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ARCHITECTURAL APPRAISAL AND CURRENT CONDITION ASSESSMENT OF OTTOMAN MINARETS IN ISTANBUL

Atyaf Akram Ahmed AL-DOORI

Master's Thesis

Supervisor

Assoc. Prof. Dr. Aykut ERKAL

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The thesis titled ARCHITECTURAL APPRAISAL AND CURRENT CONDITION ASSESSMENT OF OTTOMAN MINARETS IN ISTANBUL prepared by ATYAF AKRAM AHMED AL-DOORI and submitted on 17/01/2024 has been **accepted unanimously** for the degree of Master of Science in Architecture.

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ABSTRACT

ARCHITECTURAL APPRAISAL AND CURRENT CONDITION ASSESSMENT OF OTTOMAN MINARETS IN ISTANBUL

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Minarets are considered one of the most prominent monuments that characterize Islamic architecture, which contributed to its prosperity. According to historical studies, the idea of minarets arose before Islam, and in the Islamic period, minarets spread, and their shapes, design methods, and methods of construction developed from one era to another, especially in the Seljuk, Fatimid, Mamluk, and Ottoman eras. The most aesthetic and most famous minarets, they are distinguished by their pencil shape, graceful body, and high height. Due to the influence of time, weather factors, climatic effects, and natural disasters such as earthquakes, these minarets are exposed to great damage, represented by biological and structural damage.

Therefore, this study is concerned with evaluating the Ottoman minarets in the city of Istanbul, being the city of minarets. A reconnaissance study was conducted for ten famous minarets in the city of Istanbul, and their damage was assessed from a structural and biological standpoint. Remedial solutions were also proposed according to the results of the exploratory study to evaluate the current conditions of the minarets.

Keywords: Ottoman Minarets, Deterioration, Remedial Solutions, Damage, Minaret Assessment.

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1. THE APPRIASAL OF MINARETS

As minarets are constructed beside mosques, they are often associated with mosques and other places of worship as recognizable architectural structures. These tall, slender towers have a variety of uses, such as calling the daily prayer and pinpointing the location of a mosque. Although they may be found worldwide, minarets have a special place in Islamic architecture because of their significance in Islamic culture, history, and religion [1]. Today, the world has grown to the point where it can create mosques, including their minarets, using various materials and construction techniques. To meet the changing needs of contemporary society, it is necessary to develop modern minarets and mosques that emphasize their identity and harmonize with the surrounding urban environment. This will restore the architectural significance of mosques, allowing them to serve as both a place of worship and a cultural beacon. [2].

1.1 THE ORIGIN OF MINARETS

Studying the architecture of slender religious structures involves exploring the origins of minarets -tower-like structures closely associated with mosques and have played a significant role in their development throughout history. Interestingly, minarets were not originally a part of Islamic architecture. Initially, calls to prayer were made from the city's walls, mosque ceilings, or other nearby buildings. The most plausible explanation for the emergence of minarets is that the first such structure was created by repurposing Roman Temenos observation towers [4],[19]. It is believed that the Christian church towers influenced the minaret during the Umayyad era in Syria. Depending on the region and period, the minaret took on the form of a tower from local architecture. Therefore, the minaret's appearance, height, ornamentation, and placement varied. The height of the minaret was determined by the range of the call to prayer, which it was traditionally used for [4]. The minaret symbolizes excellent importance in confirming faith and represents a concrete doctrinal certificate of God's unity [5]. It is a significant element in planning a mosque and is influenced by various Islamic patterns from different eras, such as the Safawid, Mamluk period, Ottoman period, Mughal period, and Safawid period [5]. In countries like Egypt, India, Iran, and Turkey, mosques often have minarets in each corner of the mosque. At the same time, there is usually only one minaret in the Islamic West, as in Maghreb [6].

Currently, minarets come in various designs, shapes, and different heights. This diversity in architecture results from incorporating several elements: the boot, transition segment, body, balcony, and spire. The minaret tower includes a staircase that reinforces the entire structure. The architectural variations are based on the form, size, and decoration of each minaret's components (segments). Nonetheless, it is considered that the method in which the minaret was constructed, precisely the presence or absence of the different cross-sections, have significantly involved in forming the minaret's last emergence. It is also worth noting that specific components may be absent from a structure.

Additionally, these components may be combined with other sections or emphasized through multiplication such as balconies, some minarets have more than one balcony. Regarding minarets, various forms have been utilized, including square, octagonal, circular, and rectangular shapes. These can range from slender, pencil-shaped minarets in Ottoman mosques to multi-story minarets in Egypt or square column mosques in the Islamic West [7].

Certain types of towers, particularly multi-storied minarets, can change their geometric shape from one level to another. An example is the minaret built during the Mamluk era in Cairo, which has three levels with a square shape at the bottom, octagonal in the middle, and cylindrical at the top.

Furthermore, the number of levels and the height of the minaret naturally affect the tower's visual appearance. Towers in Morocco, Tunisia, and Algeria have a square shape resembling the Syrian-Umayyad's minarets. Many architectural historians have believed that the square-shaped Maghreb towers found in Spain, North Africa, and Syria were derived from church towers [7]. The Great Kairouan minaret, built in the 8th century, is the oldest square tower in the Maghreb, and it is believed that it inspired domestic constructors. This architectural style was adopted and reinterpreted in several local areas [7]. The Great Kairouan minaret is built on a large square base. However, it consists of three portions resting on top of each other, each with a square shape and decreasing width. The tower's overall height is around 32 meters, as shown in Figure 1.2

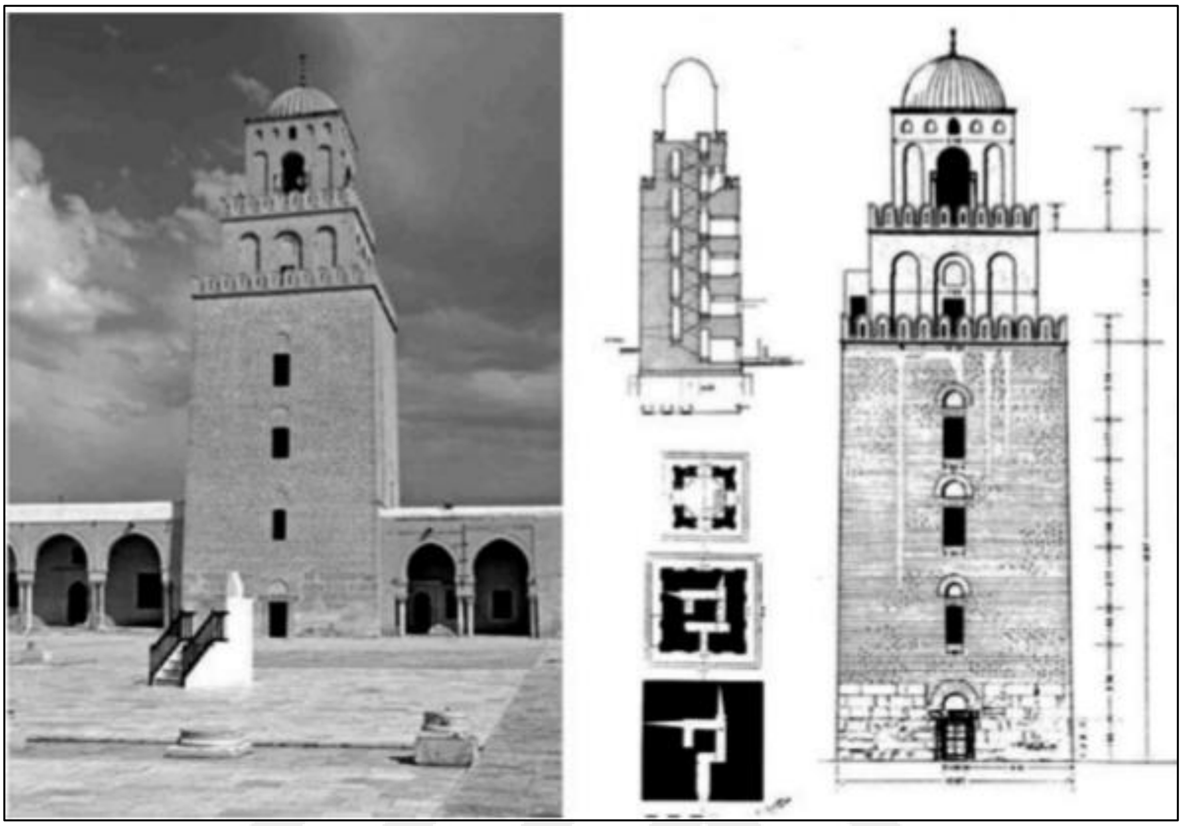


Figure 1.1: Detailed Sketch of Kairouan Minaret Comprising Elevation, Section, Plan, and View [8].

According to [9] description, the first portion has a height of 18.90m and a width of 10.70m. It gradually decreases in size as it goes upward, with a variation of approximately 50cm. The second portion is characterized by a height of 5m and a width of 7.65m. It includes three flat-bottomed curved niches on each of its four faces. The redesign of the third portion is believed to have been done during the Hafsid era and is a lantern with a height of 5.45m. It has a ribbed cupola and is adorned with circular merlons that give the impression of increasing height. This form has been used since ancient times in Africa. The pyramid pattern form of the minaret of Kairouan indicates its belonging to the old-fashioned lighting tower along the coast of Africa. The internal constitution of this building features a staircase that is surrounded by creeping supports. This staircase circles around a central pile with a square section [10]. According to [7], this minaret served as a model for mosques in Maghreb. Its appealing and unique architectural design is a remarkable achievement in Islamic architecture, which explains its widespread acceptance and use in several countries. However, this model changed when the Ottomans arrived in the Maghreb during the 16th century, introducing new shapes and novel patterns for minarets.

It is commonly observed that Ottoman minarets in Turkey have a slender cylindrical or prismatic column that tapers to a point. The column rests on a prismatic base with a larger area, and it is connected to the base by a multi-surface intermediate element, as shown in (Figure 1.6).

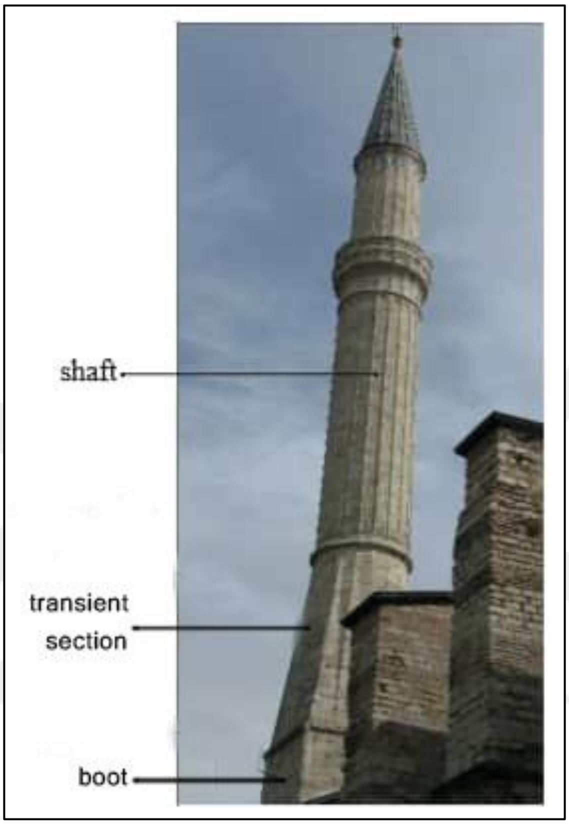


Figure 1.2: Ottman Minaret in Istanbul [16].

The Ottoman minaret is pencil-like and tall, with facets or that are mostly polygonal. Turkish curved triangle called pendentives connects a building's polygonal plan with the rounded dome above it. The body can be cylindrical or have a ring on top or bottom, and it sits on supports with a triangular- shape called "pabuç" above the foundation. These transitional regions are often adorned with Turkish triangle motifs, tall and narrow triangles angled away from each other. During the Ottoman period, minarets with octagonal and cylindrical shapes replaced square minarets with elevated, tapering towers. [14].

1.2 CLASSIFICATION OF MINARETS ACCORDING TO HISTORICAL ERAS

In the 18th century, the minaret became a significant feature of mosques during the Umayyad period. The Great Mosque, located in Damascus, was the first to incorporate a minaret, and it subsequently became a common architectural element in Islamic mosques worldwide [12]. Four towers, known as Ṣawāmi, were constructed near Umayyad Mosque. These towers became a significant element and symbol of the mosque. Additionally, they served as a guide for mobile caravans. The prototype was built in the Sham and resembled square-shaped towers. The prototypes of these minarets were spread to Africa and the Islamic world. As a result, mosques adorned with minarets increased in number, and the shapes and styles of minarets varied from region to region and over time, contributing to the booming art of Islamic architecture. Each area developed its unique patterns and designs. The region's society and civilization influenced the minaret's shape, surface, and color. Generally, the minaret comprises several elements, including the foundation, a spiral staircase or ladder that circulates the axis of the minaret and has small windows for lighting and ventilation, and a balcony where the call to prayer at the top portion of a minaret, above which there is an ornament called the finial (End ornament). It is often topped with a crescent, a symbol of Islam, made of brass or other metals.

Minarets from history can be categorized based on the most frequently used architectural models, as outlined below:

a. Umayyad pattern: The ancient pattern features a foundation closely resembling quadripartite ribs, thick walls, varied galleries, and massive construction as its defining attributes [7].
b. Abbasid pattern: The architecture of Mesopotamian culture, particularly the ziggurats, significantly impacted the design. Rounded cylindrical protrusions, small balconies, increased height, and soft surfaces on external facades with adornments and miniatures characterize ziggurats.
c. Moroccan and Spanish pattern: the minarets are enormous towers with square form, adorned with intricate designs and topped with a smaller pavilion. The primary structural material used is brick, arranged in a precise pattern from all sides. The lower part of the minaret features a specialized balcony.

d. Persian pattern: Tall, slender, circular tower that is often found in pairs surrounding a large entrance. Sometimes, the balcony is elevated, and the minaret is topped with a small dome. The design includes pointed curves for patterning and structural objectives [12]., as well as various forms of decoration and sculptures.
e. Egyptian pattern: Distinguishable attributes emerged in the Fatimid era and were refined during the Mamluk and Ayyubid eras. The minarets are often characterized by hexagonal or octagonal-shaped ribs, resembling a small chair supported by marble columns [12].
f. The Indian pattern: The building's polygonal shaft features ribs that appear near and adjoining columns, with several balconies and decorative stalactites [13].
g. Ottoman pattern: These structures are known for their height, standing at over 50 meters tall, and feature multiple minarets with a pointed shape covered in lead sheeting. The upper balcony resembles the tip of an arrow pointing towards the sky.
h. Twisted pattern: [14] has a cone shape, with a staircase that wraps around the structure's exterior.

1.3 FAMOUS MINARETS AROUND THE WORLD

A minaret can be considered a tower constructed beside a mosque, which the muezzin utilizes to call people for prayer. The call for prayer was introduced on a roof or at a high position of a building during Muhammed's period. The ancient mosques had been constructed with no minarets, and the call for prayer had been done in several other positions, like on the mosque's roof. During the era of the rightful caliphs, there was no evidence of the existence of minarets in Islamic architecture. However, it is noted that the first minarets were built at the edges of the mosque of 'Amr by Fustat by Maslama during Mu'awiya's period. Throughout history, numerous magnificent minarets have been constructed using various materials and structural techniques in different parts of the world, as shown in Figure 1.1[3].

