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Article

Geometry, material, and construction technique of the belt of Turkish triangles: An innovative architectural and structural solution developed in Anatolia for transitional zone challenges

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ABSTRACT

Between the 12th and 15th centuries, the belt of Turkish triangles, which was developed as an original solution in the transition from cubic space to the dome in Anatolia, found widespread application as a common transition element from the Seljuk Period to the Principalities and the Early Ottoman Periods. In addition to its structural features, the aesthetic values arising from the rich geometric combinations of the belt of Turkish triangles have played a significant role in its use as a transitional element. In historical buildings, where roofs or walls have been damaged for various reasons, the transitional zones between them often represent the most vulnerable areas, requiring careful intervention. Therefore, a detailed understanding and analysis of the original architectural and structural characteristics of cultural heritage buildings are of primary importance. Although the Turkish triangle belt has been examined primarily from a formal perspective in architectural history, studies that focus on material and construction techniques remain quite limited. In this context, the present study aims to provide a comprehensive analysis of the geometric/formal, material, and constructional characteristics of the transitional zones employing the belt of Turkish triangles in between the 12th and 15th centuries. Accordingly, the construction techniques of different geometric configurations have been modelled in three dimensions. The study is structured in three main stages. First, the geometric/formal features of the belt of Turkish triangles-particularly at surfaces and corners-are examined using the data obtained from literature and field studies. The geometric scheme of the transitional zone is also analysed from various perspectives, including the relationship between the substructure and superstructure as well as facade characteristics. Second, the material and construction technique employed in the belt of Turkish triangles are investigated. Finally, the construction process of different types of the belt of Turkish triangles is modelled step by step and presented in detail. Transition zone with the belt of Turkish triangles, which is composed of variations of plane and triangular prisms, exhibits geometric differences particularly in the corner units. Although the use of stone material in the construction of plane triangles is rarely encountered, the belt of Turkish triangles is predominantly built using brick, often with thick mortar joints between the units. Before the construction of the transitional zone, a single or a few rows of bricks are laid slightly projecting from the wall surface where the wall ends, in order to level the base and define the starting line of the transition zone. Once the height of the transition zone is determined according to the dome span, a wooden centering is prepared to define the base

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line of the dome. Then, depending on the design of the plane or prismatic units, guiding strings are stretched between the brick courses on the wall and the wooden framework of the dome. As the transitional zone is formed by the repetition of a quarter segment, the parts from the corners to the midpoint of each wall are constructed incrementally and simultaneously. First, the units with their base on the wall are laid in a cantilevered manner up to a certain height. Then, the intermediate units whose apex lies on the wall are added, continuing together with the rest of the structure up to the dome's springing line. As a result, the belt of Turkish triangles forms the cubic base into a polygonal form. As the number of triangular units increases, the number of polygonal sides also grows, making the transition to a circular dome base more efficient. The transition from the polygonal base to the circular dome is achieved by means of a few additional rows of bricks forming a border course. One of the key findings regarding the belt of Turkish triangles with prismatic units is that the dimensions or base width of each unit are directly related to the dimensions of the brick material used. Therefore, in belts composed of prismatic units, the number of units increases not merely for aesthetic reasons, but as a structural necessity, since the base of each prism is limited in size.

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INTRODUCTION

In the Medieval period, masonry structures were fundamentally composed of walls, superstructures, and the transitional elements connecting them. In historical buildings, domes and vaults frequently functioned as the superstructure. However, transitioning from a square or rectangular base to a circular dome consistently posed both architectural and structural challenges. To address these spatial and structural discrepancies, architects developed transitional elements that mediate between differing plan geometries.

The use of domes over cubic spaces can be traced back to both the pre-Islamic architecture of the Sasanian period and early Islamic architecture in Iran. Archaeological excavations have uncovered evidence of dome construction dating to antiquity. These early examples were generally small-scale domes employed in modest structures such as houses, granaries, barns, and storage buildings. The limited scale and simplicity of these domes reflect a lack of advanced knowledge regarding transition elements, which are essential for effectively spanning square spaces with circular superstructures (Creswell, 1969; 455-457).

Early solutions to the transition problem included rudimentary techniques such as corbelled masonry. In the western tomb at Amman, for instance, a row of cantilevered stone blocks projects outward at the corners, their upper surfaces shaped to form a circular base for the dome (Figure 1a). In the bath at Abda, a triangular stone element projects from each corner, allowing a transition to a polygonal base (Figure 1b). Similarly, at Umm Az-Zaytun in Syria, a multi-stepped transition from square to circular plan is achieved through two or three rows of projecting stones (Figure 1c).

Depending on regional practices, available materials, construction techniques, and cultural interactions, transition elements evolved into several distinct typologies over time. Broadly, these can be categorized into three principal types: the pendentive, the squinch, and the belt of Turkish triangles[1].

The pendentive is a structural solution that allows for the placement of a dome over a cubic space without requiring an intermediate transition zone. It is typically integrated within the corners of the cube and terminates as the cube itself ends. Pendentives are classified into two main types based on geometric construction: pyramidal and spherical. The pyramidal pendentive transforms the square base into an octagon, upon which additional courses transition to a circular dome base (Figure 2a). Diez (1946; 112) mentioned that these could be enhanced with folded surfaces. A prominent example is the İnce Minareli Madrasa in Konya, where the dome rests on a pyramidal pendentive formed by four folded triangular surfaces (Figure 2b).

Spherical pendentives, often termed *true pendentives*, facilitate a direct transition from a square base to a circular dome. According to Creswell (1969) and Kuban (1998), these can be subdivided based on curvature: one type has a diameter smaller than the dome (Figure 3a), while the other-termed as *shallow dome*-shares the same curvature and diameter as the dome itself (Figure 3b). The latter is not a transition element in the strict sense, as its surfaces are structurally continuous with the dome itself.

The squinch, known as "tromp" in French and "kemerli bingi" in Turkish, employs arches placed diagonally across the corners of a square base to convert it into an octagonal plan. From this octagonal base, additional layers or decorative elements like muqarnas facilitate the transition to a circular dome base. Because the squinch requires a defined transition zone, its use is generally limited to structures with smaller spans to avoid excessive height.

The squinch played a crucial role in early Islamic architecture, especially in Iran (Wilber, 1969). In the Sasanian monument at Firuzabad, squinch vaults were employed to support domes over square chambers (Figure 4a). Pope (1967) describes the difference between the squinch vault and the squinch. The squinch vault involves building diagonal arched courses in each corner that gradually form partial

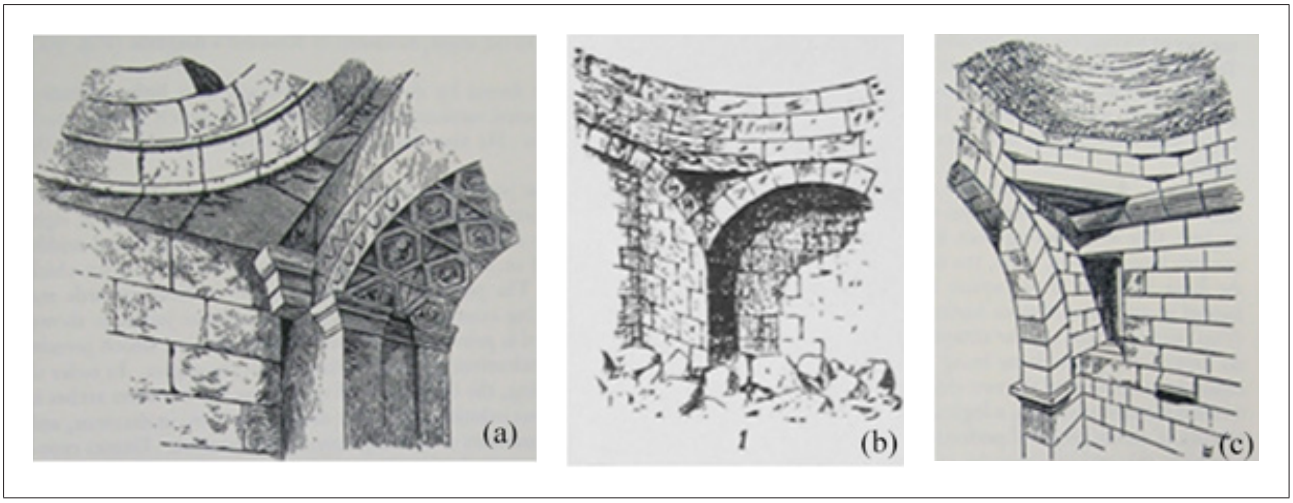


Figure 1. **(a)** Western Tomb in Amman (Creswell, 1969; 456), **(b)** Triangular cantilevered stone piece at the corner of the bath at Abda (Creswell, 1969; 457), **(c)** Umm Az-Zaytun at Syria (Creswell, 1969; 456).

cones, eventually enclosing the space (Figure 4b). In contrast, the squinch technique leaves gaps between these corner structures, which are then filled with horizontal layers that create a circular base to support the dome (Figure 4c).

