Sudan University of Science and Technology

College of Graduate Studies

Maintenance and Rehabilitation of Masonry Structures

صيانة وإعادة تأهيل الإنشاءات الحجرية

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master in Civil Engineering (Construction Engineering)

Submitted by:

Zeinab Hassan Bakri Hamad

Supervised by:

Dr. Abusamra Awad Attaelmanan

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الآية

قال تعالى:

﴿وَإِذْ يَرْفَعُ إِبْرَاهِيمُ الْقَوَاعِدَ مِنَ الْبَيْتِ وَإِسْمَاعِيلُ رَبَّنَا تَقَبَّلْ مِنَّآ إِنَّكَ أَنتَ السَّمِيعُ الْعَلِيمُ(١٢٧)﴾

صدق الله العظيم

الآية (١٢٧) من سورة البَقَرَةِ

DEDICATION

This thesis is dedicated to:

The sake of ALLAH, the Greater and the Master

The holy Mohammed, peace is upon him

My parents, my life support.

My beloved sisters and brothers.

Dear friend Sumaya.

ACKNOWLEDGEMENT

To commence with pay my obeisance to GOD, the almighty to have bestowed upon me all reasons for supplement the Master degree.

I must express my gratitude to my supervisor; Dr. Abusamra Awad Attaelmanan, for the guidance and advice he has provided me to accomplish this research.

I greatly appreciate the support received through the collaborative work undertaken with the staff of Republican Presidential Palace's Museum and the team of rehabilitation of the posts and telegraphs offices' building, during the phase of my field.

Undertaking this Master has been a truly life-changing experience for me and it would not have been possible to do without the support and guidance that I received from many people and I am grateful to all them. Special acknowledge to my parents, sisters, brothers and all my friends.

Zeinab Hassan Bakri Hamad

ABSTRACT

The purpose of this study was to develop and review features of masonry rehabilitation. It is designed to familiarize the reader with some solutions to maintain old masonry building as well as provide further outlines for special consideration of rehabilitating these types of buildings.

It is presented the main indications for masonry units' deterioration may be in need of maintenance or repair. Then it is accentuated the processes of removing deteriorated mortar from joints and replacing it with new mortar and masonry unit replacement. Also it is outlined the basic processes for conservation treatments of historical places, which may involve Preservation, Rehabilitation, Restoration, or a combination of these actions or processes.

The case study is organized to give a background of an archeological building, the general description of the problems, the new design according to nowadays use and a review of the solutions used to accomplish the rehabilitation. In which concluded that maintenance and rehabilitation for masonry buildings is a unique process and a complex for historical and archeological ones

المستخلص

الغرض من هذه الدراسة هو تطوير واستعراض ملامح عن اعادة تأهيل الإنشاءات الحجرية. وهي مصممة للتعريف ببعض الحلول للحفاظ على المباني القديمة فضلاً عن اعطاء الخطوط العريضة للنظر بشكل خاص في اعادة تأهيل هذه الانواع من المباني.

تم عرض العلامات او المؤشرات الرئيسية الدالة على تدهور وحدات البناء والتي تستوجب التدخل للصيانة او الاصلاح، وتسليط الضوء على عمليتي ازالة المونة التالفة واستبدالها بأُخرى جديدة واستبدال وحدات البناء المتدهورة. وكذلك استعرضت الدراسة العمليات الاساسية لحماية الاماكن التاريخية والتي قد تنطوي على حفظ، او اعادة تأهيل، او ترميم، او مزيج من هذه الاجراءات او العمليات.

اما دراسة الحالة فقد تم تنظيمها لإعطاء خلفية عن مبنى اثري، والوصف العام للمشاكل، والتصميم الجديد له وفقاً للاستخدام في الوقت الحاضر واستعراض الحلول المستخدمة لإنجاز اعادة التأهيل. تم التوصل الى ان صيانة وإعادة تأهيل الإنشاءات الحجرية هي عملية فريدة وتكون معقدة او مركبة في حال المباني التاريخية والاثرية.

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INTRODUCTION

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Masonry refers to mortared or dry laid natural stone as well as brick, cast stone, terra cotta and concrete block. The aesthetic characteristics of the masonry, such as the finish dressing, texture and color of the stone, brick or mortar, the coursing pattern, and the joint width and profile, along with the careful integration of decorative sculptural and functional elements, such as band courses, lintels, water tables, cornices, scuppers and carvings, all contribute to its heritage value and require careful consideration. [1]

1.2 Research Problems

The research problem includes:

1. The maintenance of masonry buildings nowadays lost their identity and the distinctive architectural form of masonry
2. Especially the historical and archeological ones lost their heritage value and without refer to the international conventions and charters in the field.

1.3 Limitation of study

Limitation of this study is Khartoum State.

1.4 Research objectives

1. Identify the maintenance and rehabilitation for masonry buildings

2. Determine the mean features for maintenance and rehabilitation of masonry buildings.
3. Clarify the basics of maintenance and rehabilitation archeological and historical masonry buildings.

1.5 Research Methodology

The study preface with definition of the rehabilitation and maintenance concept, then explain the general issues for rehabilitating masonry building and focusing on historic and archeological ones. The case study is depending on selecting a project nowadays is rehabilitating.

1.6 Research Layout

Chapter one is an introduction starting with definition of masonry concept then research problems, objectives, methodology and research layout.

Chapter two is a literature review contains definitions, information about: buildings inspection, repointing process, masonry unit replacement, organizing the work, the conservation treatments of historic places, standards and guidelines for preservation archeological buildings and previous studies.

In chapter three is the methodology conversed about the methodology of the study under a name of Outlines for Historic Preservation Project. Also it presented the current situation, the problems of a building which is the case study, past documentation, previous maintenance, tests and monitoring results.

While in chapter four involved the assessment rehabilitation of archeological building which case study set is with: research for suitable use and design and structure rehabilitation.

Finally in chapter five comprehended the conclusion and recommendations.

CHAPTER TWO

LITERATURE REVIEW

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In these last decades, maintenance and rehabilitation of masonry buildings has finally received from researchers the adequate attention owed to this peculiar composite materials with which for centuries particularly in Khartoum, the most part of historic buildings was built (e.g.: Grand Khartoum Mosque, The Government House and Gordon Memorial College as shown in **Figures** 2.1,2.2and 2.3).

Figure 2.1: Grand Khartoum Mosque 1936 [2]

Figure 2.2: The Government House [2]

Figure 2.3: Gordon Memorial College [3]

This chapter involved main definitions in field, features for maintenance and rehabilitation of masonry buildings, the basic concepts and guidelines of conservation treatments of historic places. Also there were the previous studies about these types of buildings.

2.2 Definitions

Rehabilitation entails making possible a continuing or compatible contemporary use of a historic building through repair, alterations and additions, while protecting its heritage value**.**

Maintenance is Routine, cyclical, nondestructive actions necessary to slow the deterioration of an historic place. It entails periodic inspection; routine, cyclical, non-destructive cleaning; minor repair and refinishing operations; replacement of damaged or deteriorated materials that are impractical to save.

Heritage value is (valuer patrimonial) the aesthetic, historic, scientific, cultural, social or spiritual importance or significance for past, present or future generations. The heritage value of an historic place is embodied in its character-defining materials, forms, location, spatial configurations, uses and cultural associations or meanings. [1]

2.3 Buildings Inspection

Periodic comprehensive surveys of the building's exterior should be the foundation of any routine maintenance and repair plan. This means that maintenance personnel should familiarize themselves with the properties and expected performance of the exterior wall materials. Specifically, they should look for the following indications brick masonry may be in need of maintenance or repair:

- efflorescence (*i.e.* a powdery residue on the brick surface that results from water-soluble salt deposits);
- spalling (*i.e.* missing or loose pieces of brick face);
- mortar joint deterioration (specifically mortar that has softened, broken apart, or cracked);
- loose, cracked, or displaced bricks;
- visible moisture damage (building interior or exterior); and
- mold or plant growth on masonry surfaces.

Early investigation into these conditions can prevent more costly future repairs.

In the case of water infiltration, the apparent cause may be but one effect of the problem's true source. For instance, the symptom may be deteriorating mortar, but the cause could actually be improperly installed copings or flashings or even a leaky roof—either of which could allow water to enter the wall system. It is very important to know why masonry units and mortar deteriorate. Some contributing factors design professionals frequently look for include:

- Excess moisture penetration at joints
- Contemporary conditions, such as pollution, not considered in the original building design
- Uneven settlement of the building foundation
- Thermal movement of masonry, especially at parapets
- Unequal expansion/contraction of the face masonry with the backup (this can include re-anchored face brick when improper anchorage is used)
- Weathering, including exposure to successive freeze-thaw cycles

- Capillary action causing rising dampness (water drawn into the building materials from the ground up).

Often, a combination of factors may be the culprit in masonry deterioration. For a repair or maintenance effort to achieve lasting success, the plan must address underlying conditions before other repairs are initiated. Preventive measures should also be included in the overall action plan to limit or slow future deterioration.

With historic or landmark structures, special considerations may arise during the investigation. In order to avoid high-cost change orders and delays caused by unforeseen conditions, the design professional may need to research original construction documents and records of earlier repairs and building alterations. Onsite observations complement this evaluation, as portions of the original documents may be unavailable, and building construction can deviate from that shown on plans. Test cuts, probes, photographs, and laboratory analysis may be part of investigation.

Once conservation standards and regulations have been taken into account, probable causes have been considered and drawings and construction documents have been examined, a masonry rehabilitation and maintenance program can be designed to meet the needs of a historic or landmark building. Generally, this includes establishing a scope of work, phasing, and budgeting. [5]

2.4 Repointing of Mortar

Repointing also called pointing or tuck pointing, is the process of removing deteriorated mortar from joints and replacing it with new mortar. It should be done only after underlying issues, such as leaking roofs, differential settlement of the building, unmitigated weather

exposure or rising capillary moisture have been addressed. Otherwise, the problem will soon recur, wasting time and money on multiple repairs. Some indications repointing is necessary include:

- Eroded mortar (6.4 mm [¼ in.] or more from the masonry face)
- Crumbled mortar
- Hairline cracks
- Broken bond between mortar and masonry.

