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ARCHITECTURAL PILGRIMAGE: GEOMETRIC HARMONY IN EARLY OTTOMAN MOSQUE INTERIORS

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Abstract: The main objective of this study is to take the reader on an architectural pilgrimage to learn about the geometric harmony in the structural patterns that formed the sacred interior space of early Ottoman mosques, "The Single Unit Mosque." The applied analytical approach is the preferred scientific method for employing theoretical knowledge to conduct structural and geometric analysis on some of the buildings selected in this study, with the researchers seeking to achieve tangible practical results. Since Ottoman architecture was characterized by strong construction and heavy materials through thick walls and high spacious domes, it needed distinctive building techniques to provide spatial and structural harmony between the cubic construction with its straight lines at ground level and the hemispherical construction of the dome with arched lines at the upper level. Therefore, it is necessary to identify the structural patterns and elements employed in Ottoman architecture in the early period of the Ottoman Empire and show their influence on the shape of the interior space and the extent of its breadth and beauty. This study was also devoted to clarifying the geometric compositions of structural patterns through a set of examples of analytical assessments on a selected group of Ottoman mosques. The results clarified the advantages and disadvantages of the domed Ottoman Mosque structural patterns. The research provides a significant and original contribution to the study of early Ottoman Mosque interiors, offering valuable insights into the structural innovations that defined Ottoman architecture.

Keywords: architectural pilgrimage, geometric harmony, the "Single-Unite" Ottoman Mosque, early ottoman architecture, geometry of interior space

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INTRODUCTION

The Ottoman Empire is a state founded by Turkish tribes under Osman Bey in north-western Anatolia in 1299. With the conquest of Constantinople by Mehmed II in 1453, the Ottoman state became an empire. The empire reached its peak at 1590, covering parts of Asia, Europe and Africa. The Ottomans evolved from a small community to one of the biggest and longest-lasting empires, 1299 - 1922, that left behind a rich architecture. They were great builders, engaging in extensive building activities as early as the first half of the fourteenth century in the first capital Bursa (Shaw, 2025).

Mosques were built as focal points for the gathering of people and dervishes in Ottoman cities. The mosque building was considered both practical and symbolic among the religious institutions that served as key indicators of the urban character of the Ottoman Empire (Katsarakis, 2023). From the early beginnings, the Ottomans adopted the domed cubic style as the main architectural form for their mosques, with four large walls defining the square boundaries of the prayer hall, topped with a hemispherical dome. To transition from the square base to the circular dome and bridge the spatial gap, Ottoman architects employed three primary structural systems: squinches, corner triangles (pendentives), and prismatic triangles (also referred to as Turkish triangles) (Hassan, 2010; Al Khafaji et al., 2024). Each of these construction types has distinct structural characteristics that significantly influenced the interior spatial design of early mosques. This study investigates these structural patterns and their impact on the design of "single-unit" Ottoman mosques constructed during the early period, from the 14th to 15th centuries. Early Ottoman mosques demonstrated a relatively limited use of muqarnas, an architectural element that serves both decorative and structural functions. This feature was well established in earlier Islamic architecture, particularly in regions governed by Arab Muslim dynasties, where it played a prominent role in the articulation of transitional zones and ornamental surfaces. In the early phases of Ottoman architectural development, muqarnas appeared occasionally, primarily as a decorative motif rather than a structural necessity (Ödekan, 2021).

It was not until the sixteenth century, under the innovative vision of the imperial architect Mimar Sinan, that muqarnas were fully integrated into Ottoman architectural design with both structural and symbolic significance. A notable example is found in the Selimiye Mosque in Edirne, constructed between 1568 and 1575. The mosque's monumental dome—the

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widest in the history of Ottoman architecture—is adorned with refined muqarnas compositions that contribute to both the aesthetic coherence and the structural complexity of the edifice. This marked a turning point in Ottoman architectural practice, reflecting a synthesis of inherited Islamic forms with new engineering approaches (Şenalp et al., 2024).

Recent research has explored the transformation of muqarnas from decorative to structural elements during this period. Comparative studies highlight shifts in two-dimensional and three-dimensional muqarnas design between the Bayezid II and Sinan eras, demonstrating the increasing sophistication of Ottoman architectural ornamentation (Ödekan, 2021; Naz, 2024). Sinan's innovative use of muqarnas not only exemplifies the stylistic evolution of the time but also embodies the competitive discourse of early modern Islamic architecture (Kiuiper, 2009). It is possible to comprehend the evolution of dome architecture in Ottoman mosques by examining both technical and geographical factors. The dome construction, which is distinctive in each and always reflects its time and spatial environment, is a common feature of Ottoman mosques. It is known that this architectural style has both Byzantine (Eastern Roman) and Islamic roots. A lengthy history of civilization has been shaped by Ottoman Mosque architecture, which was impacted by a number of technological and cultural elements. Although each structure has distinct qualities of its own, they are all related to and enhance one another. Thus, it is indisputable that the evolution of dome building throughout the early Ottoman era shows distinct connections between the earlier and later stages of the Central Asian, Bursa, Edirne, and Istanbul dynastic architectural traditions (Idham & Numan, 2020).

Numerous earlier studies examined early Ottoman architecture from a historical perspective or using a historical methodology. One such study is the well-known book "The Mosque in Early Ottoman Architecture," authored by Aptullah Kuran, in which the author precisely categorizes early Ottoman mosques according to the design and arrangement of their interior spaces. The earliest and best-known of these is the "Single-Unite" Mosque, which served as the model for the various Ottoman Mosque architectural forms. This amazing book served as motivation for carrying out the study, which uses a historical analytical approach to describe the "Single-Unite" Mosque through a series of analytical charts that combine the interior space with its various geometric features and the structural system with its various patterns. As is known, the interior space would not have existed without the building and construction systems, and the building would not have been possible without the need for the internal space. But things are more precise in the case of Ottoman architecture, as the building is very transparent and through the external shape of the mosque you can expect the shape of the interior space (Kuran, 1968)

By providing insights into the mosque's vertical construction system and the systems of proportion employed in early Ottoman Mosque architecture, this article seeks to explore the geometric concepts that underlie the design of these structures. To clarify what the researcher has in mind, the following question is asked: What are the structural patterns used in the early Ottoman Mosque? Was the shape of the interior space of early Ottoman mosques affected by the structural patterns and geometric shapes? Therefore, we say that the main objective of this research is to closely identify the types and shapes of structural patterns used by Ottoman architects in the architecture of the early "Single-Unite" mosque, and to know their influence on the design and formation of the interior space of the mosque. This is done through a group of mosque examples chosen by the researcher to complete this study.

METHODS

This study, which follows an applied research framework, employs both historical and descriptive-analytical approaches. The primary approach is the "historical approach", which traces the geometric patterns and structural elements utilized in the construction of the interior spaces of early Ottoman mosques according to their compositional and structural diversity, while adhering to historical evidence. To identify and classify significant architectural forms and construction processes, this method requires the study of historical records, architectural plans, and existing structures (Necipoğlu, 2005; Goodwin, 2003). At the same time, these significant structural components in Ottoman architectural history are interpreted and examined using the descriptive analytical approach in layers that are horizontally connected and vertically overlaid. According to geometric principles, this method enables a thorough examination of how particular architectural elements—such as domes, arches, and walls—shape the mosque's interior space and their effects on its horizontal arrangement and vertical development (Kuban, 2010; Öney, 1987). The mosque's spatial dynamics, particularly the interplay of form, function, and aesthetic harmony, are made clearer by these analyses.

Furthermore, the study includes a "comparative analysis" to identify the locations of architectural innovations in certain historical settings and geographical regions of the early Ottoman period through three historical architectural models. This comprehensive approach enhances our understanding of how political, cultural, and religious influences influenced the architectural representation of Ottoman Mosques. Architectural photographs and drawings are among the visual aids used to support the analytical framework and demonstrate how architectural forms changed over time.

Geometry and Structure of the Early Ottoman Mosque

The expansion of new territories under Ottoman rule led to a diversity of Turkish mosque architectural styles. Ottoman rulers permitted the construction of many new mosques to accommodate the growing Muslim population. Therefore, we note that while many previous studies have examined the history of Ottoman Mosque architecture, they have not addressed the development of the geometric pattern and structural design and its impact on the overall appearance of Ottoman mosques.