The belt of Turkish triangles was developed in Anatolia and is therefore known as the "Türk üçgeni" in Turkish (Batur, 1980). It is a distinctive transitional system composed of a band of triangular units, each inclined at varying angles. These triangular surfaces convert a square base into a polygonal form, upon which additional rows of cantilevered masonry allow for the formation of a circular dome base (Figure 5). Like the squinch, the belt of Turkish triangles necessitates a transition belt, and the belt's height increases proportionally with the dome's span.

Although often confused with fan or pyramidal pendentives (Rice, 1961; Hasol, 1995; Ünsal, 1959; Aslanapa, 2003; Boran, 2001, Şenalp & Binan, 2024) (Figure 6a), the belt of Turkish triangles (Figure 6b) represents a unique solution that gained prominence in Anatolian Seljuk, Principality and early Ottoman architecture from the 12th to the 15th centuries. Despite its formal resemblance to other elements, its geometry and construction technique differs significantly (Figure 6b).

The implementation of the belt of Turkish triangles was likely influenced not only by its structural properties but also by the aesthetic and sculptural effects it introduced to interior spaces, thanks to its rich stylistic and geometric forms. Acland (1972) highlights the flexibility of folded sur-

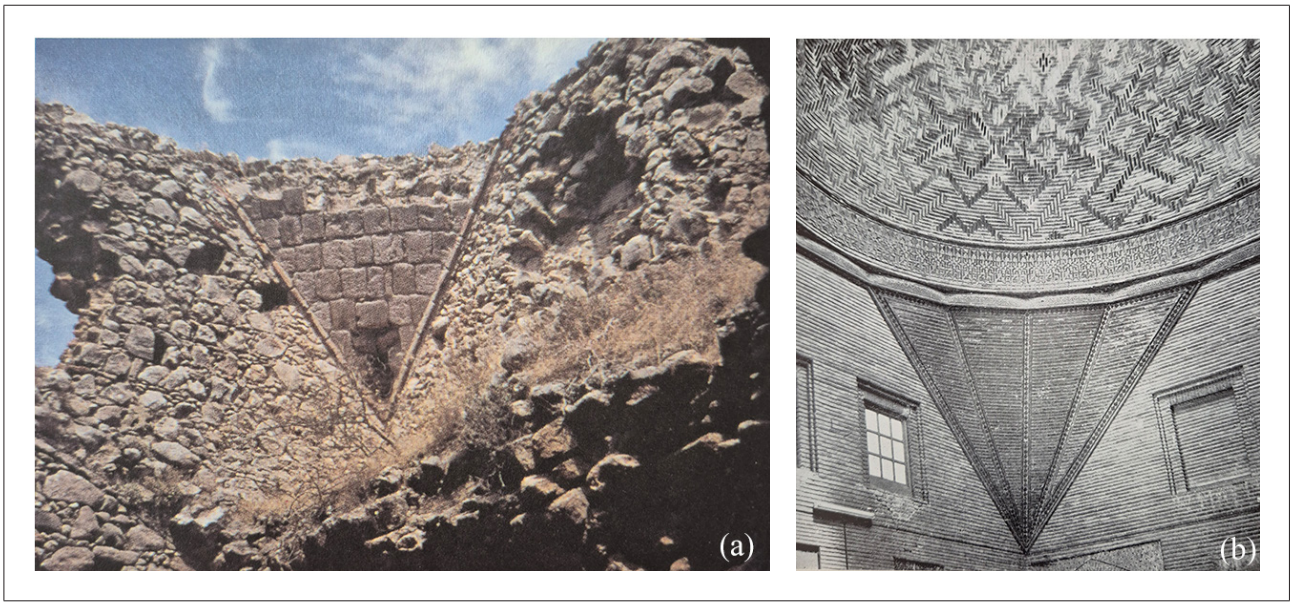


Figure 2. **(a)** Kızıl Han in Peçin (Kolay, 2017; 58) and **(b)** İnce Minareli Madrasa in Konya (Kuran, 1969; figure 105).

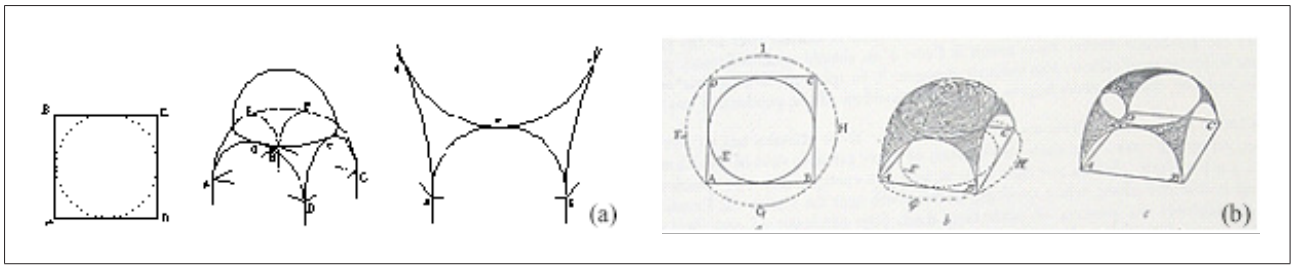


Figure 3. **(a)** Diameter of the pendentive is smaller than the dome, the spherical pendentive (Söylemezoğlu, 1955; 81) and **(b)** diameter of the pendentive is the same with the dome, pendentive or shallow dome (Creswell, 1969; 460).

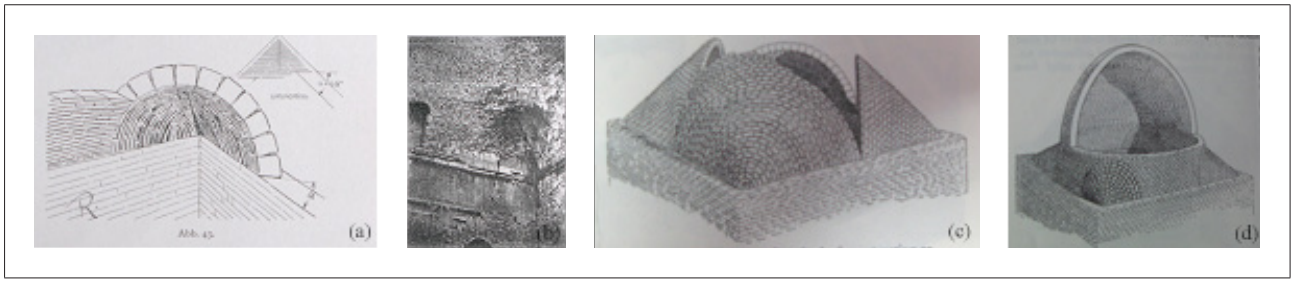


Figure 4. **(a)** Diagram showing inside of squinch (Rosintal, 1912; 32), **(b)** the squinch applied in Firuzabat (Rosintal, 1912; 33), **(c)** diagrams showing the squinch vault and (Pope, 1967; 58), **(d)** the squinch (Pope, 1967; 59).

faces in triangular or prismatic units, which facilitate transitions between different geometries. Turan (1993) stated that the belt of Turkish triangles offers a more uniform load distribution compared to pendentives and squinches. The concentrations of forces perpendicular to the wall plane and the resulting moments acting on walls with the belt of Turkish triangles are lower than those observed with other transition elements. Söylemezoğlu (1955) emphasizes that the transition from a square plan to a circular dome in Seljukid and Ottoman architecture was achieved through the use of 'triangular surfaces', which offer an impressive and aesthetically pleasing volumetric appearance distinct from squinches and pendentives. This elucidates the preference for the belt of Turkish triangles, particularly in the transition zones of bath domes, where interior walls are blind and plain, as observed in structures like Balat Bath, Peçin Bath, Mudurnu Yıdırım, Çakır, and Davud Paşa Baths in Bursa. Furthermore, Kuban (1976) noted that the structural geometric harmony offered by the belt of Turkish triangles in transitioning to fluted or segmented domes made it a preferred choice in numerous prominent baths of the period. Examples include Gazi Mihal, Saray, Yeniçeri, Beylerbeyi Baths in Edirne, and İsmail Bey Bath in İznik.

Despite its structural and aesthetic advantages, the use of the belt of Turkish triangles became unpopular after the 15th century. In Classical Ottoman Architecture, particularly in the works of Mimar Sinan, pendentives were frequently employed to enhance spatial integrity, continuity, and fluidity. Moreover, since pendentives are curvilinear forms like domes, they naturally follow one another and efficiently

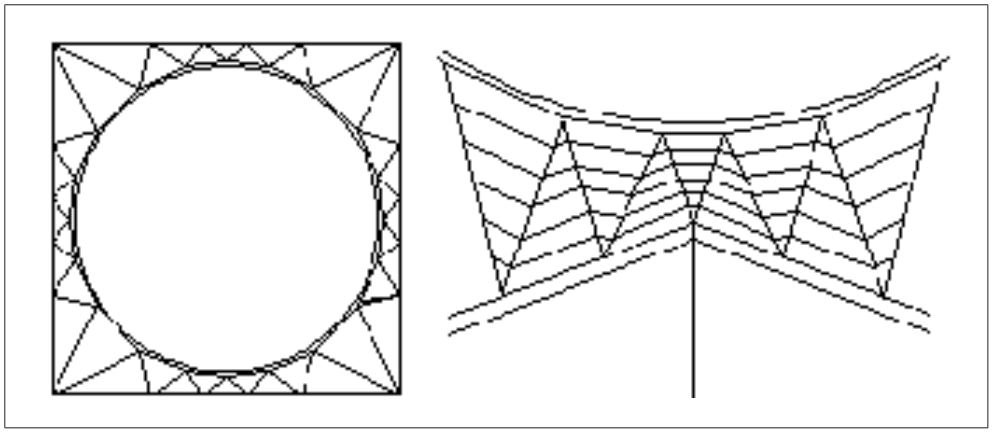


Figure 5. The band of triangles inclined in different angles (Design by Author).

