EVALUATION AND RESTORATION OF SAM CITY GRAND MOSQUE, YEMEN

(Thesis)

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MASTER CIVIL ENGINEERING STUDY PROGRAM
FACULTY OF ENGINEERING
LAMPUNG UNIVERSITY
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2024

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EVALUASI DAN RESTORASI MASJID AGUNG KOTA SAM, YAMAN

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(Thesis)

As one of the requirements for achieving a
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ABSTRACT

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This study evaluates the issues and remedies concerning the Grand Mosque in Sana'a City, where various signs of damage have emerged, including dirt accumulation, protein deposits, and plaster stains on wooden surfaces. It was found that precipitation has affected the wooden panels composing the northern wing's ceiling. Water leakage from the southern wing's ceiling, carry-ing soluble materials, has heightened moisture levels, resulting in the emergence of dark spots. Thick gypsum deposits, particu-larly beneath wooden beams and in lower sections, have caused the ceiling structure to lean towards the western wall over time. The study diagnoses damage manifestations and applies treatment and maintenance stages, starting from environmental and photographic documentation, proceeding with mechanical cleaning, filling cracks and gaps, and culminating in the protec-tion and prevention of the Grand Mosque's north wing and its five domes by addressing the gaps. This research holds signifi-cant importance in tandem with maintenance and restoration endeavors. It encompasses all intervention stages and serves as a valuable guide for future maintenance efforts, enabling restorers to evaluate completed work and make necessary adjustments to the intervention process as required.

Keywords: Grand mosque; Restoration; Mechanical Cleaning; Structural Assessment; Sustainable Preservation.

ABSTRAK

EVALUASI DAN RESTORASI MASJID AGUNG KOTA SAM, YAMAN

OLEH :
ALA ALI QASEM ALRAIMI

Studi ini mengevaluasi masalah dan solusi terkait Masjid Agung di Kota Sana'a, di mana berbagai tanda kerusakan telah muncul, termasuk akumulasi kotoran, endapan protein, dan noda plester pada permukaan kayu. Ditemukan bahwa curah hujan telah mempengaruhi panel kayu yang menyusun langit-langit sayap utara. Kebocoran air dari langit-langit sayap selatan, yang membawa material yang mudah larut, telah meningkatkan tingkat kelembapan, yang mengakibatkan munculnya bintik-bintik hitam. Endapan gipsum yang tebal, terutama di bawah balok kayu dan di bagian bawah, telah menyebabkan struktur langit-langit condong ke arah dinding barat dari waktu ke waktu. Penelitian ini mendiagnosis manifestasi kerusakan dan menerapkan tahapan perawatan dan pemeliharaan, mulai dari dokumentasi lingkungan dan fotografi, dilanjutkan dengan pembersihan mekanis, mengisi retakan dan celah, dan berpuncak pada perlindungan dan pencegahan sayap utara Masjidil Haram dan lima kubahnya dengan mengatasi celah-celah tersebut. Penelitian ini sangat penting seiring dengan upaya pemeliharaan dan restorasi. Penelitian ini mencakup semua tahap intervensi dan berfungsi sebagai panduan berharga untuk upaya pemeliharaan di masa depan, memungkinkan para pemugaran untuk mengevaluasi pekerjaan yang telah selesai dan membuat penyesuaian yang diperlukan untuk proses intervensi sesuai kebutuhan.

Kata kunci: Masjid Agung; Restorasi; Pembersihan Mekanis; Penilaian Struktural; Pelestarian Berkelanjutan.

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Stating truthfully that this thesis is the result of my own research, thoughts, and presentation and has not been submitted in any form to any university. Sources of information derived or quoted from published or unpublished works from other authors have been mentioned in the text listed in the Bibliography at the end of this thesis.

If in the future there are irregularities and untruths in this statement, then I am willing to accept sanctions for such actions. Thus, I make this statement consciously and without coercion from any party.

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MOTTO

QS. Al-Baqarah: 282

Allah Almighty wants the believing man to be a teacher to others, and to achieve this, Allah gives the believers the greatest book, which if they contemplate and reflect upon it the right to contemplate, it's going shorten them long distances in complex issues and matters, when he almighty says: "وَاتَّقُواْ اللّهَ وَيُعَلِّمُكُمُ اللّهُ وَاللّهُ بِكُلِّ شَيْءٍ عَلِيمٌ".

QS. Al-Nahl: 68

Here, Allah teaches us an integrated curriculum in civil engineering by reflecting on Surat Al-Nahl, in which Allah almighty says: " وَأَوْحَى رَبُّكَ إِلَى النَّحْلِ أَنِ اتَّخِذِي مِنَ الْجِبَالِ بُيُوتًا وَمِنَ الشَّجَرِ وَمِمَّا يَعْرِشُونَ", where Allah draws our attention to creatures of his making by explicitly mentioning them by name in the Qur'an, and among these creatures (bees), and exhorts us to reflect on the wonderful creation of these creatures, because they are school in engineering design.

QS. Al-Hashr: 2

Fortress, which is a building built for military purposes and to repel external invasions. The forts were mentioned in their well-known wording in the verse "وَظَنُّوا أَنَّهُمْ مَانِعَتُهُمْ حُصُونُهُمْ".

QS. Al-Haj: 40

The places of worship for Muslims and non-Muslims. The temples of the three major religions have been combined in one verse, which is the Almighty's saying: "لَهُدِّمَتْ صَوَامِعُ وَبِيَعٌ وَصَلَوَاتٌ وَمَسَاجِد".

QS. Al-Zukhruf: 33

The ceiling and stairs: " وَلَوْلَا أَنْ يَكُونَ النَّاسُ أُمَّةً وَاحِدَةً لَجَعَلْنَا لِمَنْ يَكْفُرُ بِالرَّحْمَنِ لِبُيُوتِهِمْ سُقُفًا مِنْ فَضَّةٍ".

QS. Al-Naml: 44

The floors: It mentioned with the word (edifice) in the story of the Prophet Solomon (peace be upon him) and the Queen of Sheba. Solomon (peace be upon him) ordered that one of the courtyards of his palaces be made of bottles and that water should flow from under it. When the Queen of Sheba arrived at that place, they told her to Enter The edifice, " قِيلَ لَهَا ادْخُلِي الصَّرْحَ ۖ فَلَمَّا رَأَتْهُ حَسِبَتْهُ لُجَّةً وَكَشَفَتْ عَن سَاقَيْهَا ۚ قَالَ إِنَّهُ صَرْحٌ مُّمَرَّدٌ مِّن قَوَارِيرَ ۗ قَالَتْ رَبِّ إِنِّي ظَلَمْتُ نَفْسِي وَأَسْلَمْتُ مَعَ سُلَيْمَانَ لِلَّهِ رَبِّ الْعَالَمِينَ".

QS. Al-Baqarah: 127

The foundations: "وَإِذْ يَرْفَعُ إِبْرَاهِيمُ القَوَاعِدَ مِنَ البَيْتِ".

QS. Al-Kahf: 94

The mentioned in the verses of the creams that are talking about some of the two-century journey station: " قَالُوا يَا ذَا القَرْنَيْنِ إِنَّ يَأْجُوجَ وَمَأْجُوجَ مُفْسِدُونَ فِي الأَرْضِ فَهَلْ نَجْعَلُ لَكَ خَرْجًا عَلَى أَنْ تَجْعَلَ بَيْنَنَا وَبَيْنَهُمْ سَدًّا".

H.R Al-Albani

"If the hour comes and one of you still have a seedling in his hand, and he is able to plant it before it came, let him plant it."

H.R Al- Imam Muslim

"A Muslim does not plant a tree, or sow crops, and a person or an animal eats from it unless it is for him as alms."

Arthar Shubinhawar

"Love without sincerity it's a building without foundation".