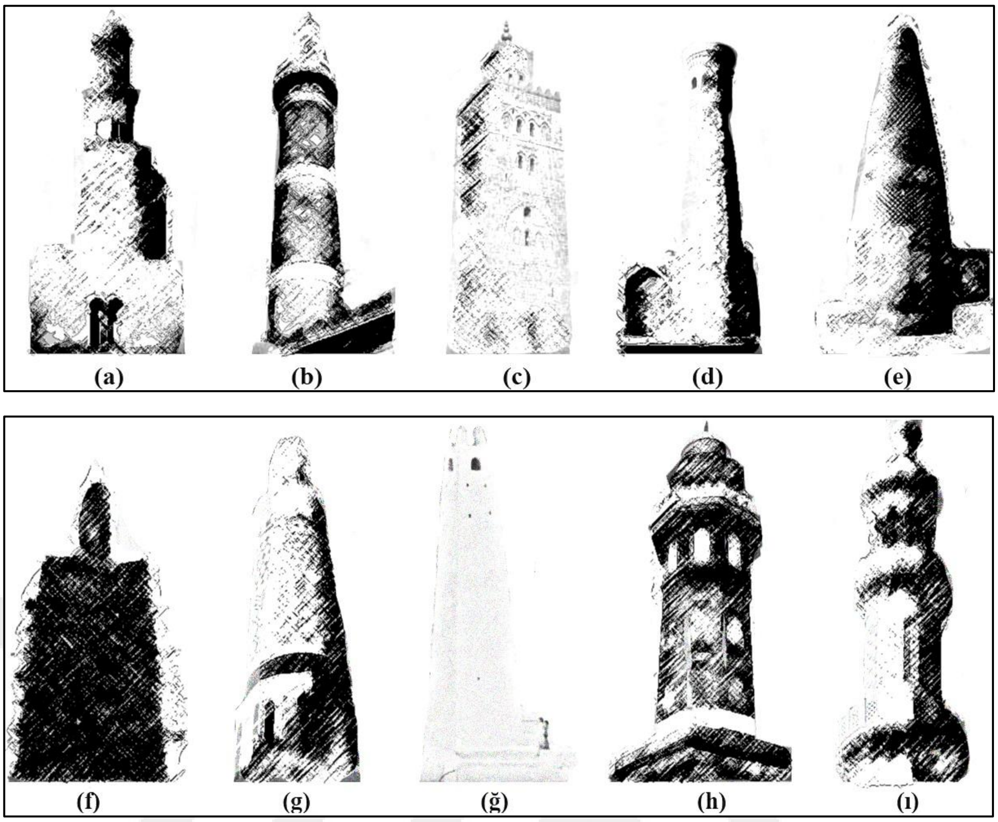


Figure 1.3: Several Minarets of Various Cultures [3].

Figure 1.1 depicts famous minarets all over the world, including (a) Ahmad Ibn Tulun, located in Cairo and built during the Tulunid Period and (b) Ayni Minaret in Diyarbakir constructed in the Ottoman period, (c) Kutubiyya minaret in Marrakesh that implemented in Almohad period1, (d)Kalyan minaret existed in Bukhara, (e) Amin minaret in China, (f) DjinguereBer minaret in Timbuktu that built during Songhay period, (g) Al-Bakiriyya minaret in Sana'a that was constructed in Ottoman period, (ğ) Mzab Saharan village minaret in Beni-Isguen, (h) Wazir Khan minaret, located in Lahore and built in the Mughal period, (ı) Amir Qurqumas minaret in Cairo constructed in the late Mamluk period.

1.4 ARCHITECTURAL FORMS OF MINARETS

While minarets are common in many mosques throughout Islamic countries, some regions, have constructed mosques without them. In these mosques, Azan is often conducted on the roof. In the larger Islamic countries, minarets typically consist of columns with a cylindrical or prismatic shape resting on a square footing. They are often linked together in a superimposed manner, as illustrated in Figure 1.3[3].

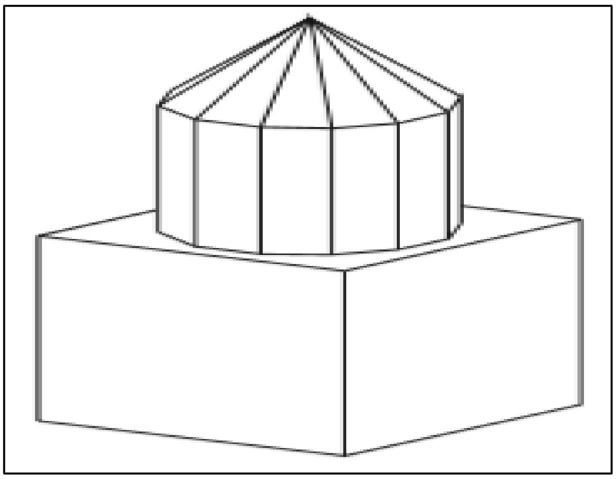


Figure 1.4: Minaret of Kunya Urgench [18].

In many mosques, including those in Cairo, such as Sultan Qaytbay, Sultan Hassan, and Al-Azhar, an octagonal shaft is placed on a square foundation by removing the protruding trihedra. This design can also be seen in Turkish mosques like Yivli Minaret and Ala-ed-Din (see Fig. 1.4). This type of minaret, as explained by [16]., is the regular pyramid intersects the prism that features a right-angled shape, containing a square-shaped foundation (see fig. 1.5).

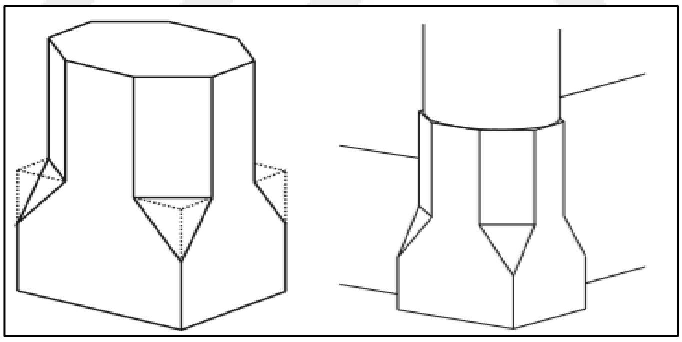
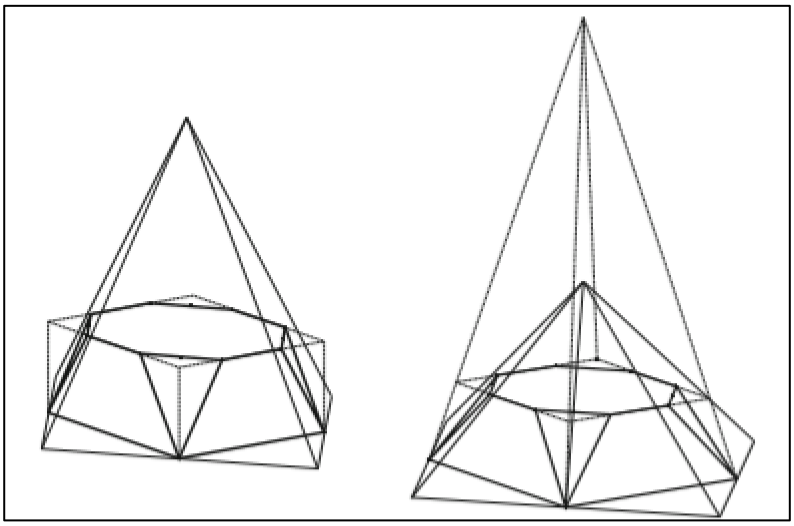


Figure 1.5: Shows Two Architectural Features: (A) a Connection Between an Octagon and a Square Using Cutting-Down Trihedra and (B) the Ala-Ed-Din Minaret [18].



(A) (B)

Figure 1.6: (A), a Regular Prism Intersects with a Polyhedron That Has a Square Foundation. (B) Two Regular Polyhedrons Intersect with A Foundation with a Square Section [18].

2. THE IMPORTANCE OF MINARETS IN SOCIETY

2.1 DESIGN AND AESTHETICS

In analyzing the complicated minaret's architectural designs, the several styles, decorations, and geometric patterns that decorated them, [25],[28] studies often concentrate on how elements such as balconies, arches, and decorative motifs influence the overall aesthetic appeal of the minaret. These elements enrich society with architectural views that exude an aesthetic spirit. The minaret is the most influential evidence of the existence of Islam in some specific regions. The appearance of the minarets influenced local customs that are related to cultural beliefs. [25].

Minarets are considered visual landmarks that attract onlookers' attention because of their outstanding image and because they carry religious and cultural symbols. In addition to being a symbol of power and authority, their architectural details, such as the arches that adorn them, muqarnas, decorations, and their distinctive shape, belong to the region where they are located, giving a unique heritage character. [26].

Although the beauty of the minarets may not preoccupy the mind of the worshipper and may not interfere with their humility and closeness to God, the architecture and decoration of the minarets reflect the value of the building in the hearts of its builders, past inhabitants, and those who had admired them. [27].

The Abbasid period (750-1260) can be considered to have the oldest example of decorating minarets, such as pointed arches surrounded by semicircular columns. After that, the minaret began to be decorated with architectural ceramics and clay, in addition to decorating it with engraved and perforated stone.[28].

The decoration of a minaret strongly influences its importance in society. Among the most famous decorations that have distinguished the minaret throughout the ages, which added aesthetic, cultural, and architectural value and raised the value of Islamic architecture in the world, can be mentioned as follows:

a. Geometric decoration: The geometric shapes used in the minaret have a formal diversity and have been closely linked to mathematics through continuous repetition and symmetry. Figure 2.1 shows the aesthetic value of the minaret through the geometric engravings.

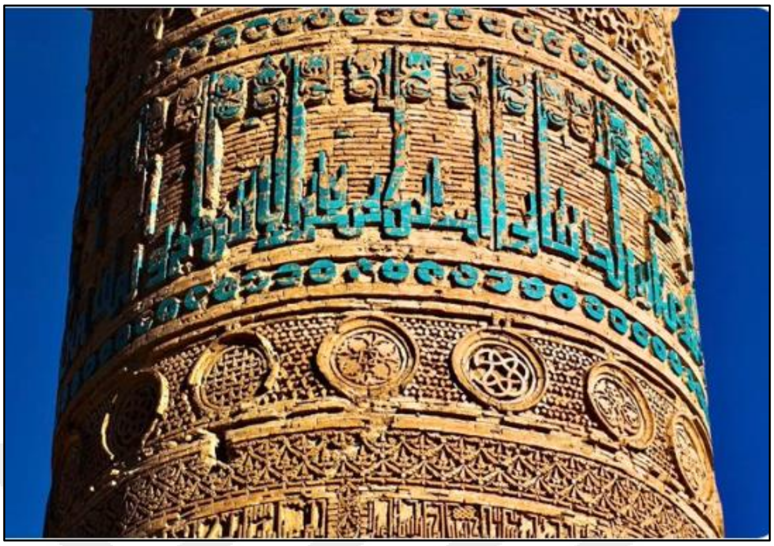


Figure 2.1: Decoration of Geometric Patterns in Jam's Minaret in Iran [31].

b. Botanical decoration: These are elements derived from plants, flowers, tree leaves, and buds and consist of plant branches intertwined in a coordinated manner.

Figure 2.2: Shows the Decorations of the Magnificent Persian Minaret [29].

c. Calligraphic decoration: Arabic calligraphy has significantly impacted the minaret through the sublime and purposeful meanings and words decorated as stripes. Figure 2.2 depicts the aesthetic values of the minaret, which are imparted by decorations and inscriptions in Arabic calligraphy, which give it a distinct heritage and cultural character.

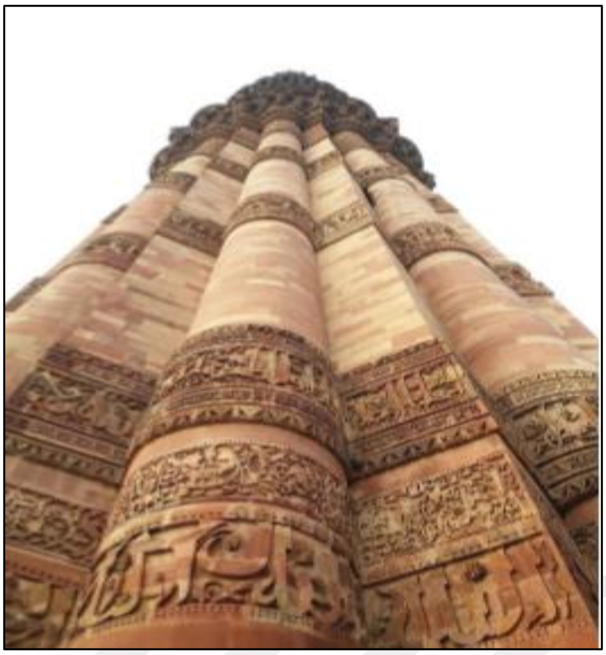


Figure 2.3: Calligraphic of Geometric Patterns in Minaret of the Sultan Muhammad Bin Qalawun in Cairo [30].

d. Three-dimensional decoration: It is represented by the muqarnas used as an element that increases the end of the minaret’s body, in addition to its fundamental importance in transforming the shape of the square into an octagon. The arches were built for two main reasons. Firstly, they help to bear the weight of the minaret building, which is quite tall. Secondly, they add to the beauty of the structure. Three types of arches are used: straight, semicircular, and pointed. Each one has its unique style and function. Visual effects are essential in achieving the minaret's aesthetic value, making it a center of attraction for onlookers, as color often performs the function of light. For a Muslim, it is a part of divine unity. As for shadows, they arise in the decorative parts protruding from the floor, performing an aesthetic function and clarifying levels. Different surfaces have little protrusion [32].

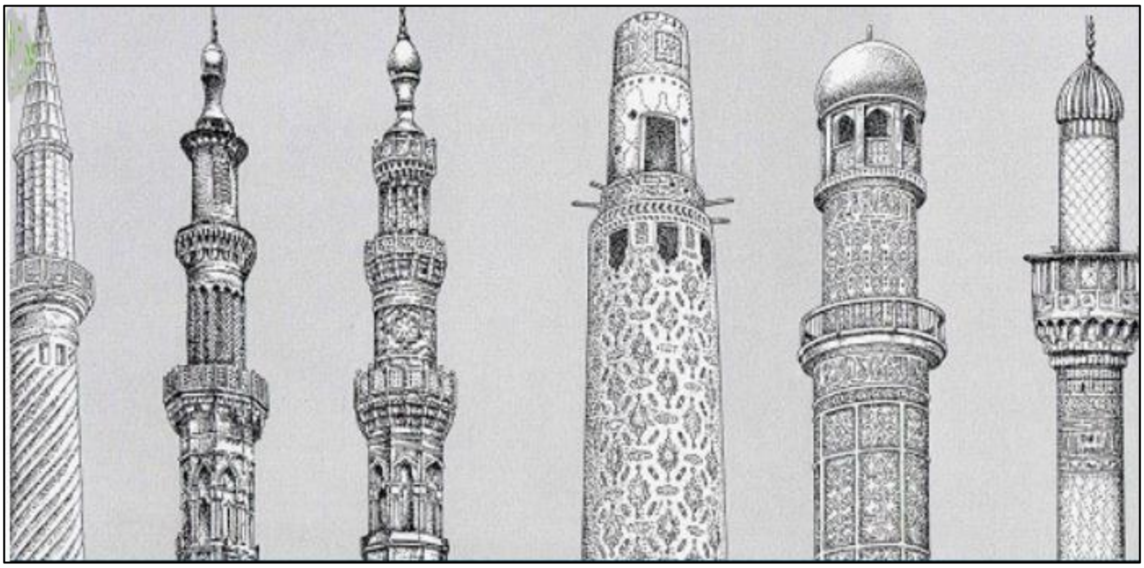


Figure 2.4: Different Decoration Patterns of Minarets [32].

2.2 SYMBOLISM AND RELIGIOUS SIGNIFICANCE

Even though minarets were constructed later, as they did not exist with the first emergence of mosques, they are one of the major landmarks that adorned Islamic cities and became one of the most significant landmarks that characterize Islamic architecture.

Due to the innovative styles and methods specific to each region, these minarets acquired their characteristics, so these minarets became a symbol of the civilization and culture of each region of its own. [19]. Although minarets were built later, as they were not present with the first appearance of mosques and were constructed afterward, they were one of the primary landmarks that decorated Islamic cities and became one of the most critical landmarks distinguishing Islamic architecture.

Also, the minaret is a symbolic concept giving the highest position to the announcement and of faith. The announcement of "Allah is the greatest" the number of worshipers who come to the mosque is affected by the appealing and pleasant minaret's design that motivates the faithful to execute their prayers at the mosque in the form of a group, enabling the mosque to be the center of activities and encouraging the Muslims to communicate [19]. The significance of the minaret in the Abbasid era was to exhibit the force of religious authority [20],[21]. Also, the minaret confirms unification and the non-devotion of idols, leading to an Islamic system for community [22].

2.3 CULTURAL AND URBAN IMPACT

Islamic world seems to maintain the design and architectural principles the minaret. Today's increasingly globalized culture blends the various civilizations and the necessity for cooperation and solidarity in response to future challenges [32]. The cultural significance of minarets can be summarized as follows**:**

a. The minarets are among the city's most prominent landmarks, and the cultural history has continued throughout the ages, making them a heritage that enhances the city's identity.
b. The minarets are characterized by wonderful architectural designs that reflect the history of Islamic architecture.
c. Some mosques contain rare manuscripts and ancient religious books that reflect the city's culture and civilization, making it a center for research and learning.
d. Minarets are considered critical historical structures that describe previous eras and the civilizations that lived here and are a point of contact between the past and present.