Figure 6. **(a)** The transition element with fan pendentive in the closed courtyard of Karatay Madrasa in Konya (Boran, 2001; figure 539) and **(b)** the belt of Turkish triangles of Alaaddin Mosque in Konya (Bilici, 2016a; 23).

transfer horizontal loads by linking the baldachin support system to the dome without requiring additional intermediary elements (Tuncer, 1984). Conversely, the growing span of domes demanded taller transition zones in the belt of Turkish triangles, while the corbelling systems proved structurally inadequate in resisting lateral forces (Yavuz, 2002; Batur, 1980).

The use of the belt of Turkish triangles was initially observed on the facades of "kümbet", as seen in the Melik Gazi Tomb dating back to 1250 in Kırşehir, marking the transition from a quadrangle plan to a polygonal base in Anatolian Seljukid architecture. Built in 1347, the Güdük Minaret in Sivas features a belt of Turkish triangles on the outside to pass from a square base to a twenty-sided shape. Inside, the transition to the sixteen-sided circular dome base is done using pendentives decorated with stalactites. This shows that different transition elements can be used together in harmony - the belt of Turkish triangles on the outside and a different methods on the inside. (Figure 7a,7b). Subsequently, from the second half of the 12th century to the beginning of the 13th century, it found application in the inner space, facilitating the transition from ground plan level to upper structure plan level (Batur, 1980). Throughout the Seljuk, Principality, and early Ottoman periods, the belt of Turkish triangles found extensive application in various types of buildings, including mosques, masjids, madrasas,

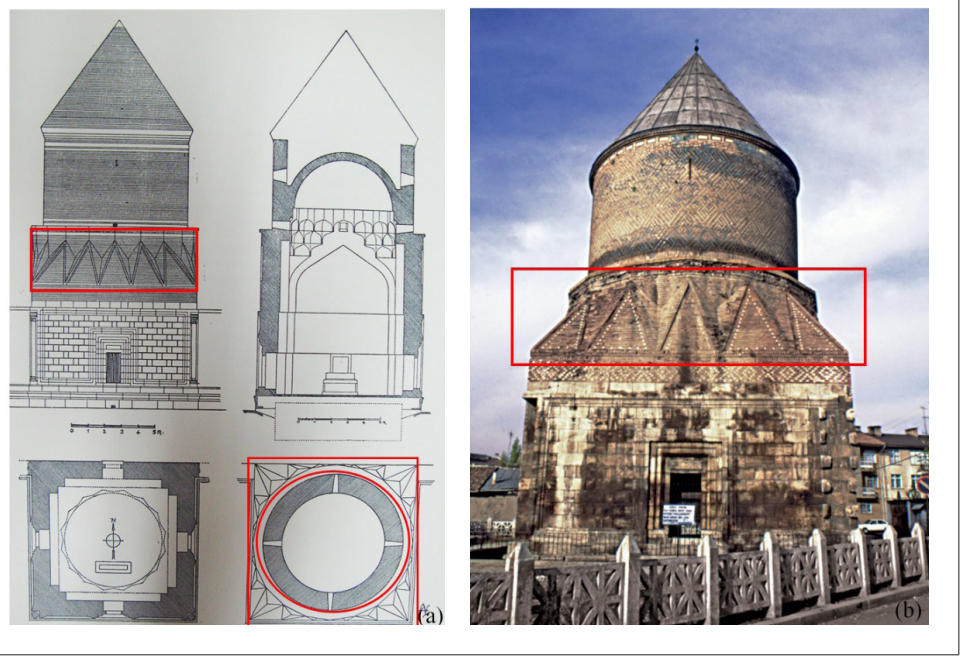


Figure 7. Sivas Güdük Minaret, **(a)** architectural drawings (Gabriel, 1934; 186) and **(b)** facade (Önkal, 1996; 214).

tombs, imarets, and zawiyas. Particularly in single-domed masjids and baths, the belt of Turkish triangles served as a key transition element (Peker & Bilici, 2006). It was also commonly employed to facilitate the transition from the square-planned minaret base to the polygonal body section or from the circular body of the column to the square-planned capital (Uluengin et al., 2001).

The use of belt of Turkish triangles in both interior and exterior spaces is quite similar, as both serve the same purpose: facilitating the transition between square and circular plan geometries. When used on the exterior, the Turkish triangle band is often combined harmoniously with a different transitional element on the interior within the same transition zone. A notable example of this is observed in the Güdük Minaret of Sivas, where the exterior employs a belt of Turkish triangles, while the interior utilizes a different transition element (Figure 7). Therefore, this study specifically focuses on architectural solutions in which the geometric transition - from a square or polygonal plan to a circular dome base - is resolved through the use of belt of Turkish triangles. For this reason, the analysis in this study is centered on the use of belt of Turkish triangles in interior spaces. Exterior uses, including those on tomb façades, minaret bases, and column capitals, are acknowledged in the literature but are not examined in detail within the framework of this research.

Despite the significant number of studies on pendentives and squinches in the history of architecture, research on the belt of Turkish triangles is limited and primarily concentrated on its morphological features[2]. Rosintal's (1912) work on transition elements is an important source that elucidates the fundamental geometrical installation principles of the Turkish triangular transition zones between disparate sections of a building, along with detailing the formal features of some well-known applications of the belt of Turkish triangles. Additionally, Batur's (1980) study, which examines the curved roof covers and transition elements of Ottoman period mosques until the end of the 16th century, holds significance in providing the general characteristics of the belt of Turkish triangles. It also catalogues structures in which the belt is utilized, supported by technical and visual documents such as plans, sections, and photographs. Kolay (2017) examined the construction techniques of buildings from the 14th century Principalities Period, assessing the form, material, and construction technique of the Turkish triangular transition belt in general terms. On the other hand, a recent thesis has predominantly focused on the formal features of the belt of Turkish triangles during specific periods[3]. Lastly, a single type of the Turkish triangular belt, composed of prismatic units, has been geometrically analyzed and parametrically produced in a digital environment, without taking into account materials and construction techniques, and a 1/10 scale solid model of the corner section has been created using robotic techniques (Çağlar et al., 2021).

In this article, beyond the form-based studies typically conducted with a focus on a specific period, building group, or region, the structures from the 12th to the 15th centuries that feature the belt of Turkish Triangles are evaluated as a whole. This is crucial in any maintenance, repair, or restoration work to preserve and transmit the original architectural and structural systems - along with the construction technology of the period in which they were built - to future generations[4]. In this context, while the architectural features of the belt of Turkish triangles are revealed in terms of form/geometry, material usage and construction technique, this study is aimed to reveal the material and construction technique relationship of the different forms of the belt of Turkish triangles, for which there is limited information, with three-dimensional models.

The methodology of this study comprises the following stages of the research. Firstly, the structures from the Seljukid, Principalities and Early Ottoman Periods, which included the 12th and 15th centuries when the belt of Turkish triangles was used, were examined. The geometric varieties on the inner surface and at the corners of the transition zone were evaluated together with their common and unusual applications. In addition, the belt of Turkish triangles between different ground plans-dome-façade organization in the transition zone were examined. Secondly, the material and construction technique used in the belt of Turkish triangles were explained with field studies and literature studies. Finally, three-dimensional models were created to illustrate step by step how the material was used and in what sequence the components were assembled to form each geometric/formal type of the belt of Turkish triangles.

RESEARCH AND FINDINGS

Geometry/Form of the Belt of Turkish Triangles

The belt of Turkish triangles is created by combining consecutive up and down triangle or triangular prism units at different angles along a horizontal alignment. The way these units come together at the corners varies, influencing the entire geometrical and formal arrangement of the belt of Turkish triangles. Kolay (2017) noted that the belt of Turkish triangles that are characterized by its thick plasterwork evolved gradually over time. In the first half of the 13th century, it was constructed with plane triangles, and towards the middle of the century, prismatic elements began to emerge. As a result, the belt of Turkish triangles can be divided into two main groups: those consisting of plane triangles and those incorporating prismatic units. On the other hand, Batur (1980) classified the belt of Turkish triangles into three main categories: the 'triangular belt', consisting of plane triangular surfaces; the belt comprising prismatic triangles; and a group of triangles with units located on the corner. The second group was further subdivided into the 'simple belt,' consisting solely of prismatic triangles, and

the 'compound belt', in which pyramids were placed within prismatic triangles. It is important to note that Batur classified the triangular prisms created for decorative purposes inside the squinches at the corners as the third type. However, since the defining feature of the belt of Turkish triangles is its continuation in the form of a band on the drum, wall, or dome skirt, it might be misleading to describe them as a distinct type of the belt of Turkish triangles.