Given the architectural focus of the study, the manuscript analyzes geometric patterns in the interior designs of early Ottoman mosques using a qualitative comparative approach, as previously described. The criteria for choosing case studies will be clarified in order to provide transparency regarding the selection of particular mosques for investigation. Referring to the importance of structural design and domed mosque architecture in the early Ottoman period in Anatolia, this study seeks to examine and analyze the development of domed architectural designs in Ottoman mosques built in the 14th century.

To achieve the main objectives of this study, authors classify three structural design concepts and examine their impact on the overall form of the mosques, particularly the vertical spatial-structural composition:

A) The first spatial-structural design relies on squinches or angular arches as an intermediate structural element above the ground cube below the upper dome. To illustrate this pattern, the Orhan Sultan Mosque was chosen for testing and analysis.

B) The second spatial-structural design relies on pendentives or descending triangles as an intermediate structural element above the ground cube and below the upper dome. To illustrate this pattern, the Bayezid II Mosque was chosen for testing and analysis.

C) The third spatial-structural design relies on Turkish prismatic triangles as an intermediate structural element above the ground cube and below the upper dome. To illustrate this pattern, the Green Mosque of Iznik was chosen for testing and analysis.

These three mosques are characterized by their horizontal layout and diverse spatial distribution, as will be explained later.

The Basic Geometry of the Early Ottoman Mosque: Circle and Square

What is most striking is that the concept of the circle and the square is always present in all the plans of early Ottoman mosques, whether by repeating the same unit or changing its dimensions. The prayer hall models were limited to only one domed square unit consisting of a simple design of an enclosed space, a circle and a square (Kuran, 1968).

The circle and square, as shown in Figure 1, are considered geometric shapes that are characterized by simplicity and clarity, and their shapes are widespread in architecture, both externally and internally. They are appeared in many historical monuments, and sometimes carry symbolic meanings and values. The square may represent: the earth, finite, manifest things, exterior effect, things encompassed and four directions. While the circle represents: sky, heaven, infinite, non-manifest essence, interior cause, all-encompassing, center, dome of the sky, an ancient and universal symbol of unity, wholeness, eternity, infinity (Spanos, 1978). The two-dimensional square represents strength, precision, and a solid foundation. It can also be seen as a representation of a flat land surface, where vertical walls are built that surround the interior space and support the domed roof. In the third dimension, as shown in Figure 2, it is the cube, the base of the building and its wall envelope at ground level. The circle represents the spherical volumes and movements of celestial bodies, and can essentially represent the upper system of the building that covers the roof and envelops the interior space from above in a more convenient way. In the third dimension architecturally it is the dome, the head of the building and the raised part of it. Its spherical body closely resembles the curved shape of the sky, and therefore it appeared strongly in religious buildings in all ancient and contemporary civilizations. Moreover, the vertical axis of the dome emphasizes the direct vertical relationship between the people of the earth and the Almighty Creator (Gharagozlou, 2015).

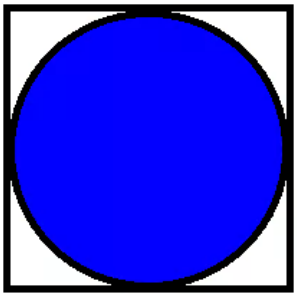

Figure 1. The Circle and Square (Source: By authors)

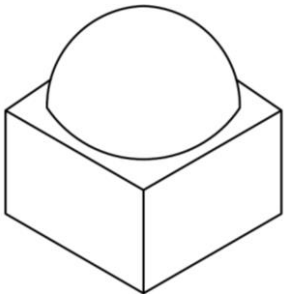

Figure 2. Three-Dimensional Circle and Square (Source: By authors)

3.2 Structural Patterns Employed in The Early Ottoman Mosque

From the early beginning, Ottoman architects did not adopt the strategy of using several rows of columns to create a mosque with large interior spaces, as was the case in the ancient Arab mosques of Damascus and Andalusia. They adopted the typology of cubic spaces free of columns and pillars to the greatest extent possible in building mosques so that the rows of worshipers would not be interrupted. To achieve this goal, Ottoman architects used wide domes to roof mosques (Kökcü, 2023).

Figure 3 shows the shape and construction method of the three main structural elements used by Ottoman architects to raise domes above the tops of mosques in the early period. Before the advent of Ottoman architecture, domes were raised above cubic buildings using squinches and pendentives to provide a circular base suitable for the upper circumference of the dome. The Ottoman architects used these two previous structural patterns in their buildings, in addition to inventing Turkish prismatic triangles, which had not been previously used in the architecture of any of the world civilizations (Freely, 2011).

The squinches are usually built at the ends of the straight walls, which are built on a square base, and the dome is placed on top of these four walls. Thus, the load is transferred from the points where the dome meets the walls, in the center of the wall. Heavy structures like a dome need uniform weight distribution and hence the load must be transferred through the corners of the box as well. The corners are closed by building short bridges, squinches, across the corners of the square to transform the base of the dome into an almost octagonal shape. The corners are closed by building short bridges, squinches, across the corners of the square to transform the base of the dome into an almost octagonal shape. This architectural solution ensures uniform weight distribution from the dome through both the walls and corners of the supporting structure. Squinches can be constructed using either a corbelling system or by building small arches, with precise mathematical relationships governing their dimensions relative to the square base (Elkhateeb, 2012). In construction, squinch is a device by which a round dome or drum is supported on a square or polygonal base. It helps transition the weight of the drum or dome to the walls of the square or polygon. It does not efficiently carry the weight and dynamic pressure of the dome: it has a low limit

on the diameter of a dome that is supported by corner squinches. It is easy to implement in almost any material with only moderately skilled labor, but it makes the overall appearance imprecise. Usually, four squinches are used at the corners of the square to transform from the square to the octagon, over which the circular circumference of the dome rotates (Labisi, 2019).

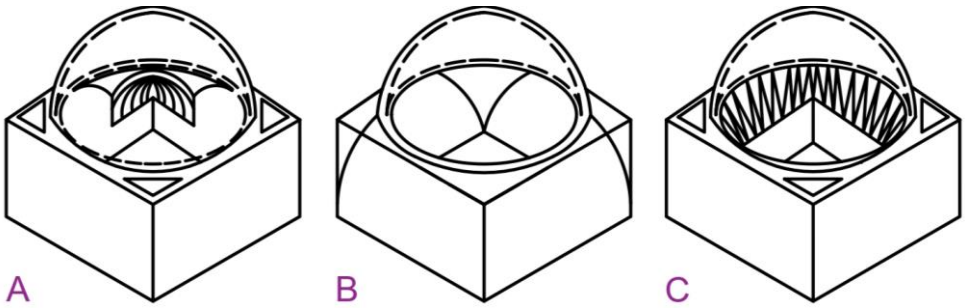

Figure 3. Transitional Structural Patterns Employed in The Single-Unite Mosque
(a) Squinches (b) Pendentives (c) Turkish Prismatic Triangles (Source: By authors)

The void of the four corners of the square can be filled with a concave triangular section of a hemisphere, pendentives, which is a constructive device permitting the placing of a circular dome over a square space that transfers the weight of a dome to a square base. The pendentives taper to points at the bottom and spread at the top to create the necessary continuous circular base for the dome. It is thought that the term pendentive originated from the Latin word, "pendent" meaning hanging down, as the triangles appear to be hanging from the dome above. (Marković, 2020).

In construction, the pendentives thus receive the weight of the dome, concentrating it at the four corners where it can be received by the piers beneath. The concave triangular section provides a smooth transition between the dome and the square base on which it is placed, and transmits the weight of the dome. Pendentives transfer the weight directly down to the corner piers by placing the dome on a second, larger, partial dome. Pendentives allows the construction of much larger domes but at a much higher cost of skilled labor and precision bearing materials (Hassan et al, 2010).