3. THE EMERGENCE OF MINARETS

3.1 THE ORIGIN OF MINARETS

The mosques established in Muhammad's era were characterized by simplicity. They were pretty short [1],[2]. The mosque's construction in the Muhammadan era was limited to being a residence for the Prophet Muhammad and his family, and in the beginning, there was no intention to build a place to gather Muslims. At that time, Muslims prayed without calling to prayer. After that, the Prophet Muhammad ordered Bilal Bin Rabah, considered the first muezzin, to call for prayer. So, it was natural for him to stand in a prominent and high place so that people could hear and see him [1].

As confirmed by [3], there were no minarets before 656 A.D, as there was no high place for calling to the call to prayer at all. The idea began in the era of Maslama bin Mukhlid, one of the governors of Egypt in the thirty-sixth year of the Hijra, who ordered increasing the mosque's area and establishing wards for calling to the prayer [3].

The minaret's origin is not apparent at first sight. Franz Pascha, "Baulunst des Islam," thinks that there is no correlation with the architecture of any other faith or race. Some studies have confirmed that the origin of the minaret arose during the era of the Umayyad dynasty in Damascus, which they came up with the idea from the towers of Christian churches, as the idea of creating a tower to call to prayer and the azhan came from the Great Church in Damascus [4].

Some historians believe the first minaret was the Great Mosque in Damascus, built by the Umayyad Caliph Al-Walid I in 705. Other studies also confirmed that the oldest trace of the appearance of the minaret was in Busra, Iraq [17].

Caliph Abdullah Yazid ordered the mosque's construction and the minaret's establishment. Al-Harith supervised the construction process in the year 720 A.D. In 724 A.D., Yazid II built a minaret adjacent to the Busra Mosque that surpassed its height. In conjunction with the construction of this minaret, the Al-Qairan minaret was established on the same date in Tunisia by Caliph Hisham bin Abdul Malik [5].

It can be concluded that the appearance of the minaret with mosques is linked to the Umayyad caliphs and the Umayyad era. Archaeologists have created two terms for the minaret. The first term is (minaret), found on an inscription in Busra in the year 724. This term refers to the call to prayer. The second term is (lighthouse), which comes from the watchtower that is provided with a torch for illumination. This term comes from a derivative Turkish that was used by the Ottoman Empire [5].

It has become necessary to have the minaret as a new architectural element required by functional necessities in the design of mosques, as required by the circumstances and needs of Muslims in their mosques so that the muezzin can ascend to it to spread his voice and hear the call to prayer as far away as possible. Over time, the minaret became an aesthetic element complementary to the mosque, one of its features, and a symbol inherent to it in a place that distinguishes it from other buildings. It became an indicator of the location of mosques in large cities and crowded neighborhoods. A stranger can infer it from a distance through a direct view of it during the day due to its towering height above the rest of the buildings. Or by seeing their high illumination at night, the minarets, with their height and ritual function, became a symbol of Islam [6].

The minaret was also used for defensive purposes in surveillance, as happened in the Moroccan borders. It was also used to send signals between cities and towns, to light fires at night and smoke during the day, and to send alerts about enemy movements [7].

According to [8], the first emergence of towers took place during the Umayyad period in Syria, in which Muslims were affected by the towers of the Syrian church. According to Cresswell, the current minaret is due to the form of the Abbasid era. Despite the existence of towers in Damascus, Fustat, and Medina in the Umayyad era, it is approved that the minaret emerged during the Abbasid era (i.e., after 750 CE).

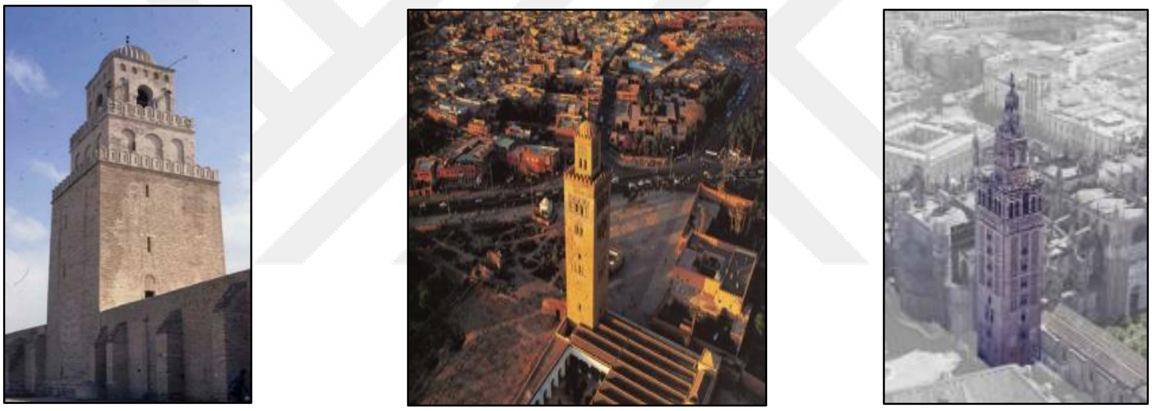
According to [8], six mosques related to that era comprise one minaret linked to the wall against the mihrab. The purpose of constructing a minaret in these buildings was to detect the force of Abbasid authority in religion. Fatimids opposed to the Abbasid force did not utilize minarets; consequently, Fatimid mosques didn't include minarets [9].

Nevertheless, [10] states that the initial minarets emerged almost 80 years after the Prophet's death. However, another theory about their emergence states that the first instance of the minaret was constituted by reusing the observed towers of the Roman temenos [11].

3.2 THE DEVELOPMENT OF MINARET ARCHITECTURE IN THE ISLAMIC WORLD

Minarets took different shapes according to other periods. The minarets began as low, square stone masonry on the ruins of the towers of the pagan institute in Damascus, Syria, where the Great Umayyad Mosque was built. As soon as the matter required the Muslim architect to increase their height, he made them terraced floors. That is, the height of each floor decreases from the floor before it as it rises higher.

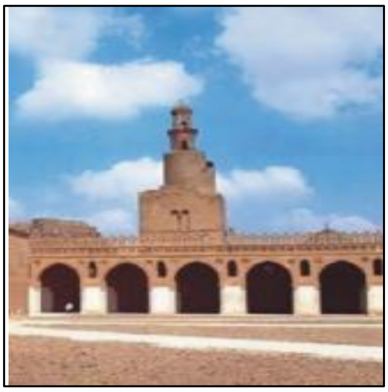
As with ship guidance lighthouses, this type of minaret moved to North Africa and Andalusia. The square minaret appeared in the Uqba bin Nafi Mosque in Tunisia, the Al-Katiba Mosque in Morocco, and the Giralda minaret in Seville in Spain, as illustrated in Figure 3.1.



(A) Ukba Bin Nafe minaret [14]. (B) Al-Kutubiyya minaret[15]. (B) Kiralda minaret[16].

Figure 3.1: Examples of Square Minaret.

Then, the spiral-shaped minaret (the Malawi minaret) appeared in the Abbasid and Tulunid eras, as This is the case in the minaret of the Samarra Mosque in Iraq and the minaret of the Ibn Tulun Mosque in Cairo [12].



(A) Samrra minaret[17]. (B) Ibn Tulun minaret[18].

Figure 3.2: Spiral-Shaped Minaret.

After that, the shape of the minaret increased. The polygonal minaret appeared in the Fatimid era, as illustrated in Figure 3.3, representing the Al-hakem minaret in Cairo.

Figure 3.3: Al-Hakem Minaret in Cairo [18].

The incense burner-shaped minaret appeared in the Ayyubid era as the minaret of Saleh Najm al-Din in Cairo.

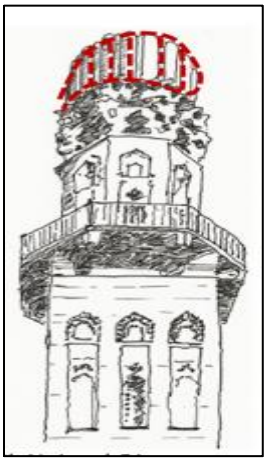


Figure 3.4: Minaret of Saleh Najm al-Din in Cairo [19].

Mamluk Egypt preferred the complex variety in the minaret as the minaret of Al-Sultan Qlawuun, as illustrated in Figure 3.5, and cylindrical minarets spread in Iraq, Iran, and Central Asia [6].

Figure 3.5: Minaret of Sultan Qlawuun [20].

The Indian minarets were cylindrical, narrowing as they rose to the top, and decorated with balconies and ribs on the body.

Figure 3.6: Qutub Al-Din minaret in India [21].

As for the minaret, In the Ottoman era, it spread in Asia Minor, Egypt, and other countries subject to the Ottoman Empire. It was cylindrical in shape or many-sided, high, thin, and slender, surmounted by a pointed conical peak [13]. The number of minarets in one mosque increased until it reached six, as in the Sultan Ahmed Mosque in Istanbul, Turkey.

(A)Minarets of Sultan Salim II [22].

(B) Minarets of Sultan Ahmed[22].

Figure 3.7: Ottman Minaret.

3.3 HISTORICAL EVOLUTION

The research on the origins and evolution of minarets [23] in Islamic architecture has revealed how they have adapted to the changing needs of society and architectural styles in different regions and periods. The architectural development of minarets throughout history has contributed to the development and prosperity of Islamic architecture, as they have been recognized by researchers and scholars as a significant member of Islamic buildings [23].

Minarets have become standard characteristics in Islamic Architecture, especially in Western Asia. These minarets have been built of bricks or rubble and are rounded cross-sections—the minaret.

Throughout history, unique architectural models and designs have given rise to minarets, which have played a significant role in enhancing the importance of Islamic architecture in society. The construction methods, techniques, and building materials used in making these minarets, along with the diverse and unique geometric decorations and shapes from different eras and civilizations, have enriched Islamic societies with heritage sciences and knowledge.[23].

Figure 2.4 depicts what minarets have introduced to Islamic architecture, which, in turn, upgraded society's culture. The development of minaret styles during history, comprising shape, depth, section, decorations, construction materials, and construction techniques, contributed to upgrading Islamic architecture. It gave human society a clear perception of Islamic architecture and its development throughout history.

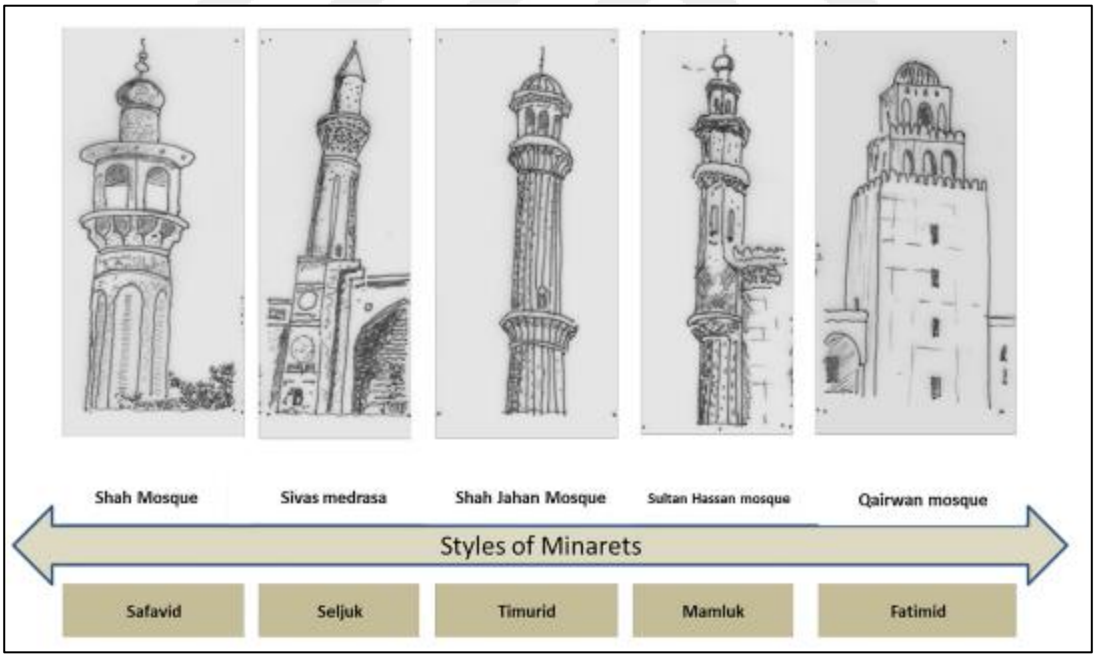


Figure 3.8: Historical Development of Minarets Styles [24].

4. OTTOMAN MINARETS

4.1 THE EMERGENCE OF THE OTTOMAN MINARET

The construction ideas of most of the Ottoman minarets come from Seljuk and Ottoman period architectural modes and construction techniques. The Ottoman Empire developed; there was development in the Ottoman minarets to keep up with the requirement to exhibit their force. Minarets in the Ottoman period can be categorized according to their height: low height, mid-height, and tall. Only sultans and members of the Ottoman dynasty constructed tall minarets and named them by their names.

Because of the high construction budget and seismic hazards, the construction of low-height and mid-height ottoman minarets was more favorable compared to the minarets ranging from 40 to 45 m in this period [33].

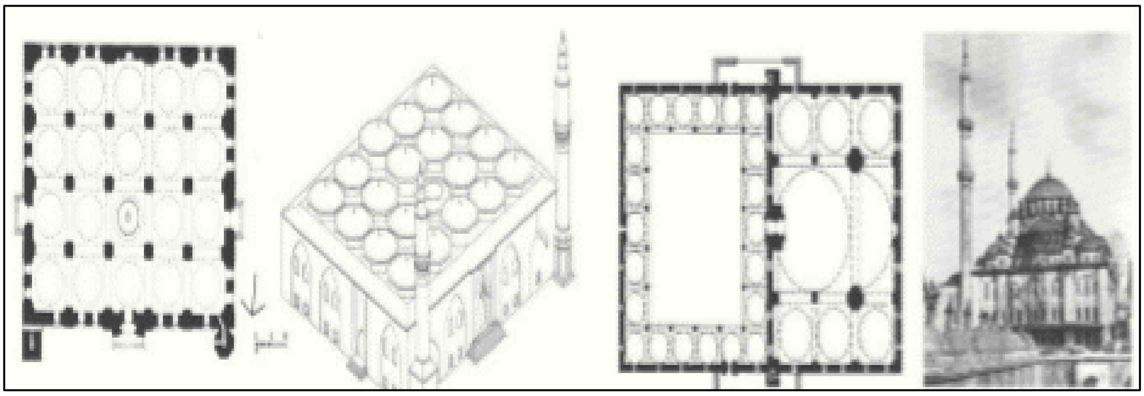
In the Ottoman era, the Ottoman Minaret was a significant component of mosques, a symbol of an Islamic city, and an indication of power; moreover, During the Ottoman era, there was a rise in the number of minarets being built in mosque designs. Minarets are constructed at the edges of closed locations or yard corners to introduce flexibility to the entire form and comply with the copula's primary structure [35].

The most significant mosque that was considered the Ottoman model before the extortion of Constantinople was the great Mosque in Bursa called Ulu Mosque Sultan Beyazit ordered constructed in 798 A.H. with two minarets placed in the corner northeastern direction and the corner northwestern [36].

After Sultan Mohammed II conquered Constantinople, he transformed the Highia Sophia church into a Mosque holding prayer.

Four minarets were constructed on mosques' corners in various periods. The church's form, featured in the Byzantine style, impacted Ottoman architecture with its tremendous height.

Sultan Mohammed II constructed the Al-Fatih Mosque in Istanbul in 867 A.H., the first mosque built in Istanbul. This mosque contained a huge copula at the center and two minarets at the corners [37], as illustrated in Figure 4.1.



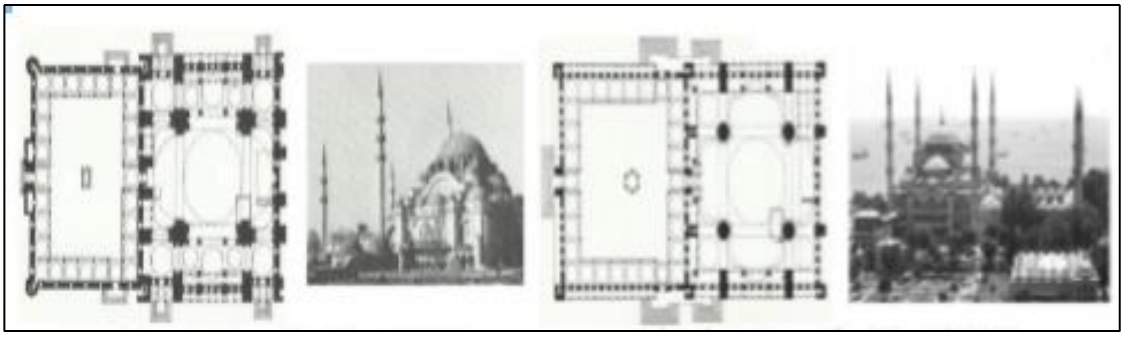
(A) Grand Mosque (B) Al-Fatih Mosque

Figure 4.1: The Beginning of Ottoman-Style Minarets [38].