It is possible to categorize the belt of Turkish triangles into two main types based on form and geometry (Table 1). The simplest form of the belt of Turkish triangles consists of triangular planes looking upward and downward (Table 1a). The connection type of triangular planes can vary in two ways at the corner. In the first case, the top point of the triangular plane is at the corner of the wall, and the base side is on the dome (Table 1b). This configuration is observed in examples such as the tomb of the Karatay Madrasa in Konya, in front of the "mihrap"[5] space in the Eski Mosque in Edirne, the tomb of the Sahip Ata complex, the masjid of Yusuf Bin Yakup Madrasa in Çay, the Alaaddin Mosque in Konya (Figure 6b), the winter room of the Sırçalı Madrasa, the Mal Hatun Tomb in Edirne, the Çelebi Sultan Mehmet Madrasa in Merzifon, The tomb of Yusuf bin Yakub in Afyon (Figure 8a) and the Hekim Bath in Tire (Figure 8b).

In the second case, the common side of two adjacent triangular planes looking downward intersects with the corner (Table 1c). Examples include the side spaces of the Karacabey Mosque in Ankara (Figure 8c), the masjid of the Sırçalı Madrasah in Konya and the winter room of Konya Sırçalı Madrasa (Figure 8d). The transition zone may consist of continuous triangular units, and at times, a window opening or a niche can be incorporated in the transition section along the central axis of the wall.

In the second type, the belt of Turkish triangles with triangular prisms can be divided into two subgroups based on geometric complexity. In the simple form (Table 1d), triangular prisms can be oriented upward and downward, referred as the belt of Turkish triangles with "baklava" or "badem"[6] as seen in Mehmet Bey Mosque, Tahtakale Mosque and Tahtakale Bath in Tire (Figure 9a, 9b, 9c, 9d). They can be positioned in pairs, where every two adjacent triangular prisms look in the same direction (Table 1e), as seen in Halil Hayrüddin Paşa Tomb in İznik, Yıldırım Madrasa, Umur Bey Bath, and Yeşil Tomb in Bursa. Similarly, while a pair of the prisms can face downward, one can face upward, as observed in Kurşunlu Mosque in Bergama. In the complex or combined form, the bases of the primary triangular prisms, resting on the wall or the circular dome base, are adorned with smaller decorative triangular prisms, known as the belt of Turkish triangles

Table 1. The geometrical typology of the belt of Turkish triangles in elevation and at the corner

	Belt of Turkish triangles composed of triangular prisms	
Belt of Turkish triangles composed of triangular planes	**Belt of Turkish triangles with simple triangular prisms** ***Bademli/Baklavalı Türk Üçgeni Kuşağı***	**Belt of Turkish triangles with combined triangular prisms** ***Göbekli Türk Üçgeni Kuşağı***
Elevation	(a)	(d) (f) (h)	(e) (g)
Corner Types	(b) (c)	(i) (k) (l)	

Figure 8. **(a)** The tomb of Yusuf bin Yakub in Afyon (Önkal, 1996; figure 414), **(b)** the Hekim Bath in Tire (Author, 2007), **(c)** the Karacabey Mosque in Ankara (Author, 2007) **(d)** the winter room of the Sırçalı Madrasa in Konya (Kuran, 1969; 215).

with combined triangular prisms[7] as illustrated in (Table 1f). While the center of the decorative prisms projects towards the space, the primary one's recess into the wall through the transition zone, as exemplified in the Tahtakale Bath in Tire and in the entrance and main spaces of Yeşil Mosque in Bursa (Figure 9c, 9d, 9e, 9f). In the belt of Turkish triangles with "badem" or combined triangular prisms, the sides of large triangular prisms and small decorative prisms, intersecting at the center of the primary triangular prisms, can be ornamented with linear bordures (Table 1g, 1h), resembling a three-armed star shape, as seen in Muradiye Mosque, Tavuk Pazarı Bath, and also intersecting at the center of the small triangular prism, as observed in Tahtakale Mosque in Tire and Yeşil Mosque in Bursa (Figure 9c, 9d, 9e, 9f).

At the corner of prismatic triangles, three general types of geometric solutions are observed. In the first type (Table 1i), the common side line of two adjacent triangular prisms looking downward is located at the corner of the wall, as seen in the tepidarium of the Tahtakale Bath in Tire, at the entrance of Orhan Gazi Mosque in Bursa, Selçuk Bath, or in the main space of Yeşil Mosque (Figure 9c, 9d, 9e,9f). The second type is very similar to the previous one, with the only difference being the absence of a corner line (Table 1k). A "badem" with flat surface projects from the corner of the wall to the circular dome base as observed in Nilüfer Hatun İmareti, Yeşil Mosque in İznik, Gazazhane Mosque in Tire and Devlet Hatun Tomb in Bursa (Figure 9g, 9h). In the third type, as seen in Mehmet Bey and Tahtakale Mosques in Tire, the triangular prism facing upwards is positioned between the wall corner and the base of the dome (Figure 9a, 9b) and (Table 1l).

In addition to the common types found in the belt of Turkish triangles, there are also unusual applications. The Leyse (Pir Ahmet) Mosque in Tire is an extraordinary example consisting of the combination of two downward-facing triangular prisms and one upward-facing plane triangle (Figure 10a). Another unconventional arrangement is seen in the Hamzabey Mosque in Bursa, where the prismatic units are arranged in the form of triangular prisms with a truncated top, deviating from the usual patterns. In the main space of the Muradiye Mosque in Bursa, the belt of Turkish triangles is composed of "badem" standing side by side and triangular prisms that resemble mirrored pairs of each other (Figure 10b). Another unique application is found in the Green Tomb in Bursa, where the region between the "badem"s standing next to each other is filled with plane triangles (Figure 10c).

There are also various types of corner solutions elaborated with triangular prisms in the Turkish triangular transition zone. While Yalınayak Masjid in Tire has four adjacent triangular prisms facing the same direction at the corner, the surfaces of the triangular prism at the corner were also differently treated in Parmaklı Masjid in Bergama (Figure 11a, 11b). Especially in baths, in contrast to the blind and plain wall surfaces, the space becomes as impressive as possible owing to the belt of Turkish triangles. For example, in the "halvet"[8] of Tahtakale Bath, each surface of the triangular prism located in the corner has been treated in such a way that it seems to be formed by the interlocking of four smaller triangular prisms adjacent to each other (Figure 11c). In Tavuk Pazarı Bath in Bursa, there is six armed star shape consisting of six triangular prisms at the corner (Figure 11d). On the other hand, in the Saray Bath in Edirne, the corner of the belt of Turkish triangles is composed of squinch with stalactites (Figure 11e).

Although the belt of Turkish triangles is typically located in a single transition zone, there are also examples that are positioned in a double transition zone (Figure 12). It can be composed of triangular planes, as seen in Beyhekim Masjid in Konya and Hamza Bey Mosque (Figure 12a, 12b), or triangular prisms, as observed in Bursa Muradiye Mosque, Bergama Debbağlar Bath (Figure 12c), Peçinler Bath, and Bursa Ördekli Bath. In the east iwan of Hamza Bey Mosque in Bursa, the double line of the Turkish triangular transition zone consists of triangular planes. The lower and upper parts of the belt of Turkish triangles are positioned as mirrors of each other. In other words, triangular planes looking up are situated on top of the triangular planes looking down. The Hoca Tabip (Aynalı) Mosque with a double line of Turkish triangular transition zone is an extraordinary example in terms of the combination of triangular prisms at the lower level with the second line of triangular planes, which also project or recess according to the folding dome (Figure 12d)

