gravimetric and AAS.

The type of elements that will be determined after the General Silicate Analysis is Major Oxides and Minor Oxides.

The analytical method used for characterizing the binding material which is taken from the restoration site, which is found inside the royal palace were done by using Mineralogical Analysis.

The First step is assigning unique identification for the unknown sample and then weighing the mass whether it is enough for sample extraction process or not, the general steps is summarized in a chart below.

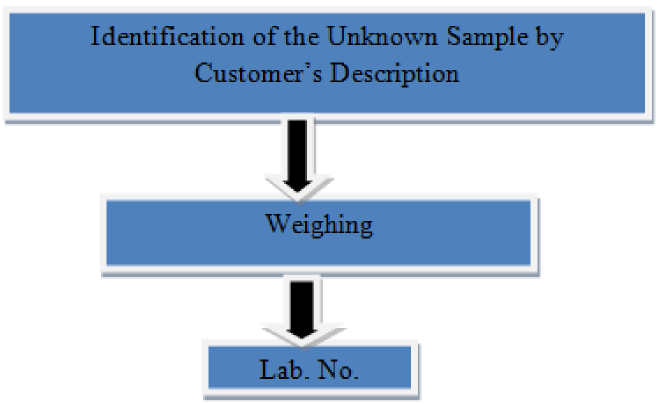


Figure 16: General Procedure for Silicate Analysis

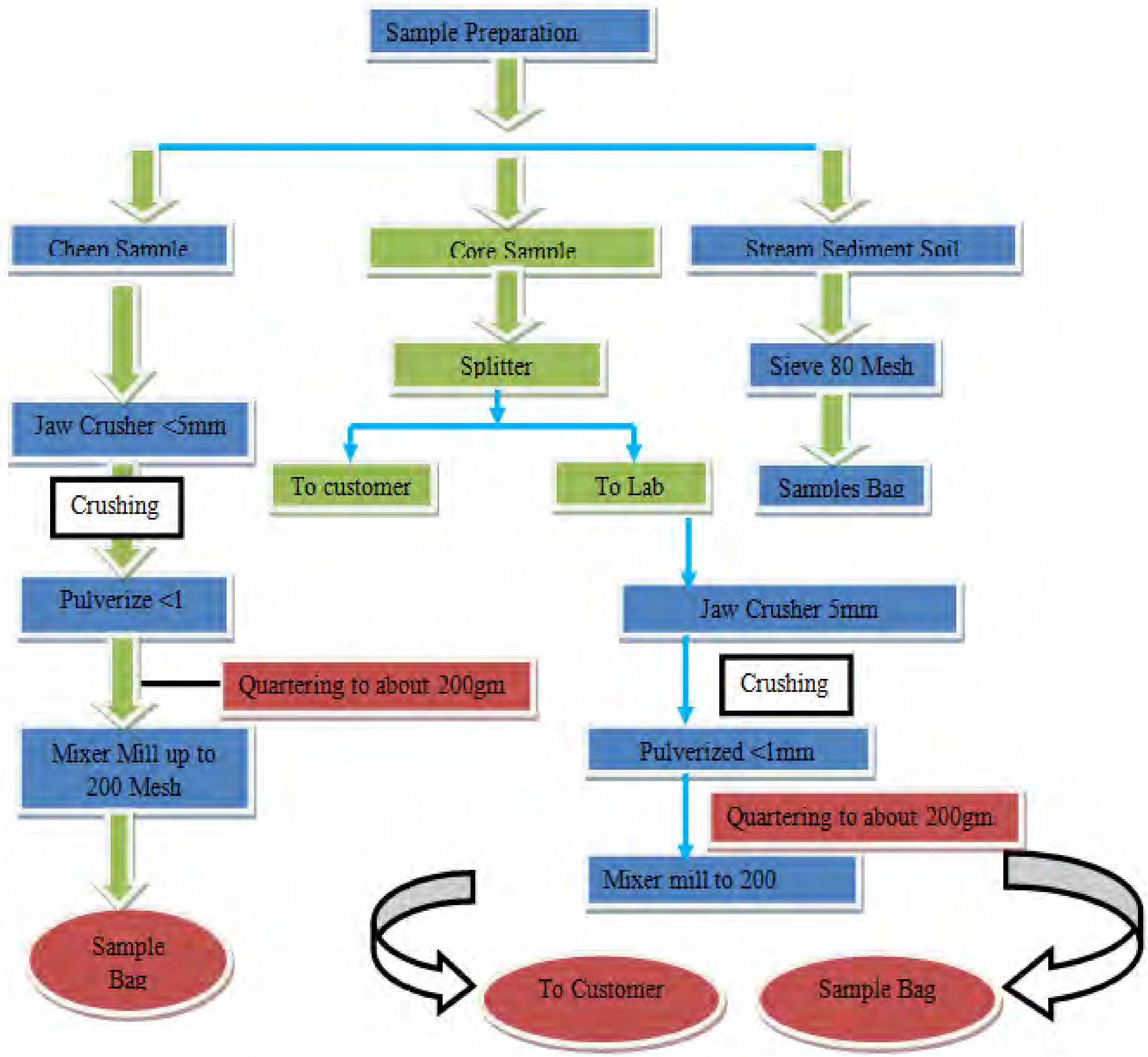


Figure 17: Sample Preparation Procedure for Silicate Analysis (Ethiopian Geological Survey Laboratory Manual 1995)

According to the Ethiopian Geological Survey Laboratory Manual, 1995 The General Silicate Analysis Sample Preparation Procedure are Listed Below:

1. Crashing sample stone, using Jaw crusher and allowing passing with 5-10 mm sieve diameter.
2. Crashing sample stone, using small Jaw crusher and allowing passing with 1-5 mm sieve diameter.
3. Try to reduce the rock sample by Quartering.
4. Select a representative sample by Quartering.
5. For proper chemical analysis; reducing stone samples up to 75micro (200 mesh) using Girl mill is required.
6. Taking the sample for specific chemical analysis.
7. Finally in order to avoid contamination it is better to use air compressor and wire brush for cleaning the sieves and pan.

Heavy Mineral Concentrate Sample Preparation Procedure:

Introduction:

Soil or stream sediments samples of about 15Kg have been panned in the field up to a black ore gray concentrate. The concentrates are handed in to the mineralogical laboratory.

For farther processing according the following steps:-

1. **Weighing and quartering**: Is the first step to know the initial amount of the sample and to take the required sample from the given one. If the sample is required for Gold no need of quartering.
2. **Sieving**: At this step the sample is separated into over size and under size with 1mm opening brass sieve.
3. **Hand magnet separation**: By using bar magnet (permanent magnet) separate the Ferro magnetic minerals of over size and under size none magnetic fractions. Ferro magnetic minerals such as magnetite, pyrrohtite are removed from each fraction.

4. **Heavy Liquid Separation**: The non-Ferro magnetic under size fraction is separate according to the specific gravity into a heavy fraction and light fraction. For this separation a heavy Liquid Bromoform is the halogenated organic liquid which has specific gravity of 2.9 and methylene iodide with specific gravity of 3.3 are used to separate heavy minerals from common rock forming minerals, usually on sized fraction of the rock or sediments.
5. **Electromagnetic Separation**: In this step process is under take that sample which has separated by heavy liquid called Heavy Fraction using Frantz Iso-dynamic separator split up according to the electromagnetic properties of the minerals in to 5 electromagnetic fractions:

- Very Strong Magnetic at 1.5 amp
- Strong Magnetic at 2.0 amp
- Medium Magnetic at 3.0 amp
- Weak magnetic at 3.0 amp
- None magnetic at 3.0 amp

After this separation the operator (technician) must weight each fraction of Electro-Magnetic Separation.

Chapter Four

4. Experimental Results and Discussions

4.1 Analytical Results for the Original Binding Material

4.1.1 Silicon Dioxide (SiO_2)

Silicon dioxide or silica, as it is commonly known as, is an important constituent of sand. However, it is found in several other forms too.

Silicon dioxide is found in nature in mainly two forms: crystalline and amorphous. Silica is also a constituent of gemstones, and traces of the compound have also been found in volcanic rocks. It is the most abundant compound of silicon found on the earth's crust, and one of the most commonly found oxides. Silica in pure sand is the amorphous form, while quartz is an example of crystalline silica (www.buzzle.com 2015).

From the total mineralogical composition of the binding material, which is extracted from the original wall of the Royal palace; Silicon dioxide (SiO_2) cover 35.46% from the total mineralogical composition.

4.1.2 Aluminum oxide (Al_2O_3)

Aluminum oxide is a chemical compound of aluminum and oxygen with the chemical formula Al_2O_3. It is the most commonly occurring of several aluminum oxides, and specifically identified as aluminum (III) oxide. It is commonly called alumina, and may also be called aloxide, aloxite, or alundum depending on particular forms or applications. It commonly occurs in its crystalline polymorphic phase α-Al_2O_3, in which it composes the mineral corundum, varieties of which form the precious gemstones ruby and sapphire (Wikimedia Foundation, http://en.wikipedia.org/wiki/Aluminium_oxide 2015).

The earliest cementitious materials were made from lime and pozzolana (a volcanic ash containing significant quantities of SiO_2 and Al_2O_3) mixed with ground brick and water.