The most famous architecture Engineer in the Ottoman era was Sinan. He was the chief royal architecture Engineer to the Ottoman court by Sultan Suleiman I. Sinan constructed many mosques with fabulous minarets that were spread in the Ottoman Empire and the Arab world [38].

The most famous mosque with minarets constructed by Senan is the Syleymaniye Mosque in Istanbul at 957 A.H. Sinan designed the mosque with four large and elevated minarets rising from the edges of the courtyard, and this mosque was the first in Istanbul that have numerous minarets [38].

A significant mosque example constructed in Sinan style was the Blue Mosque, which is placed in front of Highia Sophia and contains six minarets; four minarets were constructed at the edge of the closed region, and two minarets were at a distance from the edges of the courtyard [38].



(A) Syleymaniye Mosque (B) Sultan Ahmed Mosque

Figure 4.2: Ottoman Minarets, Sinan Style [39].

4.2 ARCHITECTURAL CHARACTERISTICS OF OTTOMAN MINARETS

The Ottoman minarets are characterized by specific architectural elements that make them unique. The minarets have a pencil form in addition to their distinction, and it is a high-rise, faceted or fluted mostly polygonal cylindrical columns as illustrated in Figure 4.3 that includes a loop on top or bottom part, supported on triangular supports that is considered transition region above the footing.

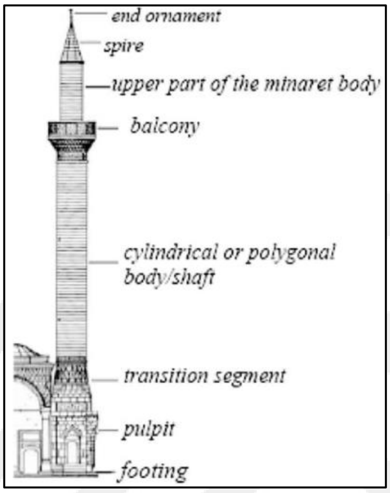


Figure 4.3: Classical Style of Ottoman Minaret [40].

In most Ottoman minarets, Transition regions were adorned with Turkish triangle decorations.

The Turkish triangle mentioned by AltuÞ is "a conversion of the arched area of the conventional pendentive into a fan as a group of long and narrow triangles constructed at an angle from each other" (Britannica online Encyclopaedia).

As triangular and muqarnas, the significant role of Turkish pendentives is to achieve the intersection between the polygonal plan of a structure and the rounded dome upper it, as illustrated in Figure 4.4. Ottoman minarets were famous for octagonal and cylindrical forms instead of square minarets in the Ottoman era.

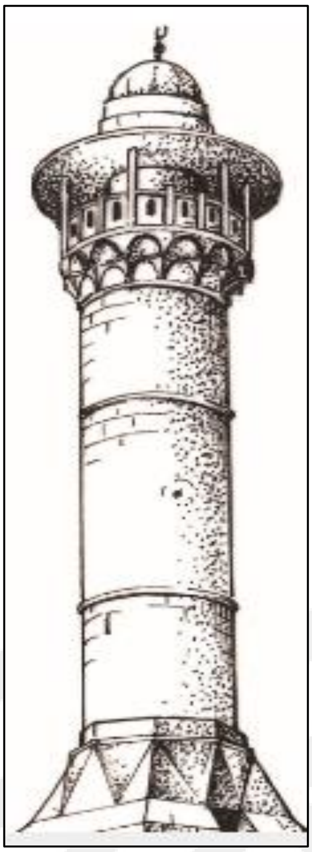


Figure 4.4: The Bab Al-Asbat minaret[41].

In general, Footings, the ground under the high-rise minarets dug up until stiff ground is achieved. The foundation materials include Gravel and other strengthening substances, and one seldom is constructed in direct up ground-level soil.

The most architectural characteristics of the Ottoman minaret can be described as follows:

a. The upper part of the minaret assumes a pencil-shape.
b. Cylindrical columns and double balconies, some of which are exhibited in brightly varicolored tile mosaics in green, blue, and white.

It is believed the weather in this area is the primary cause that resulted in the utilization of this mode at the top of the minarets; it has been noted that they also resemble the tops of church miners in the eras in Europe, as illustrated in Figure 4.5. It also complies with the cypress trees in all areas [41].

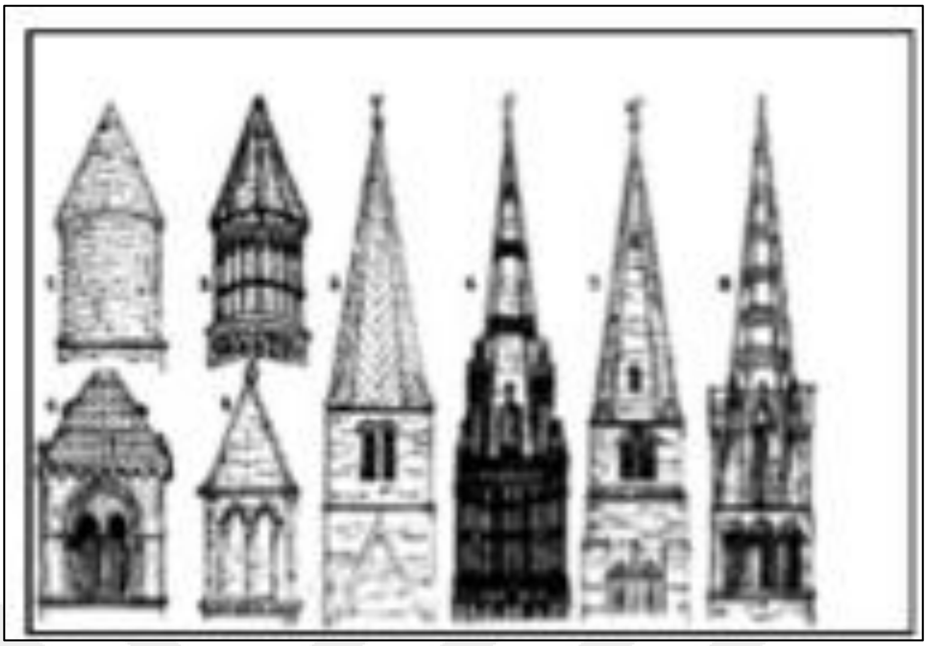


Figure 4.5: Various Churches, Europe [42].

As for the Ottoman minarets in the Levant, the many-sided minarets (16 sides) with a balcony and without a canopy, and their conical ends armored with lead, appeared, but in a limited number of mosques, and the octagonal minaret with a balcony and canopy remained more common. In Damascus, the minarets of the Ottoman era were distinguished by alternating white and black stone. The columns of the minaret as the Siba'i school are illustrated in Figure 4.6 [43].

Figure 4.6: The Siba'i School, Damascus [43].

The Ottoman cylindrical minaret represents an excellent example that reflects the global nature of the spread of this architectural element in terms of form. The Ottoman minaret is distinguished by its graceful cylindrical body, which tapers subtly with height and ends with a conical top resembling the tip of a pen. Therefore, it was known as the "Qalamiya" minaret. The Ottoman minaret is simple in composition and devoid of decoration - especially when compared to the Mamluk, Seljuk, and Moroccan minarets - and derives its peculiarity from its elegance, its towering height, its pen top, and its fixed shape, which it has largely preserved.

The spread of the Ottoman minaret in the Islamic world, which was subject to the control and rule of the Ottoman Empire, represents three cases that reflect the nature of the policy and development of the history of the Ottoman Empire, as follows:

a. Anatolia, Turkey, the Balkans, the islands of the Mediterranean, the Aegean Sea, and the Ionian Sea
b. Egypt, Sudan, North Africa, the Levant, and the Arabian Peninsula (Hijaz)
c. Yemen

In the first case, the Ottoman minaret represents the prevailing style (with some exceptions). The reason for this is that these lands, except Anatolia - due to the presence of the Seljuks, even though Seljuk architecture represented one of the most critical assets of Ottoman architecture - were conquered by the Ottoman Empire and its rule was established for an extended period, which was reflected in the prosperity of urbanization. The Ottoman Empire was the first stable Islamic rule in these countries, so Ottoman architecture represented the first Islamic architectural style there.

In the second case, these countries have a local solid Islamic heritage with deep roots (Mamluk architecture in Egypt, the Levant, Hijaz, and Andalusian Maghreb). Thus, the local architectural heritage continues to prevail in these countries. The Mamluk minaret continued its architectural formation throughout the Ottoman era (the minaret of the Al-Bardaini Mosque 1629 A.D., Mamluk style and design with some Ottoman features [44].

This did not prevent the presence of the Ottoman minaret next to the Mamluk-style minaret, and the Mamluk-style minaret also appeared (almost) with the Ottoman pen-top - in most cases representing an addition or renewal - which led to the predominance of minarets with the Ottoman pen-top in Cairo. The Turkish traveler Evliya Celebi expressed this influence by describing the Ottoman-style minarets in Cairo as minarets in the Islamic and Roman style and the style of Turkish mosques [45].

It is clear that these two cases of the spread of the Ottoman minaret reflected the reality of the policy of the Ottoman state, the relative extent of the penetration of its influence into these countries, and the acceptance of the people of the countries to Ottoman rule, as well as the interaction of the local heritage in these countries with the incoming Ottoman style. Tracking this phenomenon still requires further research into the history of the Ottoman Empire and its architectural monuments in these countries.

4.3 CONSTRUCTION TECHNIQUES IN OTTOMAN MINARET

The credit for the distinguished construction techniques in Ottoman mosques and minarets goes to the architect Sinan, as Sinan relied upon the construction techniques for mosques and minarets to provide two primary conditions: the quality of the land and appropriate foundations. For more than five centuries, the mosque, despite its enormous dimensions, survived 89 earthquakes, 15 of which exceeded 5.5 on the Richter scale, without causing any significant damage. It has been restored only four times since its construction.[46].

As a first step, Architecture Sinan dug a foundation pit measuring 150 meters by 70 meters and 6 meters deep, where it removed sandy soil 5-6 meters thick until it reached the rock layer near the surface. After that, he stuck 30,000 piles into the soil, placed tons of stone blocks on top of them, and waited more than two years. As a result, he ensured that the ground became better compacted and could hold the weights.

After that, he covered the floor with a layer of mortar 20 cm thick and placed wooden barriers on it (the flexible layer that worked like earthquake-resistant rubber pads today).

Furthermore, he built an earthen wall of cut stones and rocks, gradually narrowing the foundation's width and creating a pyramid shape. This stepped foundation allowed the building to behave solidly during vibration.[47].

Architecture Sinan also kept the foundation dry through drainage channels, which in turn isolated the building's foundations from groundwater.

4.3.1 Earthquake-Resistant Technologies of Architect Sinan

a. Khorasan mortar: In classical Seljuk and Ottoman architecture, the primary filler material between stones in buildings was Khorasan mortar. It is a mixture that has been used since the Egyptian pyramids, as it hardens under pressure and bends when shaken. But Mimar Sinan used mortar after a slight change in its content, which made it more flexible and suitable in cases of earthquakes.
b. Lead rings: To maintain the stones' flexibility and not fall due to vibrations caused by earthquakes, Mimar Sinan took the classic stonework in the minarets one step further, drilling holes in the stones and interlocking them together through lead rings. In other words, the flexible joint technology used in Japan today was used in Sulaymaniyah 500 years ago.

Sulaymaniyah minarets are characterized by flexibility that cannot be seen in any other building. Thanks to its movable joints that absorb the shock of tremors, the structure can withstand even an 8-magnitude earthquake. In other words, the minarets of the Suleymaniye Mosque rival today's skyscrapers [48].

In the Ottoman, minarets adopted limestone as the most common construction material with various mechanical qualities. [49] conducted experimental test on high-quality limestone utilized in ottoman minarets and concluded the following characteristics of materials: dry density is 23.9 kN/m3, density in the entire saturated case is 24.5 kN/m3, uni-directional compressive strength is 16.8 MPa, tensile strength is 0.90 MPa, Young's modulus is 5860 MPa, and Poisson's ratio is 0.24. Mortar located among the masonry blocks with low tensile strength presents a vital issue for minarets considered slender masonry structures in zones with high seismic intensity. Stone blocks characterize high compressive strength; nevertheless, undermined masonry requires more tensile resistance to resist bending moments caused by seismic or wind loads. Historical Ottoman masonry minarets were usually built utilizing stone blocks, solid clay bricks, or an integration of both. As a result of a strong earthquake that occurred in 1509, Ottomans found a solution for constructing rise minarets to resist earthquakes [50]. They began to utilize a developed method for connecting adjacent stone blocks with iron sections and clamps in vertical and horizontal directions, as illustrated in Figure 4.7 [51]. Iron clamp utilization in vertical and horizontal directions has enhanced the lateral ultimate capacity of minarets, which are considered slim masonry structures that are greatly subjected to wind and seismic loads. The iron reinforcement was prepared by blacksmiths using special forging techniques. The clamp that is considered horizontal bent iron parts clamp was initially named in Turkish kenet. The most popular utilization of bent iron parts in Ottoman architecture was revealed on the columns of Bursa Osman Mosque [52]. The clamps have been significantly utilized during the era of Sultan Beyazıt II (1481–1512). Sinan utilized them more efficiently in the 16th century, and the technique reached its ultimate criteria at the end of the 16th century. Vertical reinforcement bars were initially named in Turkish zıvana. There is no proof of the utilization of steel reinforcement or iron bars in minarets built before the 16th century [48]. Ottomans began broadly utilizing vertical reinforcement bars in the 17th century [50]. The vertical reinforcement bars and clamps were located in anchorage openings in the stone blocks, and then melted lead was cast in the opening to afford linking between the stone and iron reinforcement. Almost 2000 kg of lead material was utilized to construct a masonry minaret. It is potential that this extra mass varies the natural structural era and impacts the seismic performance of the minaret. However, the lead has the benefit of long-term sustainability since it is difficult to be influenced by hostile ecological conditions. A specific mortar called Horasan mortar was utilized in Ottoman minarets as a bonding material between the stone blocks. The Horasan mortar mix comprising lime was filtered and left to yeast to obtain resistance for approximately 10 to 15 years underground before being in construction.

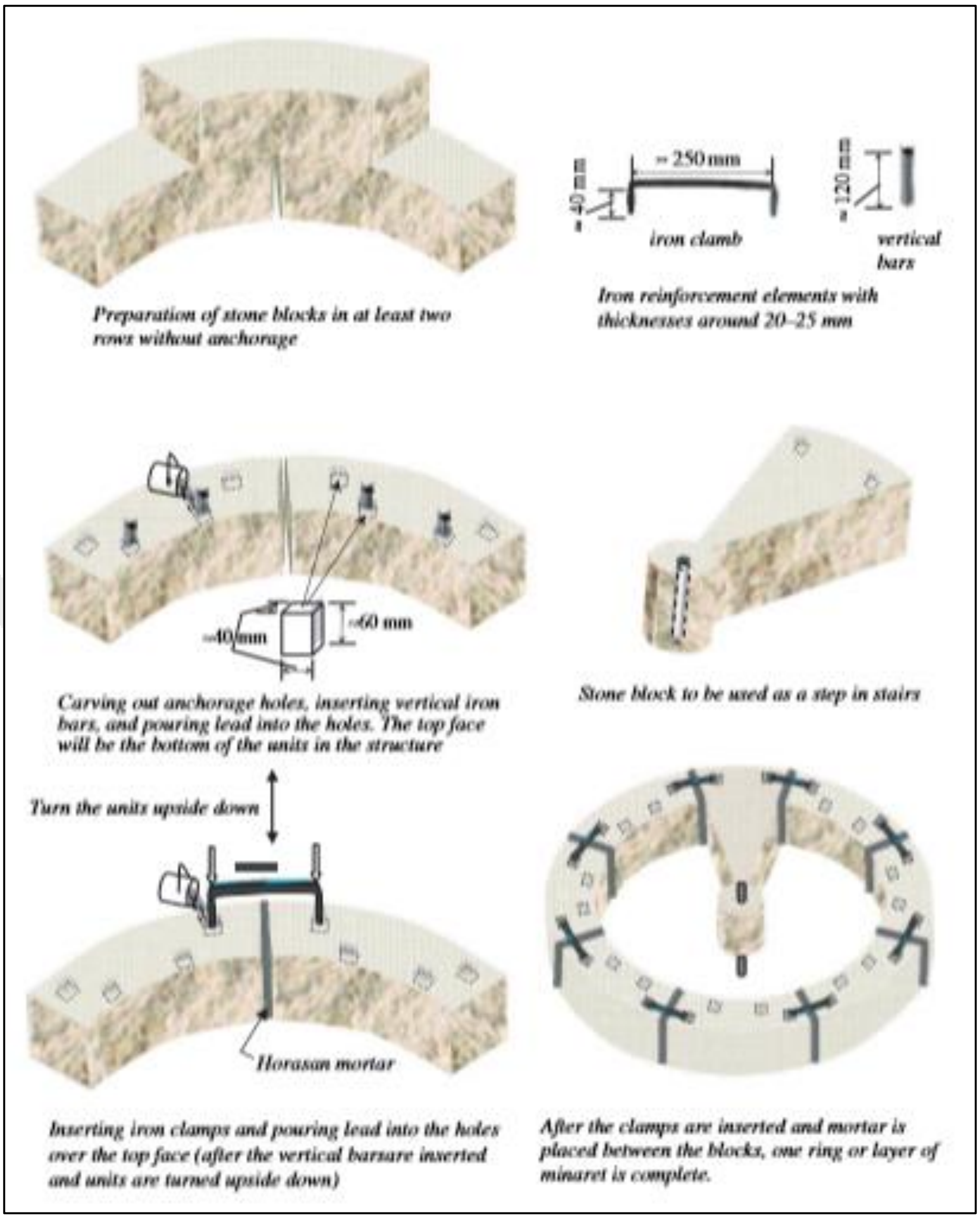


Figure 4.7: Construction Materials and Construction Techniques of Ottoman Minarets [53].