To maintain the esthetic quality of a historic or landmark building, it is necessary to examine the original techniques used in masonry construction. Pointing styles on both horizontal and vertical joints must be carefully noted, as these may differ, as might those on the different façades. Replicating original techniques as closely as possible will minimize visual discrepancies between newly repointed sections and those with original mortar intact.

To prepare the joint, old mortar should be removed to a depth of at least twice the joint width, or until sound mortar is reached. In historic structures with thin mortar joints, the power tools typically used for this purpose can damage the masonry units by overcutting. Hand chisels and, when necessary, small pneumatic grinders, present the least threat to masonry units as shown in **Figure** 2.4. Loose mortar must then be flushed or brushed from the joint.

Repointing mortar should be carefully selected and properly proportioned. Where possible, the original mortar components and proportions should be duplicated. It is helpful to examine existing mortar which has not been exposed to weather, and then to match color and texture using several preparations which have been allowed to dry.

Figure 2.4: A hammer and chisel are being correctly used to prepare a joint for repointing

When specifying a repointing mortar mix, architects look not only to create a uniform appearance between original and newly repointed wall sections, but also to select a mortar that will perform well over time. High-cement mortars do not have the flexibility and waterproofing quality of higher-lime mortars; mortar that is too hard could cause the brick to spall at the edge if movement occurs. Ideally, mortar should look like the original, but be sufficiently yielding that hairline cracks become virtually self-sealing.

Once mortar has been selected and the joint prepared, mortar should be pre-hydrated and then packed into the joint in thin layers as seen in **Figure** 2.5. Like most mortar shrinkage occurs during the hardening process, allowing each layer time to harden before the next is applied minimizes overall shrinkage.

Figure 2.5: Soft mortar for repointing

When mortar is firm, joints should be tooled to the original profile. This is especially important when only portions of a wall area are to be repointed. If old bricks have worn, rounded edges, it is best to recess the final mortar slightly from the brick face. Not only does this treatment keep new joints from appearing wider than existing ones, but it also avoids creating thin featheredges that can break off easily and so admit water.

Once the mortar has dried, but not yet fully set, a stiff nylon or natural bristle brush may be used to remove excess mortar (metal bristles should be avoided with historic brick structures). If further cleaning is required, plain water is best, as chemical cleaners can damage masonry when not used properly. Repointed joints are particularly susceptible,

because they do not fully cure for months. Washing with water before and after the use of chemical cleaners can help to avoid damage.

Successful repointing depends on the masons themselves. Experienced masons understand the special requirements for work on historic buildings and the added time and expense they require. The entire masonry crew must be willing and able to perform the work in conformance with the specifications, even when the specifications may not be in conformance with standard practice.

Repointing is both expensive and time consuming due to the extent of handwork and special materials required. It may also be more sensible when access is difficult, requiring the erection of expensive scaffolding (unless the majority of the mortar is sound and unlikely to require replacement in the foreseeable future). Each project requires judgment based on a variety of factors. Recognizing this at the outset will help to prevent many jobs from becoming prohibitively expensive.

The relationship of repointing to other work proposed on the building must also be recognized. For example, if paint removal or cleaning is anticipated, and if the mortar joints are basically sound and need only selective repointing, it is generally better to postpone repointing until after completion of these activities. However, if the mortar has eroded badly, allowing moisture to penetrate deeply into the wall, repointing should be accomplished before cleaning. Related work, such as structural or roof repairs, should be scheduled so that they do not interfere with repointing and so that all work can take maximum advantage of erected scaffolding.

Building managers also must recognize the difficulties that a repointing project can create. The process is time consuming, and scaffolding may need to remain in place for an extended period of time. The joint preparation process can be quite noisy and can generate large quantities of dust which must be controlled, especially at air intakes to protect human health, and also where it might damage operating machinery. Entrances may be blocked from time to time making access difficult for both building tenants and visitors. Clearly, building managers will need to coordinate the repointing work with other events at the site.[6]

2.5 Masonry Unit Replacement

Severely spalled or damaged masonry units should be replaced with units selected to match the originals in color, dimensions, and texture as illustrated in **Figure** 2.6. After the damaged units have been removed from the wall, all of the existing mortar should be cleared away and the surface cleaned and prepared. With the appropriate surfaces buttered with new mortar, replacement units should be pressed into position and joints fully pointed and tooled. As with repointing, mortar for masonry unit replacement should be selected to match the existing mortar in properties and appearance. [7]

Figure 2.6 Bricks replacement

2.6 Organizing the Work

In undertaking a masonry unit repair, replacement, or repointing project, the job must be planned carefully and logically. Stabilizing the structure is the priority. Any hazardous conditions identified during the investigation, especially those posing a danger to public safety, should be addressed immediately. Loose or severely deteriorated masonry unit must be removed or held in place to prevent accidents.

Any such stabilization measures, however, should lay the groundwork for the rehabilitation effort. Care must be taken not to harm the structure or to increase costs of subsequent work. For instance, it is common practice to secure dangerously loose brick with netting or screening until a more permanent solution can be implemented. However, if improper anchorage was used in previous construction, removal may be sufficiently difficult as to further damage the building envelope.

Prior to the start of masonry remediation, underlying causes of water penetration must be uncovered and corrected, or the work done will waste time and money. The mason should be skilled enough to provide commentary on discovered site conditions that may not have been apparent from the design professional's observations. Proper sequencing can also help ensure both new and existing mortar weather similarly for better matching.

In addition to the rehabilitation needs outlined in the conditions assessment or historic structures report, plan should identify the potential audience for the site, activities that will take place on the site and the benefits the rehabilitated site will bring to the community. It should also identify long-term income sources. A good business plan can help to

ensure the property will be self-sufficient over the long term. It might not be able to complete all rehabilitation work at once, particularly if the building is a large one, work might need to be phased over several years. Plan should include a timeline for completion of various phases of the work. In order to qualify for preservation grants or tax credits, plans for rehabilitating a property should preserve the property's architectural and historic integrity. Paying attention to these details in the planning stage will save a lot of grief when beginning construction. [5]

2.7 The Conservation Treatments of Historical Places:

The overarching term for protecting historical places, which is described as: all actions or processes aimed at safe guarding the character-defining elements of a historical place to retain its heritage value and extend its physical life. This may involve Preservation, Rehabilitation, Restoration, or a combination of these actions or processes. Selecting a primary treatment while any conservation project may involve aspects of more than one of these three conservation treatments, it is important to decide during the planning stage whether the project falls under Preservation, Rehabilitation or Restoration. A clear idea of the project's primary focus or objective, as provided in a conservation plan and the heritage values of the historic place will contribute to the success of a consistent and coherent conservation project.

Once the primary treatment type is established, it is important to refer consistently to the standards related to that treatment type for the overall project. If a different treatment is required for certain character-defining elements, then the related standards will guide interventions on those elements. For example, in a project where rehabilitation is the

primary treatment, it may be appropriate to preserve certain character-defining elements, such as repairable original windows or archaeological soil layers, or to restore certain missing or altered elements, such as a hedgerow or water wheel. In those cases, the Preservation or Restoration standards apply. The interventions specific to those character-defining elements can be considered as secondary treatments.

2.7.1 Preservation

Preservation involves protecting, maintaining and stabilizing the existing form, material and integrity of a historical place or an individual component, while protecting its heritage value. Preservation can include both short-term and interim measures to protect or stabilize the place, as well as long-term actions to stave off deterioration or prevent damage. This will keep the place serviceable through routine maintenance and small repairs, rather than inoperable during intrusive interventions, extensive replacement and new construction. In archaeological sites, Preservation can consist of creating or maintaining a stable environment for the character-defining elements to extend their physical life.

Consider Preservation as the primary treatment when:

(a) Materials, features and spaces of the historic place are essentially intact and convey the historic significance, without extensive repair or replacement;
(b) Depiction during a particular period in its history is not appropriate; and;
(c) Continuation or new use does not require extensive alterations or additions.

Preservation tends to be the most cautious of the conservation treatments and retains the most materials. It is therefore more appropriate when heritage values related to physical materials dominate. A plan for Preservation should be developed before work is undertaken.

2.7.2 Rehabilitation

Rehabilitation involves the sensitive adaptation of an historic place or individual component for a continuing or compatible contemporary use, while protecting its heritage value. Rehabilitation can include replacing missing historic features. The replacement may be an accurate replication of the missing feature or it may be a new design compatible with the style, era and character of the historic place. In the context of archaeological sites, Rehabilitation allows their compatible use through actions aimed at communicating and conveying their heritage value.
Consider Rehabilitation as the primary treatment when:

(a) Repair or replacement of deteriorated features is necessary;
(b) Alterations or additions to the historic place are planned for a new or continued use; and;
(c) Depiction during a particular period in its history is not appropriate.

Rehabilitation can revitalize historical relationships and settings and is therefore more appropriate when heritage values related to the context of the historic place dominate. A plan for Rehabilitation should be developed before work begins.

2.7.3 Restoration

Restoration involves accurately revealing, recovering or

representing the state of a historical place or individual component as it appeared at a particular period in its history, while protecting its heritage value. Restoration may include removing non character-defining features from other periods in its history and recreating missing features from the restoration period. Restoration must be based on clear evidence and detailed knowledge of the earlier forms and materials being recovered. Restoration does not apply to archaeological sites because archaeology does not favor one period over another. The value lies partly in the information the sites contain.

Consider Restoration as the primary treatment when:

(a) A historical place's significance during a particular period in its history significantly outweighs the potential loss of existing, non-character-defining materials, features and spaces from other periods;
(b) Substantial physical and documentary or oral evidence exists to accurately carry out the work; and;
(c) Contemporary additions or alterations and are not planned.

Restoration is most appropriate when strong associative or symbolic values have been obscured and can be revealed through removals, repairs and replacements based on historical evidence. Before the work begins, the restoration period must be selected and justified and a plan for Restoration developed. The use of traditional methods and techniques should be encouraged, where possible, in a restoration project.