Malik Bin Nabi

"Civilization is not a pile, but building and architecture".

Fiktur Huju

“Architecture is the mirror on which people’s cultures, renaissance and development are reflected”.

Stif Jubz

“Design is not about outward appearance or feeling. Design is the way these things work”.

Jamal Eabd Alnaasir

“The fearful do not make freedom, and the hesitant, their trembling hands will not be able to build”.

Ibrahim Nasr Allah

“Whoever is unable to build does not work with demolishing. Let the builders build and work”.

Burhan Ghalyun

“Modernity is a continuous process of building and rebuilding, dismantling and assembling”.

DEDICATION

Alhamdulillah, I express all gratitude to Allah Azza Wa Jalla for his mercy and grace to completed this thesis can be successfully., and the best Shalawat and greetings are always poured out to the prophet Muhammad ﷺ.

With all humility, I especially dedicate this thesis to:

A. My beloved parents, Omi and Abi (Ali Ahmad Qasem Al-Raimi and Samira Nasir Ahmad Alduwm) who have educated, cared for, raised, prayed for, supported, as well as many sacrifices and infinite love so far, may Allah always bless and protect them both.
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Bander Lampung, Jun 2024
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CHAPTER 1
INTRODUCTION

1.1. Background

The Grand Mosque in Sana'a, Yemen, is a timeless marvel of Islamic architecture, embodying centuries of history and cultural richness. Built in the early days of Islam, its design reflects a fusion of Islamic, Arab, and African influences, while its significance as a spiritual and communal center has endured through generations. Surrounding the mosque is the ancient city of Sana'a, a UNESCO World Heritage Site celebrated for its distinctive mud-brick buildings and vibrant marketplace culture. Despite the passage of time and modernization, both the mosque and the city stand as resilient symbols of Yemen's cultural heritage, offering a glimpse into a storied past and inspiring hope for the future.

a. Sana’a city:

According to (Alearshi. 2022), the name of the City Sana’a, which serves as the capital of Yemen, translates to Fortified place Positioned at the western base of Mount Nuqum. Which at an impressive elevation of over 7,200 feet or 2,200 meters" above sea level. Where it’s in the western region of the country, Sana'a has long held the pivotal role of being the primary economic, political, and religious center of the Yemen Highlands remarkably, Sana'a stands as one of the world’s oldest continuously inhabited cities, although an exact date for its establishment remains elusive. Yemeni legend attributes it is founding to Shem one of the three sons of Noah and Sana'a occupies the historic site of Ghumdān, an ancient pre-Islamic stronghold whose origins may traced back to the first and second centuries BCE.

Figure 1, the old *Sam* city. (Duclos, 2019)

b. Sam City:

Regarding to (Stiftungh, 2022), the old city is surrounded by a massive wall 20 – 30 feet 6 – 9 meters" high, pierced by numerous gates. Most notable architecturally is the Bab al-Yamen, which is the Yemen Gate in old Sana'a City, renamed liberty Gate after the revolution of 1962. Old Sana'a includes 106 mosques, twelfth hammams or baths, and 6,500 houses, all built before the 11th century CE. Multistoried tower houses made of dark basalt stone and brick decorated with intricate frieze work and beautifully carved windows. Sanaa's most notable mosque, Al-Jamie Al-Akabir, which is the Grand Mosque that contains a sacred shrine.

c. The Grand Mosque expansion and renovation:

During the reign of Al-Walid Ibn Abd Al-Malik, 96-86 AH / 705-715 AD, there was a significant period of urban development, with several religious structures undergoing expansion, including the Prophet's Mosque and the Grand Mosque of Sana'a. However, this period of growth followed by a time of turmoil and unrest that affected Yemen, particularly Sana'a. This was a result of the shift in power from the (Umayyad's) to the Abbasids, leading to new governance in Mala'a Al-Mutama. Under the new governor, Ali Al-Rabi, significant modifications were made between the years 133 - 136 AH / 752 - 755 AD. One notable amendment was the construction of the eastern gallery, which spanned 117 meters and involved the addition of walls and doors. Additionally, the Arab and oriental gallery extended at the expense of the courtyard, resulting in an imbalance in the symmetry of the two minarets. The positioning of the dome also skewed towards the west. Consequently, the new galleries, columns, and arches divided with orthogonal orientations. (Serjeant, 2020)

Figure 2, the eastern gallery. (Abdul-Mughni, 2022)

The restoration and reconstruction process began under Prince Muhammad bin Yefar after the occurrence of cracks. Some sections of the mosque, including the ceilings and walls, suffered damage in the year 265 AH / 878 CE. However,

Figure 3, Foundation inscription in the south wall of the west and east gallery. (Lawrence. 2021).

these efforts appear to have been either incomplete or insufficient. Therefore, Prince Eryeem took over in the year 270 AH / 883 CE to complete his father's efforts and rebuild the eastern arcade, raising it above the rest of the arcade. (Serjeant, 2020)

Throughout its long history, the holy mosque of the Grand Mosque has received significant attention from both rulers and the public. This is evident in the continuous efforts invested in cleaning projects, architectural improvements, and renovations carried out during various periods of Islamic history, reaching its peak in its current state. (Crill, et al. 2020)

1.2.Problem Formulation

A. Evaluate the extent to which precipitation and water leakage have compromised the structural integrity of the Grand Mosque's wooden ceiling panels and beams.
B. Identify and analyze the various forms of moisture-related damage, such as dark spots, protein deposits, and gypsum accumulation, affecting the aesthetic and structural elements of the mosque.
C. Investigate the causes and effects of the ceiling structure leaning towards the western wall, focusing on the role of thick gypsum deposits and their impact on the mosque's load distribution and stability.

1.3.Research aims and objectives

A. Conduct comprehensive documentation of the Grand Mosque in Sana'a City, such as significant accumulations of organic residues and gypsum on wooden ceilings, and structural damages.
B. Developing and implementing a systematic restoration approach. Through mechanical cleaning, filling cracks and gaps, reinforcing damaged wooden elements, and addressing structural issues.
C. Establish preventative measures and maintenance guidelines to ensure the mosque's structural integrity and aesthetic value.

1.4. Research limits

This study is limits by several factors:

1. Time and place:
   - Starting in December and ending with April during the 2023-2024 years.
   - Indonesia, Bander Lampung city, Lampung University.
2. Sample type:
   - The old and historical Grand Mosque in *Sam* city.

1.5. Research Benefits

1. For the researchers:

   Enhance expertise in heritage conservation and restoration techniques, gain recognition through publication and academic credibility, and build collaborative networks with other experts in the field, fostering professional growth and future research opportunities.

2. For the scientific community:

   Contribute to the body of knowledge on the effects of environmental factors on historical structures, introduce innovative methodologies for diagnosing and treating structural damage, and provide a comprehensive case study for future research and comparative studies in engineering preservation and restoration.

3. For the engineering community:

   Offer practical insights and techniques applicable to restoration projects, contribute to the development of technical standards, and promote interdisciplinary collaboration for holistic preservation efforts in heritage conservation, ensuring high-quality practices and fostering a collaborative approach among engineers, conservationists, and historians.

1.6.Research Authenticity

This study stands out in its originality due to its unique focus on the Grand Mosque in the old city of Sana'a, distinguishing itself from previous research by addressing specific characteristics and challenges within a distinct temporal, geographical, and engineering context. While prior studies may have explored similar issues and solutions using modern engineering methods, this research offers a novel perspective by integrating insights from diverse references and previous studies in the field. By leveraging the experiences of countries renowned for their advancements in building, restoring, and maintaining suburban and historical cities, this study aims to provide a sustainable solution tailored to the specific needs and conditions of the Grand Mosque. Through meticulous analysis and synthesis of relevant literature, this research endeavors to offer innovative approaches and practical recommendations that align with the unique heritage and architectural requirements of the historic site, thus contributing authentically to the advancement of heritage conservation practices.