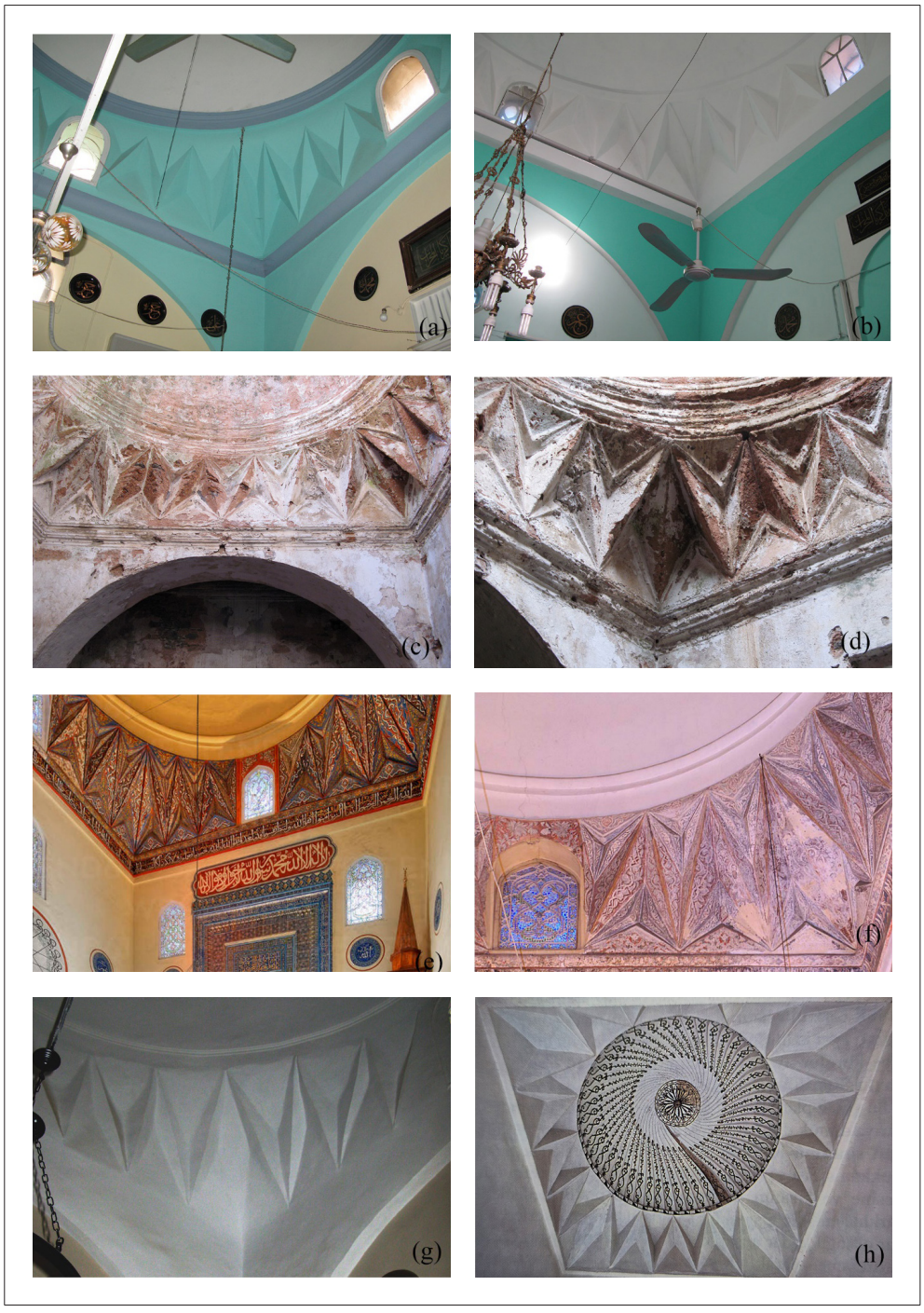


Figure 9. **(a)** Mehmet Bey Mosque, Tire (Photo by Author), **(b)** Tahtakale Mosque, Tire (Author, 2007), **(c, d)** Tahtakale Bath, Tire (Author, 2007), **(e, f)** main space of Yeşil Mosque with the ornamented belt of Turkish triangles, Bursa (İrteş, 2021; 75, 83), **(g)** Gazazhane Mosque in Tire (Author, 2007) and **(h)** Devlet Hatun Tomb in Bursa (Kuban, 2007; 155).

Turkish Triangular Transition Zone Between Different Ground Plans and the Dome

The belt of Turkish triangles offers rational solutions and provides considerable flexibility in solving the transition from different plan geometries to the dome. Namely, differentiating the inclination angles of triangular units according to their position in the transition zone, increasing their number, or adjusting the height of the transition zone can be counted among the most frequently encountered solutions. Based on the number of triangles in a quarter of the Turkish triangu-

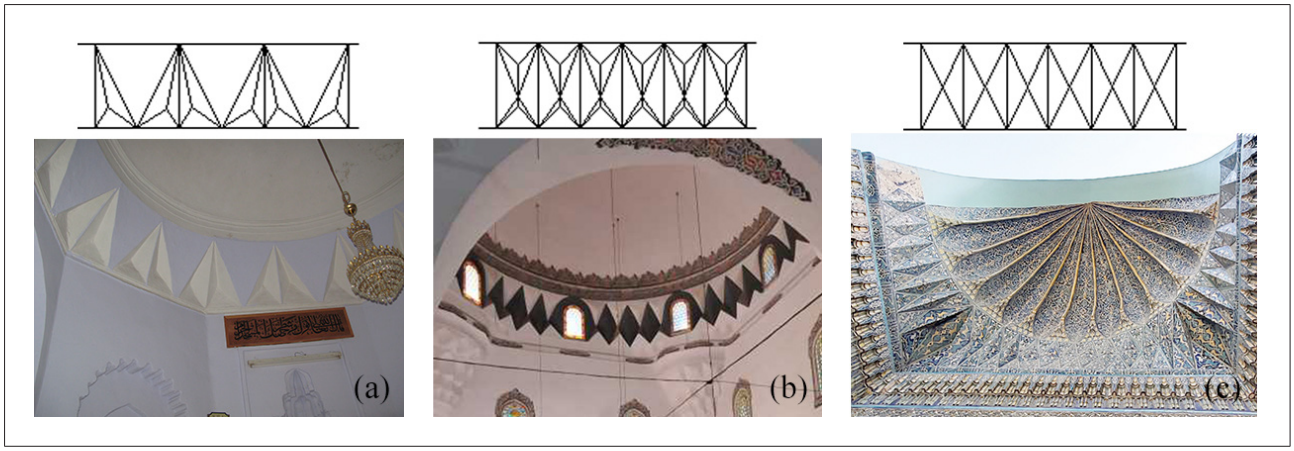


Figure 10. **(a)** Leyse (Pir Ahmet) Mosque, Tire (Author, 2007); **(b)** Bursa Muradiye Mosque (Türkiye Kültür Portalı, n.d.), Bursa; **(c)** Yeşil Tomb (Xodjoyeva, 2019; 41).

lar transition zone at each corner, a polygon-based plan is formed, for which the number of edges is multiples of four, such as eight, twelve, and sixteen, before reaching the circular dome base. As the number of triangles increases, the base on which the dome sits becomes closer to a circular form than a polygonal one. In this context, it is possible to basically divide the belt of Turkish triangles into three groups in terms of the relationship between the ground and upper structure.

The first type facilitates the transition from a square-plan base to a circular, octagonal, dodecagon, hexadecagon, or a polygonal base with twenty or more sides, upon which the dome rests (Table 2). While numerous examples of this type exist, some notable instances include: transitioning from a square plan to an octagonal dome base, as seen in the Yenicekköy Bath in Tire (Table 2a1); transitioning to a dodecagon dome base, observed in the Hekim Bath in Tire (Table 2a2); transitioning to a hexagonal dome base, visible in various locations such as the main space of the Murad Paşa Mosque in İstanbul, the main iwan, tomb, and rooms on both sides of the Taş Madrasa in Akşehir, the Sahib Ata Tomb in Konya,

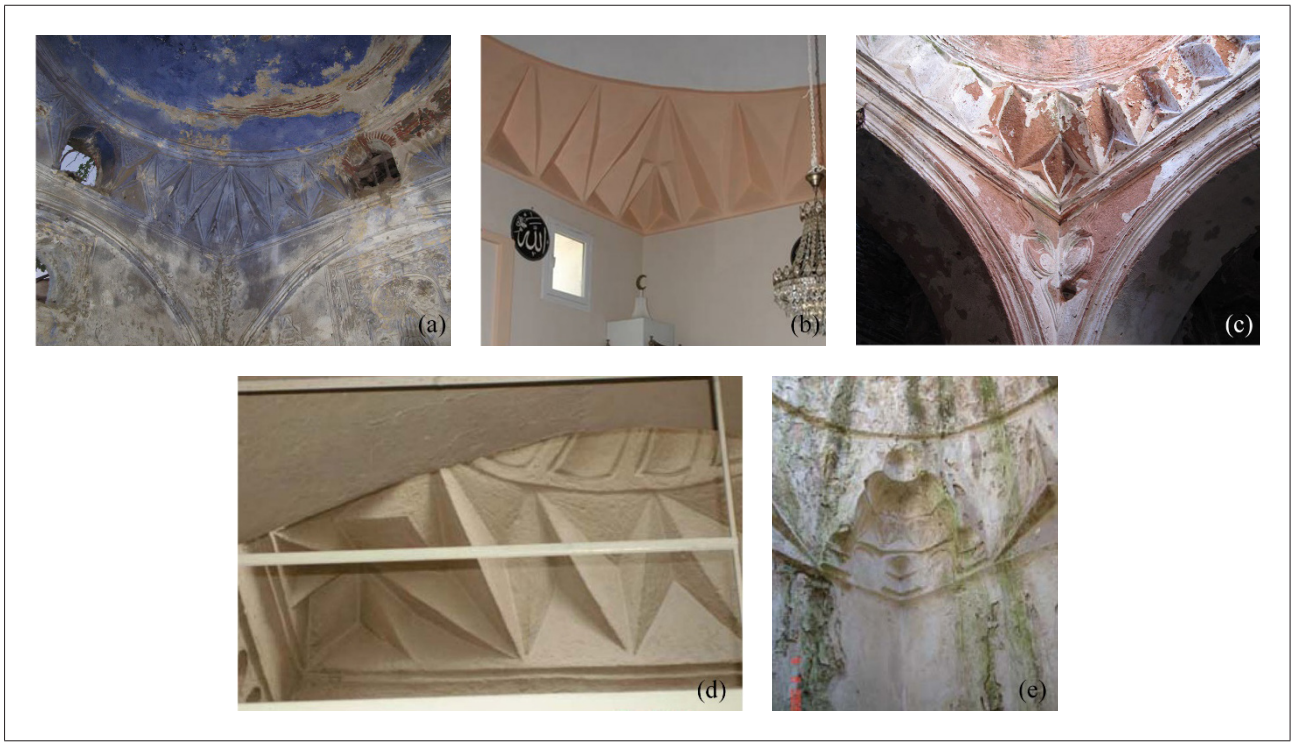


Figure 11. Corner details of the belt of Turkish triangles; **(a)** Yalınayak Masjid, Tire (Author, 2007), **(b)** Parmaklı Masjid, Bergama (Şaşmaz, 2025), **(c)** Tahtakale Bath, Tire (Author, 2007), **(d, e)** Tavuk Pazarı Bath, Bursa and Saray Bath, Edirne (Kula Say, 2007; 205, 154).