Prismatic triangles, also called Turkish triangles, are a transformative structural element commonly used in early Ottoman mosques, placed at the curved area between the corners of the ground cube and the circumference of the dome circle. It consists of a group of long and narrow triangles circling the dome built at a specific angle from each other (Goodwin, 2003).

The Prismatic triangles are built in a flexible and continuous belt around the perimeter of the dome so that the sides of the triangles are lengthened or shortened when needed or at the corners of the square to ensure smooth rotation of the dome circle. Structurally, the prismatic triangles represent an ideal base under the dome, because they transfer the weights in a balanced manner from the lower ends of the dome to the load-bearing walls at ground level. The problem with this structural element is that it is limited in height and does not have sufficient flexibility to increase the length of the building vertically. It also suits the load-bearing walls system more than the more complex construction system that depends on specific structural paths to transfer weights to the ground foundations (Kuban, 2010).

4. The "Single-Unite" Mosque and Its Structural Patterns

There were many spatial construction methods used in planning the early Ottoman Mosque with the founding of the Ottoman Empire in 1299, the oldest of which is the single-unit mosque, which is the main topic of this study. In his book "The Mosque in Early Ottoman Architecture," Aptullah Kuran classified the types of single-unit mosques into three categories: The Basic Spatial Mass, The Single-Unit Mosque with complex massing, and The Single-Unit Mosque with Articulated Interior, which will be discussed and analyzed one by one throughout this article.

During this study, the researcher will make use of the spatial classifications and nomenclature adopted by the author Aptullah Kuran in his historical study (Kuran, 1968). In order to achieve the necessary knowledge about the structural-spatial system of the single-unit mosque, this building will be analyzed horizontally and vertically and the geometric composition of the building will be known. This is done through five analytical sections, starting first from the horizontal section A-A, which is slightly above the ground level and within the level of the mihrab, secondly, the horizontal section B-B, which is at the same level as the intermediate structural systems between the ground cube and the upper dome, thirdly, the horizontal section C-C, which is From the level of the upper end of the ground cube and the intermediate structural systems, the fourth is the horizontal section D-D, which is from the same level as the neck of the cylindrical dome, and the fifth is the horizontal section E-E, which is from the level of the top of the dome, as shown in Figure 4.

4.1 The "Single-Unite" Mosque (The Basic Spatial Mass)

The single-unit mosque is the basic type of Ottoman domed spatial structure, and is the oldest and simplest model among all categories of mosques in Ottoman architecture. The structural scheme of its building consists of a square at the ground level and a dome covering the roof, and between them are the more complex structural elements that facilitate the transition from the ground square to the dome circle and close the corners of the square. The concept built upon a centralized enclosed cubical interior space, which encompasses all architectural spaces, and defined by a geometrically regular base and domical roofing. While the circular roof tends to emphasize unity and centrality, the square base tends to emphasize the directionality and spatial deployment. And while the dome distinguished with the beauty and elegance of its curvilinear shape at the top of the mosque, the cubical base distinguished with the solidity and stability (Hassan, 2010).

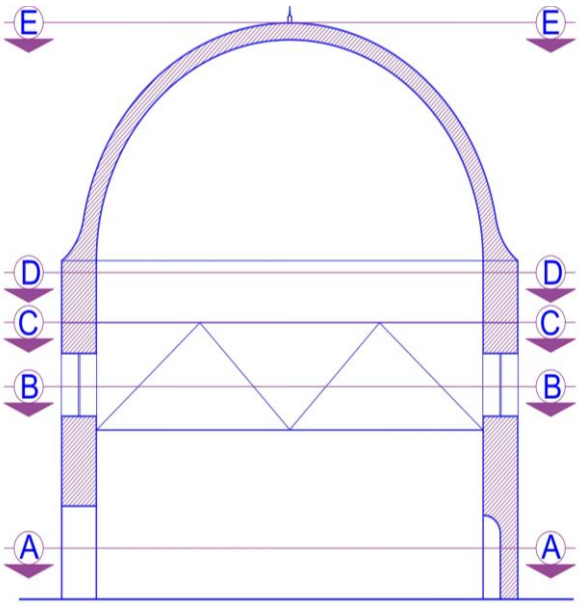

Figure 4. The Five Proposed Analytical Horizontal Sections of the Ottoman Single Unit Mosque (Source: By authors)

Figure 5. Orhan Gazi Mosque, Exterior (Source: By authors)

4.1.1 Orhan Gazi Mosque

In the Marmara area of Kocaeli, Gebze, Turkey, Sultan Orhan Ghazi (r. 1324–1361) constructed a magnificent mosque. The main prayer hall of this mosque is square in shape and has a single hemispherical dome on top, making it a perfect example of the "basic spatial mass" mosque design. The dome covers nearly the whole ceiling of the prayer hall and is positioned exactly over the ground cube, as seen in Figure 5. As a result, the mosque's exterior appears to be domed, with the dome appearing taking center stage in both its structural and spatial design (Mustafa et al., 2013). The interior of the mosque is straightforward and depicted in Figure 6. The prayer hall is bounded horizontally on four sides by four thick, flat, vertical walls. A set of arches, four of which are positioned diagonally to span the upper corners of the ground-level cube, atop the walls. A stunning ring of Arabic calligraphy surrounds the prayer hall, which is topped by a large, white dome. The mihrab, which is situated in the center of the qibla wall at the front of the prayer hall, is covered in blue glazed porcelain. The women's prayer area is atop the back part of the prayer hall, and the sole gate in the space is a pair of wooden shutters set into the back wall.

Figure 6. Orhan Gazi Mosque, Interior (Source: By authors)

According to the building design, plan and section, shown in Figure 7, the square wall height is 9.55 meters, and the dome's radius is 6.15 meters. The height of the construction (square wall and dome) is 15.70 meters. The walls are made of building stone 1.15 meters thick (Arab et al., 2012). The prayer has a square-shaped interior space covered by a hemispherical dome and consists of several structural layers built on top of each other as revealed in Figure 8. The first structural layer (A) represents the interior space of the prayer hall on the ground level. It is square in shape and surrounded by four parallel, thick walls perforated with six windows and three doors. It was built on top of the ground foundations to form the solid vertical base capable of bearing the weights of the upper parts of the building. The second structural layer (B), which is the polygonal structural system consisting of the four squinches that bridge the corners of the square, which transforms the shape of the interior space of the prayer hall from a square at the ground level to an octagon at the top of this

layer, consisting of eight sides. The third structural layer (C) represents the flat upper surface of the ground cube of the prayer hall, which combines the thickness of the upper edge of the four walls with the upper part of the corner squinches to define the uncovered space in the middle of the prayer hall and form a suitable basis for the rotation of the drum with complete flow and centrality. The fourth structural layer (D) represents the cylindrical drum. The fifth structural layer (e) represents the wide dome, which was completed in a hemispherical shape and covered the central area of the ceiling of the prayer hall.

Through the following analytical sketch of the vertical section of the mosque (Figure 9), it was indicated that the radius of the dome's circle is equal to two-thirds of the height of the ground cube of the prayer hall with the cylinder drum, while in the plan, it is noted that the diameter of the dome is equal to the length of the side of the square.