Restoration is rarely used today as the primary treatment for an entire historic place, but rather as a secondary treatment for specific character-defining elements. If changes to an historic place have acquired value over time, then Preservation or a combination of Preservation and Rehabilitation would be more appropriate.

Conservation activities can be seen as a sequence of actions — from understanding the historic place, to planning for its conservation and intervening through projects or maintenance. Because conservation is an ongoing and cyclical process, people involved in conservation must often retrace their steps to re-examine their approaches, namely, to assess the impacts of planned interventions on character-defining elements, or to obtain additional information.

Understanding a historical place is an essential first step to good conservation practice. This is normally achieved through research and investigation. It is important to know where the heritage value of the historic place lies, along with its condition, evolution over time and past and current importance to its community. The traditional practices associated with the historic place and the interrelationship between the historic place, its environment and its communities should also be considered. The understanding phase can be lengthy and in some cases, may run in parallel with later phases as the understanding of the place evolves and continues to inform the process. The information collected in this phase will be used throughout the conservation decision-making process and should remain accessible.

Planning is the mechanism that links a comprehensive understanding of a historical place with interventions that respect its heritage value. Planning should consider all factors affecting the future of an historic place, including the needs of the owners and users, community interests, the potential for environmental impacts, available resources and external constraints. The most effective planning and design approach is an integrated one that combines heritage conservation with other planning and project goals and engages all partners and stakeholders early in the process and throughout. For historic places, the conservation planning

process also needs to be flexible to allow for discoveries and for an increased understanding along the way, such as information gained from archaeological investigations or impact assessments. It is important to maintain a firm sense of the larger picture over the long term, and not to emphasize particular character-defining elements at the expense of others.[1]

2.8 Standards and Guidelines:

It is essential that the principles guiding the preservation and restoration of ancient buildings should be agreed and be laid down on an international basis, with each country being responsible for applying the plan within the framework of its own culture and traditions.

Accordingly, the Second International Congress of Architects and Technicians of Historic Monuments, which met in Venice from May 25th to 31st 1964, approved the following text:

Article 1: The concept of a 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 a 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.

Article 3: The intention in conserving and restoring monuments is to safeguard them no less as works of art than as historical evidence.

Article 4: It is essential to the conservation of monuments that they be maintained on a permanent basis.

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 a change of function should be envisaged and may be permitted.

Article 6: The conservation of a monument 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: A monument is inseparable from the history to which it bears witness and from the setting in which 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 or international interest of paramount importance.

Article 8: Items of sculpture, painting or decoration which form an integral part of a monument may only be removed from it if this is the sole means of ensuring their preservation.

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 archaeological 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 of which has been shown by scientific data and proved by experience.

Article 11: The valid contributions of all periods to the building of a monument must be respected, since unity of style is not the aim of a restoration. When a building includes the superimposed work of different periods, the revealing of the underlying state can only be justified in exceptional circumstances and when what is removed is of little interest and the material which is brought to light is of great historical, archaeological or aesthetic value, and its state of preservation good enough to justify the action. Evaluation of the importance of the elements involved and the decision as to what may be destroyed cannot rest solely on the individual in charge of the work.

Article 12: Replacements of missing parts must integrate harmoniously with the whole, but at the same time must be distinguishable from the original so that restoration does not falsify the artistic or historic evidence.

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.

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. The work of conservation and restoration carried out in such places should be inspired by the principles set forth in the foregoing articles.

Article 15: Excavations should be carried out in accordance with scientific standards and the recommendation defining international principles to be applied in the case of archaeological excavation adopted by UNESCO in 1956.

Ruins must be maintained and measures necessary for the permanent conservation and protection of architectural features and of objects discovered must be taken. Furthermore, every means must be

taken to facilitate the understanding of the monument and to reveal it without ever distorting its meaning.

All reconstruction work should however be ruled out "a priori". Only anastylosis, that is to say, the reassembling of existing but dismembered parts can be permitted. The material used for integration should always be recognizable and its use should be the least that will ensure the conservation of a monument and the reinstatement of its form.

Article 16: In all works of preservation, restoration or excavation, there should always be precise documentation in the form of analytical and critical reports, illustrated with drawings and photographs. Every stage of the work of clearing, consolidation, rearrangement and integration, as well as technical and formal features identified during the course of the work, should be included. This record should be placed in the archives of a public institution and made available to research workers. It is recommended that the report should be published. (8)

2.9 Previous Studies:

H. Meireles and R. Bento described the problems and/or pathologies of old buildings and investigated the necessary solutions for the rehabilitation and strengthening using different interventions techniques: firstly related to the foundations; then, structural interventions herein called Local and, finally, structural interventions that are affecting the whole building (Global) behavior:[9]

(a) Structural interventions related to the foundations

- Improvement of the ground soil by Jet-Grouting as shown in **Figure 2.7**.
- Improving the behavior of foundations by enlargement and or consolidation as illustrated in **Figures** 2.8, 2.9.

- Strengthening of the foundation by using micro piles isolated or in group or in row as represented in **Figure** 2.10.