From the total mineralogical composition of the binding material, which is extracted from the original wall of the Royal palace; Aluminum oxide AL_2O_3 covers 7.98% of the total mineralogical composition.

4.1.3 Iron (III) oxide (Fe_2O_3)

Iron (III) oxide or ferric oxide is the inorganic compound with the formula Fe_2O_3. It is one of the three main oxides of iron, the other two being iron (II) oxide (FeO), which is rare, and iron (II, III) oxide (Fe_3O_4), which also occurs naturally as the mineral magnetite. As the mineral known as hematite, Fe_2O_3 is the main source of iron for the steel industry. Fe_2O_3 is ferromagnetic, dark red, and readily attacked by acids. Iron (III) oxide is often called rust, and to some extent this label is useful, because rust shares several properties and has a similar composition (Wikimedia Foundation, http://en.wikipedia.org/wiki/Aluminium_oxide 2015).

According to the total mineralogical composition of the binding material, which is extracted from the original wall of the Royal palace; Iron (III) oxide Fe_2O_3 covers 11.02 % of the total mineralogical composition.

4.1.4 Calcium oxide (CaO)

Calcium oxide (CaO), commonly known as quicklime or burnt lime is a widely used chemical compound. It is a white, caustic, alkaline, crystalline solid at room temperature. The broadly used term "lime" connotes calcium containing inorganic materials, in which carbonates, oxides and hydroxides of calcium, silicon, magnesium, aluminum, and iron predominate. By contrast, "quicklime" specifically applies to the single chemical compound calcium oxide. Calcium oxide which survives processing without reacting in building products such as cement is called free lime. Calcium oxide is a key ingredient for the process of making cement (Wikimedia Foundation, http://en.wikipedia.org/wiki/Aluminium_oxide 2015).

Hence, Lime deposits are found mixed with impurities such as CO_2, Fe_2O_3, MgCO, etc. the impurities were also extracted from the original binding material during characterization.

The oldest uses of lime exploit its ability to react with carbon dioxide to regenerate calcium carbonate. When lime is mixed with water and sand, the result is mortar, which is used in construction to secure bricks, blocks, and stones together. At room temperature, the reaction of lime with carbon dioxide is very slow. It is accelerated by mixing lime with water. When lime is mixed with water, it forms calcium hydroxide, called slaked lime.

From the total mineralogical composition of the binding material, which is extracted from the original wall of the Royal palace; Calcium oxide (CaO) covers 18.70 % of the total mineralogical composition.

4.1.5 Magnesium oxide (MgO)

Magnesium oxide (MgO), or magnesia, is a white hygroscopic solid mineral that occurs naturally as periclase and is a source of magnesium. It has an empirical formula of MgO and consists of a lattice of Mg^{2+} ions and O^{2-} ions held together by ionic bonding. Magnesium hydroxide forms in the presence of water ($MgO + H_2O \rightarrow Mg(OH)_2$), but it can be reversed by heating it to separate moisture (Wikimedia Foundation, http://en.wikipedia.org/wiki/Aluminium_oxide 2015).

Magnesium oxide was historically known as magnesia Alba (literally, the white mineral from Magnesia other sources give magnesia Alba as $MgCO_3$), to differentiate it from magnesia negra, a black mineral containing what is now known as manganese. And also MgO is one of the raw materials for making cement plant. If too much MgO is added, the cement may become expansive (Wikimedia Foundation, http://en.wikipedia.org/wiki/Aluminium_oxide 2015).

Magnesium Oxide causes delayed expansion when present in large amounts. ASTM limits all cementitious materials to 6.0%. According to the total mineralogical composition of the binding material, which is extracted from the original wall of the Royal palace; Magnesium oxide (MgO) covers 5.48% of the total mineralogical composition.

4.1.6 Sodium Oxide and Potassium Oxide (Na_2O and K_2O)

Properties of Sodium oxide Na_2O: White, heat resistant, refractory. Shows strong basic properties, reacts vigorously with water (forms an alkaline solution), acids, acidic and amphoteric oxides, liquid ammonia (http://www.allreactions.com/index.php/group-1a/natrium/sodium-oxide 2015).

Whereas, Potassium oxide (K_2O): is an ionic compound of potassium and oxygen. This pale yellow solid, the simplest oxide of potassium, is a rarely encountered, highly reactive compound (Wikimedia Foundation, http://en.wikipedia.org/wiki/Aluminium_oxide 2015).

Alkalis in cement based binding materials ranges between 0.2 to 1.5 % equivalent Na_2O and K_2O due to the use of sophisticated heat exchangers in cement industry lead to increased alkali content in modern cements. Depending on the alkali content of cement pH of pore solution in normal concretes is 12.5 to 13.5 Portland cement containing more than 0.6% equivalent Na_2O may lead to expansions when used with alkali reactive aggregates. The Na_2O and K_2O equivalent is given by $Na_2O+0.66K_2O$ (0.66 stands for the difference of molecular weights of Na_2O and K_2O) Total alkali content of concrete should be less than $3kg/m^3$ (Neville 1996).

The alkali content of cementitious materials is reflected in the amounts of potassium oxide (K_2O) and sodium oxide (Na_2O). Large amounts can cause certain difficulties in regulating set times of cement. ASTM has an optional limit in total alkalies of 0.60%, calculated by the equation $Na_2O + 0.658 K_2O$.

However, in our case the alkali content in the original binding materials is 2.64 % and <0.01 % for Na_2O, K_2O respectively. This result shows us the lime based mortar is highly prone to alkali-silica reaction.

4.1.7 Titanium dioxide (TiO_2)

Titanium dioxide, also known as titanium (IV) oxide or titania, is the naturally occurring oxide of titanium, chemical formula TiO_2. When used as a pigment, it is called titanium white, Pigment White 6 (PW6), or CI 77891. Generally it is sourced from ilmenite, rutile and anatase. It has a wide range of applications, from paint to sunscreen to food coloring. Titanium dioxide (TiO_2)1 with about 80% in anatase and 20% in rutile commercially available was used. Characteristics of the TiO_2 were provided by manufacturer (Zhang August 2010, Singapore).

Titanium dioxide is the most widely used white pigment because of its brightness and very high refractive index, in which it is surpassed only by a few other materials. Approximately 4.6 million tons of pigmentary TiO_2 are used annually worldwide, and this number is expected to increase as utilization continues to rise. When deposited as a thin film, its refractive index and color make it an excellent reflective optical coating for dielectric mirrors and some gemstones like "mystic fire topaz". TiO_2 is also an effective pacifier in powder form, where it is employed as a pigment to provide whiteness and opacity to products such as paints, coatings, plastics, papers, inks, foods, medicines (i.e. pills and tablets) as well as most toothpaste (Wikimedia Foundation, Wikimedia Foundation, Inc. 2015) .

In a specific mortar mixture, due to the photo catalysis effect of TiO_2, color intensity on the contaminated mortar surface will decrease with the increase in exposure time in UV irradiation (Zhang August 2010, Singapore).

According to the total mineralogical composition of the binding material, which is extracted from the original wall of the Royal palace; Titanium dioxide (TiO_2) covers 1.80 % of the total mineralogical composition.

4.1.8 Ignition loss (LOI)

It represents the percentage weight loss suffered by a sample of cementitious materials after heating to 1000 ^{0}c. Any water bonded to hydrated cementitious particles is expelled above this temperature. The higher the LOI, the less strength the cementitious materials will develop. ASTM limits the LOI to 3.0%.

However, in our case the LOI for the original cementitious materials is 12.38 %. The result shows that the original cementitious materials were losing its strength.

Analytical Results for the Original Binding Material in Percent														
Field No.	Lab. No	SiO_2	AL_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TIO_2	H_2O	LOI
G-2	20205/14	35.46	7.98	11.02	18.70	5.48	2.64	<0.01	0.18	0.24	1.80	5.12	12.38

Table 1: Analytical Results for the Original Binding Material in Percent

4.2 Analytical Results for the Binding Material in the Restoration Site

4.2.1 Magnetite and Ilmenite

Magnetite is one of the most widespread iron oxide minerals and occurs in a variety of geologic environments. Magnetite is a mineral, one of the three common naturally occurring iron oxides (chemical formula Fe_3O_4) and a member of the spinel group (Wikimedia Foundation, Wikimedia Foundation, Inc. 2015). Magnetite is the most magnetic of all the naturally occurring minerals on earth it is a common accessory mineral in Igneous rocks, but seldom forms crystals large enough to be seen in hand samples. More often, magnetite is dispersed throughout a rock as microscopic crystals that form along the edges of iron bearing minerals such as biotite, amphiboles and pyroxenes. In this dispersed form, it seldom constitutes enough of the rock's volume to be detected by a hand held magnet, although the rock may exhibit a paleomagnetic signature that can be detected by sensitive instruments. If a mafic magma cools slowly enough, dense magnetite crystals may settle as they crystallize, to form large magnetite ore bodies with a strong magnetic character. Magnetite can also form during contact metamorphism of impure iron rich limestone, and in high temperature hydrothermal sulfide vein deposits (Minnesota 2015). On the other hand Ilmenite is the titanium iron oxide mineral with the idealized formula $FeTiO_3$. It is a weekly magnetic black or steel gray solid.

Ilmenite most often contains appreciable quantities of magnesium and manganese and the full chemical formula can be expressed as (Fe, Mg, Mn, Ti) O_3. Ilmenite forms a solid solution with geikielite ($MgTiO_3$) and pyrophanite ($MnTiO_3$) which are magnesian and manganiferous end-members of the solid solution series.