CHAPTER 2
LITERATURE REVIEW

2.1. Sana’a “Sam” city geometrically:

Regarding to (Pini, 2020), constructed using natural materials, tall buildings in Yemen are wonderfully sustainable and well suited to the hot and dry desert climate of the Arab region. Therefore entering through Bab Al-Yamen which is the huge gateway that allows access to the ancient walled city of Sana'a - is like entering another world. The tall buildings were crammed into the narrow lanes that linked the lush fruit and vegetable gardens to the old market.

Figure 4, the old Sam city map. (Lawrence. 2021).

1. Sana'a buildings

Based on (Yemen, 2022) Sana’a is brimming with buildings that are unparalleled anywhere else in the world. Their magnificence, combined with simple practicality, reflects a fascinating and inspiring architectural vision. The same when walking down the alley, it is practically impossible to estimate the true height of these buildings, but the difference between them and modern buildings is that these buildings were built of mud 300 - 500 years ago. Some skyscrapers in Yemen can be about 30 meters high.

2. Sana’a and Yemeni skyscrapers

Regarding to (Pini, 2020), the architecture of Yemeni skyscrapers is so unique that the ancient cities of Zabid, Shibam” and Sana’a joined UNESCO’S list of world heritage sites, dating back to at least of the eighth and ninth centuries, according to Trevor Marchand. Because it built of mud bricks and needs constant restoration so that it does not collapse due to

erosion factors. Therefore, what really makes Yemeni skyscrapers unique is that they still used in the same way they were hundreds of years ago.

3. Mud buildings

Based on (Pini, 2020), professor of architecture at the University of California, specializing in mud buildings that the uncovered earth is an exceptional thermal mass, as it absorbs heat and releases it slowly. During the day, the walls slowly absorb the heat of the sun that falls on them. As night falls, this heat slowly released, but the earthen buildings kept at a good temperature and this is how Sana'a city buildings work.

4. "Al-dawahi", in Sana'a City

Regarding to (Stiftungh, 2022). Linguistically, (Al-Dahiya) is an Arabic word derived from Duha, which means clarity and manifestation. Thus, it said that the light of the morning has appeared, where the opposite is night and darkness, and the darkness has dissipated. The Duha is the first hours of the day that warmth. Then from this Arabic word in its linguistic meaning and its idiomatic meaning, the name of the Al-Dahiya been derived, and its plural is Al-dawahi. This means modern cities that emerged from the noise, hustle and bustle and pollution of the city to the calmness of the countryside and the purity of its air. Al-Dahiya defined idiomatically as a predominantly newly emerging urban phenomenon that located near major cities, and defined too as a residential area whose residents live the same life of the city, but separated from the big city by empty areas or agricultural fields, as Murphy. Which defines it as transitional urban areas between the countryside and the city, separated from it by an uninhabited space that ranges between 15 - 30 km, and may reach 45 km, which defines it as specific densely populated areas, close to the residential area of the city, but not integrated with it administratively.

Regarding to (Pini, 2020), the Al-dawahi, are a phenomenon as old as the city itself. It appeared in various ancient Yemeni, Iraqi, Egyptian and

Greek civilizations. Al-dawahi appeared around the cities of Pharaonic Egypt, the Assyrian and Babylonian cities of Mesopotamia, and around the various capitals of the ancient Yemeni kingdoms. In Wadi Al-Jawf, a number of the Al-dawahi appeared around the city of Qrnaw, Yathel, Nasheq, Nashan, and Khirbet Al-Hazm. Around the Sabaean City of Ma'rib, the Al-dawahi of Sirwah, Bayhan and Harib appeared, and around the old City of Sana'a, which is one of the most important capitals of the Sheba and Himyarite states, the Al-dawahi of Ghaiman, Shibam and Sekhem, appeared. In the modern Yemeni urban scene, the city of Sana'a was until 1962 AD, surrounded by a number of the Al-dawahi such as Al-rawdah and Wadi Dhaher, which was famous for its gardens, and was known as the capital of the vineyards. That era, either to serve the local community, or to create outlets for visitors, delegations and foreign missions, and the construction of the Al-dawahi cities rich in parks was in line with civilized standards that express the progress of any nation in the past and present, and it will remain so in the future.

Based on (Alearshi, 2022), the suburban "Al-dawahi" cities were defined as improved and pre-planned urban seedlings that located near the main cities with a distance of between 20 and 40 km. Which representing poles of development and mitigation at the same time, and enjoying a combination of city services and privileges, and the calmness of the countryside and the purity of its air. Thus, there are a number of conditions and criteria to define and distinguish modern suburban cities from other cities and urban communities, where these criteria differ from one study to another.

5. Arabic "suqs" marketplaces

Based on (Stiftungh, 2022), the old souks Arabic suqs marketplaces begin at Bab al-Yamen in Sana'a and extend northward past the Grand Mosque in the area that called Suq Al-milh, but it consists of many smaller souks selling a wide variety of goods. Northwest of the old city is the former summer palace of the imam, perched on a steep rock outcrop overlooking the

Wadi Dharr. The garden suburb of Al-Rawḍah, due north of Sanaa city, has a beautiful mosque in the Moorish style. Where Qae Al-yahud, which Jewish Quarter, a walled ghetto in the western part of the city, was long a center for the practice of traditional crafts, such as fine gold and silver metalwork and embroidery. Virtually all the capital's Jews immigrated to Israel in 1949 – 1950, dealing an almost fatal blow to the handicraft economy.

6. Population of Sana'a City

Based on (Alearshi, 2022), in the late 20th century Sanaa's population grew exponentially, from roughly 35,000 in the early 1960s to more than 400,000 by the mid-1980s; its greater metropolitan area urban agglomeration exceeded 1,000,000 in the early 21st century. The city has expanded in all directions with the increase in population, but old Sana'a, reduced to one-tenth of the city's population and the area neglected until the 1980s, when, UNESCO and the Yemeni government initiated efforts to preserve and repair the walled city. In 1986 the walled city was designated a world heritage site.

The Sana'a governorate is the only governorate that is devoid of administrative capital and suffers from the modesty of medium and small cities and urban centers. It is the poorest governorate of the republic in its urban indicators, where the governorate administration, its local council, offices of all executive units, and their administrative staff are located in the capital, and this situation applies to its directorates. Which are unable to the governorate deprived of many of the services and privileges enjoyed by the rest of the governorates, as a large part of its administrative staff are from other than its sons, and the other part is from the segment of the influential and unqualified. This leads to the modest efficiency of its administrative energies, and the inability to collect resources the local and its mismanagement and investment, and even the disposal of most of its resources outside its administrative scope. Where the most dangerous of all that these two criteria - the efficiency of administrative performance and the volume of local resources - are considered the most important criteria in distributing the central

resources of the country among the governorates. All of which leads to limited local and central total resources. Thus, the modesty of the investment allocations in the governorate and the deprivation of its children negatively affect the living, cultural, educational, developmental, and local aspects. Fierce and the political and administrative participation of the governorate's community, contributed to isolating the governorate largely from its geographical surroundings and its regional scope.

The dual functional importance of the development of the “Al-dawahi” of Amanat Al-Asimah crystallizes from this point, as they are sites and poles of development for the governorate of Sana’a, which are poles and centers of relief from the capital at the same time, representing a link between the countryside and the city. The means of transportation, low cost and ease of access, and even established on virgin land characterized by its cheap prices, providing economic temptations that attract investors and businessmen away from the noise, hustle, and pollution of the capital. This helps to facilitate planning and provide services away from the overcrowded capital, as it works to absorb the population surplus. In the future to help diversify options and opportunities, to provide job and housing opportunities for all segments of society.