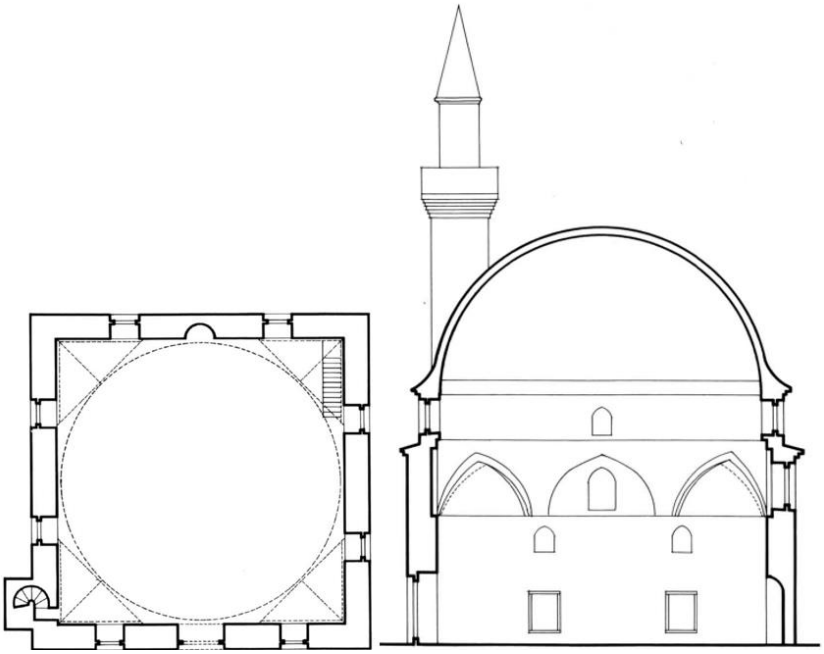

Figure 7. Orhan Gazi Mosque, Plan & Section (Kuran, 1968)

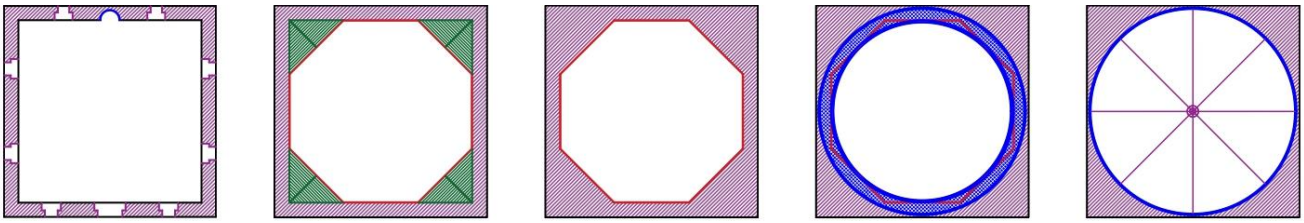

Figure 8. Structural Layers of the Orhan Gazi Mosque Plan (a) Load-Bearing Walls, (b) Load-Bearing Walls and Corner Squinches, (c) The Higher level of the Ground Cube, (d) The Cylindrical Drum, (e) The Apex of the Dome (Source: By authors)

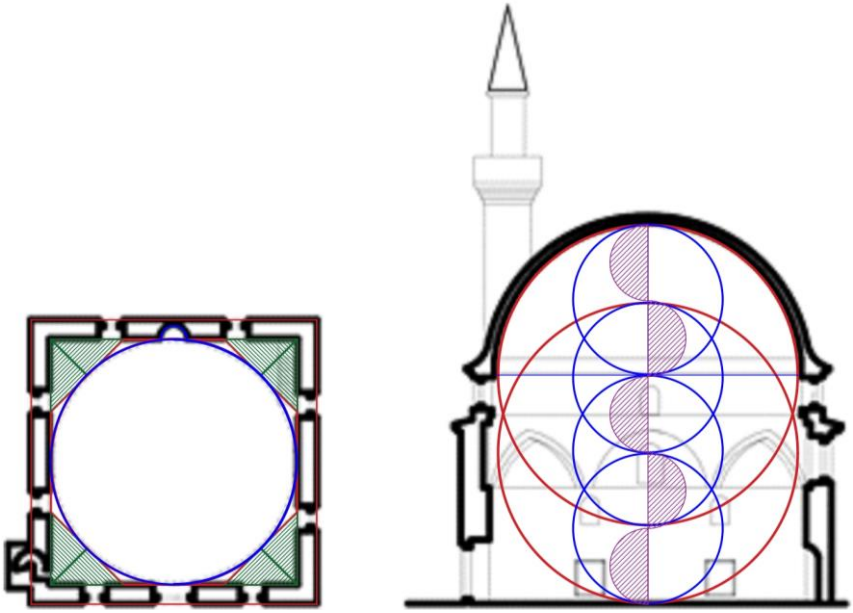

Figure 9. Orhan Gazi Mosque, Geometric Analysis, Plan & Section (Analysis by Authors)

The Orhan Gazi Mosque features a great dome with a diameter of more than 12 meters, despite its simple structural design. It also has a solid and coherent structural system made up of four layers: walls, octagon base, cylinder drum, and dome. The most intricate structural element is the octagon base, which changes the construction from square on the ground to circular at the top. The interior space of the mosque represents a single spatial unit style with a harmonious geometric formation layers consistent with the horizontal direction of the qibla axis and with the vertical direction of the dome axis.

Single-Unite Mosque with Complex Massing

The design of the interior space of this kind of Ottoman mosques is very similar to the simple single-unite mosque (the basic spatial mass), consisting of a square domed prayer hall. The difference is that the single-unit mosque with complex massing has a larger and more complex overall plan, having additional spaces such as convent rooms flanked on one or both sides of the prayer hall, sometimes with the addition of an open courtyard with a water fountain in the middle to the rear of the prayer hall (Kuran, 1968). For further clarification, what is meant by the term "Complex Massing" may also mean some buildings associated with Ottoman architecture, which may consist of a group of religious and social buildings built around a mosque, and the purpose of their construction to is provide various charitable services to the community (Bloom, 2009).

Sultan Bayezid II Mosque, Edirne

A very well-known example of this type of Ottoman Mosque is the mosque built in the European part of the Ottoman Empire. The patron of this mosque was Sultan Bayezid II (r. 1481-1512), who entrusted the design and construction task to one of the most famous architects of the time, the architect Khair ad-Din, which took four years 1484-1488. The mosque is considered one of the most prominent examples of the type of “Single-Unite” Mosque with Complex Massing. As shown in Figure 10, the mosque is a large, spacious building that occupies a distinctive location at the front of the complex near the banks of the Tunca River in the city of Edirne, to the west of Turkey today. Edirne, historically known as Adrianople, is located in the northwestern part of Edirne Province in Eastern Thrace (Goodwin, 2003).

Figure 10. Sultan Bayezid II Mosque, Edirne, Exterior (Source: By authors)

The interior of the Sultan Bayezid II Mosque is characterized by its simple square geometry and spacious construction, as shown in Figure 11. The prayer hall is bordered horizontally on four sides by four thick, flat, vertical walls, so high that their height is almost equal to their width. Above the walls, perforated with a magnificent array of vertical windows, rise four arches, with four spherical pendentives filling the upper corners of the ground cube of the prayer hall, complementing the circular arches. This streamlined composition forms a circular base above which revolves the neck of the dome, which houses 20 vertical windows. The vast dome, decorated with exquisite Arabic calligraphy and blue, covers the ceiling of the mosque in a style of extreme beauty and creativity. The marble mihrab, located in the center of the qibla wall in front of the prayer hall, is meticulously carved and houses a niche at its center, topped by a semi-conical pinnacle decorated with muqarnas. To the left of the mihrab is the exquisite marble minbar, and to the right is the sultan's platform, raised atop marble columns.

Access to it is via a special upper gate carved into the qibla wall. The only door in this space is wooden shutters set into the back wall. What we can clearly observe in Figure 12 is that the mosque building in front of the complex consists of three spatial sections: the spacious prayer hall at the front of the building, which is completely square in shape, with a side length of slightly more than twenty meters. It is covered by a huge hemispherical dome that is 21 meters in diameter, one of the biggest domes in the history of Ottoman architecture (Blessing, 2022). The dome is supported by a twenty-sided drum raised over a square plan structure with walls that are 19 meters high. Each side of the drum has a window. At the rear of the prayer hall is a central gate leading to a spacious open courtyard with a magnificent fountain in the middle.

It has three entrances and is surrounded by domed arcades on four sides. On the sides of the building, there are two guest houses, each consisting of nine square halls of equal size, which were used by dervishes and travelers (Blessing, 2022).

Two minarets rise above the mosque, to the north-east and south-west of the central dome. These minarets are of equal height of 38 meters and are decorated with a single balcony each, representing the distinctive architectural elements characteristic of Ottoman Mosque design (Kherrour et al., 2020). Such architectural features contribute to the mosque's significance as a cultural heritage site and religious tourism destination (Josan, 2009; Adascalitei & Istrate, 2020).