Although there appears evidence of the complete range of mineral chemistries in the (Fe, Mg, Mn, Ti) O_3 system naturally occurring on Earth, the vast bulk of limonite's are restricted to close to the ideal $FeTiO_3$ composition, with minor mole percentages of Mn and Mg.

Magnetite and Ilmenite are sometimes found in large quantities in beach sand. Such black sands (mineral sands or iron sands) are found in various places. However the amount of Magnetite and Ilmenite in the cementitious material which is found in the restoration site is in a trace amount.

4.2.2 Calcite

Calcite, the most common form of natural calcium carbonate ($CaCO_3$), a widely distributed mineral known for the beautiful development and great variety of its crystals.

Some natural calcites are essentially pure $CaCO_3$; others contain noteworthy percentages of other cations (e.g., Mg, Mn, Fe, boron [B], bromine [Br]), substituting for some of their calcium. In general, however, only minor substitution occurs. Only manganese and magnesium are known to substitute extensively for the calcium: mangano calcite and calcian rhodochrosite (i.e., calcium-bearing $MnCO_3$) have been identified, and solid solution has been shown to be possible from pure $CaCO_3$ to 40 percent $MnCO_3$ and from pure $MnCO_3$ to about 25 percent $CaCO_3$. Metastable magnesian calcites containing from approximately 5 to 18 percent $MgCO_3$ occur rather widely as biogenic skeletal material and as cement in some modern marine sediments (Encyclopædia Britannica 2015).

Between 60 and 70 elements have been recorded in minor or trace amounts in limestone analyses. Some of these elements may occur as substitutions within calcite; others seem more likely to represent minor constituents, such as clay minerals, within the analyzed rocks (Encyclopædia Britannica 2015).

Calcite is colorless or white when pure but may be of almost any color reddish, pink, yellow, greenish, bluish, lavender, black, or brown owing to the presence of diverse impurities. It may be transparent, translucent, or opaque.

However, the calcite concentration in the cementitious material in the restoration sites is 50% of the total mineralogical composition and the source of the parent material for calcite mineral, used for restoration work is said to be transported form Ambo area, Ethiopia.

4.2.3 Quartz

Quartz is a chemical compound consisting of one part silicon and two parts oxygen. It is silicon dioxide (SiO2). It is the most abundant mineral found at Earth's surface and its unique properties make it one of the most useful natural substances (http://geology.com/ 2015).

Quartz is the most abundant and widely distributed mineral found at Earth's surface. It is present and plentiful in all parts of the world. It forms at all temperatures. It is abundant in igneous, metamorphic and sedimentary rocks. It is highly resistant to both mechanical and chemical weathering. This durability makes it the dominant mineral of mountaintops and the primary constituent of beach, river and desert sand. Quartz is ubiquitous, plentiful and durable. Minable deposits are found throughout the world (http://geology.com/ 2015).

Physical Properties of Quartz	
Chemical Classification	*Silicate*
Color	*Quartz occurs in virtually every color. Common colors are clear, white, gray, purple, yellow, brown, black, pink, green, red.*
Luster	*Vitreous*
Diaphaneity	*Transparent to translucent*
Specific Gravity	*2.6 to 2.7*
Chemical Comp.	*Sio_2*
Uses	*Glass making, abrasive, foundry sand, hydraulic fracturing proppant, gemstones*

Table 2: Physical Properties of Quartz

According to the Mineralogical analysis result the Quartz mineral concentration in the cementitious materials which is taken from the restoration site covers around 2% of the total mineralogical concentration.

4.2.4 Carbonate and Basalt

Most carbonate rocks were deposited from seawater. These sedimentary carbonate rocks are common on every continent and have formed through most of geologic history; they are still forming today in the tropics as coral reefs and at the bottoms of shallow seas

Limestone has many industrial uses and can be used as mined or processed into a wide variety of products. It is the raw material for a large variety of construction, agricultural, environmental, and industrial materials.

Basalt is a dark colored, fine grained, igneous rock composed mainly of plagioclase and pyroxene minerals. It most commonly forms as an extrusive rock, such as a lava flow, but can also form in small intrusive bodies, such as an igneous dike or a thin sill. It has a composition similar to gabbro. The difference between basalt and gabbro is that basalt is a fine grained rock while gabbro is a coarse grained rock.

Unweathered basalt is black or gray. Pliny used the word basalt, which is said to have an Ethiopian origin, meaning a black stone (encyclopedia.org 2012).

Basalt is used for a wide variety of purposes. It is most commonly crushed for use as an aggregate in construction projects. Crushed basalt is used for road base, concrete aggregate, asphalt pavement aggregate, railroad ballast, filter stone in drain fields and may other purposes. Basalt is also cut into dimension stone. Thin slabs of basalt are cut and sometimes polished for use as floor tiles, building veneer, monuments and other stone objects.

However, the rock fragment of Carbonates and Basalts in the cementitious material in the restoration sites is 46 % of the total mineralogical composition.

No.	Sample No.	Lab. No.	TW/HWT (gm)	Magnetite	Ilmenite	limonite	Calcite	Quartz	R.F of carbonate and Basalt	Remark
1	G-1	20209/14	10/9.95	Tr	Tr		*50	2	46	*= Clay size Calcite R.F = Rock Fragment Tr =Trace Element

Table 3: Analytical Results for the Binding Material in the Restoration Site

Oxide formula	*Shorthand notation*	*Percentage by mass in cement*	*Percentage by mass in the original binding material (Lime) based*
CaO	*C*	*65.0*	*18.70*
SiO2	*S*	*22.0*	*35.46*
Al2O3	*A*	*6.0*	*7.98*
Fe2O3	*F*	*3.0*	*11.02*
MgO	*M*	*2.0*	*5.48*
K2O + Na2O	*K + N*	*0.6*	*2.65*
OTHER	*…….*	*3.6*	*2.22*
H2O	*H*	*1*	*5.12*

Table 4: Weigh against Percentage by mass in cement and Percentage by mass in the original binding material (Lime) based

Calcium	Silicon	Aluminum	Iron
Limestone	Clay	Clay	Clay
Marl	Marl	Shale	Iron ore
Calcite	Sand	Fly ash	Mill scale
Aragonite	Shale	Aluminum ore refuse	Shale
Shale	Fly ash		Blast furnace dust
Sea Shells	Rice hull ash		
Cement kiln dust	Slag		

Table 5: Source of parent materials (A.M.Neville 1986)

Chapter Five

5. Method of Construction of Fasil Ghibbi Palace

Construction history is full of examples of lack of success. The importance of ancient constructions has been for long exclusively associated with the use of the building, meaning that successive changes were made to the building in order to fulfill its new function. Presently, modern societies understand built cultural heritage as a landmark of culture and diversity, which should last forever, being the task of the current generation to deliver the heritage in good shape for the generations to come. This act of culture poses high demands to engineers because deterioration is intrinsic to life (as an example the expected life of a modern building is fifty years).

The analysis of historical masonry constructions is a complex task that requires specific training. The continuous changes in materials and construction techniques that swiftly moved away from traditional practice, and the challenging technical and scientifical developments, which make new possibilities available for all the agents involved in the preservation of the architectural heritage, are key aspects in the division between the science of construction and the art of conservation and restoration.

5.1 Stone Masonry Construction

Masonry construction has been used for at least 10,000 years in a variety of structures homes, private and public buildings and historical monuments (International Building Code 2003).

Stone masonry is a traditional form of construction practiced for centuries in the regions where stone is locally available. It is still found in old historic centers, often in buildings of cultural and historical significance, and in developing countries where it represents affordable and cost-effective housing construction (Lutman 2014). The masonry of ancient time’s involved two major materials: brick manufactured from sun dried mud or burned clay and shale; and natural stone. The first masonry structures were unreinforced and intended to support mainly gravity loads. The weight of these structures stabilized them against lateral loads from wind and earth quakes (International Building Code 2003).

This construction type is present in earthquake prone regions of the world, such as Mediterranean Europe and North Africa, the Middle East, India, Nepal, and other parts of Asia. The World Housing Encyclopedia contains nine reports describing stone masonry housing construction practices in Greece (WHE Report 6), Italy (WHE Report 28), India (WHE Report 8 and 80), Nepal (WHE Report 47 and 74), Palestinian Territories (WHE Report 49), Slovenia (WHE Report 58), and Algeria (WHE Report 75) (Lutman 2014).

The most impressive castle within the enclosure is the original built by facile des, c1640, partially restored in the mid-20th century, and more fully restored, using the original construction methods, with UNESCO funding between 1999 and 2002. Fasildas's castle is made of stone and shows a unique combination of Portuguese, Axumite and even Indian influences. The ground floor consists of receptions and dining areas. The walls are decorated with the symbol similar to the Star of David, which became the emblem of the Ethiopian royal family after the Solomonic dynasty reclaimed the throne in the 13th century. The first floor roof of the castle was used for prayer and religious ceremonies and it is also were Fasildas's addressed the towns folk. Fasildas's prayer room, also on the first floor, has four windows, every one of which faces a church. Stairs lead from the roof to the small second floor that Fasildas's used as his sleeping quarters. Above this is an opening balcony which was probably the watch tower. This third floor platform, 32 meter above the ground, offers views in all directions; on a pure day, you can even see lake Tana on the horizon, emphasizing the strategic advantage of choosing Gondar as a capital. The construction materials used for the constructing the palace wall system is wooden floor.