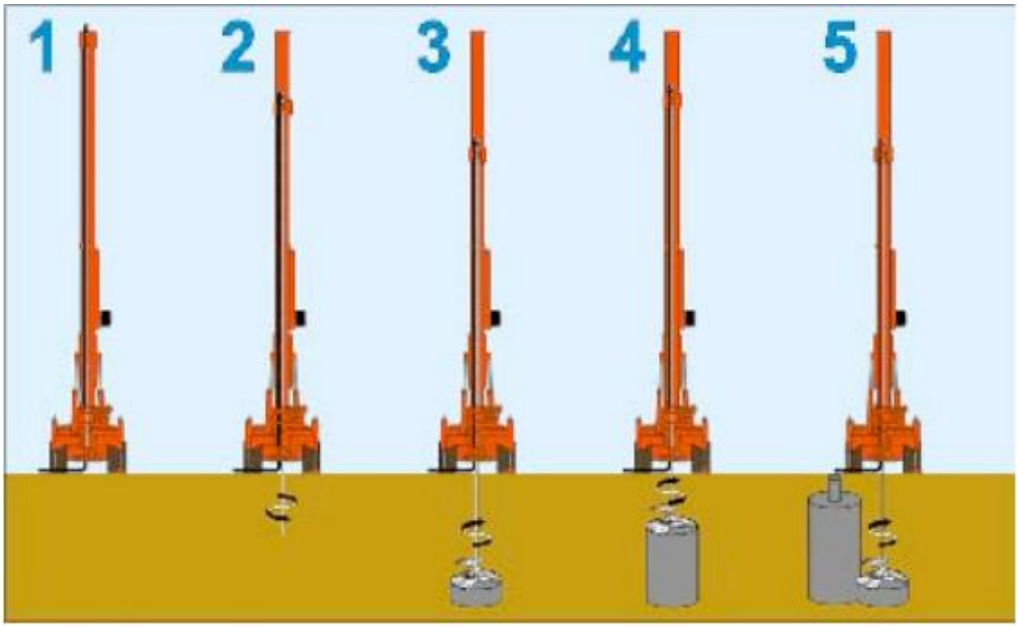


Figure 2.7: The faces of jet–grouting

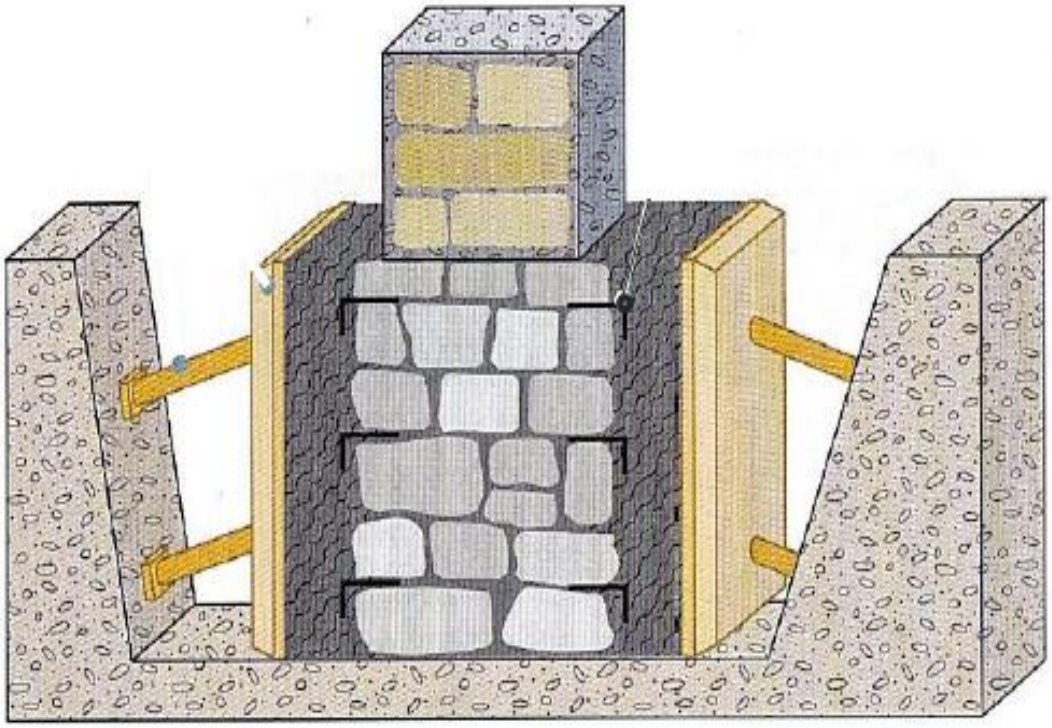


Figure 2.8: Enlargement of the foundation

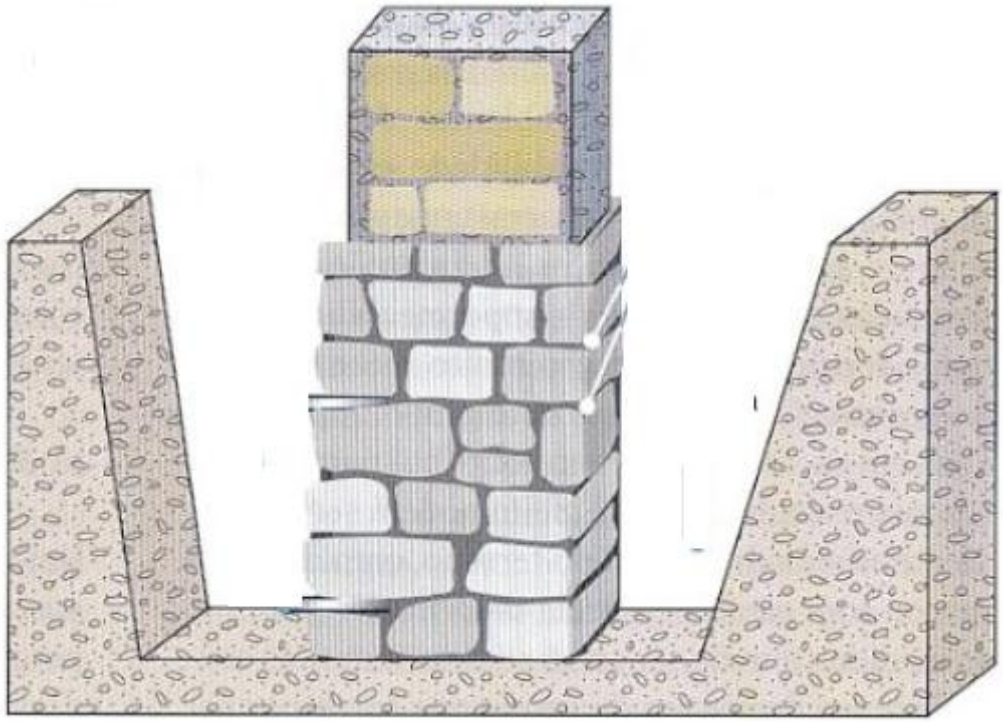


Figure 2.9: Consolidation of the foundation

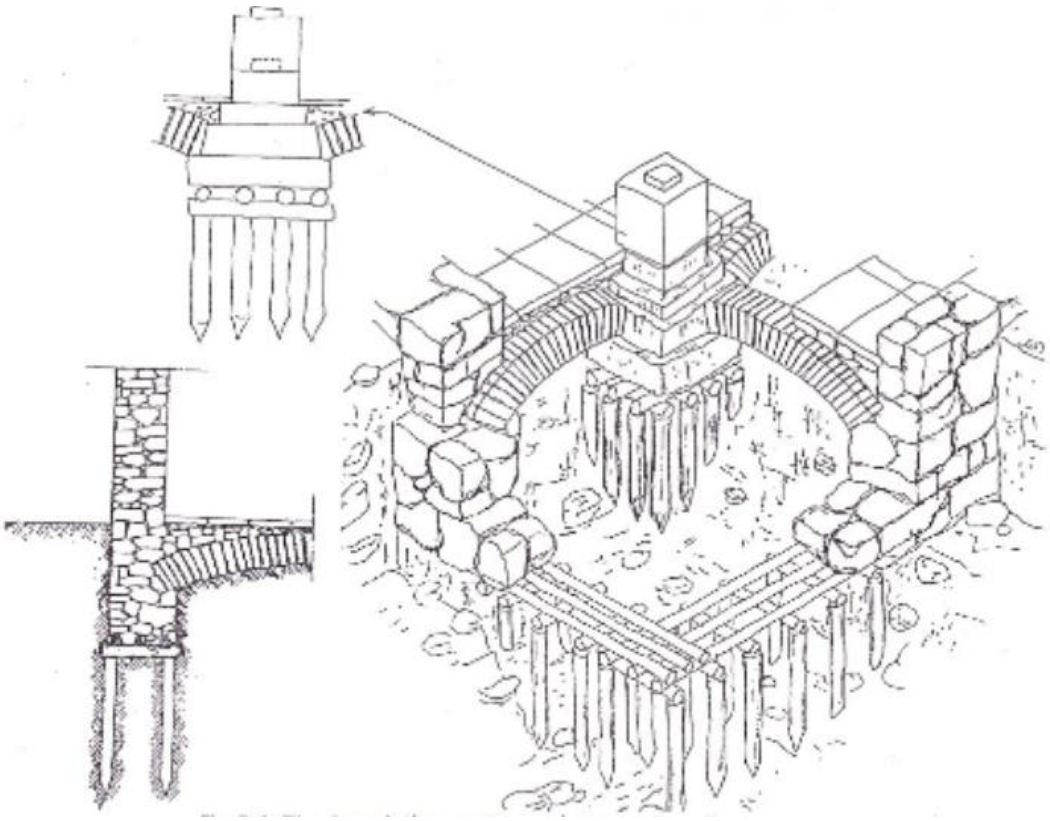


Figure 2.10: Micro piles for strengthening foundation

(b) Interventions for structural improvement as presented in **Figures** 2.11-2.14:

- Injections in cracks
- Strengthening roof diaphragms with plywood
- Transversal anchorage in walls
- Strengthening masonry column with jacketing
- Repair of damaged wood elements

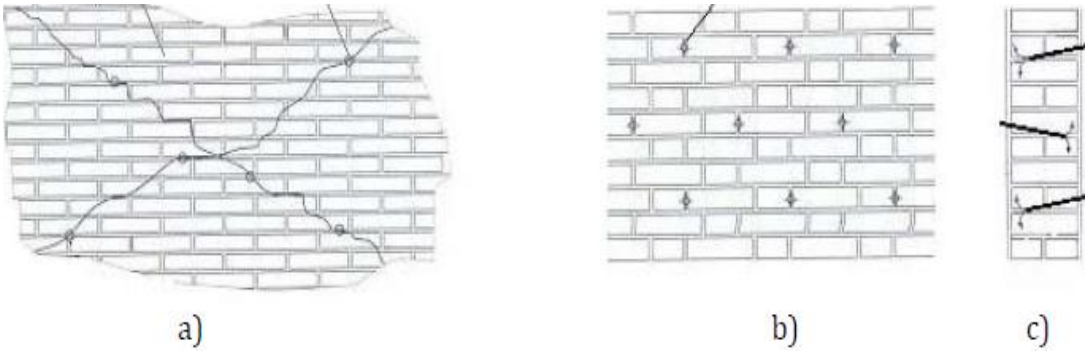


Figure 2.11: (a) injection in external/face diagonal crack; (b) injection for the internal cracks; (c) side view

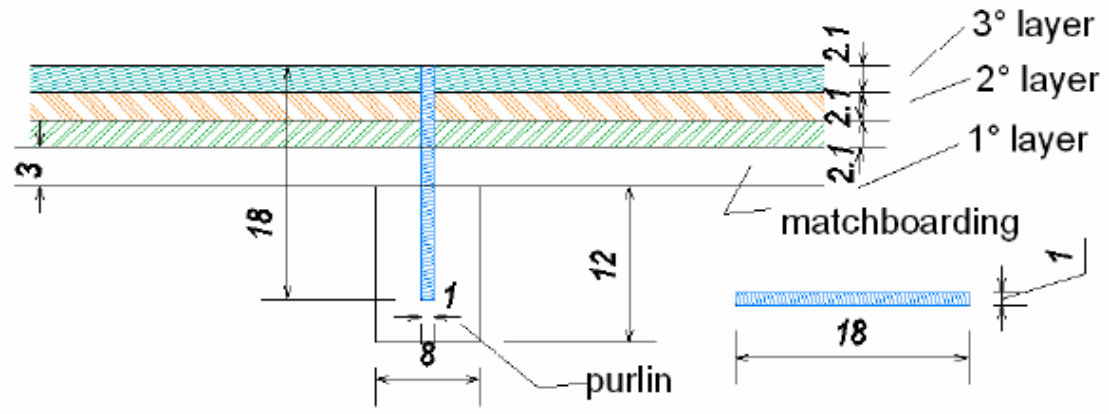


Figure 2.12: Scheme of the intervention on the roof diaphragm, consisting in the application of multilayer panels and chemically anchored steel connectors

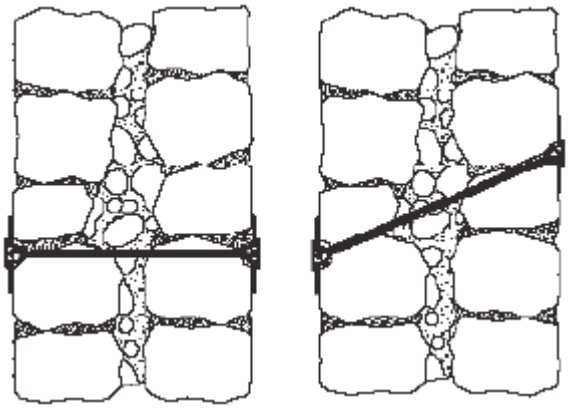


Figure 2.13: Face to face connector in wall of two layers

Figure 2.14: a) Rotten wood joists at the connection to the wall; b) Rotten wood elements

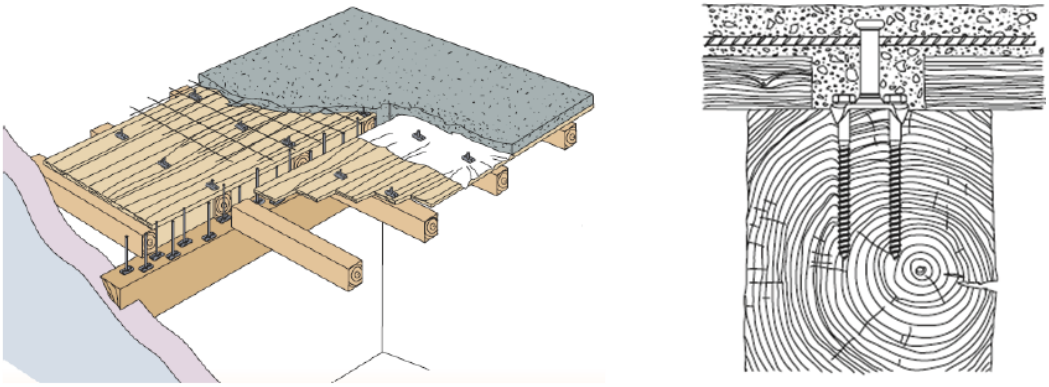
(c) Global interventions for structural improvement as represented in **Figures** 2.15-2.25:

- Strengthening of masonry walls with reinforced cement coating.
- Strengthening of masonry walls with polypropylene meshing.
- Strengthening of floors and improving the connection floor/wall.
- Strengthening with composite materials (CFRP and GFRP).
- The use of horizontal tie-rods.