There are large number of urban communities that surround the municipality of the capital Sana’a City. Where they been classified into two types: the first: rural urban communities, and the second: urban or semi-urban urban communities that can be detailed as follows:

a. Rural Al-dawahi, which the outskirts of agricultural villages, the old and inherited urban communities represented in rural agricultural villages. Which mostly inhabited by their original inhabitants, and characterized by their character and local building materials, and their authentic Yemeni rural construction. Which still exercises its agricultural role of cultivating the land and raising animals. Where there are 140 rural villages in the Municipality of the capital, of these, 55 villages have become walled, and are located between the folds of the urban fabric of

the Capital Municipality in the form of irregular rural pockets within its urban surroundings. In addition, 45 villages are located in a continuous range with the urban countryside, which is destined for urban surrender. In addition, 40 villages surround the urban mass of the city and within the boundaries of the Capital Municipality, representing a nucleus of random urban expansion around the capital. In addition to the presence of 3,117 agricultural villages located within the administrative borders of Sana'a Governorate, surrounding the capital, from all sides, represented by urban centres around which random housing multiplies, and expands horizontally at the expense of agricultural lands and the neighbouring rural environment.

b. The semi-urban dawahi suburbs, which were identified about 20 urban or semi-urban dawahi suburbs around the capital city of Sana'a, are located within the circular range proposed by the study to define the suburbs of the capital city. In addition, a circular distance surrounding the city from all sides, its center is Tahrir Square and its radius is 50km, of these, 18 are located within the administrative borders of Sana'a governorate. In addition, two of them are located outside the administrative boundaries of Sana'a governorate. The total population of the suburbs of Amanat Al Asimah, in Sana'a city estimated at 63,371 people, with a total area of 26.3 km². These Dawahi or Suburbs are very different in their population size and populated area.

2.2.Evaluation and restoration for old buildings in general

1. Evaluation:

a. Structural assessment.

Study of (Miano wt al., 2019), Highlighting the use of different analysis methods and the effectiveness of retrofit strategies for improving buildings' seismic safety.

The study of (Naseralddeen, 2020) reviewed construction documents and conducted field visits for visual inspections. Data collection,

on-site investigations, and geotechnical analysis follow, along with structural evaluation and field/lab testing of construction materials. Engineering structural analysis assesses performance under various loads.

Study of (Huang wt al., 2016) Highlights deterministic analysis, reliability analysis, and probabilistic approaches for structural assessment. Inadequate capacities in structural elements prompt reliability analysis, estimating reliability indices, failure probabilities, and partial safety factors. The study evaluates reinforced concrete elements in existing buildings and recommends repair methods based on a probabilistic approach.

b. Material analysis.

Study of (Barnaure et al., 2020) highlighted Structural assessment of buildings involves destructive, minor-destructive, and non-destructive methods. Destructive methods are reliable but intrusive, and potentially unsuitable for heritage buildings. Minor-destructive methods are preferred for limited impact, while non-destructive methods offer quick but qualitative results, requiring complementing with other methods for precision. Testing methods like acoustic emission, ultrasonic pulse velocity, and rebound hammer tests provide insights into masonry strength and damage levels.

Study of (Döndüren et al., 2017) focused on the "*Edirne-Merkez Demirtaş*" (Timurtaş) mosque, using finite element modeling to conduct static analysis. Recommendations included filling capillary cracks with epoxy plaster, stitching wider cracks with iron plates, and disinfecting and filling larger cracks according to the original material and mesh system. Testing structural capacities and static analysis offer insights into the repair and strengthening of historical buildings.

Study of (Carabaño et al., 2017) Highlighted that building material evaluation has shifted from traditional, limited criteria to prioritizing sustainability with the adoption of life cycle assessment (LCA). LCA offers

a holistic analysis, considering environmental impact across a material's life cycle. This comprehensive approach promotes informed decision-making in construction, emphasizing long-term implications and encouraging more environmentally responsible practices. The evolution towards LCA reflects a growing commitment to sustainability in the construction industry.

c. Historical documentation.

Study of (Hamamcioglu-Turan et al., 2021) highlighted methods used for evaluating the heritage characteristics of historic structures including architectural photogrammetry, pictorial photography, site observations, and historical research. These techniques allow for a comprehensive assessment of the architectural elements, damages, construction techniques, and material deterioration.

d. Environmental analysis.

Study of (Gravagnuolo et al., 2021) highlighted that the future direction involves exploring interoperability between dynamic energy simulation software, BIM, and LCA. The methodology for assessing environmental impacts in historic building conservation utilizes a circular economy perspective through LCA. Includes carbon emissions LCA, evaluates impacts before and after retrofit, and considers the energy required for demolition.

Study of (Angrisano et al., 2021) highlighted that through Life Cycle Assessment (LCA), it was able to achieve Europe Level(s) life-cycle carbon certification for proposed design scenarios, highlighting the sustainability of energy retrofits for historic buildings. Thus, focusing on Villa "*Vannucchi*" in San Giorgio a "*Cremano*" used LCA to assess an energy retrofit project. Hemp material for thermal insulation significantly reduced environmental impacts compared to traditional materials. LCA, a standardized method, quantified resource consumption, environmental

impacts, and emissions, guiding the selection of the most sustainable approach for the historic villa's energy retrofit.

Study of (Karimi et al., 2022) highlighted that sustainable rating systems assess buildings in areas like energy, water, resources, waste, indoor air quality, ecology, operation, maintenance, innovation, and, in some cases, economic and social impacts. These evaluations cover a building's entire life cycle, from design to operation, providing a comprehensive view of its sustainability across environmental, economic, and social dimensions.

e. Functional assessment.

Study of (Hashim et al., 2012) highlighted that functional performance assessment of the old building used Post Occupancy Evaluation (POE) and site observation, focusing on space, security, comfort, and operational cost. Results identified significant issues in space and comfort, while overall satisfaction was good. Challenges included the need for uniform maintenance practices, technical training for staff, and maintenance standards for historical public buildings.

2. Restoration:

a. Seismic Restoration.

Study of (Zhang et al., 2021) highlighted that traditional restoration for historic buildings involves methods like structural enhancements and steel elements, risking damage to the original structure and artifacts. An alternative proposed is an isolation system with a weak restoring force using elastic sliding bearings and jack reaction joints. Applied to Shanghai's Yufo temple, this system improved seismic performance without affecting the superstructure.

Study of (Baharet al., 2012) highlighted that seismic restoration of old buildings employs techniques like post-tensioning, micro piles, and composites (carbon fiber, GFRP) to enhance earthquake resistance. Seismic

isolators, traditional and modern, absorb energy and reduce forces during earthquakes, making them suitable for critical structures. These methods improve structural integrity, reduce collapse risk, and preserve historical significance.

b. Foundation reinforcement.

Study of (Elsamee et al., 2013) highlighted that reinforcing old building foundations involves strengthening existing structures, adding new foundations, and incorporating shear walls. In a Cairo sweet factory, a deteriorated foundation reinforced with a new raft foundation, and shear walls added for improved seismic performance.

Study of (Selmani et al., 2023) highlighted that in restoration the old Illyria Hotel, the foundation reinforced by strengthening existing columns with metal lattice structures, adding bars to building blocks A and B foundations, and constructing new shear walls connected to the existing structure. Satisfactory results achieved, meeting compliance targets using conventional solutions like jacketing and shear walls. This approach effectively enhanced the structural integrity and stability of the old building during retrofitting.

c. Structural upgrades.

Study of (Bansal, 2018) highlighted that structural upgrades in old buildings, achieved through restoration, enhance strength and safety. Methods include adding structural elements, reinforcing foundations, and seismic restoration. Results vary, but the goal is to improve performance, longevity, and adaptability while preserving historical significance. Restoration increases stability, disaster resistance, and provides a safer environment, allowing old buildings to accommodate modern needs without compromising their historical value.