[51] described a detailed description of components of Ottoman minarets and construction material for each component as illustrated in Figure 4.8 as follows:

a. Base:

The foundation consists of solid connected stone blocks that characterize with high rigidity. The foundation is usually connected to the neighboring mosque's walls.

b. Pulpit:

The pulpit is a tiny part of the minaret with a height ranging from 5 m to 10 m. It is built below the minaret and utilized for its entrance. In Ottoman minarets, it is featured in square or octagonal form. But usually, it can include a polygonal form with (10- 12 -16) faces.

c. Transition Segment:

The height of transient segments is ranged from 2m to 3 m. It offers movement from the pulpit to the cylindrical or polygonal shaft. The smooth transition is characterized by utilizing cut stones, pyramids, planes or inverted triangular-shaped elements. It is also of varying size and height.

d. Cylindrical or polygonal column (shaft):

It is the tallest component of the minaret. It presents approximately 2/3 of the minaret's height. It has a cylindrical form. Also, It can be in Square and orthogonal forms.

e. Stairs:

They are a significant element of the minaret's structural system. They were manufactured with steel, stones or timber substances.

f. Balcony:

The balcony utilization has just architectural and visual goals since it shows an aesthetic aspect.

g. The above component of the cylindrical/ Polygonal shaft:

This component is located between the spire and the balcony.

h. Spire:

The spire is the upper component of the minaret that acts as a ceiling. It has a conical form or copula. It can or can't be constructed from a similar material as the upper shaft.

i. End Ornaments:

It is a small component that has no structural significance. It is only symbolised at the end of the minaret. It is located at the peak of the minaret.

5. THE CONDITIONS OF OTTOMAN MINARETS

5.1 ASSESSMENT TOOL

This study basically researches the condition of a group of Ottoman minarets whose mosques were mostly renovated.

These minarets are one of the most essential elements of their mosques, with which they were in harmony. They also have symbolism and significance in Islamic religious architecture in the Ottoman era, which is one of the reasons for their survival. The research employs an inductive descriptive approach for conserving the minarets, using literature survey and site-survey. Attention was paid to monitoring all aspects of adverse effects and risks threatening these monuments. In this chapter, we will look closer at each minaret, the history of the minaret, its height, the architect who designed it, and its architectural characteristics. We will also have a field review, investigating a set of selected minarets and answering 13 questions to get a clearer idea of each minaret's condition.
Below, the list of the selected minarets for this thesis is as follows.

Table 5.1: A List of the Minarets That will be Examined by Atyaf Al-Doori.

No	Mosque/ Minaret	Location	Mate rials used	Heig ht	Architec t	Singl e/ Attac hed	During which Emperor	Main Architectural Characteristi cs
1.	Hagia Sofia	Fatih/Istan bul,Sultan Ahme.	Stone & Brick	50m-60m	Mimar Sinan	Attac hed	Sultan Mehmed II	Prismatic base, multi-surface cylindrical body with one balcony, a cone-shaped upper body, and an end ornament cotted with lead.
2.	Fenari Isa Minaret	Fatih/Istan bu,Akşems ettin.	Brick s	15m	Ali ben Yusuf	Attac hed	Sultan Beyaz id II	Square base decorated with triangles. Thin cylindrical body with one balcony and a cone-shaped upper body.

Table 5.1: A List of the Minarets That will be Examined by Atyaf Al-Doori "Table Continued".

3.	Firuz Aga Minaret	Fatih/Istanbu,Binbirdirek	Stone & Brick	15m	Firuz aga	Single	Sultan Beyazid II	Cylindrical base and a cylindrical body with geometric decorations, and one balcony resting on muqarnas pillar.
4.	Pertevinyl Valide minaret	Fatih/Istanbu,İskenderpaşa	Stone	29m	Montani Effendi	Single	Sultan Abdulaziz	Prismatic base, grooved cylindrical body with one balcony resting on muqarnas pillar, with polygonal prism end ornament.
5.	The Blue Mosque	Fatih/Istanbul, Binbirdirek	Stone	64m	Mehmed Aga	Attached	Sultan Ahmed I	Square base. Grooved cylindrical body with two/three balconies and a cone-shaped end ornament.

Table 5.1: A List of the Minarets That will be Examined by Atyaf Al-Doori "Table Continued".

6.	Yeni Cami minaret	Fatih/Istanbul, Rüstem Paşa	Stone	52m	Davut Aga	Attached	Sultan Mehmet IV	Square base. Grooved cylindrical body with three balconies adorned with muqarnas decoration and a cone-shaped end ornament.
7.	Findikli Molla Çelbi Camii	Beyoğlu/ Istanbul, Ömer Avni	Stone	15m	Mimar Sinan	Single	Sultan Murad III	Square base. Grooved cylindrical body with one balcony and a cone-shaped end ornament.
8.	The Nusretiye minaret	Beyoğlu/ Istanbul, Kılıçali Paşa	Stone	40m	Krikor Amira	Attached	Sultan Mahmud II	Square base. Slim fluted body with two balconies bordered with lace-like cornices, and a cone-shaped end ornament.

Table 5.1: A List of the Minarets That will be Examined by Atyaf Al-Doori "Table Continued".

9.	The Dolma bahce minaret	Beyoğlu/ Istanbul, Ömer Avni	Stone	27m	Garabet Balyan	Single	Abdulmejid I	Circular base. Grooved cylindrical body with one pentagonal shape balcony adorned with muqarnas decoration, and a cone-shaped end ornament.
10.	Kılıç Ali Paşa Camii	Beyoğlu/ Istanbul, Kemankeş Karamustafa Paşa	Stone	31m	Mimar Sinan	Attached	Sultan Murad III	Circular base. Grooved cylindrical body with one balcony adorned with muqarnas decoration and a cone-shaped end ornament.

5.2 DESCRIPTION OF THE MINARETS FOR INVESTIGATION

The description of the Ottoman Minarets included in this study are as follows:

5.2.1 Case Study 1: Minaret of Hagia Sofia Cami

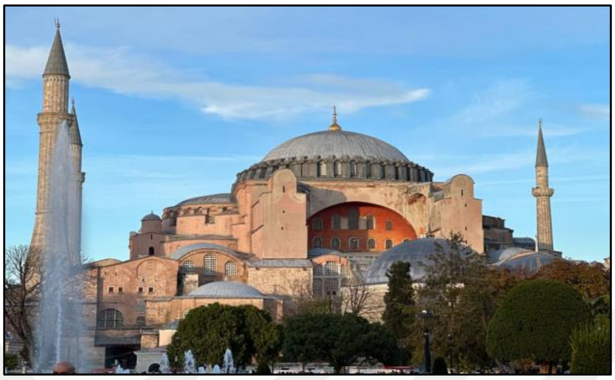


Figure 5.1: Hagia Sofia Mosque [77].

From the lavish Christian decoration to the high-rise attractive minarets. Hagia Sofia was built as a church in the 6^{th} century (532-537) by the Byzantine emperor Justinian I, and in 1453, Sultan Mehmed II changed it to a mosque. The mosque contains 4 minarets:

a. Southeast minaret: This minaret was the first to be established by Sultan Mehmed II in 1481. Then, it was rebuilt from bricks and heightened by Sultan Beyazid II to match the new rising minarets. [54]

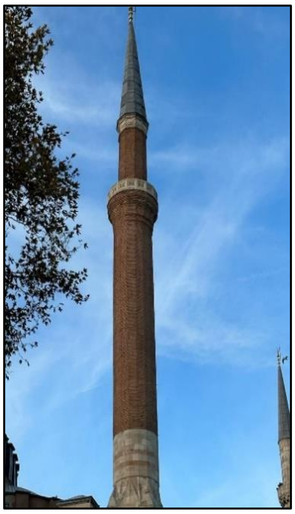


Figure 5.2: Southeast Minaret [77].

b. Northeast minaret: It was built by Mohammed II from wood when he occupied the city. It was rebuilt by Selim II when he conducted the first Ottoman rehabilitation of Hagia Sophia Sofia between (1573-1577). [55].

Figure 5.3: Northeast Minaret [77].

c. South-western and north-western minarets: These minarets were built by Sultan Murad III in compliance with his father, Sultan Selim II's wishes, as the number of the minarets in a mosque signifies its importance. [56].

Figure 5.4: Soth-Western and North-Western Minarets [77].

5.2.2 Case Study 2: Minaret of Fenari Isa

Figure 5.5: Fenari Isa [77].

Finari Isa, which is also named Molla Fenari mosque, is composed of two churches (Constantine Lips Monastery and Loannes Prodromos church) constructed in separate periods and consisting of a grave chapel. What makes the building crucial in terms of architectural history is that it has four small chapels on four sides of its dome. It's not possible to find this feature in any other Byzantine church. Emperor Leon VI and Empress Theodora constructed the Constantine Lips and Prodromos church in 907. At the end of the 15th century, in the era of Sultan Bayezid II, the church in the south was transformed into a small mosque, and the monastery was transformed into a zawiya by Fenarizade Alaeddin Ali Efendi, who was from an Ottoman ulama family. A minaret was built on the south church. The social complex was ruined by fire in 1633 and was repaired by Gran Vizier Bayram Pasha in 1636. [56,57].

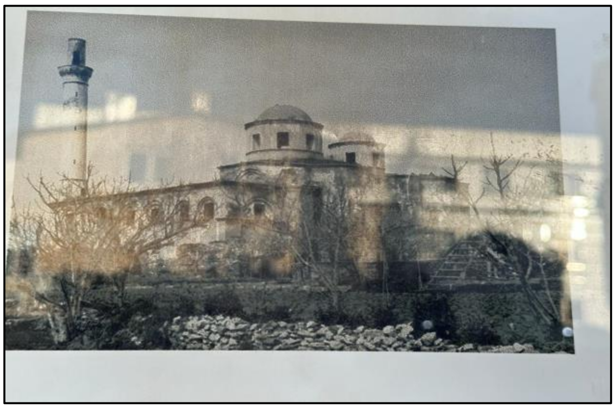


Figure 5.6: Shows the Damage in the Minaret Before Restoration [77].

5.2.3 Case Study 3: Minaret of Firuz Aga Cami

Figure 5.7: Firuzaga [77].

Firuz Aga was constructed by Firuz Aga, who was the chief treasurer of Sultan Bayezid II. The mosque was constructed in 1491. The single balcony minaret of Firuz Aga Mosque is on the left, and the boot at the body is exceptionally short-chequered. The main body diameter and the boot diameter are almost the same. The balcony is in a classical style adorned with muqarnas decoration. It's worth mentioning that the tomb of Firuz Aga is located in front of the left wall where the minaret is present. [58].

5.2.4 Case Study 4: Minaret of Pertevinyal Valide Cami

Figure 5.8: Pertevinyal Valide [77].

Pertevinyal Valide mosque is believed to be one of the last mosques to be built during the Ottoman era. Dedicated to Sultan Mahmud II, second wife. Although there is no exact information about the origin of Pertevniyal Valide Sultan, whose real name is Hasna Kater Besîme, she most likely has Romanian origin.[59][60] It is also claimed that she is of Kurdish or Circassian origin. In 1829, She became Mahmud's wife. Upon the death of Sultan Abdülmecid on June 25, 1861, when his Sultan Mahmud's son Sultan Abdulaziz ascended to the throne, Pertevniyal Sultan received the title of Valide Sultan. She remained Valide Sultan throughout her son's entire reign. He had Pertevniyal Valide mosque built. Pertevinyal Valide has two minarets on the sides made of cut stone. Balconies with floral decorations and muqarnas distinguish these minarets. The minarets placed on the sides of the entrance in the north of the building are on square bases with grooved bodies, a balcony, and stone heads. [61].

5.2.5 Case Study 5: Minaret of The Blue Mosque

Figure 5.9: The Blue Mosque [77].

The blue mosque, which is also named Sultanahmet mosque, is considered one of the most significant Islamic structures in Istanbul. As mentioned before, the number of minarets in a mosque signifies its importance. There are six minarets dominating the city's skyline, four with three balconies around the central space in Sultan Ahmet and two with two balconies on the courtyard wall. The minarets were built according to the traditional Turkish style, and a spiral staircase ascends to the balconies. [62].

Four minarets are standing at the corners of the mosque. Each of these minarets is shaped like a pencil. The six minarets are 64m in height. The tops of the domes and the spires of the minarets are covered with lead, and the end ornament is made of gold-plated copper. The diameter of the minaret begins to decrease starting from the upper neck of the first balcony and it continues to decrease until the end ornament. [63].

5.2.6 Case Study 6: Minaret of Yeni Cami

Figure 5.10: Yeni Cami [77].

Yeni Cami (the new mosque), construction started in 1597 and was finished in 1663. The reason why it took almost 66 years for the mosque to be constructed is that Safiye Sultan, the wife of Sultan Murat II and the mother of Sultan Mehmet, wanted a mosque built in her name. Davut Aga drew the plans and started laying out the foundation. When they began digging the foundation, water was pouring out, which delayed the construction. During that time, Sultan Mehmet III died, and according to tradition, the mother of the Sultan was sent to an old palace, so the mosque was abandoned for almost 57 years. During Sultan Mehmet VI's reign, his mother saw the mosque in a terrible state and decided to complete the building. Mustafa Aga started the construction using Davut Aga's drawing, and the mosque was opened for worship in February 1663. The mosque is a beautiful example of 17th-century Turkish architecture. It has two 50m tall minarets with a square base. Grooved cylindrical body with three balconies adorned with muqarnas decoration and a cone-shaped spire. [64].

5.2.7 Case Study 7: Minaret of Fındıklı Molla Çelebi Camii

Figure 5.11: Fındıklı Molla Çelebi Camii [77].

Fındıklı Molla's founder is the Anatolian Kazasker Mehmed also known as the Hubbî Molla or Molla Çelebi. Fındıklı Molla is a simple attempt by Sinan, the Architect. The central dome was expanded to the sides with five semi-domes, except for the northern direction, and since the semi-dome in front of the mihrab was more profound than the others, the mihrab section was extended outside. The square-based, cylindrical-bodied minaret located in the northwest corner of the mosque was renovated in late periods. The balcony form of the minaret has decorations under the cone and on the balcony. The minaret is accessed from the outside via a low arched door in the narthex and from the inside via another door in the same direction.[65].

5.2.8 Case Study 8: Minaret of Nusretiye Cami

Figure 5.12: Nusretiye [77].

The Nusretiye mosque was built together with the military buildings due to the importance given to the military by Sultan Mahmud II. Due to that, instead of being surrounded by several foundation buildings like in other mosque complexes of the sultan, its single outhouses are the military buildings that were built in front of the cannon foundry. The Nusretiye mosque was completed in 1826. The mosque was known as the mosque of Tophane. Sultan Mahmud II gave it the name Nusretiye (victory). As Sati Efendi wrote, the minarets were demolished and rebuilt during the 1960s because one of them was bent dangerously, so it was removed and rebuilt.

5.2.9 Case Study 9: Minaret of The Dolmabahçe Cami

Figure 5.13: The Dolmabahce Mosque [77].