- Retrofitting by post-tensioning
- Strengthening with ring beams:
- Retrofitting by introducing RC shear walls
- Strengthening with RC or steel frames

Figure 2.15: a) Masonry wall from the inside with steel mesh, b) spraying of the cement grout into the wall

Figure 2.16: a) Implementation of PP band method of retrofitting in Kathmandu Valley b) anchorage throughout the wall



(a) (b)

Figure 2.17: a) Example of the reinforcement of a wooden floor with a cooperating reinforced 'concrete slab, b) Basic connectors Tecnaria

Figure 2.18: In plane stiffening with metallic diagonals and reinforcement of connection floor wall

Figure 2.19: Photo of the connection with L-shaped steel plates between wooden floor and masonry wall

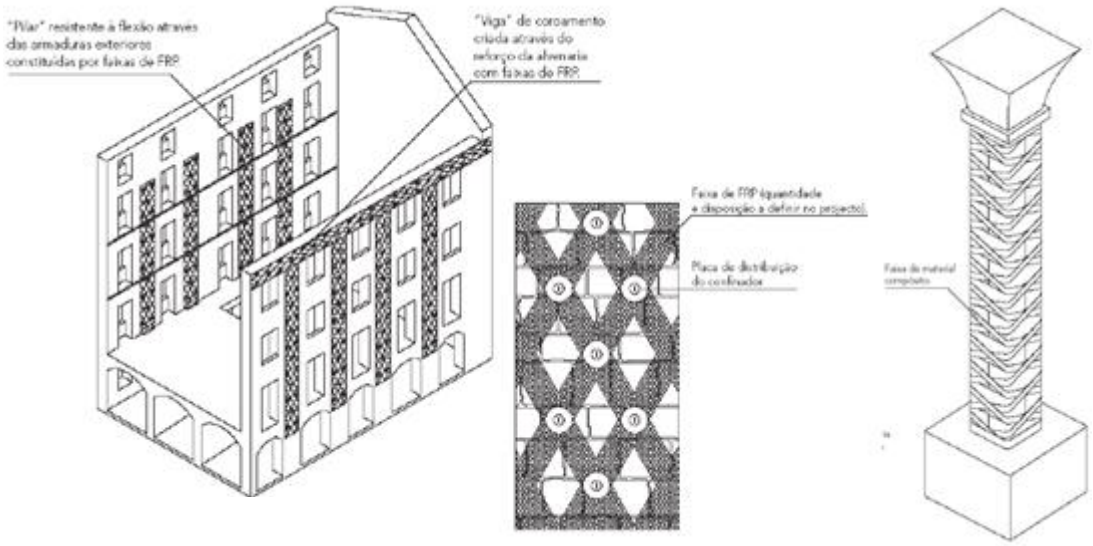


Figure 2.20: Application of CFRP/GFRP on a building, wall and column

Figure 2.21: Tying of masonry vaults with tie-rods in steel

Figure 2.22: Close-up view of a post-tensioning anchorage

a) b)

Figure 2.23: Details of the reinforcement of the ring beam (left) and view of the ring beam after filling with the concrete

Figure 2.24: Photo of the reinforcement of two perpendicular shear walls

Figure 2.25: A concrete moment frame inside the façade of a large URM building in Wellington

Jacqui Donnelly presented; the behavior of old buildings, a way to make maintenance and repair programs, and procedures to carrying out a maintenance inspection by poses some of the questions that should be asked during the course of a maintenance inspection.[10]

They focused to the damp problems, causes, types, inspection procedures and solutions. Finally they provided the guide lines by Checklists for maintenance inspections.

Maria Rosa Valluzzi, Luigia Binda and Claudio Modena proposed a strengthening technique, based on the insertion of steel bars in the bed joints as shown in **Figure** 2.26; to prevent very specific damage represented by diffused thin cracks, which can lead to long terms effects up to a sudden collapse.

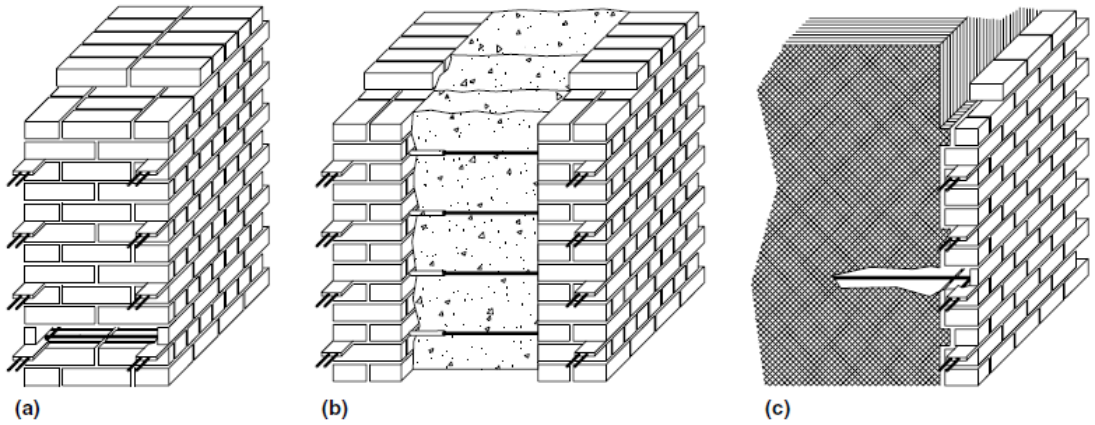


Figure 2.26: Example of application of the technique on different types of brick masonry walls: (a) solid bearing wall; (b) multi-leaf wall; (c) multi-leaf wall with external veneer wythe

They explained the mechanical behavior of brick masonry structures subjected to overloading phenomena. Experimental tests and numerical analyses showed that the presence of the bars allows control of the cracking phenomena, keeping the structure in the desired safety conditions. Application of the strengthening technique to two masonry churches is briefly described. [11]

Emily R. Hopps and Peter M. Babaian discussed how to rehabilitate a historic masonry building, perform the necessary repairs, and maintain the historic aesthetic while using contemporary materials and details. Although the materials and details used to repair and protect historic masonry buildings from future deterioration can be a major source of disagreement in the preservation community. Changing the fundamental construction of an historic masonry wall system is typically discouraged, even if it improves long-term performance and has little effect on building aesthetics. [12]

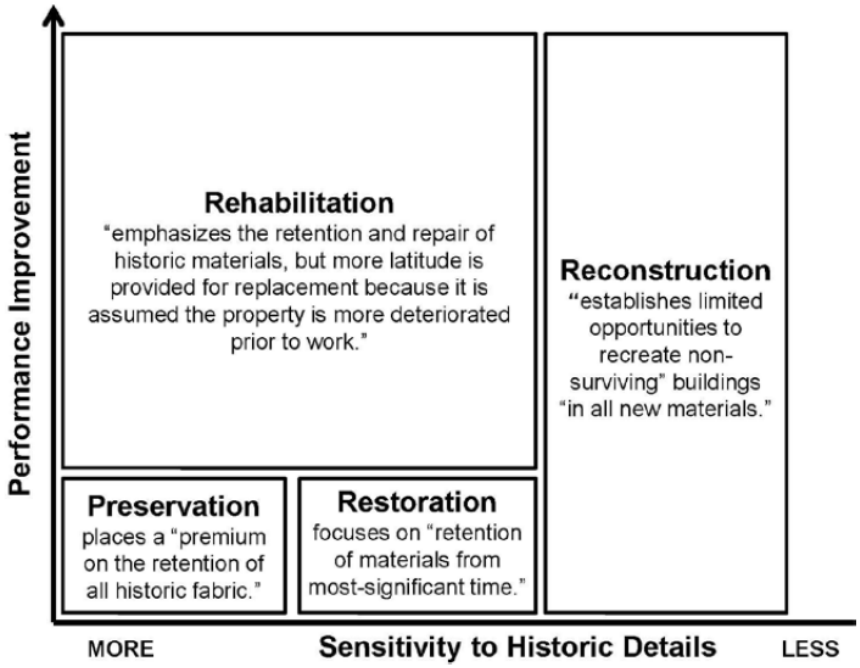


Figure 2.27: Performance versus historic sensitivity for preservation standards

Maria Rosa Valluzzi presents a methodological approach to the study of historical structures in particularly hazardous conditions. Preliminary knowledge, diagnostic methods and assessment procedures are selected and proposed for specific structural problems, in order to define proper improvement techniques to increase safety levels according to preservation and restoration criteria. Both stone and brick masonry structures and their performance under severe horizontal (seismic) and vertical (high-compression) actions, respectively, are examined. The use of traditional, modern and innovative materials and techniques is also discussed, in the light of experimental validation, in order to calibrate analytical and numerical models for reliable analyses and simulations. [13]

Mazin Yahia outlined the restoration and maintenance of archeological buildings, phases of restoration and the classifications of archeological building according to possibility of maintenance. Also provide information on the preliminary studies of the restoration,

maintenance and rehabilitation of the posts and telegraphs offices building. [14]

Safa Hussein Mohammed Modwi accentuated the restoration of historical building, methods of restoration and reconstruction patterns of archeological buildings. Furthermore submitted an overview of historical buildings in Sudan and presented two buildings as example of restoration.[15]

CHAPTER THREE

METHODOLOGY AND CASE STUDY

CHAPTER THREE
METHODOLOGY AND CASE STUDY

3.1 Introduction

Imbued with a message from the past, the historic monuments of generations of people remain to the present day as living witnesses of their age-old traditions. People are becoming more and more conscious of the unity of human values and regard ancient monuments as a common heritage. The common responsibility to safeguard them for future generations is recognized. It is our duty to hand them on in the full richness of their authenticity. So intervening on an historic building, that is any action or process that results in a physical change to its character-defining elements must respect and protect its heritage value. Rehabilitation one of these of interventions, which define is the action or process of making possible a continuing or compatible contemporary use for a historic place or of an individual component, through repair, alterations and or additions, while protecting its heritage value, more than just minor repairs are needed, may include the replacement of missing elements and/or the introduction of new features.