Study of (Lin et al., 2023) highlighted that the structural upgrades in the old building included reinforcing load-bearing brick walls, replacing

floor slabs, and improving seismic performance. Results showed enhanced indoor quality, added functional spaces, and preserved historical value. Façade renovation and solar panel integration contributed to a green retrofit, improving sustainability.

d. Energy efficiency improvements.

Study of (Danial et al., 2023) explores Restoration methods for an existing office building's energy efficiency, including HVAC, lighting, insulation, window, and control system upgrades. Results from design builder and Revit demonstrate a 68% reduction in annual energy consumption, with notable improvements such as a 63% cut in HVAC energy through high-efficiency heat pumps. Emphasizes the effectiveness of these retrofits for certifications like LEED. Revit yields faster results with fewer materials, while design builder demands more precise data entry and longer simulation times.

Study of (Malaysia et al., 2020) highlighted that various technical interventions and retrofit measures implemented to reduce the building's energy use. However, it states that with all the improvements applied to the building, there is a potential to reduce total energy system demand by 45%. Emphasizes the importance of enhancing the energy efficiency and environmental sustainability of historic buildings.

e. Accessibility enhancements.

Study of (Buda et al., 2021) identifying conservation-compatible retrofit solutions for historic buildings, aiming to reduce energy demand while preserving heritage values. Involved a collaborative literature review, addressing barriers like legislation and economic viability. Detailed the assessed retrofit solutions for various building components. Findings emphasized tailored solutions and the need for collaboration among academics, practitioners, and decision-makers in planning energy retrofit measures for historic buildings.

Study of (Andersson et al., 2016) highlighted that the checklist protocol designed to evaluate physical, visual, acoustic, climatic, and emergency accessibility requirements. The goal is to identify areas where improvements could made to enhance accessibility for people with disabilities. Suggests that the checklist protocol could revised to include clearer language, visual aids, and a rating system to better assess and address accessibility needs.

f. Preservation of historic features.

Study of (Besen et al., 2018) mentioned that Restoration old buildings refers to the process of upgrading or renovating existing buildings to improve their energy efficiency, functionality, and overall performance. This can include adding insulation, upgrading windows and doors, improving HVAC systems, and implementing other measures to reduce energy consumption and improve indoor comfort. Restoration old buildings is important for reducing greenhouse gas emissions, conserving resources, and preserving historic structures.

2.3.Review of past researches

Table 1.Review of the past papers:

No	Author/ Year	The Title	Method	Results
1	(Al-wali, 2020)	Traffic jams and their urgent solutions in the city of Sana'a in the Republic of Yemen.	❖ Analyzing the current situation of these bottlenecks in the city. ❖ Analyzing the geographic phenomenon of the administrative	❖ Modesty level of urban planning for city streets. ❖ The narrowness of most of the city's streets, thus reducing its carrying capacity. ❖ Failure to enforce the traffic law; to reduce the occurrence of traffic jams in the city.

			territory of the city of Sana'a	❖ The lack of parking for vehicles in the city, and the limited pedestrian paths in it. ❖ Overtaking on sidewalks by shop owners and sellers. ❖ Excessive use of motorbikes and taxis in the city, and the failure of their drivers to comply with the traffic law.
2	(Ersoy, 2022)	Applying a phase model for the renewables-based energy, transition in the Development of a Phase Model Sustainable Transformation of Yemen's Energy System	❖ Expert interviews and on-site research by local institutions, relevant stakeholders with expertise in the energy sector or political institutions, and academia. ❖ Databases from the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA).	❖ The current path towards renewable energy sources appears to be a challenge for Yemen; however, renewable energy sources represent a sustainable long-term perspective for Yemen. ❖ The energy transition in Yemen is still in its early stages, and upgrading renewable energy sources faces many challenges, especially in the capital, Sana'a

No	Author/ Year	The Title	Method	Results
3	(Al-Akwa, et al., 2021).	The Disaster of Yemen's Flash Floods Impact of and Local Responses to the Torrential Rains and Flooding in 2020 Introduction	❖ Establishing a road project with a length of approximately 3,300 m, tourist, economic, health and social, interspersed with dams and water barriers, to reduce flood disasters.	❖ Sustainable development by building dams and water barriers to reduce the risk of floods and expand the green area in the area in order to raise the groundwater level. ❖ Saila Sanaa project with a length of approximately 3,300 m, a tourism and aesthetic project, a successful transportation project.
4	(IOM, 2022).	An overview of the organization's operational activity in the capital, Sana'a	❖ Repair and maintenance of water and sanitation systems and provision of water, sanitation and hygiene services to support the health and safety of the capital's community	❖ IOM has offices in Sana'a to implement a multi-sectoral response directly in the water and sanitation sectors. ❖ Rehabilitation of infrastructure for basic public services and creation of basic infrastructure.
5	(Al Qatabri, 2020)	Infrastructure and its role in tourism development in Yemen	❖ Liquid waste has become one of the main sources of urban environmental pollution in Sana'a, where there is a sewage network. These networks cover only 30%	❖ Seeking to rationalize water consumption and consider imposing water tariffs on a regular basis. ❖ Creating investment opportunities for the private sector in the areas of operation, management and maintenance.

No	Author/ Year	The Title	Method	Results
6	(Al-Tiri, 2022)	The Road and Road Transport Sector in Yemen: Critical Issues and Priority Policies	❖ Preparing a strategic program to expand rural road projects in Yemen, especially in the capital. ❖ Giving priority to rural road projects that link agricultural, livestock and fish production areas to consumption and processing centers and to export ports.	❖ Develop borderland ports, develop systems, facilitate transit procedures, by improving infrastructure, providing equipment, means of work, and service facilities. ❖ Implementation of comprehensive surveys to know the status of the road network in terms of damages and the costs needed to reconstruct the destroyed roads in coordination and cooperation with the official authorities.
7	(Olmoforni, 2020)	An emergency assessment of the waste situation in Yemen United Nations Development Program Yemen	❖ Rehabilitation of waste collection vehicles. ❖ Improving the waste disposal site. ❖ Revitalization of the recycling industry.	❖ Lack of spare parts is the main obstacle to effective vehicle maintenance, with lack of maintenance skills and tools as a secondary issue. ❖ Rehabilitation of heavy machinery that is not currently operating allows compression and daily coverage of the waste that has been disposed.

No	Author/ Year	The Title	Method	Results
8	(Aljawzi, 2022)	Assessment of Water Resources in Sana'a Region, Yemen Republic (Case Study)	❖ Using several rain gauges and meteorological stations recording rainfall data for various projects in the Sana'a Basin. ❖ Establishment of fifty-six rain gauges and meteorological stations throughout the study area in different places, twelve of which are considered meteorological stations, while the others are considered rain gauges.	❖ Find the amount of annual precipitation to be in the range of 160-367 mm annually. ❖ The number of rain-gauging and meteorological stations in the study area reached fifty-six, but only six stations were found operating in 2020. ❖ There were 233 projects, 168 dams and 65 reservoirs, with a storage capacity of 64.65 million cubic meters and 0.24 million cubic meters.
9	(Wolfrey, 2021)	What is the secret of the unparalleled architecture in the ancient cities of Yemen?	❖ Start with a stone foundation, usually about two meters deep, and then put mud bricks on it in such a way that one brick is overlapped with two on top, and so on. Then building the lofts slowly, they put wooden joists to support the house during construction, and added floors.	❖ The uncovered earth is an exceptional thermal mass, as it absorbs heat and releases it slowly. During the day, the walls slowly absorb the heat of the sun that falls on them. As night falls, this heat is slowly released, but the earthen buildings are kept at a good temperature.