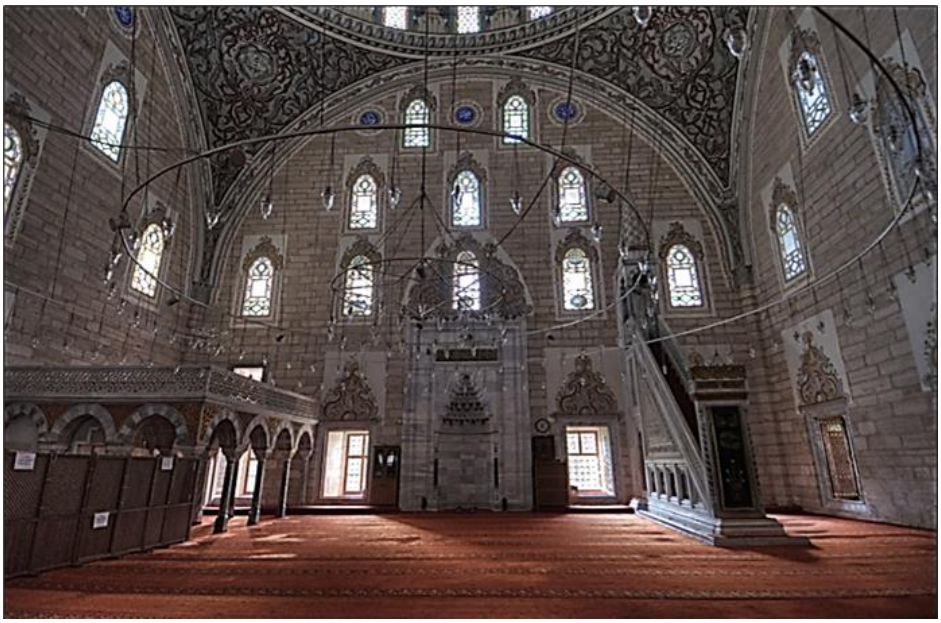

Figure 11. Sultan Bayezid II Mosque, Edirne, Interior (Source: By authors)

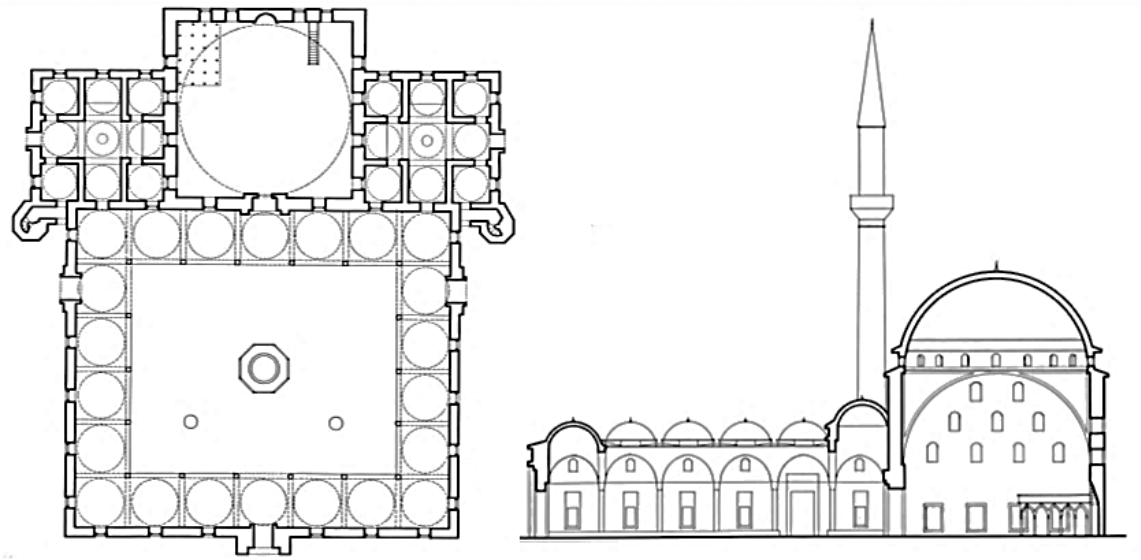

Figure 12. Sultan Bayezid II Mosque, Edirne, Plan and Section (Kuran, 1968)

The prayer hall, Figure 13, with its square structural layout, acquired a typical cubic shape, devoid of any structural obstacles at the ground level, despite the vast interior space of the prayer hall. The structural layers are arranged on top of each other as follows. The ground floor prayer hall's interior is depicted in the first structural layer (A). It has four parallel walls surrounding its square form. The four walls have two important functions. In addition to being perforated with a large number of windows distributed on four levels to illuminate the interior space with large amounts of natural lighting during the day, they have an important structural role as they encompass the mass of pillars that support the large upper dome, measuring a little more than 20 meters in diameter. The second structural layer (B) is the four corner pendentives that occupy the corners of the square in the plan. It is the most flexible layer placed in the middle of the prayer hall space, and it is what allows the transformation from the cubic shape of the prayer hall on the ground level to the semicircular shape of the upper dome. The upper surface of each pendant provides a quarter-circular shape, and with the presence of four pendants it completes the circular shape that is perfectly suitable for rotation of the base of the dome at the top. As for the third structural layer (C), it represents the flat upper surface of the ground cube of the prayer hall, combining the thickness of the upper edge of the four walls with the upper part of the corner pendentives, which surround the uncovered space in the middle of the ceiling of the prayer hall and form a suitable base for the drum to rotate in a completely smooth and central manner. The fourth structural layer (D) represents the perforated cylindrical drum with a large number of windows.

Finally, the wide dome, in its hemispherical shape, was placed at the central peak of the building so that it covers the central part of the roof of the prayer hall, and is represented by the fifth structural layer (E).

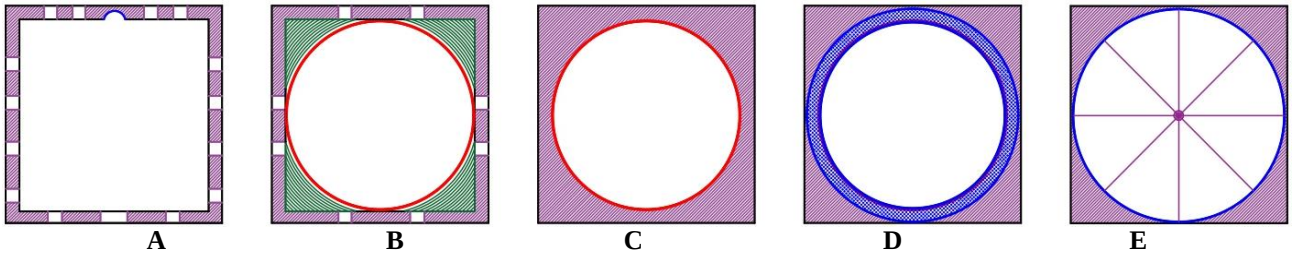

Figure 13. Structural Layers of the Sultan Bayezid II Mosque (a) Load-Bearing Walls, (b) Load-Bearing Walls and Corner Pendentives, (c) The Higher level of the Ground Cube, (d) The Cylindrical Drum, (e) The Apex of the Dome (Source: By authors)

What distinguishes the structural system of this mosque building is that the four pendentives begin to protrude and tilt at the middle of the height of the walls in a curved line resembling the arch of the dome until each arch meets its corresponding arch at the central summits of the four walls of the prayer hall, and so on until the spaces between the perimeter of the dome and the corners of the ground cube of the prayer hall are filled to form a typical circular base above which the hemispherical dome rotates smoothly in the sky of the mosque.

The interior space of the prayer hall in this mosque, shown in Figure 14, with this structural configuration characterized by the presence of the pendentives, acquired a pure cubic geometric shape consisting of a single spatial unit topped by the magnificent hemispherical dome. The flowing shape of the corner triangles contributed to making the interior space more harmonious and integrated, especially with regard to the compositional relationship between the wide upper dome and the spacious ground cube. Geometric analysis shows that the height of the dome is the same as the height of the arc of the pendentives, and is approximately equal to half the total height of the walls of the ground cube.