So in this chapter, it discussed methodology of the study under a name of Outlines for Historic Preservation Project. Also it presented the current situation and the problems of a building which is the case study.

3.2 Outlines for Historic Preservation Project

3.2.1 Survey and Carrying Out Inspection

The purpose of survey and inspection is to get an overall accurate view of the entire property. This will help to set goals and objectives to

fulfill needs. Begin with a complete inspection, which will give a detailed critical review of all parts of the building and grounds. (This should be done by a broad and detailed knowledge of the building trades, both past and present. An understanding of how the building was meant to work when it was built and acknowledge of modern technologies are both necessary to accurately determine conditions.). It is important to determine the previous maintenance, cleaning or waterproofing efforts made to the building. Structure-specific background information regarding previous maintenance enables a contractor to understand the repair history and plan new work accordingly.

A preliminary in-situ survey is useful in order to provide details on the geometry of the structure and on the visible damages (cracks, out of plumb, material decay) also identify the points where more accurate observations have to be concentrated. Following this survey a more refined investigation has carried out, identifying irregularities (vertical deviations, rotations, etc.). In the meantime the historical evolution of the structure has known in order to explain the signs of damage detected on the building.

The geometrical survey, including a measure of the loss of verticality or horizontality in the load bearing elements and the type and distribution of cracks in the crack pattern is the first information collected; the type of cracks and their geometry for understanding the causes of damage. Furthermore the type of cracks and their direction help in interpreting even a mechanism of collapse.

To carry out a physical survey used a checklist and camera to make sure nothing has been forgotten or overlooked and it done by a team who has a broad and detailed knowledge of the building trades, both past and present. An understanding of how the building was meant to work when

it was built and acknowledge of modern technologies are both necessary in accurately determine conditions.

Inspect the building methodically to avoid missing any part or element. It is a good idea starting at the highest point of the building, and works downwards through the outside of the building and then systematically inspecting the interior, starting in the roof space. Without avoiding awkward or inaccessible spaces as it is often in these spaces that problems first show up.

3.2.2 Historical Background

On-site investigation as well as archival and oral history research should be carried out as a basis for a detailed assessment of current conditions and previous maintenance and repair work. Known changes should be documented in a chronology or report. If no existing plans are found, then a photographic survey should be carried out and drawings or sketches prepared to record current conditions.

3.2.3 Tests and Monitoring Results

Before repairs and rehabilitation of damaged structures it is essential to carryout detailed condition assessment of the building with nondestructive tests so that suitable remedial measures and repair techniques could be employed.

3.2.4 Research for Suitable Use and Design

It is the mechanism that links a comprehensive understanding of an historic place with interventions that respect its heritage value. Planning should consider all factors affecting the future of an historic place, including the needs of the owners and users, community interests, the potential for environmental impacts, available resources and external

constraints. The most effective planning and design approach is an integrated one that combines heritage conservation with other planning and project goals and engages all partners and stakeholders early in the process and throughout. For historic places, the conservation planning process also needs to be flexible to allow for discoveries and for an increased understanding along the way, such as information gained from archaeological investigations or impact assessments. It is important to maintain a firm sense of the larger picture over the long term and not to emphasize particular character-defining elements at the expense of others.

3.2.5 Structure Interventions

When strengthening an old building, one must focus first on understanding how it is working, then the problems and/or pathologies must be encountered and only then one can start prescribing the necessary solutions for the rehabilitation or strengthening. The common pathologies for old masonry buildings are mainly related to their age, changes and exposure to humidity. On the other hand the masonry can be also damaged, desegregation, crushing, fracture and cracking. The most common causes are related with foundation settlements, movements of thermal origin and horizontal thrusts.

3.3 Case study

The building illustrated here in **Figure** 3.1, is an archaeological building which was built at era of bilateral governance in Sudan, it is one of the oldest governmental institutions in the country and it was the main building of posts and telegraphs offices. It has a distinctive classical character reflected symmetric around the center axis at repeated pattern of the elements used to form the facades with red brick and sandstone cladding at the entrance and confirmative with steep roof tiles and the

sandstone mantle with decorations at the last floor's windows repeated by another frieze on the level of ground floor's windows.

Figure 3.1: The building of the post and telegraph offices

The building is built as a U-shape and embraces an inner hall lounge overlooking the north on sub-street that separates it from the building of the Ministry of Finance and National Economy. It's main façade overlooking the south on University Street. It is bordered at the east with Presidential Palace's Mosque separates them by Mehairaa Bint Aboud Street and from the west by Al-Khalifa Street at the west direction as shown in **Figure** 3.2.

Figure 3.2: An aerial photo illustrate the location of the building

3.3.1 Structural Problems and Need for Intervention

The building was damaged by the time factor due to weather conditions and humans with obvious signs of deterioration in different sides. The structural problems include the following topics:

1. Missing and slipped tiles of roof, so this was caused damage of internal roofs as shown in **Figure** 3.3

Figure 3.3: Internal and external view of damaged roofs [16]

2. Disintegrating mortar, cracks, loose masonry units and damp walls. Also walls suffer from growth of some plants and distortion the façade by coating. **Figures** from 3.4(a) to 3.4(e) demonstrate the problems.

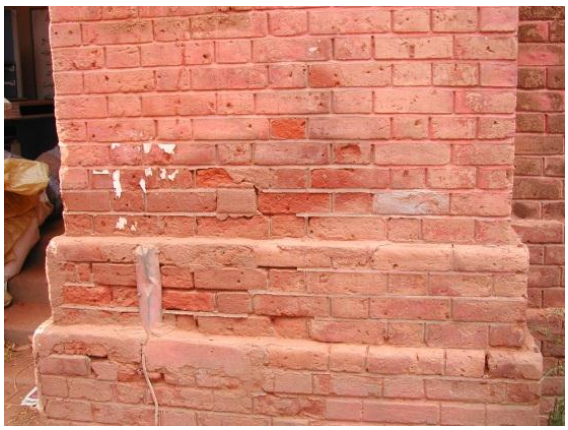


Figure 3.4(a): Disintegrating mortar [16]

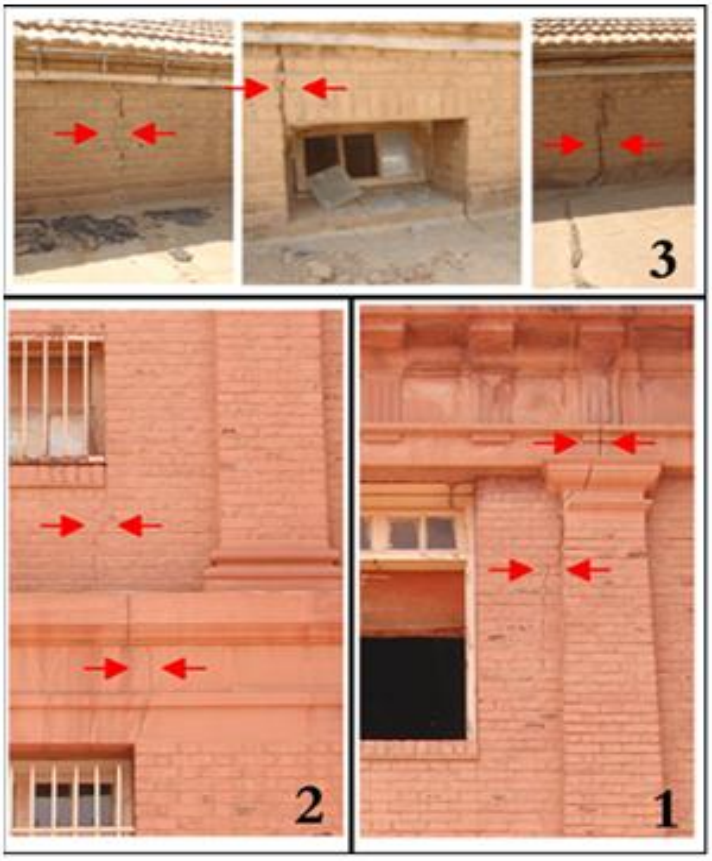


Figure 3.4(b): Cracks in different sides [16]

Figure 3.4(c): Loose masonry units [16]

Figure 3.4(d): Damp walls [16]

Figure 3.4(e): growth of some plants [16]

Figure 3.4(f): Coating distort the façade [16]

3. Most of the windows and doors are damages partially or completely and others are replaced by modern materials. Also some others are closed by brickwork as presents in **Figure** 3.5

Figure 3.5: Nonconformance windows' materials [16]

4. The building's essential services (such as cooling, water, sewage, firefighting, electricity, cabling) connected by scattered way, which deformed outer appearance of the building as illustrated in the **Figures** 3.6.

Figure 3.6(a): Scattered way for connecting cooling [16]

Figure 3.6(b): Scattered way for connecting water [16]

Figure 3.6(c): Scattered way for connecting sewage [16]

Figure 3.6(d): Scattered way for connecting firefighting [16]

5. Added random extraneous elements, which lost the building its general essence as shown in **Figure** 3.7

Figure 3.7: Random elements obscure the main building

3.4 Past Documentation and Previous Maintenance

The process for masonry repair on old building begins with fact-finding, it is important to find the past reports of previous maintenance if it is found and visual documentation from a variety of periods to have a clear understanding of the evolution of the building. So there are some previous data:

1. The building was and until to this rehabilitation for posts and telegraphs offices but in different names according to the develop in different times, **Figure** 3.8 shows a map drawn in London illustrate the location of the building at era of bilateral governance in Sudan, which prove that the same building is for posts and telegraphs offices from that time.