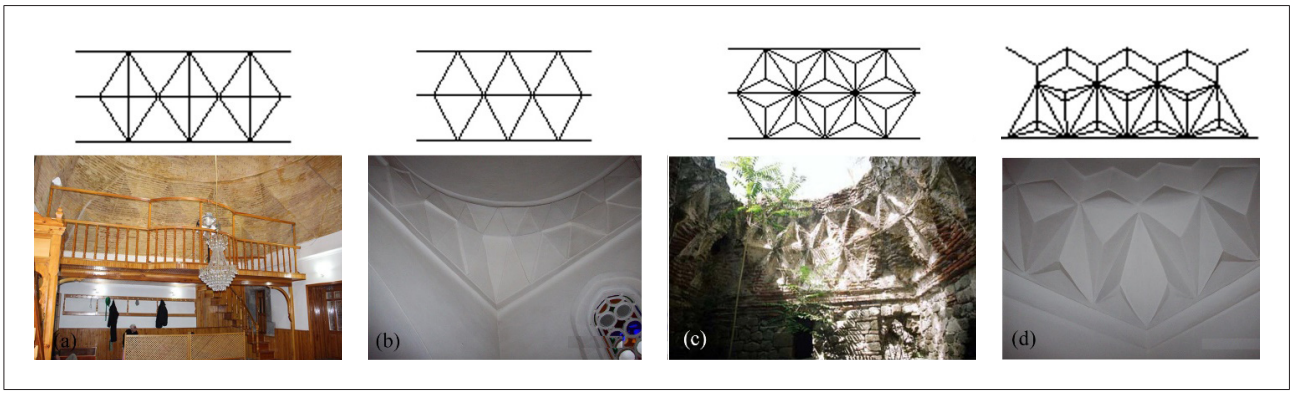
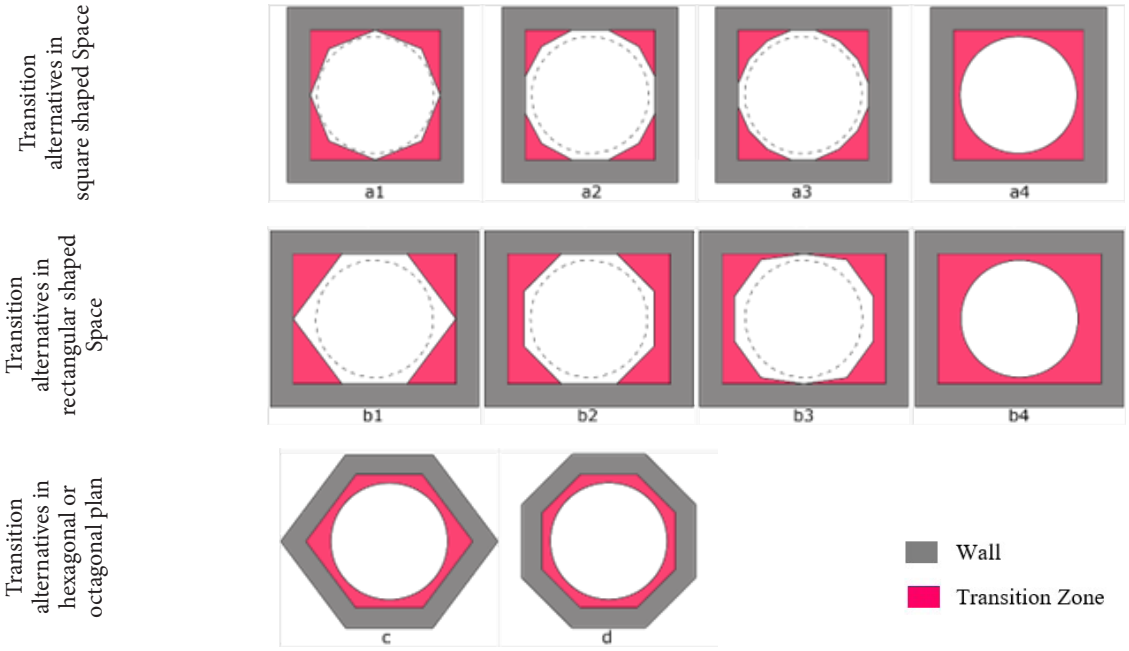


Figure 12. Triangular planes and prisms with double transition zone; **(a)** Beyhekim Masjid in Konya (Çolak, 2025) **(b)** Hamza Bey Mosque in Bursa (Şimşek, 2010; 316), **(c)** Debbağ Bath in Bergama (Kula Say, 2007; 164), (d) Hoca Tabip (Aynalı) Mosque in Bursa (Şimşek, 2010; 362).

the masjid of the Gök Madrasa in Sivas, the Nureddin İbn-i Sentimur Tomb in Tokat, and in front of the *mihrap* space of the Eski Mosque in Edirne (Table 2a3). Additionally, such transitions extend to a twenty-sided dome base, exemplified in the front of the "mihrap" space of the Alaaddin Mosque in Konya and the Yavaşca Şahin Mosque in İstanbul. Moreover, they extend further to a twenty-four-sided dome base, as seen in the women's section of the Tahtakale Bath in İstanbul, and even to a twenty-eight-sided dome base, showcased in the Hacı Özbek Mosque in İznik (Table 2a4).

The second form is employed to transition from a rectangular plan to a hexagonal, octagonal, hexadecagon, twenty-sided polygonal base, or a circular base upon which the dome rests (Table 2b1, 2b2, 2b3, 2b4). In such applications, due to the dome opening often aligning with or being close to the structure's short side, the triangular units on the shorter side protrude more and are inclined to close the gap between walls and the dome. Examples of this transition achieved through the use of the belt of Turkish triangles include: from rectangular planned structures to an octagonal dome base, showcased in Nilüfer Hatun in İznik; to dodecagonal and hexagonal dome bases, as observed in the Yıldırım Bath in Mudurnu; to a dodecagon dome base, evident in the narthex of the Karahasan Mosque in Tire; to octagonal, dodecagonal, and hexagonal dome bases, as seen in the Karacabey Bath in Ankara; to a hexagonal dome base, displayed in the side domes of the İvaz Bey Mosque in Manisa; and finally, to the base of a twenty-cornered dome, exemplified in the dressing area of the Demirtaş Bath in Bursa.

Table 2. Geometric relationship between plan layout and the base of the dome with belt of Turkish triangles



The third form involves transitioning from an octagonal or hexagonal plan base to a circular dome base. For instance, the middle section of the portico of Nilüfer İmaret in Bursa employed double transition elements: the first transitioned from a rectangular plan to a hexagonal base using large triangular units, while the second transitioned from the hexagonal base to a circular dome base. Similarly, various locations such as the Leyse (Pir Ahmet) Mosque, the dressing hall of the Tahtakale Bath in Tire, Yeşil Tomb in Bursa, and the cold area of the Davut Paşa Bath in Bursa utilized the belt of Turkish triangles for transitioning from octagonal spaces to circular dome bases. The Cem Sultan Tomb in Bursa also showcases a transition from an octagonal-planned space to a circular dome base (Table 2c, 2d).

The belt of Turkish triangles serves not only to facilitate transitions from regular geometries but also to adapt irregular ground plans to polygonal bases supporting domes as in the Parmaklı Masjid in Bergama (Figure 13a). Furthermore, builders have demonstrated exceptional skill in dealing with rectangular planned spaces. Here, the space is initially converted into a square plan by utilizing arches on one or both short sides. Subsequently, the belt of Turkish triangles is employed to transition to a circular dome base. This technique is evident in structures such as the tomb in Tokat Gök Madrasa and the adjacent rooms on either side of the main iwan in Konya Sırçalı Madrasa (Figure 13b, 13c).

The belt of Turkish triangles can be used as a part of double transition zone. Initially, pyramidal pendentives facilitate the transition from a square to an octagonal plan base. Following this, the belt of Turkish triangles aids in the transition to a circular dome base (Table 3a, 3b, 3c). This technique is exemplified in various structures such as the central space of Demirtaş Mosque, the tepidarium of Demirtaş Bath, the main iwan of Yıldırım Madrasa, and Yıldırım Hospital (Darüşşifa) in Bursa.