However, the methods of construction for Fasil palace walls were by stone masonry. The type of construction materials which is used during the construction of the royal palace was mainly Rock because there was abundance of rock supplying sources around Gondar, Ethiopia.

It has been said that the type of rock that was used to construct the walls were of a kinds that is *Beha Dingay* and Basaltic Rock. The former was collected from a place called *Azezo* around *Kuskuam Mariam*; and the latter was collected from a place called *Gemenedba sellassie*.

Moreover, considering its height that is 32 meter and accessibility of modern Crane facility; the method of material transportation at the time of construction makes the construction more challenging. However, after inspecting the whole Palace sides, a traditional kind of pulling mechanism were used by the people at that time in order to construct the mason. It has been said that wooden beams were used as a ramp during the masonry construction.

These wooden beams are imported from a place called *Armachiho or Dembeca* local name *werk mider.* The holes are positioned within 4 to 5 meter distance from the ground and also found within the same interval for the next level of the wall of the palace.

As it is seen in the (picture 19), it is possible to observe the holes. Meanwhile the holes were covered by the same kinds of stone probably at the end of construction for the aesthetical purposes. However, anyone can physically observe that the covered holes for the wooden beams are visible on different sides of the walls.

Figure 18: Covered holes for the wooden beams in the main Castel.

According to (Pankhurest 1985) during the Fasil Palace construction, Indians craftsmen were apparently playing an increasingly active role in Ethiopia where there is evidence of their being responsible for the erection of palaces, churches and bridges. Almeida reports that “when some stone masons come from India, brought by the Patriarch,” the emperor employed them at his palace at “Ganata Yesus” between “Danqaz” and “Gorgora” where he “Built a palace of stone and lime, a structure that was a wonder that country, and something that had never been seen not yet imagined and it was such as would have value and be reckoned a handsome building everywhere (see Figure 15).

Figure 19 : Stone masonry Palace building in Gondar, Ethiopia.

Masonry consists of a variety of materials. Raw materials are made into masonry units of different sizes and shapes, each having specific physical and mechanical properties. Both the raw materials and the method of manufacture affect masonry unit properties.

The word “masonry” is a general term that applies to construction using hand placed units of clay, concrete, structural clay tile, glass block, natural stones and the like (International Building Code 2003). One or more types of masonry units are bonded together with mortar, metal ties, reinforcement and accessories to form walls and other structural elements.

The most important characteristic of masonry construction is its simplicity. Laying pieces of stone or bricks on top of each other, either with or without cohesion via mortar, is a simple, though adequate technique that has been successful ever since remote ages (Lourenço 1996). Other important characteristics are the aesthetics, solidity, durability and low maintenance, versatility, sound absorption and fire protection. Load bearing walls, in fill panels to resist seismic and wind loads, pre stressed masonry cores and low rise buildings are examples of constructions where the use of structural masonry is presently competitive (Lourenço 1996).

5.2 External Influence on the Historic Ethiopian Construction

During the period of Emperor Susneyes, commercial contacts between Ethiopia and India, suffered through the period of difficulty resulting from the invention of Gran Ahmed and the Portuguese incursions, were resumed in the late sixteenth and early seventeenth centuries. The record, of this period suggest that the old trading connection were revived, and that there was extensive commerce between the Red sea area and India, accompanied by considerable Indian sea faring in Red sea and gulf of Aden waters (Pankhurest 1985).

The coming of Portuguese, which at first disrupted the Middle East's trade with India, later led to an intensification of cultural contacts between Ethiopia and India. Travelers between Ethiopia and the west, some of them Ethiopians, often journeyed by way of Portuguese India, where a hand full of Ethiopian ecclesiastics are known to have studied both art and music, while the Portuguese, soon the masters of several major ports of the sub continents, were instrumental in bringing a number of Indian craft man to Ethiopia where they played an innovative role in the field of bridge and possibly also palace and church buildings (Pankhurest 1985).

After the expulsion of the Jesuits Susneyes son and successor Fasiladas took an over greater interest in the East, dispatching emissary to both the Moghal empire and the Dutch, East Indies, from which many luxuries were imported, while craftsmen from India played no negligible rule in Gondar (Pankhurest 1985).

According to (R.Pankhurst 1965), A diplomatic mission from Yemen arrived to Gondar in 1648. It was led by Hasan ben Ahmed el Haimi who wrote: "We went to the King's stronghold and climbed a high building, a stately edifice which ranks among the most wonderful of wonderful buildings and among the most beautiful of exceptional wonders, constructed of stone and lime. And there is in that town, indeed in the whole of Abyssinia, no other but it (as it is of very pleasing appearance and handsome design), because all other dwellings in these localities are only nests of grass. The builder of the edifice was an Indian and the characteristics of his design correspond to the methods of his country. --"

However, according to the evidence I heard from the tourist guide of the castles however, during that time in order to avoid external interference in the country's political, cultural and religious aspects the royal class was declaring a closed door policy administration system in all over the Abyssinian kingdom, so the probability of finding Indians or Portuguese craftsmen during the construction of Fasil Palace were negligible. And they are also justify that, during their presence they are simply putting different types of emblem in the internal part of the main palace after the construction of the palace. Simply using cement as a plastering material and you can just spot it by looking that, it is added during their percent just for showing peace, prosperity and love of the ruling period. (See the Figure below)

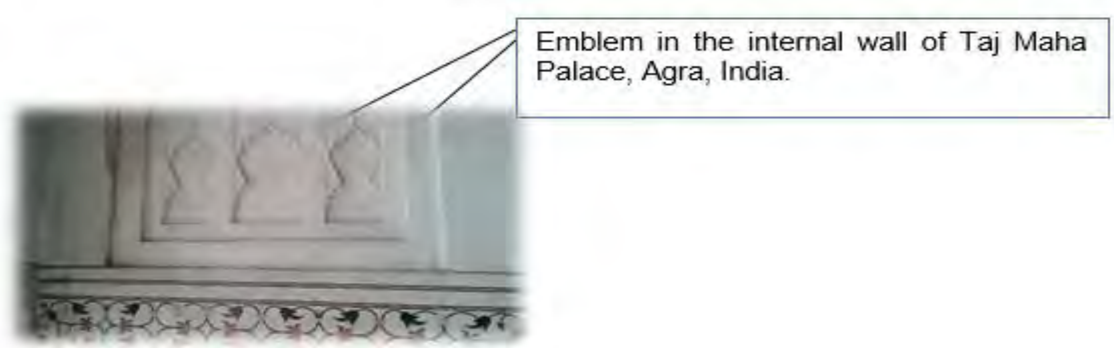


Figure 20: Pictures of different types of Emblems in the internal wall of the Fasil and Taj Mahal main Castel.

Indian craftsmen, as the Jesuit explain, were in fact responsible for the local production of mortar (which, we may note, had already been utilized, by Indians we may surmise, at both “Barie Ginb” and “Guzara”). Mendes recalls that in 1624 a “noble Indian, by throwing in to the fire glittering white pebbles that had eyes like Pumice. As he had seen done in “Cambaya”, extracted a very glutinous lime” which was used first at the palace of “Ganta Yesus”, and later in various churches, while Almeida declares in similar View that “an intelligent person from India discover a kind of fine light and as it were worm-eaten stone; in the “Baroche” district of “Guzarat” he had seen it made in to lime or “Chunambo”, as it is called in India, and “Nora” as it is called here.

As (Ramos n.d.) quotes from (Kropp 1984), It is most interesting that the written Ethiopian documentation for this period has been either manipulated, suppressed, or – when kept – very combative in defense of the Orthodox point of view. Particularly for the reign of king Fasiladas, the heir of the “Catholic” king Susenyos, and generally considered the restorer of the Orthodox faith and founder of the city of Gondar (that progressively became the royal siege, until the mid-19th century), an important written record is missing: that of the extended chronicle of the king. Still, not only later kings’ chronicles present relevant data that helps interpret Gondar’s early period, but few versions of abridged chronicles are known (based on churches’ saints’ calendars, or “sinkesar”) and contemporary texts such as the “gadla of Saint Wallata Petros” or the determinations of the Q’bat’s sinode of 1658 in “Aringo”, Gojjam, promoted by Fasiladas himself, are important aides to the study of Gondar’s foundation.

As (Ramos n.d.) quotes from (Ranasinghe 2001), Oral legends from Gondar do not confirm that there ever was a (Muslim of Banyan) Gujarati mason, trader or holy man active in Northern Ethiopia at the moment of the foundation of Gondar, in the wake of the expulsion of the “Portuguese” (i.e., the Jesuit missionaries). But, when crossed with the solitary and somewhat incongruous reference to a “Banyan mason” in Susenyos’ chronicle and with material remains (pictorial, architectural, decorative), they give indirect testimony that the “Portuguese” (i.e., “Ferenj”, or Westerners) were not the only foreigners whose presence was influential in the Ethiopian royal court in the first half of the 17th century. That an Abdel Bashit is “remembered” by the Muslim minority but not by the Orthodox Christian majority is a clear sign of the workings of deletion as a major factor in the construction of any hegemonic discourse (be it Ethiopian or Portuguese). In the present state of affairs, though, it would be too bold to assert with any certainty that a Gujarati did intervene in the building of the imposing Fasiladas castle in Gondar. But this is a path worth treading in future research on the historic international connections of the Ethiopian royalty.