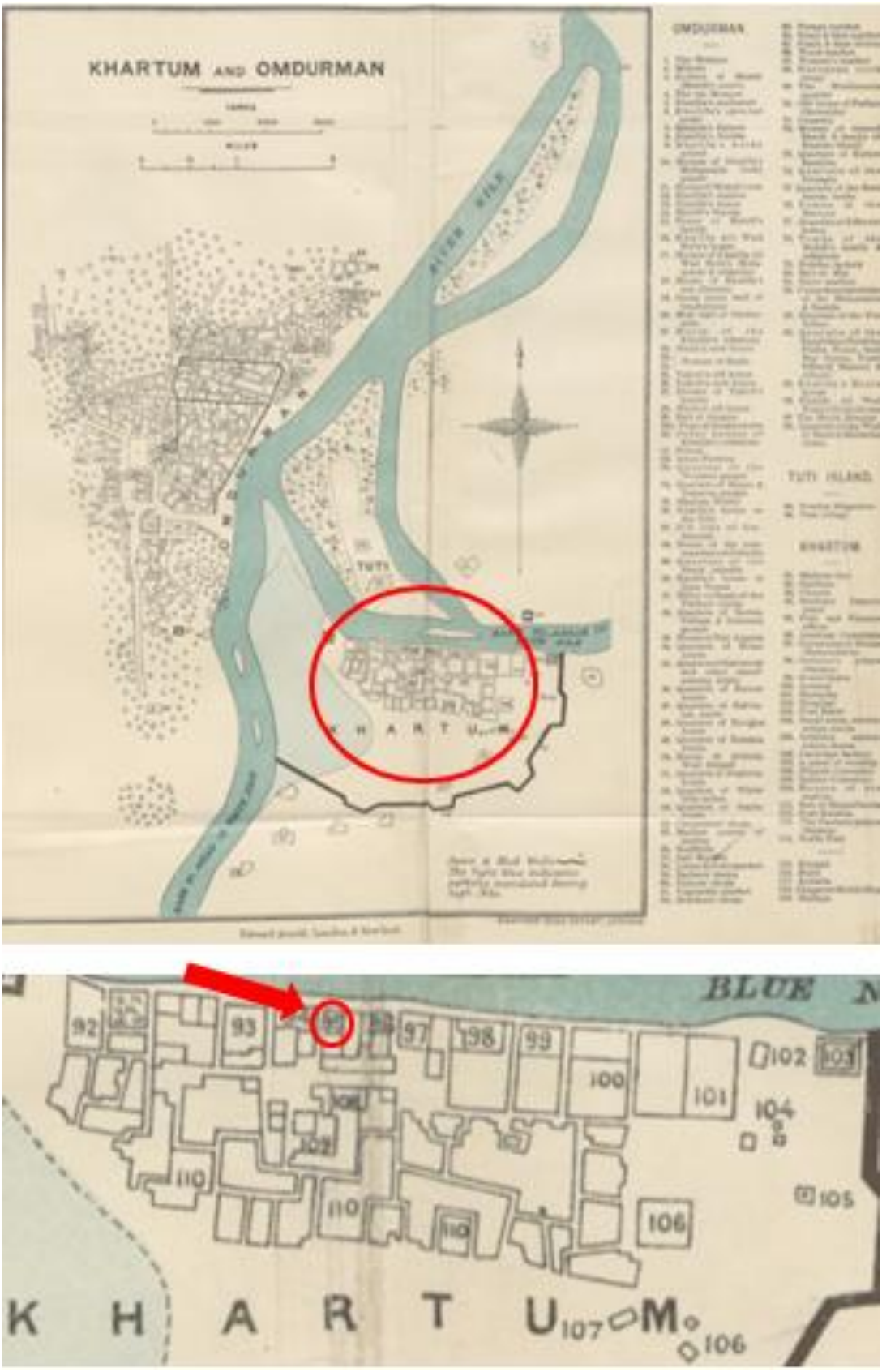


Figure 3.8: A map illustrates the location of the building at era of bilateral governance [17]

2. Aerial photos at era of bilateral governance show the location building in **Figure** 3.9.

Figure 3.9: An aerial photo show the building closed with the Finance Offices and near the Governor's Palace [17]

3. The posts and telegraphs offices was established in two stages, first stage was completed in 1928, **Figure** 3.10(a) viewed aerial photos signifying: stage one for south side and parts from the east and west wings, stage two for the extension parts of them. **Figure** 3.10(b) illustrated the building under construction at stage one.

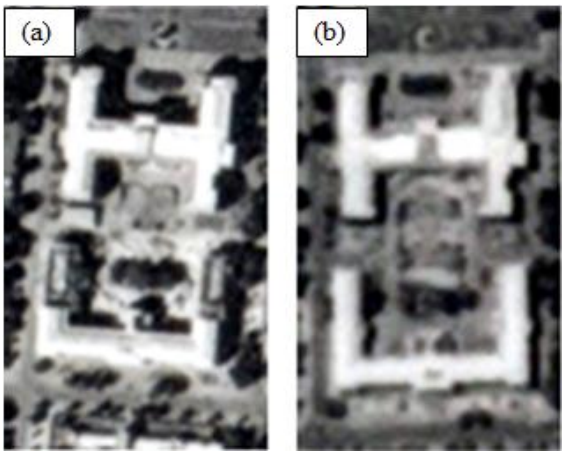


Figure 3.10(a): Aerial photos show the building before and after completion of wings (a) in 1950 (b) in 1957 [16]

Figure 3.10 (b): The north side of the building during the construction of stage one [17]

4. Unfortunately, no reports for previous maintenance or rehabilitation data, so for understanding the history of the building, depend mainly for survey, inspection and tests.

3.5 Tests and Monitoring Results

Obviously the results obtained in situ have controlled with laboratory tests carried out on materials sampled from the construction. Non-destructive evaluation techniques applied for several purposes:

i. Detection of hidden structural elements
ii. Qualification of masonry and masonry materials
iii. Evaluation of the extent of mechanical damage in cracked structures
iv. Detection of the presence of voids and flaws
v. Evaluation of moisture content and rise
vi. Detection of surface decay.

CHAPTER FOUR

ASSESSMENT REHABILITATION OF ARCHEOLOGICAL BUILDING

CHAPTER FOUR

ASSESSMENT REHABILITATION OF ARCHEOLOGICAL BUILDING

4.1 Introduction

To achieve a goal of the maintenance and rehabilitation of old masonry buildings is an important issue since these buildings constitute the historical centers of many cities and thus deserve attention from the state authorities for preservation purposes. This will fact by maintain damage according to standards and rehabilitate the building to update different modern uses from inside without twiddle the external value of the building. To achieve this goal here is practiced of a project for maintenance and rehabilitation of an archeological building which here is the case study.

4.2 Research for Suitable Use and Design

1. The building was built as a U-shape, the southern wing consists of two floors with a partial basement at the western side, the eastern and western wings represent a northern extension of the building and connect to the southern wing at the two entrances and each wing consists of three floors with a basement as seen in **Figure** 4.1.

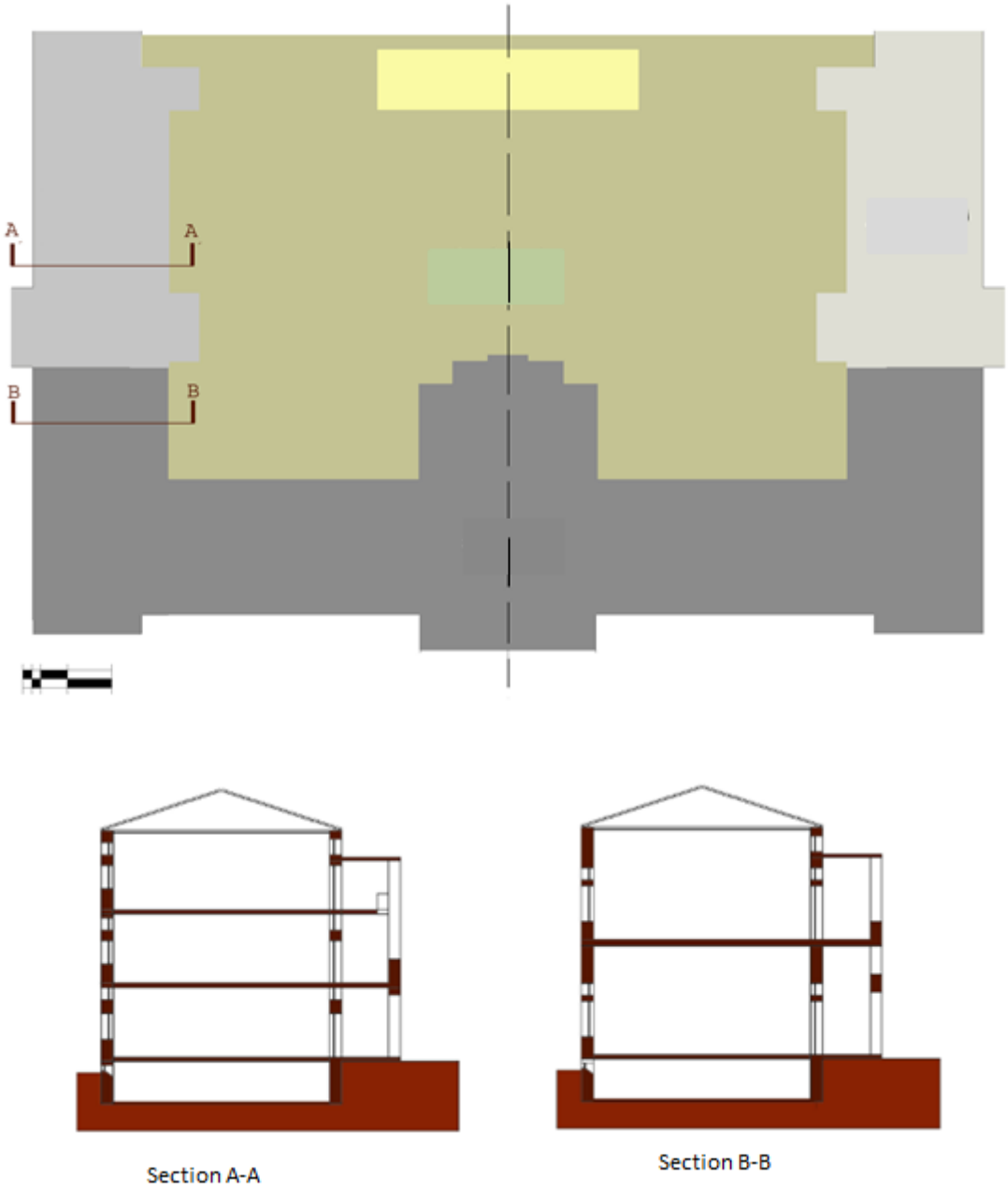


Figure 4.1: Sections for the building [16]