The Façade Organization in the Turkish Triangular Transition Zone

The belt of Turkish triangles requires a transition zone that can be situated either within a drum or embedded inside the wall without a drum. In both scenarios, the design of the Turkish triangular transition zone significantly influences the organization of the facade. The reflection of the Turkish triangular transition zone onto the facade can be categorized into three main types (Table 4).

The simplest among these is the drumless application (Table 4A, 4A1), where the dome emerges directly behind high walls as in the Sırçalı Masjid in Konya and the Beçin Yelli Mosque in Muğla (Table 4a, 4b), that was mostly used in the Seljuk period. Later, during the Principalities and the Ottoman period, the use of octagonal drum was observed.

In the second type, sloped wall pieces used at the corners of the drum serve as retaining walls (Table 4B, 4B1) for structural support in early periods. In these cases, both the drum and walls maintain the same level on the facade. At corner regions where the slope towards the dome is most significant within the transition area, external buttress support often becomes necessary alongside the walls as seen in the Hacı Özbek Masjid in İznik and the Kumacık Bath in Amasya (Table 4c, 4d). This additional support addresses the high pressure and tensile forces transferred from the top to the bottom.

In the third type, the primary factor influencing the exterior reflection of the belt of Turkish Triangles is the varying wall thickness, extending from the wall to the top cover. There's a direct correlation between the dome's thickness and its span, leading to a proportional increase in the dome's section, drum and the main walls as the opening expands (Reyhan et al., 2013). Kuban (2007) highlighted an average ratio of 1/10 between the wall thickness and the dome opening. This gradual increase is visible in the drum part forming the transition region, highlighted by the presence of eaves in numerous structures between the walls and the drum (Table 4C, 4C1, 4C2, 4C3, 4C4). These eaves, which delineate the

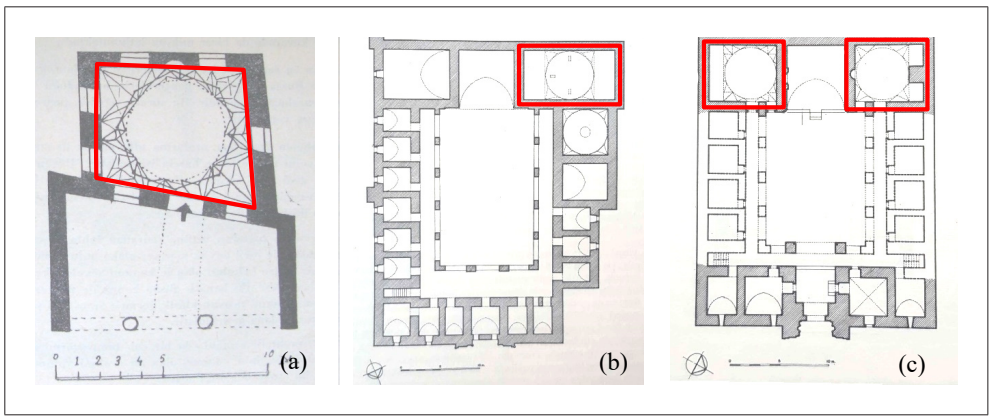
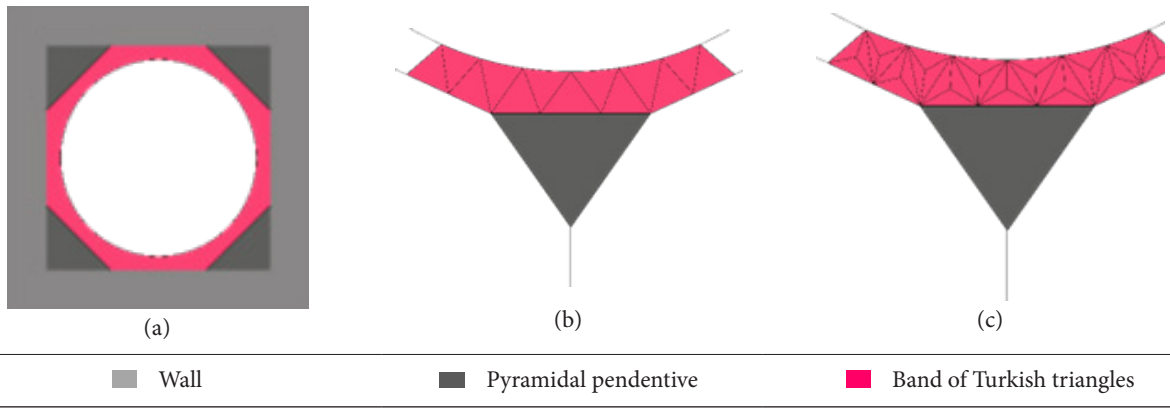


Figure 13. **(a)** Parmaklı Masjid in Bergama (Bayatlı, 1956; 23), **(b, c)** Gök Madrasa in Tokat and Sırçalı Madrasa in Konya (Kuran, 1969; 74, 99).

Table 3. Double transition zone: (a) Plan layout, (b, c) pyramidal pendentive and belt of Turkish triangles with triangular plane and triangular prism.



wall and the drum, can either be a straight line, observed in structures like the Muradiye Mosque in Bursa, the Yeşil Mosque in İznik, and the Ayas Ağa Mosque in Amasya (Table 4e, 4f, 4g), or they may gradually continue based on the positioning of the buttresses supporting the corners, as seen in the Acem Reis Mosque in Bursa (Table 4h).

Particularly during the Principalities Period, one of the commonly encountered architectural features is the use of a double row outer drum, exemplified in structures like the Rum Mehmet Pasha, Narin, Tahtakale, Gazazhane, Karahasan, and Kara Hayrettin (Güdük Minaret) Mosques in Tire. Kolay's (2017) findings suggest that in such instances, the horizontal plane where the two drums meet forms the base or skirt of the dome, marking the starting point of the dome structure (Figure 14). Additionally, it's noted that the lower levels of the outer drum align with the Turkish triangular transition zone.

This section presents a systematic classification of façade configurations related to the transition zone in which, Turkish triangles are used. The classification into three façade types reveals not only stylistic preferences but also structural responses to geometric and spatial needs across periods. By identifying consistent patterns - such as the presence or absence of drums, the role of buttresses, and the proportional relationships between wall thickness and drum - this analysis establishes a foundation for understanding how form and construction logic intersect. These findings pro-

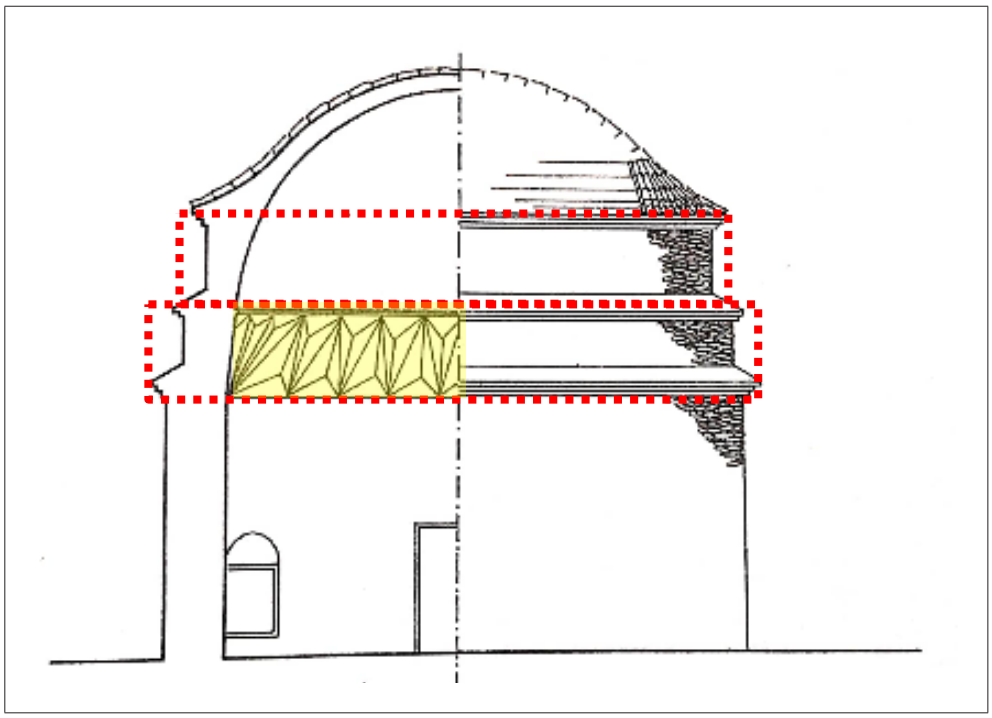
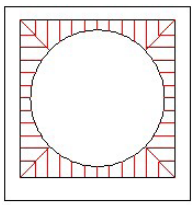
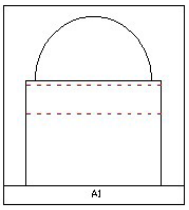
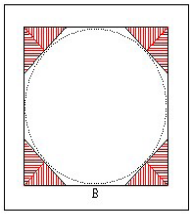
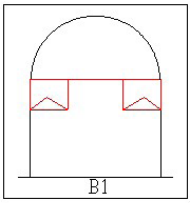
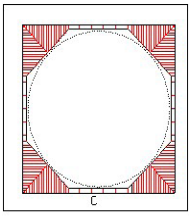
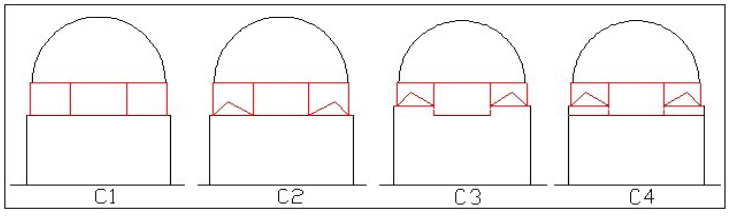
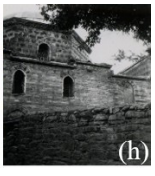


Figure 14. Karahasan Mosque in Tire (Kolay, 2017; 107).