However according to (Pankhurest 1985) Ethiopia is the hay-day of the Gondar monarchy , it may be conclude as thus for far from isolated, and enjoyed indeed fairly close economic, diplomatic and cultural relations with India and the east, particularly with Gujarat, the Mugal empire, and Dutch East Indies.

Chapter Six

6. Factor Affecting the Durability of Historical Heritages

6.1 Durability

Durability is the measure of a structure's performance with respect to a specified time period. Therefore, to ensure adequate performance of the structure over its design life, durability should be understood and considered (Saba, Inversigation of the Durability of Structures June 2013).

6.2 Definition

Ancient builders have shown their concern for durability of their structures, as many of them still stand today. In the past, the scales of the structures constructed compared to those of modem days were much larger. Durability is one of the factors that led to the construction of structures of such measure. Due to the large quantity of materials used, which added up to the dead weight of the structure, the structures were less vulnerable to deterioration. This is reflected in the design of many historical structures, a few examples of which are the pyramids in Egypt, the Coliseum in Rome, Fasil Ghibe Palace in Ethiopia and the Great Wall of China. The design of these structures illustrated the concern of the designers at the time, to deterioration and degradation of the materials used. Hence, using a large quantity of material weight resulted in a robust structure, which helped increase the resistance of the structure to the aggressive environment and its implication on the structure's performance. However, nowadays, the demand is for long, slender, lightweight designs. In contrast to most historical structures, the weight of such structures needs to be minimal. Despite the fact the materials used today have gotten more durable, lightweight designs increase the structure's susceptibility to deterioration. Moreover, every design consideration is crucial in the design of such structures since minor errors may result in severe consequences.

Designing for a durable structure is a challenge. The definition of durability varies from one person to another. What is the design life of a structure? What type of loads does it resist? Do engineers design a structure or a product to last forever? These are a few questions that the term durability raises. By definition, the term durability can be defined as the ability of a material to remain serviceable for at least the required lifetime of the structure of which it forms a part. The specified design life can typically be 50 or 100 years, but for many structures this is not well defined, and then the durability should be such that the structure remains serviceable more or less indefinitely, given reasonable maintenance (Domone 2002). (Saba, Investigating The Durability of Structures June 2013) Also refers durability as the ability to withstand damage, decay and deterioration over a period of time. The more durable the structure is, the longer its lifespan. However, many factors come into play when designing for a durable structure. Some of these factors are, the type of structure being built, the types of materials used, the environmental conditions the structure will be interacting with and its required performance. Therefore, it is important to identify the purpose and the conditions surrounding the structure. These factors will help in directing the design path of the structure and aid in the decision making process of material and geometry used, construction sequence, and maintenance procedures that will be carried out (Saba, Inversigation of the Durability of Structures June 2013). Since the scope this research is focuses on the historical buildings binding materials, some of the factors are discussed below.

6.3 Factor Affecting Durability of Lime Mortar

Mortar deterioration occurs through different chemical, physical, mechanical, biological, etc., processes. Very often, more than one alteration mechanism takes place simultaneously and also frequently chemical processes or biological processes, etc., have physical or mechanical effects; it means that is quite difficult to establish a classification of the deterioration mechanisms of mortars (A. Palomo, M.T. Blanco-Varela, S. Martinez-Ramirez, F. Puertas and C. Fortes 2006).

It is well known that various deterioration mechanisms, due to environment interaction with building materials, can occur, in which water always plays a primary role.

In particular, mortar deterioration may be produced by:

a. Physical causes, as in the case of freezing-thawing, leaching out, crystallization of water soluble salts;

b. Chemical causes, due to ettringite and/or thaumasite production as a result of the reaction between sulfate salts and hydrated calcium silicates or aluminates which are present in mortars based on cement, hydraulic lime or lime-pozzolana; and
c. Biological causes, as in the case of formation of algae, lichens and fungi.

So, we will point out here some of the processes of deterioration commonly observed in this kind of materials.

6.3.1 Dissolution and Leaching of the Components of Hydrated Mortars

Pure waters, proceeding from the condensation of the fog or of the water vapour, and the soft waters, rain water or melted snow and ice, contain little or nothing of calcium. When these waters get in contact with the hardened mortar they spread through the porous system of the material and dissolve the hydrated phases which are rich in calcium (A. Palomo, M.T. Blanco-Varela, S. Martinez-Ramirez, F. Puertas and C. Fortes 2006).

The $CaCO_3$, main constituent of lime mortars and lime plus pozzolana, has an equilibrium pH of 9.93 which is moderately far from the neutral. Then, when $CaCO_3$ it is put in contact with water, this product will be dissolved until reaching the equilibrium. If waters also contain dissolved CO_2 the solubility of the $CaCO_3$ will be very superior. In turn, $Ca(OH)_2$ is the most soluble constituent of Portland cement and hydraulic lime pastes (1230 mg/l) and it is therefore the most easily phase to be leached (A. Palomo, M.T. Blanco-Varela, S. Martinez-Ramirez, F. Puertas and C. Fortes 2006).

The dissolution of the mortar binder can cause an increment in the porosity of the system and consequently in the permeability giving place to the decrease of mechanical strengths and to an increase of the susceptibility for being attacked by other aggressive agents (A. Palomo, M.T. Blanco-Varela, S. Martinez-Ramirez, F. Puertas and C. Fortes 2006) .

Leaching process of calcium salts from mortars can also have other undesirable effects from the aesthetic point of view. Frequently, the leached ($Ca(HCO_3)_2$) precipitates on the surface of the material or even on adjacent materials giving place to white efflorescence's of $CaCO_3$ (A. Palomo, M.T. Blanco-Varela, S. Martinez-Ramirez, F. Puertas and C. Fortes 2006) .

6.3.2 Interaction of the Mortars with the Atmospheric Pollutants

The air contains pollutants in three states: gassy, solid particles and substances dissolved in drops of water. The most important pollutants are: SO_2, NO_x and CO_2. During the last decades the problem of the acid rain has acquired serious dimensions. The pH of the rain uses to be between 4 and 4.5. This acidification is due, in principle, to the effect of the HNO_3 and the H_2SO_4 that are respectively formed for reaction of SO_2 and NO_2 with the water. These acid waters in contact with the mortars and concretes give place to the formation of calcium nitrates, sulphates, bicarbonates, etc. Some of these salts are highly soluble and easily leached (A. Palomo, M.T. Blanco-Varela, S. Martinez-Ramirez, F. Puertas and C. Fortes 2006).

Among the gassy atmospherical pollutants the most dangerous one is SO_2 while the nitrogen oxides were generally considered, for a long time ago, no important concerning its aggressive effect (A. Palomo, M.T. Blanco-Varela, S. Martinez-Ramirez, F. Puertas and C. Fortes 2006).

However, it has been recently proven the strong synergy effect produced by SO_2 and NO_2 when they are together:

$SO_2 + NO_2 + H_2O \longrightarrow H_2SO_4 + NO$………………………………..… (Equation 6.1)

6.3.3 Crystallization of Soluble Salts

The crystallization of soluble salts in the porous system of the mortars frequently produces deterioration. Salts are produced from the ions that water has extracted from altered rocks, floors, mortars, concretes, bricks, etc. The aerosols of marine environment and atmospheric pollutants of industrial or urban environment, contribute to the deposition of salts in those mentioned materials. The metabolism of live organisms can also be the source of some ions (Macedo 2010).

Given the porous nature of building materials, the ions penetrate and circulate through them as diluted solutions. A salt will crystallize when the water evaporates and the activity of ions in the solution overcomes that of saturation; but also when the relative humidity of the atmosphere in the surroundings of the material is inferior to that of equilibrium of a saturated solution of this salt. In this way, in a porous system containing accumulated salts, they will crystallize and they will be dissolved again depending on the relative humidity of the air (Macedo 2010).

Lime mortars, lime and pozzolana mortars, are in general quite porous and permeable materials, consequently they admit a considerable amount of solution in the porous system and they facilitate the evaporation process. It is deduced therefore that mortars are weak materials susceptible of deteriorating for crystallization of salts. Hydraulic lime mortars and cement mortars are much less porous and permeable than lime and lime plus pozzolana mortars (especially if the former ones were submitted to a good curing process), then the volume of liquid circulating through them and the on the other hand, the point where the crystallization takes place is determined by a dynamic balance between the rate of evaporation of water from the surface and the rate of access of the liquid to this point (A. Palomo, M.T. Blanco-Varela, S. Martinez-Ramirez, F. Puertas and C. Fortes 2006).

If the access rate of the liquid to the surface of the material is a slightly superior to that of evaporation, then the salt crystallization takes place on the surface giving place to the characteristic efflorescence's which are not harmful but are indicating that in another point an internal crystallization is going on. If the rate of migration of the liquid from the inner porous system of the material till the surface is not superior to that of the evaporation rate, then a fair dry area will be developed under the surface. The solid crystals will precipitate inside the material (in the interface among the dries off areas and humid areas), giving place to flakes, bladders... etc. Finally if the rate of access of the liquid is slow, regarding that of evaporation, the deposits gather inside the material and no superficial deterioration is observed; however successive cycles of crystallization dissolution can mechanically destroy the mortar (A. Palomo, M.T. Blanco-Varela, S. Martinez-Ramirez, F. Puertas and C. Fortes 2006).