No	Author/ Year	The Title	Method	Results
10	(Al-Ahnomi, 2021)	The old city of sana'a: a living history under threat	Establishment of absorbing basins around the capital, the task of which is to contain the torrential rains that flow heavily towards it, as the capital needs 20 giant basins, according to a study prepared with the participation of experts from Russia.	❖ Work is now underway to establish a single basin in Wadi Al-Ajbar, south of the capital, Sana'a, with a capacity of more than 150,000 cubic metres, which is a very small percentage compared to the volume and quantity of torrents that come from that valley and from the Sanhan area district. ❖ It built hundreds of kilometres of roads of iron-reinforced concrete targeting the streets through which rainwater passes a lot, or the low streets where the rainwater is congested.
11	(Al-Absi, 2021)	Rain water causes severe bottlenecks in the capital's secretariat, and movement is still slow	❖ Develop water harvesting infrastructure to reduce torrential flow risks. ❖ Assess flood damage and support emergency response for affected hom.	❖ A rainwater drainage maintenance project has started in Amanat Al Asimah with local and international partners. ❖ The Mayor inaugurated a rainwater drainage canal in Bani Jarmouz, Bani Al-Harith district.

No	Author/ Year	The Title	Method	Results
12	(Al-Sarari, 2021)	The weather and the Jabal Al-Lawz torrent lurks in the capital, Sana'a	❖ There are at least four large dams to the south and east of Amanat Al Asimah, resident's fear that their collapse, if accompanied by heavy rains, will lead to the erosion and cracking of thousands of buildings in the southern third of the capital in general.	❖ Deployment of early warning systems in 26 points along the Liquid. ❖
13	(Al Bakali, 2022)	The torrential rain threatens the capital... the renewed disaster	❖ Sequester and collect this water and treat it and work on sedimentation of what could deposited from what this water carries, so that rainwater after it descends to the ground called sewage water.	❖ Implementing some of the projects represented in caravans, expanding and cleaning old caravans, expanding and cleaning flood drain channels, in addition to paving some streets and neighbourhoods with stones, and building surface bridges in some of the capital's streets

No	Author/ Year	The Title	Method	Results
14	(Asem, 2022)	Amanat Al-Asimah in the face of torrential rains that fall on the capital, Sana'a	❖ Deployment of early warning systems in 26 points along Al Sailiya and its tributaries	❖ These treatments were concentrated within the city, and did not include the neighborhoods located at the front of the torrents
15	(Al-jadid, 2021)	Rain floods the streets of Sanaa and threatens the collapse of ancient buildings	❖ Inventory of abandoned and damaged buildings, carry out emergency repair and maintenance, and oblige building owners to cooperate with the concerned authorities.	❖ The torrential rains flooded many residential neighbourhoods in the Al-Siyasiya area in the south of Sanaa, and in the Bani Al-Harith area in the north
16	(Euronews, 2022)	Ten people, including four children, died in Yemen as a result of the floods	❖ Almost complete interruption of traffic in a number of streets and intersections due to torrential rains.	❖ Local authorities faced difficulties in raising funds for the maintenance of important and historical sites in the impoverished country.

CHAPTER 3
RESEARCH METHODS

3.1 Research design

The study followed an inductive and analytical approach to diagnose the case of the Grand Mosque in the capital of Sana'a, to know its urban situation and its existing problems, and to anticipate what would be the situation in the future if the seasonal floods spontaneously continually. Through using of references and previous studies in this field, to benefit from the experiences of countries that have made strides in building Al-dawahi suburban cities.

3.2 Place and time of research

This study completed during the years 2023–2024, beginning in December and ending in April, in Lampung City, Indonesia, at the University of Lampung, jl. Profe. Dr. Ir. Sumantri Brojonegoro No.1, Gedong Meneng, Kec. Rajabasa, Ciudad de Bandar Lampung, Lampung 35141.

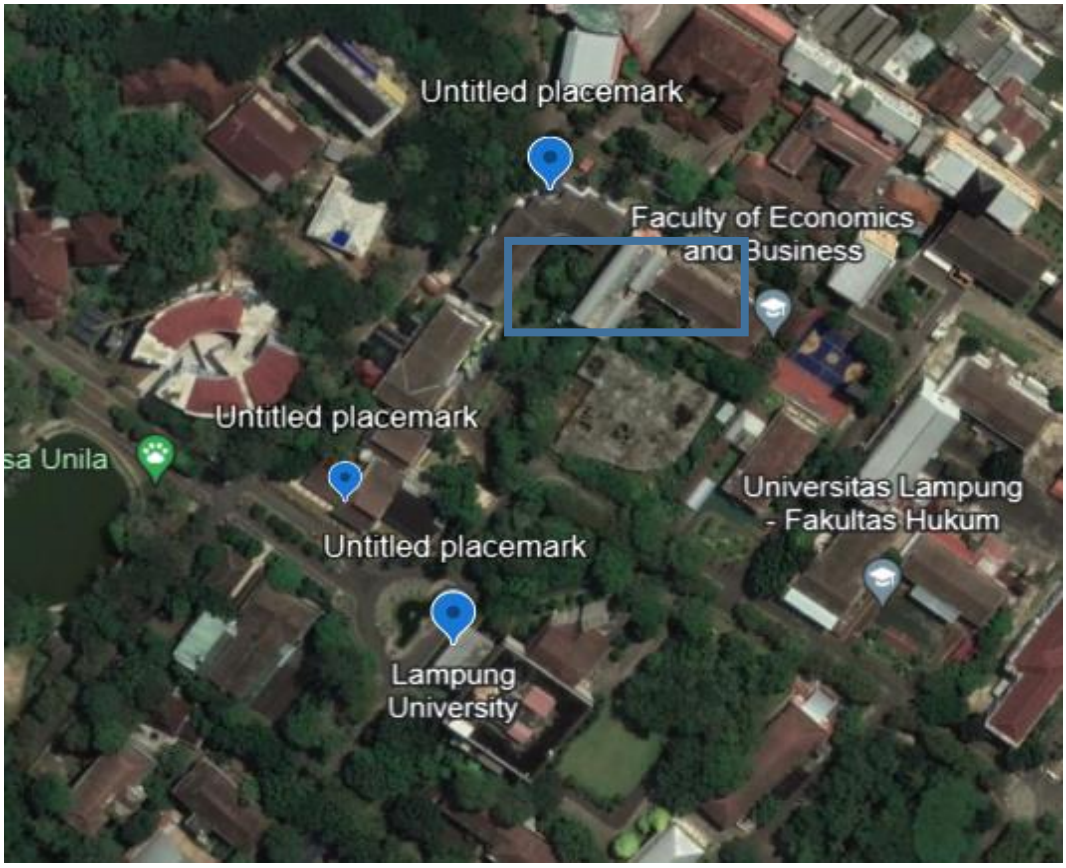


Figure 5, Lampung university location.

3.3 The place and time of the sample type

This study completed regarding the Grand Mosque in Sana'a City, Yemen, during the years 2023–2024, beginning in December and ending in April.

Figure 6, the Grand Mosque in Sana'a city location.

3.4 Research Instruments

a. The results of previous studies.

b. Books, researches, and articles that dealt with the same issue.

3.5 Procedure

1. **Method of collecting information:**

    a. Obtaining permission from the Faculty of Engineering at Lampung University to allow the start of scientific research.

    b. Obtaining a permit from the Yemeni embassy in Indonesia to start scientific research.

    c. Obtaining help from the researcher's friend who is living in the research area for the documentation process.

2. **Analyse the current situation of the city:**

    a. The impact of seasonal floods on people's lives.

    b. Floods and landslides that lead to the destruction of facilities, infrastructure, and public and private property.

    c. Soil and gravel erosion potentially that lead to the blockage of the sewage network and the accumulation of water in the streets.