2. According to the location of the building and the sitting extension of the Ministry of Finance and National Economy, so is decided to make the building affiliated to the Ministry of Finance and National Economy. **Figure** 4.2 shows the closed relation between two buildings

Figure 4.2(a): The closed relation between the buildings of the Ministry of Finance and National Economy & the posts and telegraphs offices

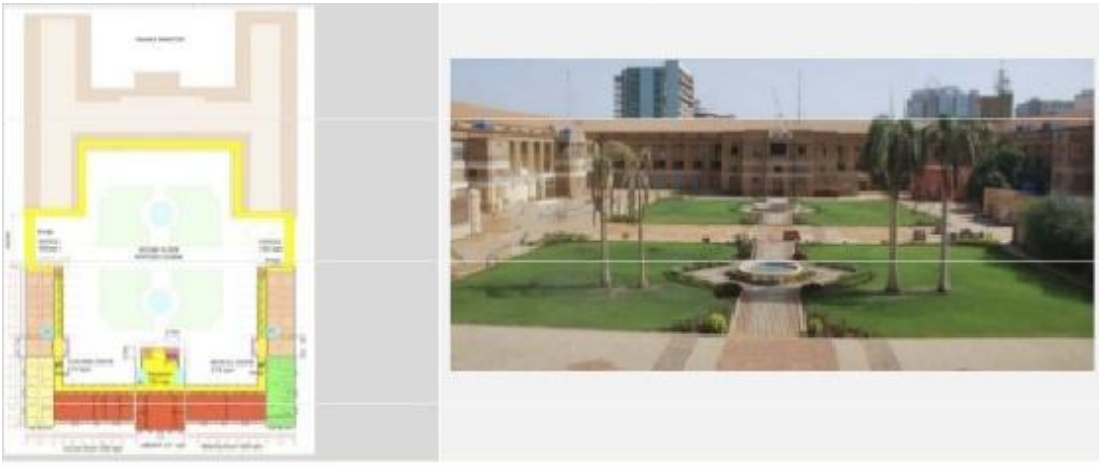


Figure 4.2(b): The two buildings as one unit (the Ministry of Finance and National Economy & the Posts and Telegraphs offices) [16]

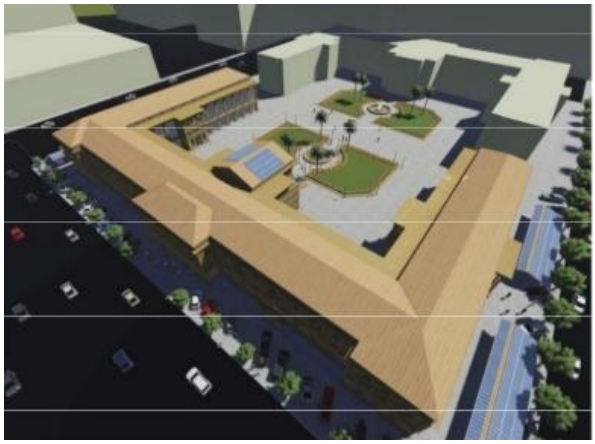


Figure 4.2(c): The two buildings as one unit (the Ministry of Finance and National Economy & the Posts and Telegraphs offices) [16]

3. To evaluate the relative importance of the various spaces, the assessment should identify architectural features and finishes that are part of the interior's history and character. So it is useful to add elevators and stairs without cause any damage to the main building. Installing permanent partitions in secondary spaces and making use of demountable partitions, when subdivision of a character-defining space is required to accommodate a new use as shown in **Figures** 4.3(a), 4.3(b) and 4.4.

Figure 4.3(a): New stairs and elevators at the main north entrance [16]

Figure 4.3(b): Adding stairs at the main north entrance [16]

Figure 4.4: Inside the building after removing old partitions

4. One reason for improving the structural system of a given building, for instance, the objective of changing its use an adaptation to new usages and facilities, secondary services are those which deliver cooling to rooms and corridors, electricity, data services to sockets, water and drainage to and from bathrooms and kitchens. Limited work has taken place in connection with some maintenance work such as:
    - Replace the outside bathrooms by new bathrooms inside the building by build new wall inside the specific area as cladding to install connections.
    - Install the electricity and data services networks inside walls as illustrated in **Figure**4.5.
    - Change the cooling system to a center cooling to avoid the units on facades. Also add glasses curtain walls at halls to safe cooling inside.
    - Replace the water's tanks with anther in hidden place.

Figure 4.5: Installation of electricity network

5. The maintenance tasks associated with windows and doors will involve ensuring they remain weather tight and operational and that the different materials of timber or metal, glass and putty are kept in good condition. The external windows will be double as they are, the external unit will be timber and the internal unit will be metal with glasses which are the same design in the past. Also the doors and internal windows will be metal with glass as they are. **Figure** 4.6 shows the maintenance of internal doors and windows.

Figure 4.6: Maintaining internal doors and windows

4.3 Structure Rehabilitation

Depend on preliminary survey and tests the causes of damage related to time, water penetration, humidity, vegetables attack. So it is very important to do some interventions to stop cracks, deterioration, segregation and safe the building. On the other hand, it is very important documenting all interventions that affect the features that support traditional practices, and ensuring that this documentation is available to those responsible for future interventions:

4.3.1 Structure Intervention in Roofs

To stiffen and strengthen the roof diaphragm, one can adopt an intervention that is compatible with the original timber structure by replacing the damaged members and add insulator layer before fix roof tiles as seen in **Figure** 4.7.

Figure 4.7: Structural interventions in roofs [15]

4.3.2 Structure Intervention in Foundations:

According to penetration from outside and settlement by time, some cracks occur. To solve the problem some intervention is done by

injected, maintained damage and covered foundations to caulked voids as shown in **Figure** 4.8.

Figure 4.8: Excavate foundations for maintenance

4.3.3 Structure intervention in walls:

1. Inject cracks to maintain by use suitable grout, internal and at face to preserve the original aspect of the exterior of the wall. For large cracks will be bonded before injection. This solution is based on the injection in holes previously made with injection tubes and spread throughout the wall, to fill with the grout the internal cracks. For the external cracks the coating should be removed previously and the injection tubes may be used also. A cementitious based grout is used. To deliver a specific injection grout one must carry on in situ and laboratory tests to refine the grout.
2. Repair brickwork by care for the important contributors factors to the visual character of brickwork, namely the brick itself and the craftsmanship. Between these, there are many more aspects worth noting, such as color range of bricks, size and shape variations, texture,

bonding patterns, together with the many variable qualities of the mortar joints, such as color, width of joint and tooling, e.g. shown in **Figure** 4.9.

3. Repointing mortar joints after solve deficiencies that result from other problems. The root cause of the deterioration—leaking roofs or gutters, differential settlement of the building, capillary action causing rising damp, or extreme weather exposure—should be dealt with prior to beginning work. So the repointing will be after determining the most appropriate solutions to the problems and eliminate the source of the problem**.**

   To do repointing begin with Finding an appropriate Mortar Match Preliminary is necessary to ensure that the proposed repointing work is both physically and visually appropriate to the building. Analysis of un-weathered portions of the historic mortar to which the new mortar will be matched can suggest appropriate mixes for the repointing mortar. In creating a repointing mortar that is compatible with the masonry units, the objective is to achieve one that matches the historic mortar as closely as possible, so that the new material can coexist with the old in a sympathetic, supportive and, if necessary, sacrificial capacity. The exact physical and chemical properties of the historic mortar are not of major significance as long as the new mortar conforms to the following criteria:

   - The new mortar must match the historic mortar in color, texture and tooling.
   - The sand must match the sand in the historic mortar. (The color and texture of the new mortar will usually fall into place if the sand is matched successfully.)

- The new mortar must have greater vapor permeability and be softer (measured in compressive strength) than the masonry units.

4. Protecting and maintaining interior and exterior features through appropriate repairs to their functional parts and by using appropriate surface treatments, such as cleaning, rust removal, limited paint removal and reapplying protective coating systems in kind.

Figure 4.9: Bricks replacement in columns [15]

Finally **Figures** 4.10(a) and 4.10(b) shows northern and southern view for the building after finishing rehabilitation.

Figure 4.10(a): North view for the building after rehabilitation [16]

Figure 4.10 (b): South view for the building after rehabilitation [16]

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Throughout this research it was concluded that:

1. The maintenance and rehabilitation of masonry buildings is a unique process; according to masonry units' features.
2. For historic and archeological buildings can be disruptive and complex; it is essential that the principles guiding should be agreed and be laid down on an international basis, with each country being responsible for applying the plan within the framework of its own culture and traditions.

5.2 Recommendations

For the maintenance and rehabilitation of masonry building, it was recommended that:

- Document all stages of building's maintenance including the preliminary studies stage, to facilitate the absorption of future maintenance.
- Recruitment skilled labor in the interest project, especially for activities related to masonry features.
- Refer to international and local charters at maintenance of archeological and historical buildings.

The rehabilitation of masonry buildings is very important issue essentially this type of buildings represent most of the archeological buildings, it is recommend that to many researches about:

- The technics and workmanship in maintenance of masonry buildings.
- The rehabilitation of archeological buildings in Sudan, problems, challenges and solutions.

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