During the crystallization process high pressures are generated due to the growth of the crystals and due to its hydration. The destructive effect depends both on the mechanical characteristics and on the porous structure of the material. The higher the mechanical strength, the higher the resistance to crystallization pressures; in this sense it is evident that cement mortars are stronger materials than lime or lime and pozzolana mortars and therefore they will be less susceptible of deterioration (A. Palomo, M.T. Blanco-Varela, S. Martinez-Ramirez, F. Puertas and C. Fortes 2006).

In turn the crystallization pressure is inversely related with the radius of the pores in such a way that materials with high volume of small pores will be submitted to very intense crystallization pressures capable of destroying the material. Lime and lime and pozzolana mortars, in general, present, higher porosity and pore size than those of cement and hydraulic lime mortars; then the internal pressure due to salt crystallization is not a very important alteration factor for lime and lime plus pozzolana mortars (A. Palomo, M.T. Blanco-Varela, S. Martinez-Ramirez, F. Puertas and C. Fortes 2006).

6.3.4 Expansive Reactions Due to Hydration of CaO and MgO

When the slaking process of lime is not enough intense, the final product could contain some crystalline CaO and MgO (magnesium coming from dolomites). Also hydraulic lime and Portland cement can contain this crystallized oxide as a consequence of bad dosages, incomplete clinkerization, etc. The reactions of hydration of MgO and CaO (to give portlandite and brucite) are slow and expansive and they can cause cracking problems and even the breakdown of mortars or hardened concretes (A. Palomo, M.T. Blanco-Varela, S. Martinez-Ramirez, F. Puertas and C. Fortes 2006).

6.3.5 Volume Changes Due to Thermal Variations or Water Presence

The temperature variations can produce dilations and contractions in the material and so creating tensions. The rendering of walls with several layers of renders of different characteristics was usual practice in the past and it still is at present. Frequently these different materials possess different thermal or hygric expansion coefficients. Under certain circumstances tensions can take place in the materials, giving place to cracking and breaking down of the layers (A. Palomo, M.T. Blanco-Varela, S. Martinez-Ramirez, F. Puertas and C. Fortes 2006).

(Mitchell July 2007) Also state that, Lime mortared and rendered stone buildings have a natural ability to both hold and evaporate moisture from the walls, thus maintaining a state of balance with the surrounding atmosphere. Lime mortars and rendered surfaces can therefore absorb and evaporate moisture freely. In less permeable masonry, such as walls built of granite, the function of the lime mortar joints becomes more critical to allow for the free passage of moisture.

Lime mortars have an inherent flexibility which hard setting cement mortars do not. Small scale movements caused by subsidence or settling and thermal movement can generally be accommodated. Hairline cracks in lime mortars chemically seal themselves, and are often described as being 'self-healing' (Mitchell July 2007).

6.3.6 Deterioration Due to Biological Causes

The bio deterioration is the process of destruction of a material due to live organisms or the products of its metabolism. The attack of natural materials through biochemical and biological processes as well as the influence that microorganisms have in the formation of ground is well known. The process of colonization of a mortar is favored by its characteristics (porosity, composition and roughness). These characteristics favor the retention of water in the material and the consequent growth of algae and Ciano bacteria. These last ones form a superficial bio layer, similar to a mucous, favoring the retention of sand and powder and being an appropriate substratum for the growth of other live organisms that can even promote the growth of superior plants (A. Palomo, M.T. Blanco-Varela, S. Martinez-Ramirez, F. Puertas and C. Fortes 2006).

Lichens and mosses appearing in winter months with increasing humidity related to climate speeds up the deteriorations on monumental buildings. The non-removal of rain water from damaged roof covers or any joints of the building lays is the groundwork for the growing of mosses and plants on the building. Biological weathering can be also described as the disintegration of stone and stone minerals due to the chemical and/or physical effects of an organism that change the stone color or ease the decay process of stone.

In general, the biological weathering takes place by the help of plants, animals, fungus, algae, bacteria, lichen etc (BrankoGlisic, Daniele Inaudi, Daniele Posenato, Angelo Figini and Nicoletta Casanova, 2007).

6.3.7 Deficient Intervention Actions

Improper restorations by applying incompatible materials help to accelerate the process of the deterioration of the lime mortar (Macedo 2010).

6.4 Major Causes of Deterioration of Mortars in Fasil Ghibbi Palace

It is well known that various deterioration mechanisms, due to environment interaction with building materials, can occur, in which water always plays a primary role.

Figure 21: Deterioration of rendering Mortar

In particular, it is better to classify the major cause of mortar deterioration in the Royal Palace compound:

I. ***Physical causes***: As in the case of crystallization of water soluble salts.

II. ***Chemical causes***: Due to ettringite and/or thaumasite production as a result of the reaction between sulfate salts and hydrated calcium silicates or aluminates which are present in mortars based on hydraulic lime or lime-pozzolanas; and (See the Figure below).

Figure 22: Mortar deterioration due to Chemical Reaction

III. ***Biological causes***: As in the case of formation of algae, lichens and fungi. These specific causes have been the chief problem in the external face of the walls.(See the Figure below)

Figure 23: Mortar deterioration due to Biological Causes

IV. ***Mechanical actions***: E.g. impact, overloading, vibration, blasting etc. hence the Royal Palace is located on the center of the city, vibration which is prompt by the nearby traffic load is one of the problem. Proper follow up and care has to be on check points, it is better to limit the number of visitor at a time for proper monitoring and reducing the mechanical impact caused by some irresponsible individuals. .(See the Figure below)

Figure 24: Mortar deterioration due to Mechanical action

Chapter Seven

7. Conservation and Restoration of the Historical Heritage

Heritage buildings and monuments in any country are mute testaments of its glorious past. Ethiopia has a very rich historic background which is evident from various buildings, forts, temples, lands capes, objects of historic era. Many of these were constructed several hundred years ago when the Ethiopian Civilization was at its peak. Their architecture, design and construction at the time when computers, code of practice, design guidelines, research institutions and modern construction techniques did not exist makes one to realize the wisdom and expertise of our forefathers. These structures have managed to survive for hundreds of years while most of the modern constructions need repair after couple of years of service.

Work is not performed frequently to reverse decay of the building after its initial construction. Physical materials of an earlier time, that might have been state of the art at the time of construction, might have failed and now need replacement with contemporary better functioning, but aesthetically similar materials. Such reasons make it mandatory to investigate a systematic approach in the area of heritage conservation.

7.1 Standards for Preservation, Rehabilitation, Restoration and Reconstruction

Guidelines lead the stakeholders such as historic building owners and building managers, preservation consultants, architects, contractors, and project reviewers to develop the best suited approach prior to treatment. The standards given by the U.S, Archeology and historic preservation: secretary of the Interior's standards and guidelines, The National Park Service, U.S. are as follows [http://www.cr.nps.gov/local-law/arch_stnds_8_2.htm]:

1. The historic character of a property should be retained and preserved. The replacement of intact or repairable historic materials or alteration of features, spaces, and spatial relationships that characterize a property should be avoided.

2. Each property should be recognized as a physical record of its time, place, and use. Work needed to stabilize, consolidate, and conserve existing historic materials and features should be physically and visually compatible, identifiable and properly documented for future research.

   Distinctive materials, features, finishes, and construction techniques or examples of craftsmanship that characterize a property should be preserved.

3. The existing condition of historic features should be evaluated to determine the appropriate level of intervention needed. Treatments that cause damage to historic materials should not be used.
4. Deteriorated historic features should be repaired rather than replaced. Where the severity of deterioration requires replacement of a distinctive feature, the new feature should match the old in design, color, texture, and, where possible, materials. Replacement of missing features should be substantiated by documentary and physical evidence.
5. New additions and adjacent or related new construction will be undertaken in such a manner that, if removed in the future, the essential form and integrity of the historic property and its environment would be unimpaired.
6. Replacement of missing features from the restoration period should be substantiated by documentary and physical evidence. A false sense of history should not be created by adding conjectural features, features from other properties, or by combining features that never existed together historically.

Hence effort of restoration should bring back the building to its original form and beauty without necessarily sacrificing authenticity. The monument must therefore be analyzed and appreciated to enable the recapturing of the original fabric and character of the heritage structure through judicious investigation & scientific methodology and it must be complemented and enhanced with the minimum of intervention and at a reasonable cost.

7.2 Conservation

The growing interest in the historical heritage in most countries during the past century has led to a constant change in conservation and restoration ideas. Conservation is defined as "all the processes of looking after a place so as to retain its historical and cultural significance, it includes maintenance and may according to circumstance include preservation, restoration, reconstruction and adaptation, and will be commonly a combination of more than one of these. Conservation should make use of all the disciplines which can contribute to the study and safeguarding of a place.

Techniques employed should be traditional but in some circumstances they may be modern ones for which a firm scientific basis exists and which have been supported by a body of experiences".