The construction of the Dolmabahçe mosque was started with the order of the Bezmi Alem Valide Sultan and completed by his son, Sultan Abdulmejid I, in 1853. The mosque was constructed as a mix of baroque, rococo, and empire styles with localized art background and taste with an exciting interpretation. The minarets, which were separated from the main body of the mosque, are on two corners of the mosque. The minarets are distinctive with their long, thin forms. The bottom of the balconies was decorated with acanthus leaves. The ground of the sanctuary was made of bricks, and its dome interiors and pendentives were ornamented in Western style with gold and oil painting handcrafts.

5.2.10 Case Study 10: Minaret of Kılıç Ali Paşa Camii

Figure 5.14: Kılıç Ali Paşa Camii [77].

The Kılıç Ali Pasha Mosque, which was opened in 1580, is located at the end of Boğazkesen. It is a remarkable mosque that has an interesting construction story and architectural features. It has welcomed those coming from the sea and served as one of the city's gates through which it opened to the outside world for many years. The construction of Kılıç Ali Pasha Mosque involved the work of three notable individuals. One of them was Kılıç Ali Pasha, also known as "Big Captain", who founded the work. The second was Mimar Sinan, an architect who revolutionized the architectural style of the Ottoman Empire and contributed unique works to Ottoman history. The third person was Demircikulu Yûsuf Efendi, a highly talented calligrapher who added his special touch to the mosque. The design of the mosque's sanctuary resembles that of the Hagia Sophia. In the Kılıç Ali Pasha Mosque, Sinan made an unexpected application of using the plan of Hagia Sophia and incorporating elements of Ottoman period Turkish architecture on a smaller scale. This mosque is one of the last notable works of his long career. [54],[65].

5.3 ASSESSMENT OF THE CONDITION OF MINARETS

The aim of this section is to evaluate the current condition of minarets via assessing the deterioration in the following aspects: biological deterioration, chemical deterioration, and mechanical deterioration.

In order to conduct the assessment process, the following procedures were executed as follows:

a. Thirteen questions were prepared and set for evaluation process regarded as:
   a. Discoloration of minarets
   b. Blackening in the minaret's surfaces
   c. Salt damage in minaret's surfaces
   d. Vegetative formation
   e. Crack formation
   f. Surface erosion
   g. Moisture damage
   h. Separation of blocks
   i. Tear and rupture damage in blocks
b. Each question was given four categories according to the size of damage as follows:
   a. No damage was scaled zero value.
   b. Slight damage was scaled between 5% to 15 %
   c. Mid damage was scaled between 15% to 30 %
   d. Severe damage was scaled above 30% to 100%
c. Depending on assessment questions, a case study was conducted by performing a site visit for each minaret.
d. The results of the site visit were analyzed and discussed to evaluate each type of deterioration.

5.3.1 Observed Discoloration in the Surveyed Minarets

The minarets were evaluated according to any discoloration overtime due to environmental effects. The discoloration in the minarets makes these minarets lose their aesthetic, and the color change indicates the pollution to which these buildings are exposed as a result of weathering. Chart 5.1 illustrates the percentages of discoloration in the minarets selected.

Chart 5.1: Observed Rate of Discoloration.

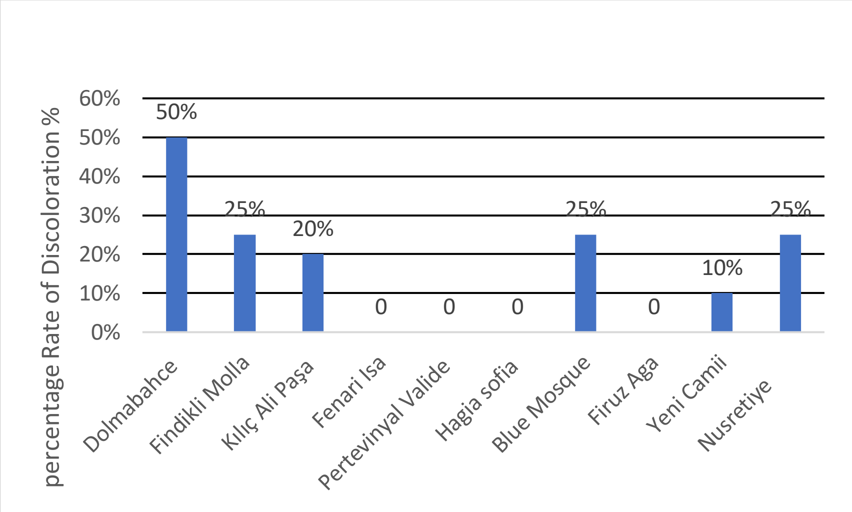
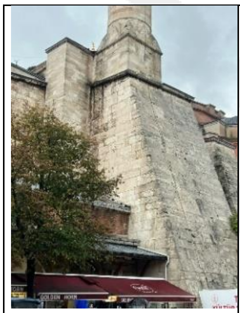


Chart 5.2: Observed Discoloration Images.

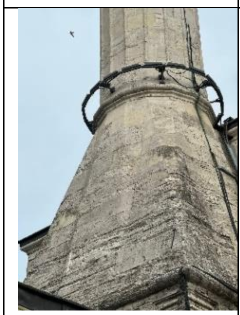
				
(A)Hagia Sofia	(B)Dolmabahce	(C)Fenari Isa	(D)Findikli Molla	(E)Firuz Aga.
				
(F)Ali Paşa	(G) Nusretiye	(H) Pertevinyal	(I)Sultan Ahmed	(I)Yeni Cami.

It can be noted by Chart 5.1 those minarets of Fenari Isa, Pertevinyal Valide, Hagia sofia and Firuz Aga have not experienced discoloration or change in the color of the stone blocks while minarets of Yeni Cami, Nusretiye, Findikli Molla, Findikli Molla, Kılıç Ali Pa have experienced slight to mid deterioration according to discoloration. Dolmabahce Minaret is the only minaret with significant deterioration. Therefore, it can be said that the minarets in the city of Istanbul are exposed to slightly to moderate color discoloration as a result of the weathering, humidity, and influential winds laden with dirt, dust, and atmospheric pollution. The main reason for the change in color is the result of chemical reactions occurring on the surfaces of stones after rain, in addition to pollutants. Also, compositions that result in pollution can react and produce new minerals, often followed by structural deterioration.

5.3.2 Observed Blackening on the Surface of Minarets

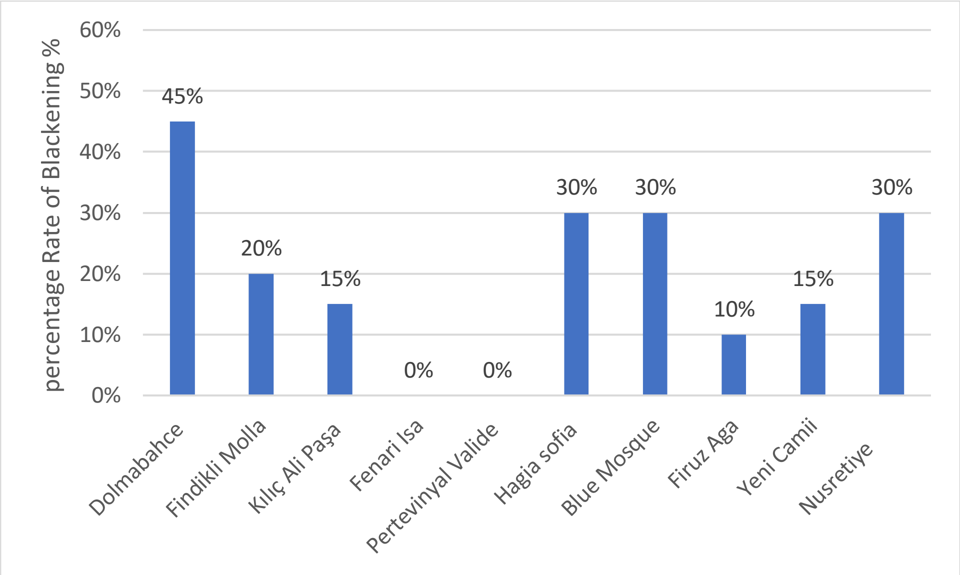
This section investigates whether concentration of fine molecular from traffic, residential heating, power depletion and natural disasters affected the surfaces of minarets, resulting in blackening of the surfaces of minarets. To assess these negative influences, field investigation as illustrated in Chart 5.3 of the selected minarets was conducted to assess the percentage of blackening on the surfaces. The assessment conducted has been organized in Figure 5.18 that illustrates the percentage of blackening in each minaret.

Chart 5.3: Observed Blackening Images.

				
(A)Hagia Sofia	(B) Dolmabahce	(C)Fenari Isa	(D)Findikli Molla	(E)Firuz Aga.
				
(F)Ali Paşa	(G) Nusretiye	(H) Pertevinyal	(I)Sultan Ahmed	(I)Yeni Cami

The information's presented in Chart 5.4 shows that the level of blackening deterioration in the selected minarets ranges from 0% to 30%. This indicates that the blackening deterioration in most of the minarets is slight to medium, except for the minaret of Dolmabahce, which has the highest percentage of blackening at 45%. This blackening is because the impact of atmospheric pollutants to constitute compositions that access the surfaces and react with its substances. Air pollution, when complied with suitable climatic conditions, can result in a great minimization of the serviceability of stones.

Chart 5.4: Observed Rate of Blackening.



5.3.3 Observed Salt Deterioration in the Surveyed Minarets

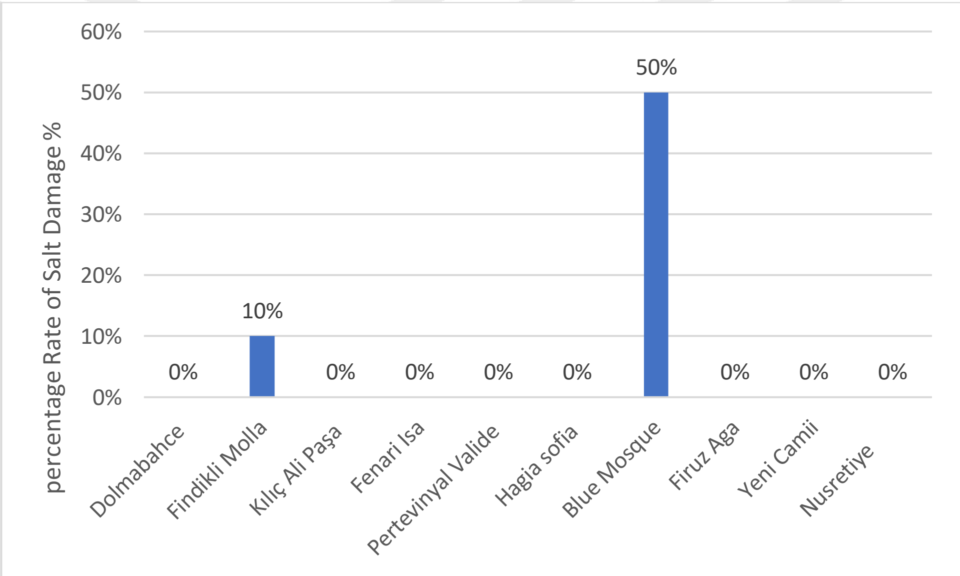
Salts cause mechanical and physicochemical damage, especially to archaeological monuments located in coastal areas, as they are transferred to building materials through rain, atmospheric humidity, groundwater, and other various sources, and take many forms in the building, including:

a. Salt masses are deposited on the surfaces of stones, taking various forms.
b. Contrasting colors (white or gray spots).
c. Fission in the surface layers of building materials, as the deposition of salts inside building materials leads to mechanical stresses that contribute to the separation of the outer layers and their fall. The thickness of the split layers ranges from a millimeter to a few centimeters, resulting in the crystallization of salts in the form of a white powder that covers the locations of the splits. Peeling of the surface also causes the loss of a large percentage of building materials.
d. Salts work to gradually disintegrate the surfaces of building materials and cause them to fall into form.
e. Grains, crystals, or fragments, especially limestone. We notice this phenomenon on wet surfaces that are not exposed to direct rainfall.

f. When dry and wet periods alternate, the rate of peeling increases as the soluble salts are present close to the surfaces, which causes the disintegration of the bonding grains of the materials and the weakening of the mechanical resistance of the materials construction and increasing pores in external surfaces.
g. A white-colored deposit and a black-colored deposit. The latter is formed because of deposition, where the gypsum is black due to salts (gypsum) and carbon particles dispersed in the atmosphere. These deposits cause mechanical stress on the stones.

Salt damage assessment of the minaret was conducted via field investigation as illustrated in Figure 5.15 and percentages of salt damage assessment were presented in Chart 5.5.

Chart 5.5: Observed Rate of Salt Damage.



It can be noted that salt damage appeared only in Findiliki Molla minaret by percentage 10% which considers slight damage while the percentage of salt damage in Sultan Ahmed minaret up to 50% that considers high salt damage and the Figure 5.20a shows the salt damage in (a) Findikli Molla in which it can be noted the appearance of cavities as a result of alternating periods of dryness and humidity. We also notice a rate of peeling because of the presence of soluble salts close to the surfaces, which causes the disintegration of the bonding grains of the materials, the weakness of the mechanical resistance of building materials, the increase in pores in the external surfaces, and the appearance of cavities of different sizes. Limestone is a porous stone through which it speeds the evaporation with the help of the wind.

Figure 5.15 b illustrates the peeling in the surface of Sultan Ahmed minaret because of salt damage in which it is possible to peel the surface layers, because of the absorption of salt into the blocks of stones, which may lead to mechanical pressures that contribute to the breaking of the outer layers and their collapse.

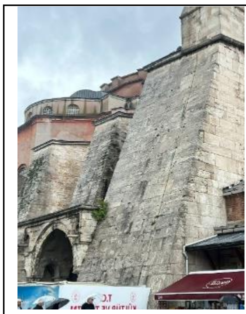
(A)Findikli Molla (B) Sultan Ahmed

Figure 5.15: Observed Salt Damage Images.

5.3.4 Observed Vegetative Formation on the Surveyed Minarets

Biological damage factors associated with plants and microorganisms have been visually checked, which are formed because of the accumulation of rainwater or seepage water in the rocks of archaeological buildings, where plant seeds carried by winds and birds settle, usually in the cracks and joints between rocks, and live and grow. These plants, especially when they penetrate joints and cracks, cause buildings materials to crack. Buildings made of carbonate stones are eroded by acid secretions from root cells, resulting in distinctive marks called root marks. Therefore, damage to these minarets resulting from plant formations was assessed and Figure 5.15 illustrates the rate of vegetative formation in selected minarets.

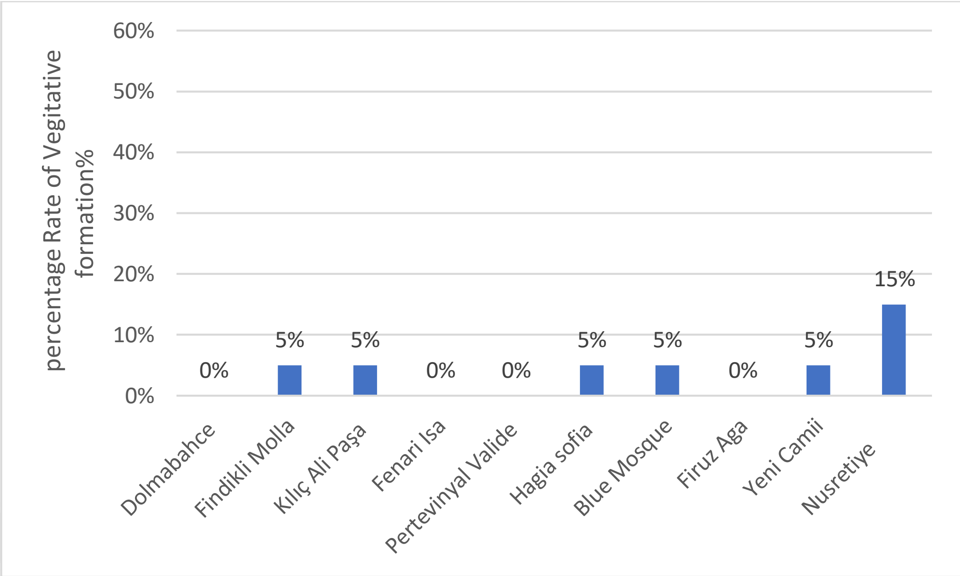
Chart 5.6: Observed Vegetative Formation Images.

		
(a)Hagia Sofia	(b)Findikli Molla	(c)Ali Paşa
		
(d) Nusretiye	(E)Sultan Ahmed	(F)Yeni Cami

Vegetative formation is illustrated in Chart 5.6 depicting the minarets of Hagia Sofia, Findikli Molla, Ali Paşa, Nusretiye, Sultan Ahmed and Yeni Cami while there is no vegetative formation in the rest of selected minarets.

Chart 5.7 depicts the percentage of vegetative formation in the minarets, which can be considered as slight.