3. **Analyse the current situation of the mosque:**

    a. North wing:

    - Various signs of damage on the wooden ceilings in the five corridors of the “Qibla”.

    b. The five domes in the north wing, the first portico:

    - Damages in the structural integrity.

    c. South wing:

    - Increased humidity due to water leakage, which causes dark spots to appear.

    d. East wing:

    - A thick and cohesive deposit of plaster was observed.

    e. West Wing:

    - The roof extremely deteriorated condition.

4. **Restoration samples:**

   a. Determine the age of the wooden roof by radiocarbon dating.
   b. Examination and analysis of the type of wood through.
   c. Examine and analyses wooden parts to determine the type of damage.

5. **Sustainable solutions for the mosque:**

❖ **Procedure:**

a. Registration and documentation.

- Comprehensive documentation of every step in the maintenance and repair process.

b. Mechanical cleaning.

- Using chisels, medium-sized hammers, and surgical scalpels, the large accumulation of organic residues and gypsum adhered to the wooden.

c. The five “muqarnas” domes in the northern portico:

- Fixing and fillings the gypsum fillings at the bottom of the domes.
- Insertion of iron supports to reinforce the wooden arches below the domes.
- Removing the stone marble slabs covering the tops of the domes and extracting the unsafe wood panels and plaster blocks.
- Carefully document unsecured planks and assign them numbers.
- Digging trenches to install steel reinforcement around the main dome.
- Connect the supporting metal rod between the original brackets of each walkway by placing two beams side by side. Its edges are shaped like the Latin letter (T).

d. Protection and prevention (disinfection):

- The wooden beams used to protect the roof from the exposed areas above immersed in a biocide solution for two days.

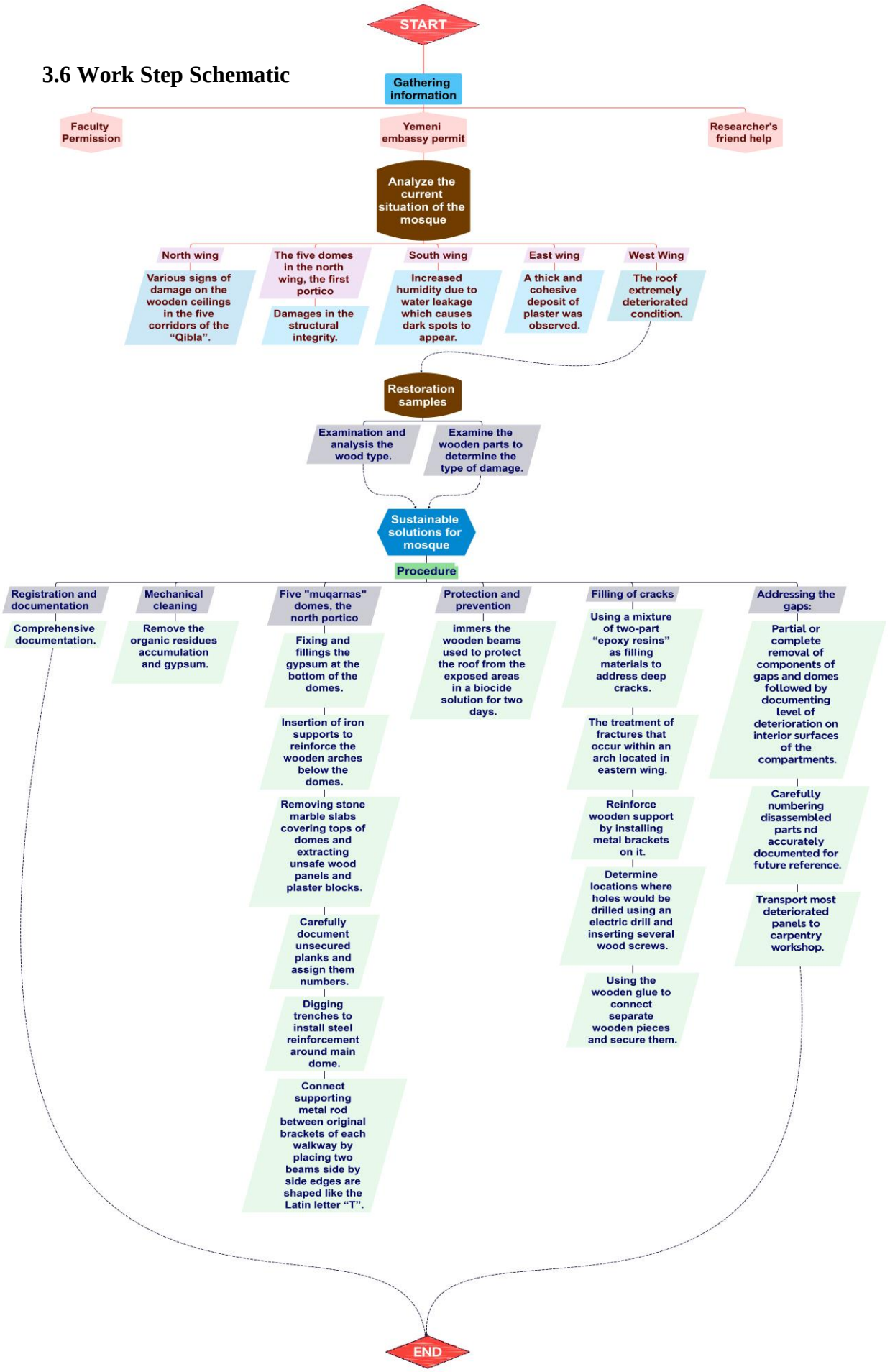
e. Filling of cracks:

- To address deep cracks, a mixture of two-part “epoxy resins” used as filling materials.
- Focusing on the treatment of fractures that occur within an arch located in the eastern wing.
- Reinforce the wooden support by installing metal brackets on it.
- Determine locations where holes will be drilled using an electric drill and inserting several wood screws.
- Use wood glue to connect separate wooden pieces and secure them using metal brackets, wooden dowels, or pressure with rubber to reassemble the loose wooden elements.

f. Addressing the gaps:

- Partial or complete removal of components of the gaps and domes followed by documenting the level of deterioration on the interior surfaces of the compartments.
- The disassembled parts are carefully numbered and accurately documented for future reference.
- Transport the most deteriorated panels to the carpentry work.

3.6 Work Step Schematic



3.7. Data analysis

This study uses the inductive approach, where data, conclusions, and hypotheses collected and tested to arrive at engineering solutions that help in solving the problem of the historic Grand Mosque in Sam City. Through using references and previous studies in this field and benefiting from the experiences of countries that have made strides in the restoration of old buildings. Where this study adopted the following references to derive appropriate and sustainable solutions for the Grand Mosque in Sana'a City:

a. The results of previous studies.

b. Books, research, articles and magazines that dealt with the same issue.

Torrential rains in the Yemeni capital, Sana'a, are a serious and ongoing problem. The city suffers from heavy rains during the winter, and this rain causes water to accumulate in the streets, valleys, and neighborhoods. Torrential rains are a common problem in many cities worldwide, including the Yemeni capital, Sanaa, and specifically the City of Sana’a. It characterized by mountainous and rugged terrain, which makes the drainage of surface water difficult. When large amounts of rainfall occur in a short period, the water collects in the valleys, streets, and flows very quickly, leading to floods.

The problem of torrential rain must be dealt with seriously and the necessary measures taken to protect residents and reduce the risk of deaths, injuries, floods, landslides, destruction of property and infrastructure, that affecting the daily lives of residents.

Through further research, it has become evident that there are three points that should addressed regarding the impact of seasonal floods on people's lives in Sana’a City.