7.2.1 Compatibility

Compatibility is a term that has often been used in relation to the conservation of cultural heritage. In a simple description of compatibility, as (Ngoma, Characterisation and Consolidation of Historical Lime Mortars in Cultural Heritage Buildings 2009) quoted from Teutonico et al. (1997) state that; "the introduced treatments or materials will not have negative consequences". (Van Hees 2000) Define compatibility as; "the new materials should be as durable as possible without (directly or indirectly) causing damage to the original material".

7.3 Restoration of Heritage Structure

The deterioration of monuments is familiar to anyone who has looked closely at the historical buildings and associated structures. While there are few monuments that seem to be little affected by centuries of exposure to the weather, the majority of monuments are subjected to gradual deterioration. In addition to natural weathering, monuments are also subjected to deterioration from anthropogenic factors, such as air pollution and soluble salts. Furthermore, these deterioration mechanisms have be enhanced by inappropriate design, poor construction practice and eventual unsuitable conservation interventions.

According to (Botre March,2013) building restoration refers to the process of correctly revealing the state of a historic building, as it looked in the past and recovering the same by various measures while respecting its heritage value. Restoration involves returning the existing fabric of a place to a known earlier state by removing accretions or by reassembling existing components without introducing new materials. Conservation means the process of retaining structure's historical, architectural, aesthetic, cultural significance. Preservation stands for maintaining the fabric of a place in its existing state and retarding deterioration whereas reconstruction implies returning a place as nearly as possible to a known earlier state and distinguished by the introduction of materials into the fabric. Restoration is defined as the act or process of accurately depicting the form, features, and character of a property as it appeared at a particular period of time by means of the removal of features from other periods in its history and reconstruction of missing features from the restoration period.

In the United States, the Secretary of Interior is the head of the National Park Service which owns and maintains thousands of historic buildings and has been a leader in historic preservation for over 100 years. The standards were developed in 1975 and updated in 1992. The standards deal with the "...materials, features, finishes, spaces, and spatial relationships..." of historic buildings and are divided into preservation, rehabilitating, restoration and reconstruction. It helps to understand what building restoration is in context with the other standards:

- **Preservation** "places a high premium on the retention of all historic fabric through conservation, maintenance and repair." All materials added to a building over its life are retained and only work which is necessary to protect it from deterioration is carried out. (Dominique M. Hawkins 1995) Also define preservation as the act or process of applying measures necessary to sustain the existing form, integrity, and materials of a historic property, generally focuses upon the ongoing maintenance and repair of historic materials and features rather than extensive re-placement and new construction. New exterior additions are not within the scope of this treatment; however, the limited and sensitive upgrading of mechanical, electrical, and plumbing systems and other code required work to make the properties functional is appropriate within a preservation project.

- **Rehabilitation** is a standard for preservation but is more lenient because it presumes the building is so deteriorated that it needs some repairs to prevent further deterioration.
- **Restoration** includes preservation, leaving as much material untouched as possible, reconstruction to replace missing elements, and repair work to bring the building to a historically accurate condition in one particular time period. This may include removing some historic building elements (after documenting them) to make the building historically accurate for a specific date in history.

  According to (Dominique M. Hawkins 1995), it is also defined as the act or process of accurately depicting the form, features, and characteristics of a property as it appeared at a particular period of time by means of the removal of features from other periods in its history and reconstruction of missing features from the restoration period. The limited and sensitive upgrading of mechanical, electrical, and plumbing systems, and other code required work to make the properties functional is appropriate within a restoration project.

- **Reconstruction** allows the re-creation of a missing building or element in all new, appropriate materials. According to (Dominique M. Hawkins 1995) it is a process of depicting, by means of new construction, the form, features, and detailing of a non-surviving site, landscape, building, structure, or object for the purpose of replicating its appearance at a specific period of time and in its historic location.

The first steps in a restoration to the Secretary's standards are to study the building and choose a time period for the restoration. The new use of the building should be consistent with the original use or at least with the time period of the restoration. Materials which were added after the chosen time period must be documented and then may be removed while preserving and repairing the appropriate materials. Materials missing may be reconstructed to "...match the old in design, color, texture, and, where possible, materials." which are evidence based. Modern chemical and physical treatments may be gently used if they do not damage the historic materials, and archaeological resources will be preserved or mitigated. The standards allow sensitive alterations of historic buildings to meet the spirit of the codes and regulations, if necessary (Wikipedia 2015).

7.3.1 Systematic Approach for Restoration

Restoration and conservation is a fine balancing act, learning to judge just the right amount of intervention at the right time. Restoration of architectural heritage requires a multi-disciplinary approach. It is known that heritage structures are meticulously designed and skillfully constructed structures. An equally competent and compatible strategy is required for their preservation.

According to (Avrami E. 2000) in the cultural heritage conservation field, we are consistently faced with challenges on three fronts:

- Physical condition: Behavior of materials and structural systems, deterioration causes and mechanisms, possible interventions, long-term efficiency of treatments, etc.
- Management context: Availability and use of resources, including funds, trained personnel, and technology; political and legislative mandates and conditions; land use issues, etc.
- Cultural significance and social values: Why an object or place is meaningful, to whom, for whom it is conserved, the impact of interventions on how it is understood or perceived, etc.

All these challenges should be given due consideration to arrive at the best possible technique of restoration which will not only be effective but also economical. The proposed approach leads a restorer to efficient restoration practice by giving a logical sequence of various activities to be followed in restoration works. Identification of various problems and devising the most suitable method to tackle the same is the restorer’s task. Choosing the most appropriate treatment, requires careful decision making about building's historical significance, physical condition existing on the date of restoration, proposed use and mandated code requirements etc.

A general restoration approach shown in Figure below may be adopted as a basis or guide for taking up work of restoration. According to the suggested systematic approach, restoration of heritage structure involves evaluation of structure to expose its actual condition. Evaluation is done based on documents and physical evidences by assessment of condition of structure which includes inspection, diagnosis and cause analysis. Evaluation may be exploratory or immediate. Immediate evaluation includes repairs of immediate nature which are desirable or necessary. Hence evaluation of the structural performance of buildings submitted to severe loading conditions is the most valuable source of knowledge regarding their weaknesses and the ways they respond to extreme conditions. These extreme conditions may be historic fire, weathering of material, chemical reactions, water seepage, adverse weather conditions etc. Traces of their past performance can be retrieved by careful examination of its main elements or can be found in historic documents. On the basis of the evaluation report, quantum of deviation from original condition of the structure is known. It should then be treated by a suitable treatment which may include restoration, reproduction and reconstruction. The encountered problems need strategic planning so as to device suitable technique. Accordingly, a repair strategy can be devised. Repairs may be desirable or necessary. Method to be followed and the extent of changes to be made will depend upon the class of structure and limiting alterations that can be carried out.

Materials and features from the restoration period are identified, based on thorough historical research. Next, features from the restoration period are maintained, protected, repaired and replaced, if necessary. It also includes removal of features from other periods; missing features from the restoration period may be replaced, based on documentary and physical evidence, using traditional materials or compatible substitute materials.