Chart 5.7: Observed Rate of Vegetative Formation.



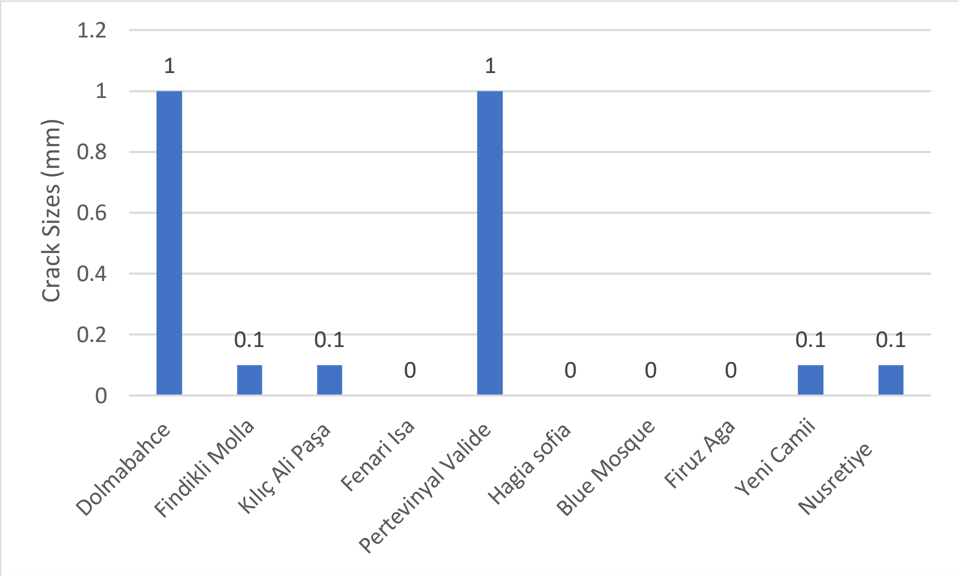
5.3.5 Observed Crack Formation in the Surveyed Minarets

The causes of each type of cracking depend on many different factors, and may affect appearance as well as the structure, diminishing the durability of the structure. Cracks may represent the level of minor damage, and they may even indicate the problems of greater magnitude.

In order to investigate the structural safety of the minarets, formation of structural cracks were assessed and size of these cracks were measured. These cracks can be in various forms or sizes and may require repairing quickly.

After assessment process of the selected minarets via site investigation, it was revealed that the size of cracks formed in the studied minarets was 1mm. The crack size of 1mm was noticed only in minarets of Dolmabahce and Pertevinyal Valide mosque while the rest of the minarets were either without cracks or with hairline cracks with size of 0.1 mm. These values are tolerable with respect to the durability of minarets in addition to their ability to withstand stress [73].

Chart 5.8: Observed Rate of Cracks in the Surveyed Minarets.



5.3.6 Construction Materials Used in Minarets

It's important to have knowledge about the construction materials used to build the minarets. Determining the building materials used in building minarets is important because it helps determine the necessary measures to preserve these minarets and ensures a good definition of the maintenance measures necessary to be carried out, to preserve these minarets, and restore them according to the current approved heritage model.

Table 5.2 can Illustrate the construction material used in the selected minarets and the table shows that stone was a basic construction material to construct Ottoman minarets in Istanbul city and utilization of brick was limited, due to the high ability of stone blocks to resist both vertical and horizontal loads that are required in Istanbul city being zone exposed to seismic load potential.

Table 5.2: The Construction Material Used in the Surveyed Minarets.

Name of the minaret	Stone	Brick	Combination of Brick and stone
Dolmabahce	✓	_	_
Findikli Molla	✓	_	_
Kılıç Ali Paşa	✓	_	_
Fenari Isa	_	_	✓
Pertevinyal Valide	✓	_	_
Hagia sofia	_	_	✓
Blue Mosque	✓	_	_
Firuz Aga	✓	_	_
Yeni Camii	✓	_	_
Nusretiye	✓	_	_

5.3.7 Observed Separation Between Masonry Blocks in the Surveyed Minarets

The structural integrity and lifespan of a minaret can be reduced due to the separation of masonry blocks. Therefore, an investigation was conducted to assess the separation between masonry blocks for each minaret. The results showed that there was no separation noticed between blocks for all selected minarets, except for the Yeni Camii minarets. The investigation revealed a very slight separation between masonry blocks in the Yeni Camii minarets, which did not exceed more than 10% of the surface of the minaret.

Figure 5.16: Separation Formed in Yeni Camii.

5.3.8 Observed Surface Erosion on the Surveyed Minarets

Environmental factors, particularly wind and storms, are considered to be the most significant causes of erosion. They are responsible for the destruction and decay of all materials on the surface of the earth's crust, including archaeological buildings. The impact of wind and storms on the demolition and decay of archaeological buildings increases and becomes more severe when they carry sand grains with them as they pass over them. The Earth's surface contains sand grains with high hardness (Hardness 7). Wind speed and intensity are estimated by their ability to carry more and larger sand grains. In extreme cases, sand-laden winds can be seen as moving saws with high hardness, eroding ancient buildings to varying degrees depending on the hardness of the materials used in construction. Wind and storms are most active and aggressive in the case of sedimentary stone building materials (sandstone and limestone), as well as mud brick buildings. Archaeological buildings are prone to erosion caused by wind and storms. This erosion rate increases significantly when the building materials, such as stones or mud bricks, lose the hardness of their surfaces. This can happen due to prolonged exposure to large temperature changes during the day and night, as well as different seasons of the year. To know about the environmental effect on the erosion of surface minarets, a site visit was conducted for each element and the field investigation is illustrated in Chart 5.9.

Chart 5.9: Observed Surface Erosion Images.

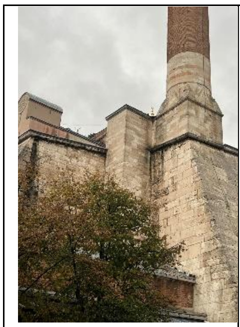
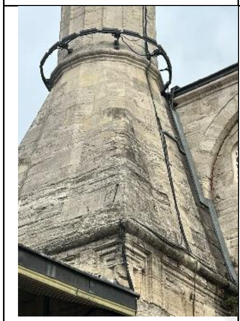
				
(A)Hagia Sofia	(B)Dolmabahce	(C)Fenari Isa	(D)Findikli Molla	(E)Firuz Aga.
				
(F)Ali Paşa	(G) Nusretiye	(H) Pertevinyal	(I)Sultan Ahmed	(J)Yeni Cami

Chart 5.9 shows the amount of surface erosion in minarets that requires treatment. This erosion reduces the mechanical properties of stones and consequently reduces the serviceability of the minarets.

Chart 5.10: Observed Rate of Surface Erosion.

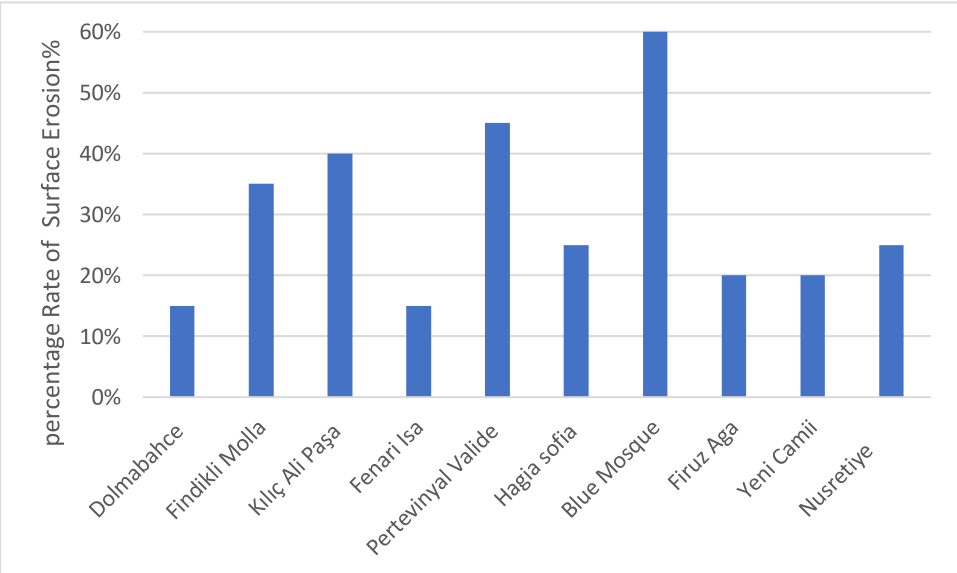


Chart 5.10 shows that all minarets are exposed to surface erosion because of environmental effects. The surface erosion in minarets ranges from 10% to 60% which requires a treatment solution to avoid more erosion.

5.3.9 Observed Damage due to Vandalism Attack in the Surveyed Minarets

Vandalism means the damage caused to archaeological buildings as a result of wars or the authorities or individuals demolishing historical buildings or distorting them and changing their features for reasons including: the desire to renovate the old building to obtain modern architecture that would be more useful, including neglect or ignorance of the value of the building as a result of the deterioration of the general cultural level.

In many other cases, weak oversight, and lack of awareness among citizens encourage abandoned historical buildings and neglected archaeological ruins as quarries from which individuals take their stones and building materials, thus increasing their ruin and destruction. Thieves may resort to vandalizing archaeological and historical buildings to steal their decorative and late elements.

5.3.10 Type of Moisture Damage in Stone and Mortar

Several types of moisture can damage archaeological structures and these types can be classified as follows:

a. Rising damp: This process occurs when moisture rises through capillaries in masonry structures.
b. Penetrating damp: This type of damage can occur as a result of structural defects, such as a faulty roof covering or leaking rainwater pipes.
c. Condensation damp: When humid air comes into contact with a cold surface, the air gets cooled to a point where it can no longer hold the moisture. This causes the excess water to condense and fall onto the surface as droplets.
d. Leakages: Masonry leakage can be caused by either holes in the external walls resulting from the collapse of improperly sealed abandoned tubes, or the formation of cracks in masonry walls and gaps in mortar joints due to aged or deteriorated mortar. To assess the causes of moisture damage in the minarets, a field investigation was conducted to evaluate the different types of dampness. The results were tabulated in Table 5.3, which shows

that most of the moisture damage in stones and mortar is due to either penetrating damp or leakages.

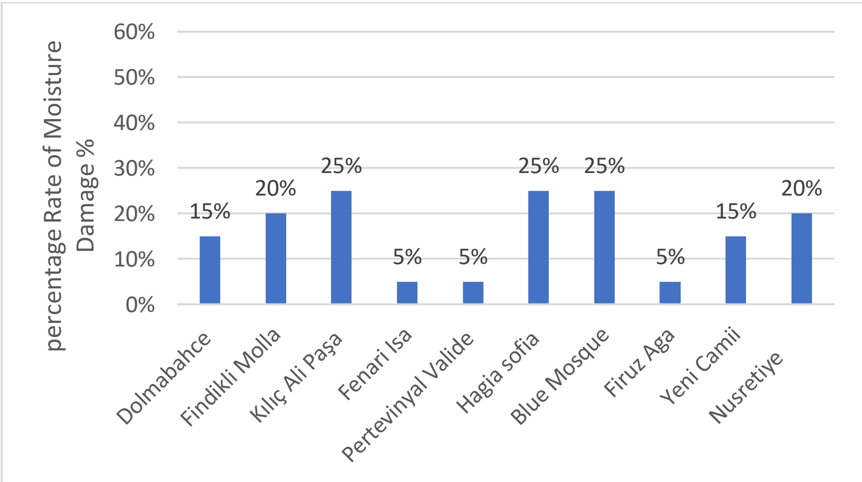
Table 5.3: Observed Moisture Damage.

Name	Rising Damp	Penetrating Damp	Condensation damp	Leakages
Dolmabahce	_	✓	_	_
Findikli Molla	_	✓	_	✓
Kılıç Ali Paşa	_	✓	_	_
Fenari Isa	✓	_	_	_
Pertevinyal Valide	✓	_	_	_
Hagia sofia	_	✓	_	_
Blue Mosque	_	✓	_	_
Firuz Aga	_	✓	_	_
Yeni Camii	_	✓	_	✓
Nusretiye	_	✓	_	_

5.3.11 Observed Moisture Damage in the SSurveyed Minarets

It was found that all minarets selected as case study are exposed to moisture damage that is either because of rising damp as illustrated in Pertevinyal Valide and Fenari Isa or due to penetration damp and leakages in the rest of the minarets. Chart 5.11 shows that on average, the moisture damage affecting the minarets ranges from slight to moderate damage, ranging from 5% to 25%.

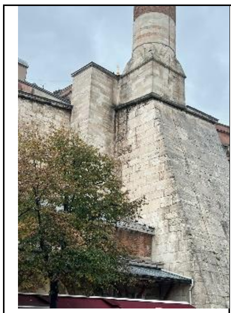
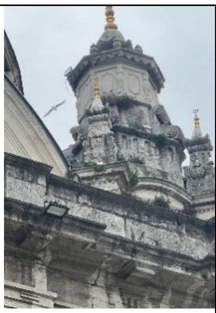
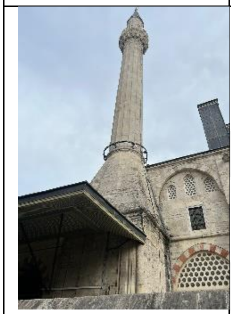
Chart 5.11: Observed Rate of Moisture Damage.



The causes of moisture damage in these minarets can be interpreted as follows:

a. Rain is considered an important source of water that activates and interacts with other spoilage factors, such as salt. The rainwater that falls is pure, but when it enters the atmosphere, a change occurs in its composition. As it falls on the roofs, it begins to dissolve and drain the salt that are present inside and outside the building materials in buildings. Rainwater mixes with atmospheric pollutants and when it falls on stones and various building materials that contain calcium and magnesium carbonates in limestone, dolomite, and mortar, these carbonates turn into bicarbonates that are easy to dissolve in water. When these porous stones are exposed to evaporation, the layers of stones and mineral components shrink. Rain helps atmospheric pollution gases to transform into acids, especially sulfuric and nitric acid, which attack building materials and work to cause chemical and physical transformations in the components of these materials, which results in corrosion, fragmentation, and peeling of stone surfaces and the decorative elements and units they carry.
b. Ground water is loaded with dissolved salt ions that are very harmful to foundations and archaeological building materials, such as chlorides and sulfates, which often precipitate on the surface of the archaeological building after the water evaporates due to heat, in addition to the salts already present due the components of stones and building materials, and the ground water rises from the bottom to the top due to the capillary system, carrying with it Salts Na, K, Ca, Mg4, SO3, NO, C, which are the ions that water contains. Ground water greatly affects archaeological buildings, increasing the peeling of these walls and the appearance of cavities in the stones. Figure 5.28 shows the moisture damage in the walls of minarets in which it can be noticed the loss of the bonding material between the stones, in addition to the appearance of peeling in the surface layer and the appearance of cavities in the stone.

Chart 5.12: Observed Moisture Damage Images.

				
(A)Hagia Sofia	(B) Dolmabahce	(C)Fenari Isa	(D)Findikli Molla	(E)Firuz Aga
				
(F)Ali Paşa	(G) Nusretiye	(H) Pertevinyal	(I)Sultan Ahmed	(J)Yeni Cami

5.3.12 Investigation of Previous Reconstruction or Renovation

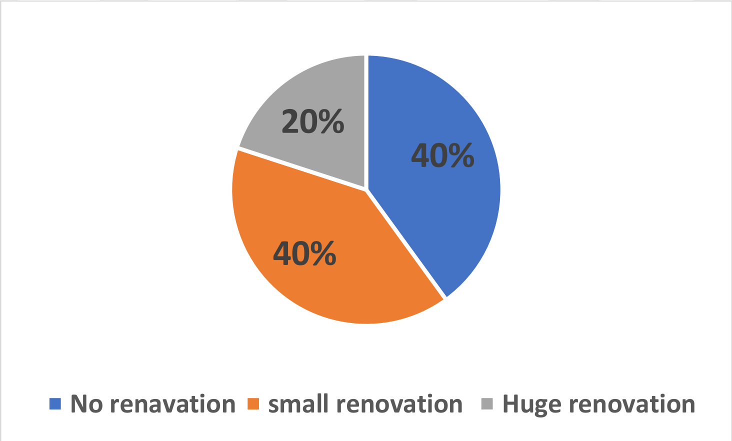
Table 5.4 illustrates the investigation results of any previous reconstruction or renovation of the minarets.

Table 5.4: Investigation of Previous Reconstruction or Renovation.