1. The impact of seasonal floods on people's lives, where could indeed cause fatalities.
2. Floods and landslides that lead to the destruction of facilities, infrastructure, public and private property.

3. Clogged sewage network and water accumulation in the streets and neighbourhoods, which negatively affects the roads and streets in the city.

❖ **The main problem of the study:**

Further research has clarified that the points mentioned above also pertain to the construction condition of the Grand Mosque in the heart of Sana'a City. Recent floods completely submerged the mosque due to its proximity to Alsaayilah Al-euzma, resulting in extensive damage, particularly biological damage. This issue serves as the focal point of this study.

The Grand Mosque site:

The famous Grand Mosque is located in the historical city of Sanaa, right next to the Suq Al-milh, along its east-west axis and situated to the south of the city's long wall, and it is notable for its proximity to the Yemen Gate. (Al-Sunaidar , 2024)

Figure 7, General view of the Grand Mosque. (Lawrence, 2021)

Planning:

The design of the Grand Mosque in Sana'a city inspired by the Prophet's Mosque in Al-Madinah. The general architectural layout of the mosque includes a spacious central courtyard surrounded by four corridors, with the Qibla (Prayer Direction) portico being the longest. The building extends from north to south, and its external dimensions are approximately 78 meters by 64.70 meters.

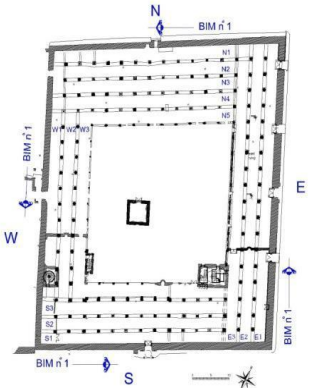


Figure 8, Plan of the Great Mosque arcades. (Abdul-Mughni, 2022)

The mosque was constructed using porous basalt stone for its exterior walls. It features twelve entrances, with five on the eastern side, three on the western side, one on the Qibla wall, and one on the southern side. In the center of the mosque, there is a spacious courtyard with dimensions of 38.90 meters by 38.20 meters.

Additionally, the mosque adorned with two minarets, each rising to a height of 17 meters. These minarets designed in the traditional Yemeni style, influenced by Ayyubid architectural elements. (Al-Sunaidar , 2024)

1. North wing:

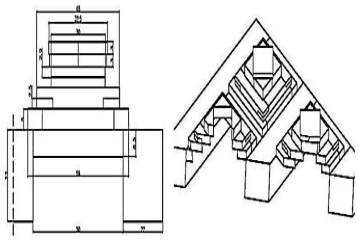


Figure 9, a drawing showing the hierarchical formation of the roof trusses of the Grand Mosque. (Abdul-Mughni, 2022)

- This wing features an impressive space with a depth of approximately 18.5 meters. It consists of five exhibition halls, each characterized by a consistent architectural design. The ceilings of these halls supported by vertical wooden arches mounted on the Qibla wall. It is worth noting that there are five square-shaped chambers built in between each pair of arches. These chambers were constructed using 17 wooden panels.
- Inside the mosque, the Qibla wall displays two beautifully ornamented Mihrabs. The first Mihrab, located to the west of the entrance designated for the congregation, intricately designed and recessed. The second Mihrab almost situated east of the mentioned door, where a flat panel made of gypsum and faces the central courtyard. The upper two panels of the wall appear plain without any decorative elements. However, the two middle panels adorned with elegant inscriptions in calligraphy. The lower panels of the wall surrounding the entrance adorned with arches supported by three columns. A wide frame surrounds the entrance, and each level of the panels separated by a metal belt secured with gravel-studded nails. (Abdul-Mughni, 2022)

2. South wing:

- The southern part of the building consists of three levels of entrances, forming four corridors. Each level features 15 columns of various shapes, adorned with Sabaean crowns. These crowns display intricate designs with multiple facets or Christian motifs and are topped with arches and intricately carved columns from that period.

The crowns also support round arches, and the second and third corridors have a top panel reaching a height of 45 meters. The first corridor is the tallest, with a height of 580 meters. The roof of the fourth corridor constructed using contemporary wooden beams covered with transparent wooden panels.

- Inside this corridor, there a mihrab that suffered, damage during the expansion but is still visible. Additionally, there is another mihrab dating back to the expansion that took place in the Grand Mosque in 1386 Hijri in 1966 CE. The overall dimensions of the southern corridor are 6040 meters by 1510 meters. (Rognon, 2020)

3. East wing:

    - The wing located in the eastern section of the mosque extends along the eastern wall to form the eastern wing. This particular wing is notable for being the longest, with a length of approximately 4150 meters and a width of 11 meters. Structurally, it consists of three bays, with two rows of columns in each bay, totalling 18 columns. These columns support arches perpendicular to the qibla wall. The wing takes on a circular column shape with a tapered design. Its ceiling reaches a height of about 655 meters and supported by arches that are 20 centimetres thick. The wing has a square cross-section and features cohesive ornamentation. The lower facade displays a variety of decorative elements. (Freely ., 2021)

4. West wing:

    - The western section of the mosque covers an area of 3975 × 1190 meters and includes three aisles and twelve arcades supported by arches. The arcades supported by a series of 55 columns, and in the seventh arcade, there is a dividing wall that separates the rear section from the rest of the mosque. In addition, an altar been installed in this area. The western part of the first aisle houses the foundations of the mosque.

CHAPTER 5
CONCLUSION

5.1. Conclusion

This study holds great importance in conjunction with maintenance and restoration efforts for the Grand Mosque in Sana'a City. It covers all stages of interventions and serves as a valuable reference for future maintenance work. Furthermore, it allows restorers to assess completed work and make necessary updates to the intervention process if needed. Where this study estimated the procedure of The Grand Mosque maintenance and restoration through:

1. The procedure commenced with environmental and photographic documentation, encompassing thorough documentation of each stage in the maintenance and repair process. Mechanical cleaning was performed, involving the meticulous removal of significant accumulations of organic residues and gypsum adhered to the wooden ceilings of the corridors. The next steps included fixing and filling the gypsum at the base of the five domes, as well as reinforcing and stabilizing wooden elements damaged by biological agents, which answers the first objective of this study.
2. The gap between the secondary inner ceiling and the outer ceiling was sealed using coarse cotton fibers reinforced with gelatin resin. Special attention was given to addressing fractures within an arch located in the eastern wing in order to keep the original condition by attaching metal brackets and by drilling holes using an electric drill, followed by the insertion of several wooden screws, which answers the second objective of the study.
3. The procedure proceeds by efficiently reassembling the disassembled wooden parts and connecting them with wood glue for stability. Either partially or entirely, removing parts of the gaps and domes was followed by documenting the extent of damage inside. The most damaged panels were transported to the carpentry workshop to start the treatment and to fill the gaps caused by complete decay; alternative wooden panels were crafted using Cordia abyssinica wood, which answers the third objective of the study.

This study has illuminated the profound importance of a holistic approach to the maintenance and restoration of the Grand Mosque in Sana'a City. By meticulously documenting, each stage of the intervention process from environmental and photographic records to intricate mechanical cleaning and structural repairs—this research provides a robust framework that not only preserves the mosque's historical integrity but also ensures its longevity for future generations.

5.2. Recommendations

1. Using reclaimed wooden elements from previous structures in the construction of the Grand Mosque emphasizes the importance of regular and ongoing maintenance procedures for the wooden compartments of the mosque every three months. This includes closely monitoring their condition, addressing any changes promptly, and ensuring their general preservation.
2. Highly recommended the installation of exhaust and ventilation systems to remove fumes generated during religious ceremonies involving the burning of incense. This preventive measure aims to prevent the accumulation of dense black residues on the wooden surfaces.

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