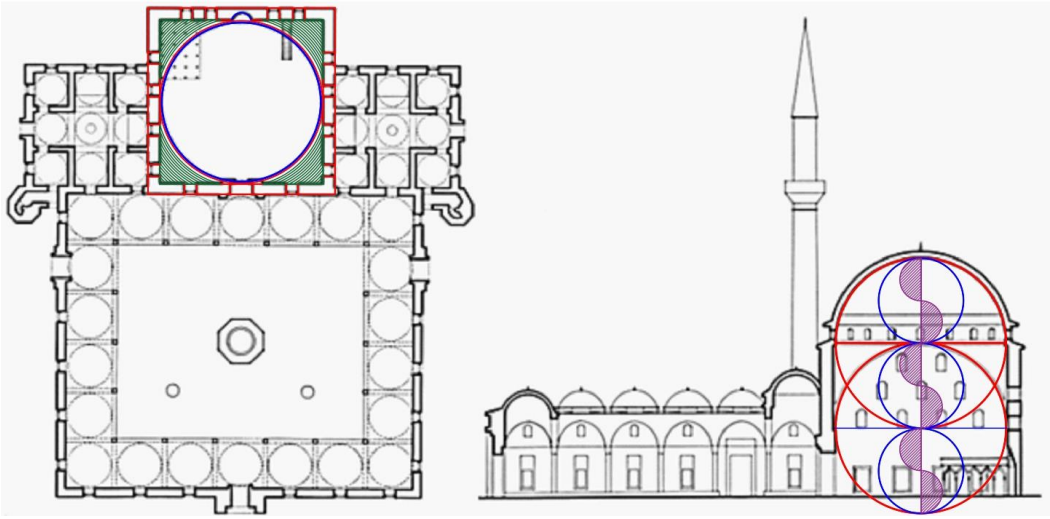

Figure 14. Sultan Bayezid II Mosque, Geometric Analysis, Plan & Section (Analysis by Authors)

4.3 Single-Unite Mosque with Articulated Interior

In this type of early Ottoman Mosque, the single-unit mosque with an articulated interior, the prayer hall retains its fundamental square geometry beneath the hemispherical dome, but with the expansion of the interior space, usually but not exclusively in a direction opposite to the location of the mihrab (Kuran, 1968).

4.3.1 Green Mosque, Iznik

The Green Mosque, built in 1392, in İznik is a good example of the early single-unit type with articulated interior. It is located near the Lefki Gate on the eastern edge of the city. It was founded by Hayreddin Pasha, Grand Vizier to Murad I, also known as Çandarli Kara Halil, and completed by Ali Pasha, his son and successor as Grand Vizier (Hassan et al., 2012) Designed by architect Hacı ben Musa, the mosque has a spacious transverse portico preceding the prayer hall. It features the usual three bay arrangement with a prominent pointed dome at its center, raised above an octagonal base. The main hemispherical dome protrudes from the front of the mosque above the prayer hall, as shown in Figure 15. The name of the mosque comes from the color of the ceramic tiles that cover the single minaret that rises from the northwest corner of the building. It is composed of brick and has green, turquoise, and yellow clay coverings. İznik was famous for its high-quality ceramic production. The mosque was severely damaged over time and was restored by the General Directorate of Endowments between 1956 and 1969 (Freely, 2000). Such restoration projects are essential for the preservation and valorization of archaeological and heritage sites, enabling their transformation into sustainable cultural tourism destinations (Kherrour et al., 2020). The interior section of the Green Mosque is entered by a three-aisled portico, which acts as a buffer

between the exterior and the interior space. The approach's spatial rhythm and aesthetic harmony are enhanced by the succession of vaults that articulate the portico's ceiling in addition to providing structural stability. A noticeable canopy vault atop the middle aisle highlights the axial orientation and directs the visitor's attention to the main entrance. The portico's prominent architectural element is the rectangular marble frame set into the central arch and embellished with muqarnas (stalactite) motifs. This ornamental element highlights the main entry point's importance within the architectural hierarchy by serving as a visible and metaphorical marker of it (Akboy-İlk, 2023).

Figure 15. Green Mosque of Iznik, Exterior (Source: By authors)

As visitors enter the main prayer hall, they are greeted by a remarkable hemispherical dome that crowns the center worship area and has a diameter of around 11 meters. As we can see in Figure 16, the dome is supported by a circular drum with four windows that are evenly spaced, letting natural light flood the inside and provide life to the area all day long (Al-Roumi, 2024). Triangular ornamental portions add to the drum's surface, adding to the base of the dome's structural articulation and visual dynamism. Grey marble panels covering the lower parts of the prayer hall's interior walls give the room a more substantial and elegant appearance while also improving its thermal and acoustic properties (Karaman & Şenel Solmaz, 2021). Directly in line with the qibla wall at the front of the room is a finely carved marble mihrab. The intricate ornamentation of this mihrab reflects the creative complexity typical of Islamic architectural traditions as well as the religious significance of its purpose (Al-Roumi, 2024; Jalalah & Alqahtani, 2024).

Figure 16. Green Mosque of Iznik, Interior (Source: By authors)

As displayed in Figure 17, the plan of the Green Mosque, Iznik, shows that it is rectangular in shape parallel to the qibla axis, and the presence of the wide transverse portico that precedes the prayer hall increases the extension of the mosque's rectangle. Interiorly, the prayer hall is also rectangular in shape, perpendicular to the qibla wall. It is divided spatially into two parts, the first in the foreground expressing the main space of the mosque. It is wide and very high, consisting of a single space unit under the wide dome. The space is square in shape surrounded by three thick walls with an open back arcade consisting of two columns and three arches. The rear part is rectangular in shape and parallel to the qibla wall, giving the prayer hall more space to accommodate a larger number of worshipers when needed. The roof of the back space is divided into three sections by two deep arches that support the two columns that in turn support the dome in front (Sürmelihindi, 2023).

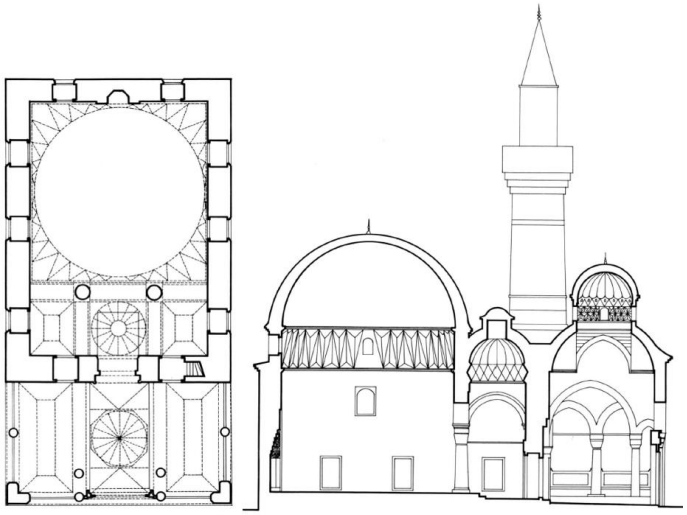

Figure 17. Green Mosque of Iznik, Plan and Section (Kuran, 1968)

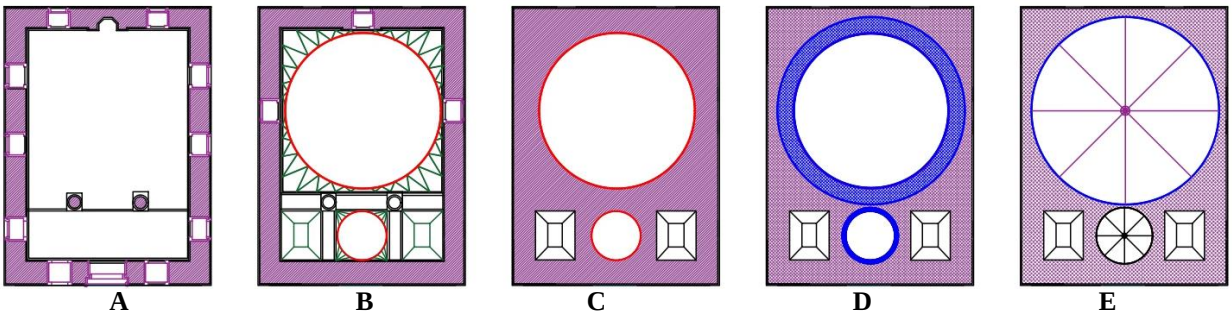

Figure 18. Geometric analysis of the structural layers of the Green Mosque of Iznik, Plan (Source: By authors)