Name	No Renovation	small renovation	Huge renovation
Dolmabahce	✓	_	_
Findikli Molla	_	_	✓
Kılıç Ali Paşa	_	✓	_
Fenari Isa	✓	_	_
Pertevinyal Valide	✓	_	_
Hagia sofia	_	✓	_
Blue Mosque	✓	_	_
Firuz Aga	_	_	✓
Yeni Camii	_	✓	_
Nusretiye	_	✓	_

Chart 5.13 can illustrate that 40% of the studied minarets in Istanbul city are without renovation or reconstruction and 40% of minarets were exposed to partial renovation while only 20% of the minarets were exposed to huge renovation.

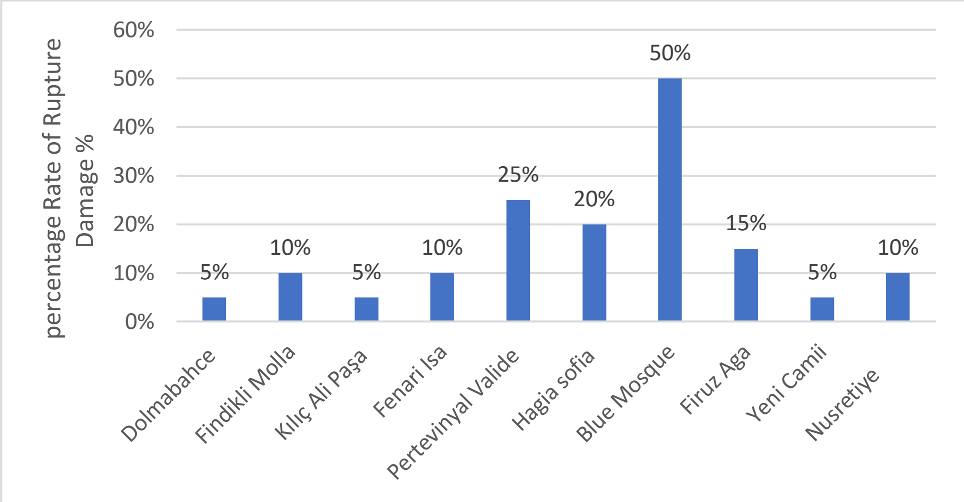
Chart 5.13: Observed Rate of Renovation of Minarets.



5.3.13 Observed Rupture or Tear Damage in the Stones or Bricks of the Surveyed Minarets

Chart 5.14 shows the percentage of damage caused by ruptures in stones or bricks of the minarets. It can be observed that all minarets have experienced slight to medium rupture in stones, with the percentage ranging from 5% to 25%. However, the Sultan Ahmed minaret has suffered extensive damage in both stones and bricks, which requires treatment solutions.

Chart 5.14: Observed Rate of Rupture Damage.



6. REMEDIAL SUGGESTIONS

6.1 PRELIMINARY REMEDIAL SUGGESTIONS

Chapter five investigated and assessed the current conditions of minarets and showed that various damages occurred in these minarets: moisture, salt, air pollution, environmental effect in stones, surface erosion, crack formation, damage due to vegetative formation. Most of these damages exhibit an extent of slight to medium and some of these deteriorations are at a significant level. These damages can be roughly classified as biochemical deterioration, chemical deterioration and mechanical deterioration. This chapter suggests remedial solutions to handle these deteriorations of the minarets studied.

6.2 SUGGESTED REMEDIAL SOLUTIONS FOR CHEMICAL DETERIORATION

Remedial solutions for chemical deterioration can be divided into two parts as follows:

6.2.1 Mechanical Cleaning

It is initially done using different types of brushes in terms of size and roughness to remove dust. It is possible to remove solid deposits from antiquities using blunt knives and scalpels. When cleaning, care should be taken to exclude sharp tools so as not to injure the surface. Cleaning should be done from top to bottom. Some machines or devices can also be used in cleaning operations, such as Cleaning Abrasive Air, Cleaning Laser, and Ultrasound.

6.2.2 Chemical Cleaning

If mechanical cleaning operations are not useful, one can resort to using chemical cleaning methods if the condition of the monument allows it, using various appropriate detergents. For cleaning, distilled water or water mixed with neutral soap and ammonia can be used. Impure water should be avoided as it can damage the surface. Organic solvents such as trichloroethylene, ethyl and methyl alcohol, acetone and other materials can also be used, depending on the nature of the dirt attached to the surface and the nature of the construction material.

Salt-free water is considered the safest chemical for cleaning archaeological materials. It is preferable to be followed by a quick wash using an organic solvent such as alcohol or acetone to help speed up the drying of the surface before the water penetrates the pores of the material, which leads to dissolving the salt in the pores and then transporting them. To other places in effect, thus crystallizing and destroying it. It would be very useful to try the performance of the method beforehand on a similar construction material. [68]

6.3 SUGGESTED REMEDIAL SOLUTIONS FOR MOISTURE DAMAGE

Preventive techniques can prevent biological deterioration on minaret stones by altering their ecological surroundings and physicochemical factors, making it difficult for biological growth to occur. This method efficiently reduces unfavorable growth by controlling biodeteriogens' environmental viability. Although this method is effective for some parameters, such as deposits of organic debris, dirt, and pigeon droppings, it may not be effective for controlling moisture, fluctuations in temperature, and light in the external environment. However, these factors can be controlled by modifying the physicochemical factors of the stone surface using preservation techniques. By administering regular preventive measures that minimize the reasons for humidity in minarets and maintain moisture levels. The degree of biological growth can be minimized, and its growth can be limited, solutions such as fixing gutters, and other water-shedding system; enhancement of drainage systems, and water proofing in order to control rising ground moisture; all help in making the stone masonry of the minarets dry. Adjacent vegetation can be used as a preservation solution in archaeological sites. It can also be utilized around minarets to alter the local climate and consequently minimize the biological growth around masonry minarets. That is, by selecting the right vegetation, it is possible to decrease the water level, reduce the evaporation process, minimize salinity, pollution, and erosion.[64].

There are two more solutions for minimizing moisture damage and they can be described as follows:

a. Reducing surface and sub-surface water through Vertical Moisture Barriers: The method of vertical water barriers is used to reduce the amount of surface seepage water that reaches the foundations and the lower parts of the walls, and it is either walls around the foundations or in the form of holes and channels dug around the walls that collect water around the walls.

b. Submerged Drainage: The covered drainage method is used to prevent surface and horizontal seepage water from accumulating or to keep the groundwater level low enough that it does not reach the foundations of walls and cause capillary action. Basically, this method involves installing a network of porous pipes on the roofs of buildings at depths that correspond to the level of groundwater or seepage water. The pipes lead to a group of deep wells dug outside the building that collect the water, which can then be pumped away from archaeological sites [66].

Another recommendation is using breathable waterproofing masonry cream like Stormdry Masonry Cream on the outer walls is recommended to build an effective hydrophobic barrier from moisture.[67].

6.4 SUGGESTED REMEDIAL SOLUTIONS FOR SALT DAMAGE

The most effective methods to reduce salt damage according to study conducted by [65] can be classified into two categories as follows:

a. Mechanical elimination of salts in crystalline shape by cleaning efflorescence.
b. Dissolution and extraction of ions from solutions can be achieved using poultices or electrochemical methods with anodes and cathodes.

According to [66], it is recommended to use the technique of isolating the foundations to prevent ground water from reaching the walls. Additionally, it is suggested to strengthen weak stone blocks with suitable hardening solutions that do not clog the pores of the stone. Furthermore, the surfaces of the stone blocks should be cleaned by removing and extracting salt with mechanical methods or with appropriate solutions that do not affect the condition of the stone surfaces.

Dry removal of salt is considered one of the simplest means of removing salt, in which mechanical methods are used, especially for salts present on the surface. The tools used to remove them are like the tools used in mechanical cleaning. Removing salt from stones or building materials; Ammonium carbonate can be used to help dissolve calcium sulphate salts (gypsum), converting them into ammonium sulphate, which is then easily soluble in water by repeated washing.

The process of washing the salt gave good results in eliminating the salt or reducing their presense, so the stone can be washed for 40 minutes with pure water and then left to dry for 7 days, and the process repeated. Mechanical and chemical cleaning can be used together to get good results. The use of cleaning methods varies according to the soiling material and the type of trace material.[70].

Cleaning with compresses is considered a safe and effective method for cleaning antique surfaces and old building materials, as well as removing and extracting salt. Compresses are safer than cleaning using some mechanical cleaning methods. Compresses are often used to clean decorative surfaces that require care when cleaning them.

The compress consists of two basic components: the compress material (the compress medium) and the cleaning agent. The cleaning agent may consist of more than one compound depending on the dirt that needs to be removed, and when removing and extracting salt. This process works by allowing the material to absorb the water in the compress, which dissolves the salts present in it. As the water from the compress evaporates, the salt solutions begin to drain away. [70].

6.5 SUGGESTED REMEDIAL SOLUTIONS FOR MECHANICAL DETERIORATION

Strengthening means rebounding, cohesion, and improving the properties of a material or stone that has been exposed to weathering, lost its cohesion, cracked, and lost some of its parts [72]. The strengthening process is considered one of the most dangerous maintenance works due to its irretrievability and the possibility of causing undesirable effects such as losing the reinforced surface [73]. Therefore, there are some specifications that should be available in the appropriate reinforcement material [74], which are:

a. Its ability to achieve a good penetration rate.
b. its ability to prevent water from leaking into the material and at the same time prevent its exit from it.
c. to resist the aging factor and increase the strength of the material and not affect the color of the surface.
d. to be compatible with the properties of the building material.

Strengthening Methods can be described as follows:

a. Consolidation by Immersion: This method can be used for antiquities that can be moved and transported to a restoration laboratory, whether on site or outside, such as stone blocks falling from the walls of an archaeological building. The strengthening process is carried out by following the following steps [75].

a. The trace is immersed in acetone for a period to open its pores, which facilitates the penetration of the hardening material.
b. The effect is placed in a prepared basin and immersed in chemical hardeners dissolved in appropriate organic solvents.
c. Then the thin layer that formed on the surface is removed using organic solvents
b. Strengthening by injection: The carried out by using tools such as syringes (medical) of different sizes or using rubber tubes, which are filled with strengthening material and then injected into the trace through the cracks. In the absence of such outlets, holes are made for injection, and it is preferable to keep it away from engravings and writings. Care should be taken to remove any reinforcement material that leaks onto the surface immediately using pieces of cotton moistened with acetone and wrapped in gauze [75].
c. Brushing strengthening: This method is applied to surfaces with cohesive grains, using different sizes of soft brushes. The strengthening process is carried out by lightly touching the surface of the effect with the strengthening material. While this technique may be straightforward to employ, it is not ideal for large, permanent structures. Due to the gradual process involved, a significant amount of hardener is lost through evaporation, leading to the hardener melting on the surface and causing distortion. [75].
d. Strengthening by spraying: This method is used to strengthen the surface with weak formations that can be transported to the laboratory. The strengthening is done by spraying using a tube with several holes, where the strengthening material is sprayed towards the surface to be strengthened, considering covering the surface tightly or using a polyethylene cover to reduce the evaporation of organic solvents. For this method to be successful, the hardener must have a low viscosity [75].
e. Strengthening by saturation using the paper covering technique: The theoretical basis of this method is based on keeping the surface of the trace, as well as the paper covering, constantly moist and wet for several hours or days, while avoiding evaporation until the greatest possible depth of saturation occurs. Strengthening is done by covering the surface with a paper cover that is adhered to a light adhesive, while continuing to keep it moist with the strengthening liquid by covering it with a plastic cover [75].
f. Reinforcement using tubes (Mirovsky method): This strengthening method involves spreading the strengthening material within the stone's structure in the form of semi-circles. By repeating the process, large areas of the monument's surface can be

strengthened by converging and overlapping the semi-circles in both vertical and horizontal directions. The method uses bottles with nozzles fixed onto the stone's surface, which release the hardening solution when pressed. [76]

7. CONCLUSIONS AND RECOMENDATIONS

This thesis provides information about the origin of minarets, emergence of minarets during eras, and description of Ottoman minarets. It also shed light on the aesthetic architectural aspects of these minarets and researched the construction materials that were used and the construction methods by which the minarets were constructed and then moved to adopting a case study consisting of 10 minarets in the city of Istanbul to evaluate, the current damage to the minarets, considering the biological, chemical and mechanical factors. The damage occurring in these minarets was evaluated through a field exploratory study through which the necessary measurements were made to achieve the objectives of the study, and based on the assessment minarets that were conducted, remedial solutions were proposed to restore and preserve these minarets.

7.1 CONCLUSIONS

According to the evaluation of the Ottoman minarets according to the biological, chemical, and mechanical damage, the following conclusions were drawn:

a. A slight to moderate change was observed in the color of the stones that make up most of the Ottoman minarets, with the exception of the Dolmabahce minaret. A noticeable change in the color of the stone was observed, in 50% of the minarets. The reasons for the color change are attributed to environmental influences, dust, and dirt over time, and to falling rainwater and its interaction with atmospheric pollutants.
b. It was observed that there was blackening in the stones on the studied Ottoman minarets at a rate ranging from 10% to 45%. This blackening is due to pollution resulting from smoke and exhaust fumes from cars and factories and the effects of acid rain, and humidity.
c. No salt damage was observed except in the Sultan Ahmed mosques, at a rate of 50% and Findikli Molla, at a rate of 10%, as this damage caused the appearance of cavities in the stone.
d. The damage resulting from vegetative formation was slight, ranging from 5% to 15%in all.
e. There is no risk of cracks formations, as the crack values according to the recorded measurements ranged between 0.1mm and 1mm. These values are considered acceptable

and do not seem to pose a substantial threat to the safety of the minarets, but they definitely should be monitored regularly.

f. No separation between the stones was observed in the minarets studied.
g. Surface erosion was observed in the minarets studied, ranging from 10% to 60%. It can be considered that the damage from surface erosion is moderate to severe.
h. No acts of vandalism were observed in the studied Ottoman minarets.
i. When evaluating the studied minarets according to moisture damage, it was found that moisture damage ranges from light to moderate.
j. It was found that all the Ottoman minarets studied were made of natural stone, and in a small number of minarets, bricks could were used with natural stone.
k. According to the literature about the previous rehabilitation of the minarets, it was found that 40% of the minarets were not reconstructed, preserved, or restored, while 40% of them had undergone minor restoration operations, while 20% of these minarets had witnessed significant restoration operations.
l. The assessment of the minarets depicted that the damage resulting from biological damage, some remedial solutions were proposed to preserve, restore, and reconstruct these minarets.

7.2 RECOMMENDATIONS

After the evaluation process was conducted in this study, it was noted that these minarets were exposed to biological, mechanical, and mechanical damaging factors. Accordingly, the following suggestions are recommended in general:

a. Directing efforts by the government and concerned parties to preserve this heritage by carrying out the necessary maintenance and preservation operations to protect it from all factors of damage.
b. Conducting experimental tests to assess the damage in depth, in addition to conducting experiments to preserve the stones, strengthen them, and reinforce them structurally.

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APPENDIX A

1. Is there any discoloration or color change over time due to environmental effects?

a) No

b) To a slight extent

c) To a medium extent

d) To a large extent

2. Is there any blackening on the surface of the minaret?

a) No

b) To a slight extent

c) To a medium extent

d) To a large extent

3. Is there any salt damage on the surface of the minaret?

a) No

b) To a slight extent

c) To a medium extent

d) To a large extent

4. Are there any vegetative formations in parts of the minarets?

a) No

b) To a slight extent

c) To a medium extent

d) To a large extant

5. Is there any crack formation? If yes. What is the size of these cracks?

a) No

b) Hairline cracks (0.1mm)

c) Fine cracks (1mm)

d) Cracks width (5mm)

e) Cracks width of (5-15mm)

f) Extensive damage (15-25mm)

g) Structural damage (more than 25mm)

6. What are the construction materials used in each minaret?

a) Brick

b) Stone

c) Combination of brick and stone

7. Is there a separation between masonry blocks?
a) No
b) Small amount
c) Medium amount
d) Large amount
8. Is there any surface erosion on the surface of the masonry blocks because of environmental effects?
a) No
b) Small amount
c) Medium amount
d) Large amount
9. Is there any damage due to vandalism attacks?
a) No
b) Slight damage
c) Medium damage
d) Large damage
10. Is there damage to the stone or mortar because of moisture?
a) Rising damp
b) Penetrating damp
c) Condensation damp
d) Leakages
11. What is the extent of moisture damage on the walls?
a) No
b) Slight damage
c) Medium damage
d) Large damage
12. Can we notice any reconstruction/renovation to the minaret?
a) No
b) A small portion of the minaret
c) A large portion of the minaret

13. Is there any rupture and wear and tear damage in the stone/bricks of the minaret?

a) No

b) A slightly damaged

c) Medium level damaged

d) Largely damaged