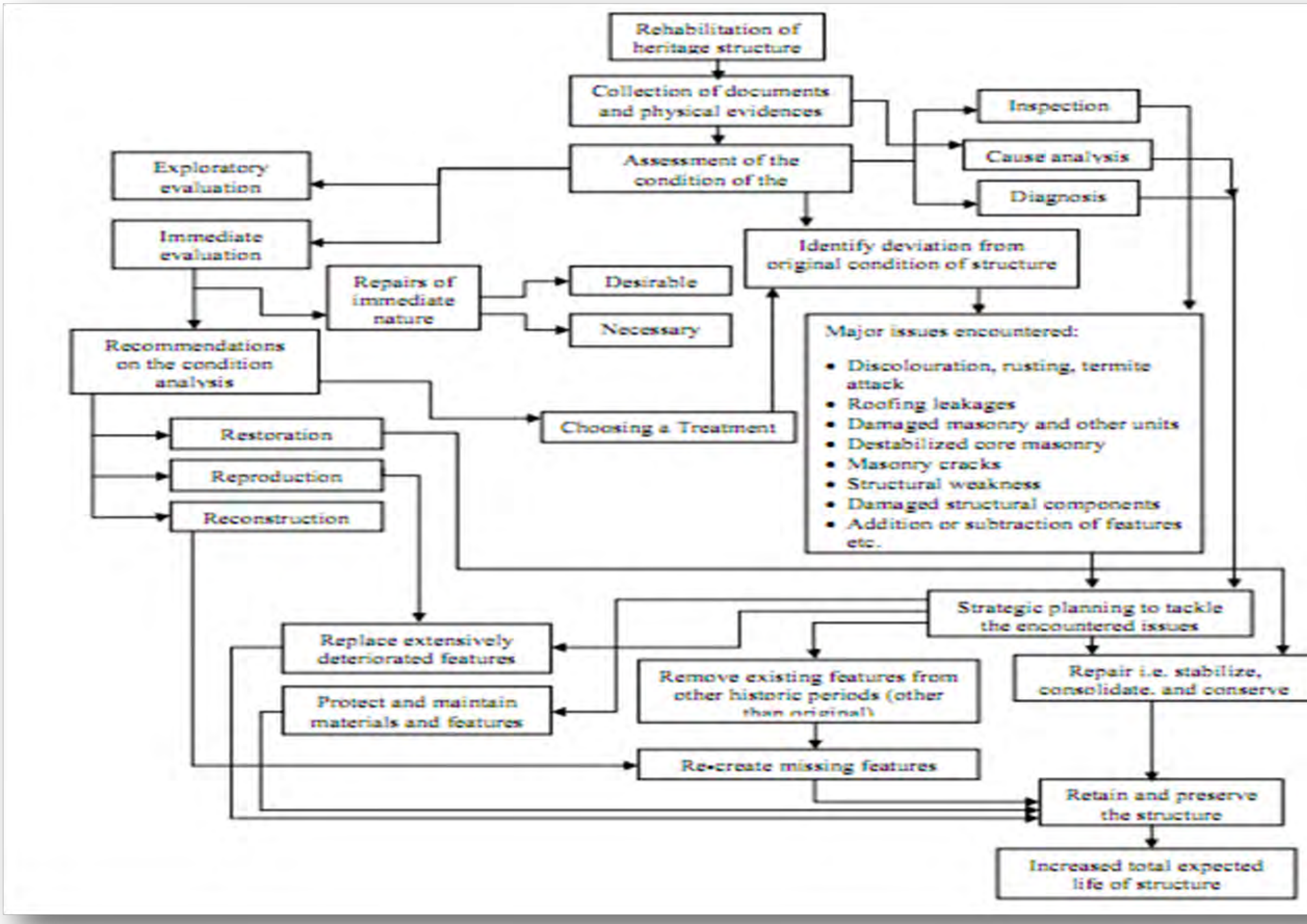


Figure 25: Systematic approach (Sayali Sandbhor Mar-2013)

7.4 Major Problems and Remedial Measures

7.4.1 Major Problems

Masonry walls in the royal palace is show some degree of movement depending on factors such as shrinkage, temperature gradients, the degree of restraint from foundations, etc., as well as durability condition due to biological attack. Deterioration caused by such factors and its treatment is examined on site.

Major problems encountered in the assessment of masonry wall and the corresponding plan of action is as stated below.

7.4.1.1 Tilting Of Masonry Walls & Damaged Masonry with Loose Bonding

The major case for leaning of the masonry wall in the royal palace may perhaps due to the existence of algae, shrub and different kind of Grass on unusual part of the wall. Lack of proper follow-up; for the last time restoration activities and restoration practices was done in the past around 1989 in collaboration with UNESCO.

Hence the upper portion of the wall was leaning out of plumb. Masonry damage was the result of aging of the structure and materials, poor water proofing, wrong loading conditions like vibration due to traffic load etc. The destabilization of older walls due to the deterioration of the inner core rubble between the exterior and interior faces of masonry needed proper attention. (See the Figure below)

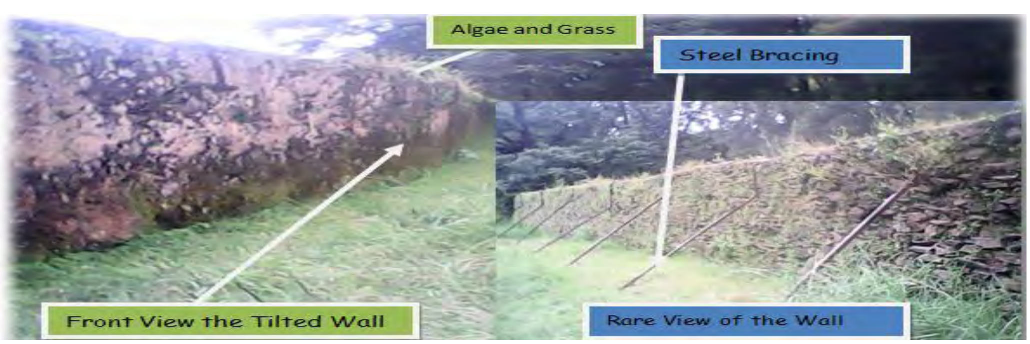


Figure 26: Leaning Of the Masonry Wall in the Royal Palace Near to the Main Road

The second dilemma which is related to durability issue of the Royal palace is the loose bondage of mortar in between the masonry stone layer and also the removal of the top pointing surface due to a number of reasons; in addition to the above listed impact mechanical impact caused by human beings should also have to be considered. (See the figure below)

Figure 27: Some spotted sites which shows critical mortar deterioration

7.4.1.2 Limitation of Skilled Craftsman for Restoration

Some of the traditional crafts in Gondar were lost due to different reason. In building construction, it became difficult to find experienced stone masons or carpenters for restoration. The architects were no longer learning about these skills during their studies in universities. As both practical and theoretical knowledge were not being taught, the maintenance of some historic buildings was at risk, as some non-compatible techniques began to be used.

In other European countries such as Germany or France, young workers were getting trained and worked under supervision in the restoration of historic buildings. When they finished their training period, they could find private owned companies to maintain and repair buildings as many other constructions in Europe were erected with these techniques. Some even created their own business (Colina 2014).

7.4.2 Remedial Measures

The royal palace administration in collaboration with UNESCO; were trying to maintain the integrity of the wall, by providing a support structure like bracing steel in some specific wall portion of the palace which exhibit major deflection as shown in the figure below.

Figure 28 : Bracing steel in some specific wall portion

For the deteriorated palace wall, which was originated due to losing its binding mortar; periodic mortar re-pointing is adopted in the Royal palace according to the palace administration effortless treatment work usually done at the end of the rainy season. (Shown in the figure)

Specific procedure was followed during the preparation of re-pointing mortar for the restoration purpose. These procedures were discussed in chapter two.

Figure 29: Mortar re-pointing in the internal and external appearance of the palace wall

Chapter Eight

8. Conclusion and Recommendation

8.1 Conclusion

The method of construction for the Royal palace walls were by stone masonry. The abundant type of construction materials which was used during the construction of the Royal Palace was mainly by Basaltic Rock and Pumice or “*Beha Dingay*”; which is transported from”*kuskuam mariya”* and “*Azezo”* respectively; because there was abundance of rock supplying sources around Gondar, Ethiopia.

Moreover, considering its height that is around 32 meter and accessibility of modern Crain facility; the material transportation at the time of construction was challenging. But, after inspecting the whole building sides I concluded that:-

1. The people at that time used a traditional kind of pulling mechanism in order to construct the mason. It is also possible to observe the rectangular holes which were covered by the same kinds of stone probably at the end of construction for the aesthetical purposes. However, anyone can physically observe that the covered holes for the wooden beams are visible on different sides of the walls.
2. The methods of construction for Fasil palace walls were by stone masonry. The type of construction materials which were used during the construction of the royal palace was mainly Rock for wall construction in combination with lime because there was abundance of rock supplying sources around Gondar, Ethiopia. Wood also used for the construction of floors, stair cases, windows and doors as well as balustrade,
3. The type of binding material which was used during the construction of the Royal palace is identified as Lime (CaO) or by its local name Nora.
4. The major cause of deterioration of the Royal Palace is due to various reasons, some of which are long life, lack of periodic maintenance, unchecked growth of

trees, grass, algae & mechanical impact on the wall surface by Visitors, irregular inspection, material deterioration and weathering effect etc. Also, modern codes and building standards, observance of cultural context, conservation criteria, traditional and innovative methods etc. pose major challenges in restoration of Royal Palace.

5. The best therapy to reduce decay is preventive maintenance. Adequate maintenance can limit or postpone the need for subsequent intervention.

8.2 Recommendation

This research study demonstrates clearly that the study of historical buildings is very important for the formulation of intervention techniques and help to establishing proper follow up for the future.

Based on the gaps identified in this research work, the following recommendations are made for the future researchers to bring integrated and valuable knowledge contributions to the country.

- ✓ Materials used in the repair of the Royal Palace buildings should have one essential requirement: not to accelerate deterioration of the adjacent materials.
- ✓ Each property should be recognized as a physical record of its time, place, and use. Work needed to stabilize, consolidate, and conserve existing historic materials and features should be physically and visually compatible, identifiable and properly documented for future research.
- ✓ Distinctive materials, features, finishes, and construction techniques or examples of craftsmanship that characterize a property should be preserved.
- ✓ Re-pointing mortars should be as durable as possible, without causing damage to the existing masonry (a dense mortar, for example, could retard the drying of the masonry).
- ✓ I recommend re-pointing mortar joints at more frequent intervals than to have to repair damaged masonry units during restoration.
- ✓ Currently mounted Security system (Surveillance Cameras) in the Royal palace has to be fixed for proper follow-up.

- ✓ Plate numbers that shows the time duration of mortar which is being used for the restoration work has to be set in each barrel.
- ✓ Better to remove Grass, algae and shrubs manually from the palace wall face by hand mainly at the middle of rainy season.
- ✓ There is a need to introduce a good trend of monument restoration in the research institutes to keep the current state of the palace for longer time.
- ✓ The Gondar palace administrators are better to place an internationally accepted symbol in order to protect access in to the protected perimeter; concerning safety matter.

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Annexes: Laboratory Results and Photos.

Figure 1: Raw materials in Senkale Lime Factory (Source: Eskinder Desta)

Figure 2: Lime Packaging unit in Senkale (Source: Eskinder Desta)

Figure 3: Limestone Quarry Site (Source: Eskinder Desta)

Figure 4: Disposed materials (Source: Eskinder Desta)

Figure 5: Restricted door which lead to Balcony (Source: Eskinder Desta)

Figure 6: Hydration Pond in Fasil Ghibbi Palace Restoration Site (Source: Eskinder Desta)