The ascending order of the structural layers in the Green Mosque, as shown in Figure 18, is illustrated as follows. The four sturdy walls of the mosque with the two columns constitute the first structural layer that grew at the ground level (A), which was prepared to accommodate the weight of the upper structures of the mosque's roof. As for the second structural layer (B), located high on the sides of the prayer hall square, it was built in the form of a strip of Turkish prismatic triangles extending over the three walls and the arcade slanting towards the center of the square to form a circular ring at the top of the prayer hall cube. This is done in order to shift from the ground square to the upper circle of the dome. Two additional arches support the two columns and provide a suitable base to cover the rectangular space at the back of the prayer hall. As for the third structural layer (C), it consists of two sections. The first is in the front and represents the area of the flat upper surface of the ground cube of the prayer hall, as it combines the thickness of the upper edge of the walls with the upper part of the Turkish prismatic triangles that surround the exposed space in the middle of the ceiling of the prayer hall. It forms a suitable base for the drum to rotate completely smoothly and centrally. The second is at the rear of the prayer hall and represents the area of the upper thickness of the five arches and walls, and thus the roof of this area becomes divided into three sections. The result was a circular base well prepared for the growth of the highest structural stages, the drum and the dome. The fourth structural layer (D) represents the two cylindrical drums. Finally, the fifth structural layer (E), where the dome in its hemispherical shape was placed at the top of the front of the mosque so that it covers the middle part of the roof of the prayer hall, and behind it is the small dome that covers the middle part of the back rectangle.

The figure shows the stages of construction, from the ground walls and columns, through the triangles, up to the circle of the dome at the top of the building. In the cross section of the green mosque, (Figure 19) the dome sits at the top of the mosque's vertical formation, resting on the strip of Turkish prismatic triangles, with a hemispherical configuration devoid of windows and similar to the structural composition of the two previous mosques. The radius of the dome in this mosque is equal to one-third of the total height of the dome's vertical axis, and it is more graceful and extended than the previous two mosques, which gives the interior space a vertical shape parallel to the dome's axis, consisting of a ground part with straight lines and right angles, topped by the circular part of the triangles strip, and then the circular and hemispherical dome.

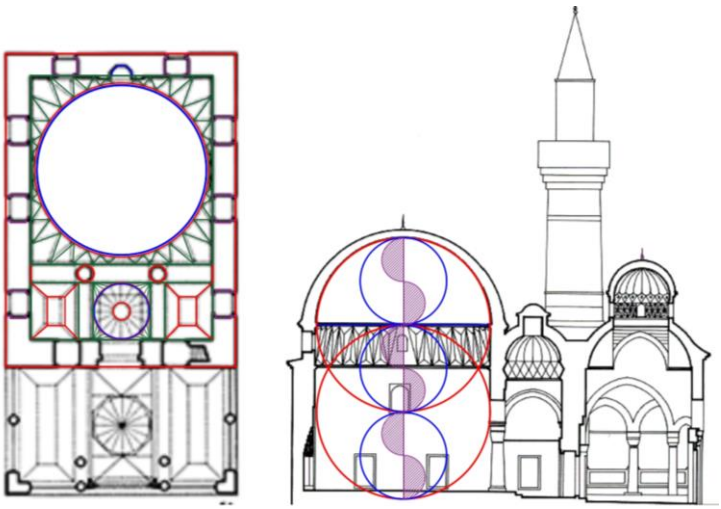

Figure 19. Green Mosque of Iznik, Geometric Analysis, Plan & Section (Analysis by Authors)

Designing the Structure of the Ottoman Single-Unit Mosque

From the above analyzes, we find that the early Ottoman architects adopted the domed architectural form as a preferred method in designing their mosques. This may be due to the visual and expressive value of the dome as a distinctive architectural element that requires precision in design and mastery in construction over the square area of the prayer hall. The reason they chose this design may be their desire to show a geometric representation of the relationship between the flat earth like a square and the arch of the high dome of the sky. Or perhaps this is due to their desire to build a prayer hall free of any construction barriers that would interrupt the rows of worshipers.

The analysis charts presented in this study illustrates how to plan the method of constructing the structural patterns of the three types of single-unit Ottoman mosques. It has been shown that the mosque has a vertically organized structural composition that contains a group of structural elements distributed mainly within three layers placed on top of each other, which can be summarized through the following stages:

First, The Lower Structural Layer: which represents the ground walls. At this stage, the size of the interior space and its geometric pattern are determined. The direction of the mosque building and the locations of the main interior elements on the plan, such as the mihrab, the Minbar, spaces of the rows of worshipers, and the gates through which entry and exit from the mosque are also determined. All the architectural examples mentioned in the study showed great similarity in plan at the ground level. They all have a square plan, with four walls delimiting their interior space, except for the Green Mosque in Iznik, which has a rectangular plan parallel to the axis of the mihrab, with an interior expansion located to the back of the prayer hall, separated by two columns and three arches. In addition, the walls perform other very important functions, as they carry the weight of the upper layers of the building, and they carry the windows that allow daytime lighting to pass through the interior space. They also contain the aesthetic aspect interiorly by accommodating the mihrab and the decorations, colors, and texture appropriate to the prayer hall interiorly.

Second, The Intermediate Structural Layer: which represents the various intermediate structural patterns between the ground walls and the upper dome. It is the most complex elements in terms of geometric shape and construction technology. Its basic function lies in transforming the geometric shape of the cube of the prayer hall from the wide square shape in its lower part to the polygonal or circular shape in its upper part, so that it is suitable for building the circular base of the dome above its upper surface. The geometric patterns of these structural elements varied in the four mosque models presented in this study, although they all perform the same function. In the prayer hall of the **Orhan Ghazi Mosque**, squinches were employed to bridge the four corners of the prayer hall, producing a regular octagonal geometric shape at its top, on top of which a cylindrical drum was built as a base for the upper circular dome.

In the spacious prayer hall of the **Bayezid II Mosque** in Edirne, four corner pendentives were employed to fill the space between the circle of the dome and the corners of the ground cube. They have a streamlined shape that is completely consistent with the flow of the spacious dome of the mosque. They also, by their streamlined nature, provide a circular base that is completely identical to the circle of the dome. In the prayer hall of the **Green Mosque in Iznik**, Turkish triangles were used in the form of a circular belt, consisting of densely repeating prismatic triangles facing each other, flexible in their composition so that they increase in length when needed to fill the space in the upper corners of the square of the prayer hall, to form a circular base that is very suitable for the dome to rotate over it.

Third, The Upper Structural Layer: It represents the ceiling layer that demarcates the upper boundaries of the interior space. It roofs the interior space in the best possible way, through which it does not require any stand-alone structural elements at the ground level, so that the prayer hall remains open, integrated horizontally and vertically, and free of any visual obstacles. Geometrically, all the domes of the mosques included in this study took a roughly hemispherical shape. They were all solid and built on top of a cylindrical drums perforated with a small number of windows. Only the dome of Bayezid II Mosque, which had a cylinder drum perforated with sixteen windows distributed regularly around the dome, flooding the interior space with abundant daylight. What most draws attention about the shape of the dome is its celestial appearance and its high location, which gives the mosque's architecture a visual and expressive value that is

unmatched by any other architectural roofing elements. In the plan, the dome is erected based on a central axis, directing its construction inward to dominate the interior space of the mosque with its structural splendor. It also stands out high above all architectural elements to dominate the external form of the mosque building.

Designing the Structural Pattern of the Single-Unit Mosque Plan

Nowadays, dome design begins by calculating the loads and stresses applied to the structure, either through manual methods with specialized tools for analysis. These domes are often utilized in mosques, halls, and theaters to cover large spaces without the need for supporting columns. Reinforcement of domes is carried out in two stages: lower reinforcement, where diagonal steel bars are placed from the top of the dome to the circular beam, and upper reinforcement, which resists the upper moments under the dome. The construction of domes follows specific steps, including setting up circular scaffolding for workers, repeating the scaffolding every 2.5 meters, and starting the concrete pouring from the top. The formwork specialist ensures the correct thickness and dryness of the concrete to prevent it from spreading. Before pouring, internal reinforcement and carpentry work must be completed. Dome designs vary in shape, from spherical to oval or onion-shaped, often influenced by Sassanian and Byzantine styles. In Islamic architecture, domes are constructed on different floor plans, such as circular or square, and built with brick using either horizontal or vertical methods. These methods rely on layers of brick or adhesive materials to form the dome's structure.

However, in analyzing single-unit mosque plans, which were commonly used in Ottoman mosques, the designs were often simple yet highly geometric. These mosque layouts typically relied on basic geometric forms, such as squares and circles, to create a balanced and harmonious structure. Despite their simplicity, the accuracy of these forms was crucial for maintaining the integrity of the design. Even a small deviation in measurements could disrupt the entire geometric harmony of the plan. The Ottoman architects placed significant emphasis on precision, as their designs were based on intricate geometric principles. The single-unit mosque plans, though appearing straightforward, demanded meticulous attention to detail. Any minor inaccuracy in the dimensions of the basic square or other geometric forms could cause the entire structure to lose its proportionality and coherence, leading to a flawed representation of the intended design. Recent studies have illustrated the design and geometric methods used in single-unit mosque plans, emphasizing the critical role of precision in maintaining geometric harmony (Al-Hassani & Al-Tai, 2024; Bonner, 2017).

Method of Determining the Wall Thickness

From an arranging standpoint, walls are the lowest structural layers. They support the higher structural weights, anchor the structure, and link it to the foundation while sitting precisely above the earth as shown in Figure 20. The following points explain how to determine the thickness of these walls for a single-unit mosque:

1. Start by drawing the interior square ABCD as shown in the plan.
2. Add the horizontal (1,2) and vertical (3,4) axes, along with the diagonals AD and BC.
3. Insert the diagonal A2 into the half-square A1B2.
4. Using A as the center and a radius of A2, draw arcs to intersect diagonal BC at points "b" and "c."
5. Repeat this process with points B, C, and D as centers to locate points "a" and "d."
6. Finally, connect the intersection points (a, b, c, d) of the arcs to form the outer square abcd, determining the wall thickness.

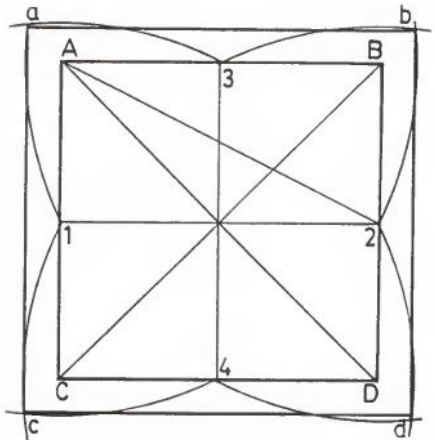

Figure 20. Single Unit Mosque,
Determining the Wall Thickness (Source: By authors)

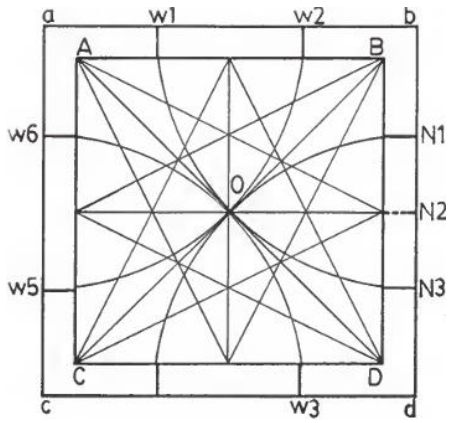

Figure 21. Single Unit Mosque,
Locating Wall Openings (Source: By authors)

Method of Locating Wall Openings

The method of determining the locations of wall openings is described in Figure 21 through the following points:

1. Using point A as the center and a radius equal to A0 (where 0 is the center of the square ABCD), draw an arc intersecting "ab" at (w2) and "ac" at (w5).

2. Repeat this step using points B, C, and D as centers to determine the window positions on the northeast (w1, w2), northwest (w5, w6), and southwest (w3) walls.

3. This same method is used to locate the two niches (N1, N3) on the southeast wall, while the traditional mihrab (N2) is positioned symmetrically along the horizontal axis (1,2).

DISCUSSION

It is clear from the above that the interior space of the single-unit mosque is enveloped through a specific set of structural elements starting from the ground on which the mosque stands, then the load-bearing walls define its boundaries and horizontal dimensions of the cubic building. Then, the transformation structural elements with the most precise geometric pattern, such as squinches, pendentives, and Turkish triangles, begin to draw the upper borders of the interior space of the mosque, as they occupy an essential part of the ceiling area, in addition to being a structural base that supports the drum and dome, which in turn covers the central area of the mosque's ceiling and allows the extension of the upper space in a hemispherical shape that ends vertically at the inner peak of the dome. No matter how diverse the construction techniques used to build the interior spaces of the single-unit mosque are, they are very similar in the shape of the cubic base of the prayer hall and in the shape of the upper hemispherical dome. The diversity appeared in the intermediate structural layer, squinches, pendentives, and Turkish triangles, which is more complex in terms of construction technique, but more flexible in geometric form and structural function. While the walls help support the dome and the upper weights the dome covers the roof of the mosque, as for the intermediate structural elements, they combine the two functions. They bear the weights of the upper dome and contribute to covering the corners of the cube around the dome at the same time.

The important note here is that the intermediate structural patterns remain limited in their dimensions and in their contribution to increasing the size of the interior spaces of the mosque, especially in the vertical dimension. Only the Sultan Bayezid II Mosque looked spacious and elevated from the inside. Perhaps the presence of the pendentives helped expand the interior space and expand the diameter of the dome because of its structural characteristics through which it distributes the overhead weights over larger areas of piers and load-bearing walls. This is in contrast to the squinches and Turkish triangles found in the Orhan Gazi Mosque and the Green Mosque in Iznik, which transfer the weights of the dome directly to the upper ends of the load-bearing walls within a very short distance, thus limiting the extension of the building and the size of the dome and the interior space (Figures 7, 10, 13). The geometric composition of the dome made the intermediate structural elements in the center of the building respond to its compositional characteristics, as they were placed in a centrally symmetrical geometric manner around the vertical axis of the dome, and with the same geometric and structural logic, the four walls were built at ground level, as they are opposite each other and symmetrical as well. This is what can be called the structural dominance and architectural influence of the dome on the interior space, until the interior shape of the prayer hall seemed completely central around the vertical axis of the dome. The presence of the mihrab at the front of the building, in the middle of the qibla wall, created another central axis in the plan of the mosque, with its head at the mihrab and extending horizontally with the direction of the qibla. It also provided balance in the design with the vertical axis of the dome.

CONCLUSION

The study concluded the following results:

A) In the early single-unit Ottoman Mosque, it is clearly evident that the purpose of the envelope construction is to serve the components of the interior space. Everything that surrounds the interior space is a structural pattern consisting of several layers placed on top of each other to create an integrated and vertically extended interior space of three layers: the ground cube space, the upper hemispherical dome space, and between them is the irregular middle space with its semi-cylindrical shape.

B) The architecture of Ottoman mosques was characterized by solid construction from its beginning, as demonstrated through this study, and this explains their need for diverse structural patterns to create a unified and open interior space free of structural obstacles that might divide the space or interrupt the rows of worshippers.

C) The single-unit mosque has distinctive geometric characteristics that are consistent with the structural patterns used in building its interior spaces, especially with regard to the size of the diameter of the dome and its relationship to the size of the interior space and its horizontal and vertical extension, which is what was explained in the analytical charts presented in this study.

D) The architectural design of the single-unit mosque brings together worshipers in one square-shaped place under the umbrella of single dome, in a clear reference to equality among all believers inside the mosque and not dividing them into social or ethnic classes. In this way, the architectural design of the mosque responded to the idea of equality between people encouraged by Islamic law.

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