Table 4. (a) Sırçalı Masjid in Konya (Bilici 2016b; 470), (b) Beçin Yelli Mosque in Muğla (AA, n.d.a), (c) Hacı Özbek Masjid in İznik (SALT Research, n.d.a), (d) Kumacık Bath in Amasya (Yarar, 2020; 189), (e) Muradiye Mosque in Bursa (SALT Research, n.d.b), (f) Yeşil Mosque in İznik (SALT Research, n.d.c), (g) Ayas Ağa Mosque in Amasya (Tanman, 1991; 202) and (h) Acem Reis Mosque in Bursa (SALT Research, n.d.d).

Plan Layout	Facade
 A	 A1
	 
 B	 B1
	 
 C	 C1 C2 C3 C4
	   

vide essential groundwork for the subsequent discussion on construction techniques, where the physical realization of these morphological choices will be explored in detail.

MATERIAL USAGE AND CONSTRUCTION TECHNIQUE IN THE TURKISH TRIANGULAR TRANSITION ZONE

Material Usage

The belt of Turkish triangles is usually constructed with brick and mortar, and rarely with stone as in Yanköy İçkale Masjid and Vacidiye Madrasa (Figure 15a, 15b), a choice made due to brick's suitability in forming narrow surfaces. However, there are instances where both brick and rough cut or rubble stone were combined in constructing the belt of Turkish triangles, as seen under the plaster in the damaged parts of the transition zone like the Molla Arap Mosque (Figure 15c), Yalınayak Masjid (Figure 15d)), the Tahtakale Bath (Figure 15e) and Karagazi Bath (Figure 15f) in Tire, and the Selçuk Hatun Masjid in Edirne. This combination results in stronger connections between the long stones and the core of the wall in the transition zone as the triangular units project into space (Figure 15c). Batur (1980) observed that the material of the inner part of the transition element corresponds to that of the dome, while the exterior of the drum aligns with the material of the walls.

While the belt of Turkish triangles was generally plastered, there are remarkable exceptions with unplastered buildings showcasing regular brickwork, such as the Ulaş Baba Tomb

Figure 15. Stone usage; **(a)** Yanköy İçkale Masjid in Antalya (Boran, 2001; foto 224), **(b)** Vacidiye Madrasa in Kütahya (Kolay, 2017; 59), brick and stone hybrid usage; **(c)** Molla Arap Mosque, **(d)** Yalınayak Masjid, **(e)** Tahtakale Bath and **(f)** Karagazi Bath in Tire (Author, 2007).

and the winter classroom of the Sırçalı Madrasa in Konya. Notably, the Vacidiye Madrasa in Kütahya is among these exceptional structures where the surfaces of plane triangles, constructed with stone, were intentionally left unplastered. Önkal (1996) noted that when stone is employed for the triangular belt, as seen in the Seyid Şeref Tomb in Kayseri, the final dressing of the triangular surfaces is executed after the blocks are laid.

The use of bricks varied in size and shape across different sections of buildings in various periods. Tunay (1984), in examining brick use in Byzantine architecture, highlighted size differences ranging between 20 cm and 40 cm, differing not only across periods but also within structures within the same era. During the early Ottoman Period, brick sizes resembling Byzantine dimensions, 14x28 cm and 30x30 cm with a thickness of 4 cm (rarely 4.5 cm), were common (Kutlu, 2017). In the Ottoman Period, typical brick sizes observed in domes were noted as 39–40 × 27–28 × 4–4.5 cm for full bricks and 30–32 × 21–24 × 3–4.5 cm for half bricks, (Reyhan et al., 2013). Meanwhile, the vault of the Süleymaniye Complex used 35×35×4.5 cm full bricks and half bricks (Kolay, 2016). Diri Akyıldız (2018), in a study of the construction technique of Edirne baths from the 14th and 16th centuries, specified that the main structure of transition elements was built using bricks and half-length bricks with dimensions of 27.5×27.5×4-4.5 cm and 24×27.5×4-4.5 cm, respectively. Additionally, bricks with dimensions of 19-20×19-20×4-4.5 cm were used in horizontal and vertical alignments. Horizontally, bricks were used in belt of Turkish triangles, pendentives and rings, while both vertical and horizontal alignments were employed in muqarnas.

Standard brick sizes and shapes are commonly used for smooth surfaces such as walls or domes. Conversely, the belt of Turkish triangles, particularly those with "badem" and combined triangular prisms, exhibit complex arrangements of triangular prisms with folding surfaces that directly influence the material's shape and size. To achieve the desired shapes for these prisms, bricks may have been divided or trimmed with specific adjustments, allowing them to conform to the varying shapes and bends dictated by the transition zone's geometry, both externally and internally within the wall.

Özdural's (1996) study on muqarnas details methods of dissecting and composing forms to create diverse ornamental patterns. For instance, he demonstrates various approaches for composing figures by dividing a square into triangles, rectangles, hexagons, and decagons (Figure 16). Adam (1994) points out that in Roman architecture brick was deliberately cut into triangular pieces and was often used in walls in triangular form as in the Pompeii's masonry walls. Although the brick was used in the whole square form, trimming was a widely used technique in order to help in positioning and to line up the corners. In addition, the insertion of the corner of the triangle into the mortar in the core of the wall creates a stronger bond than the regular bricklaying. Especially in constructing the belt of Turkish triangles with triangular prisms, the focus lies on dense mortar and the expertise of the master, rather than standard material sizes. Since the size or shape of the material changes according to the geometry of the belt of Turkish triangles.

Construction Technique

There is limited information about the construction technique of the belt of Turkish triangles. The fundamental questions in regards to the construction technique are how such precise forms were achieved in the triangular elements, whether any specific geometrical formulas were applied, how materials were positioned within complex geometries, and whether masons employed any form of formwork. Additionally, understanding the sequence in which triangles with intricate shapes were constructed is pivotal. To shed light on these queries, examinations are conducted on damaged transition zones where materials are exposed due to collapse or plaster loss. Insights are also drawn from existing literature that explore the construction techniques related to the geometry of the belt of Turkish triangles.

It's conceivable that masters might have utilized molds to shape the complex triangular units and prisms, ensuring a smooth surface or holding them in place, particularly at the corners where the transition zone's largest openings exist. However, in the belt of Turkish triangles, plaster has conventionally been employed to achieve a smooth surface (Figure 17a, 17b), with rare exceptions like the Vacidiye Madrasa in Kütahya and the Sırçalı Madrasa in Konya.

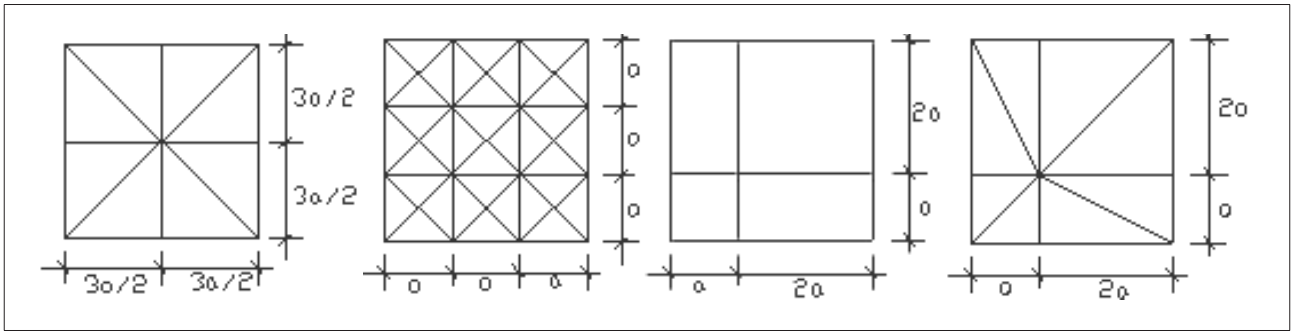


Figure 16. Dividing the square shape brick into smaller pieces (Adam, 1994; 147).

Examining damaged structures such as the Molla Arap Mosque, Karagazi Bath, and Tahtakale Bath in Tire reveals rough brickwork forming triangular prisms beneath the plaster (Figure 17c, 17d). This contrasts with the smooth appearance of plastered surfaces (Figure 17a, 17b). These findings discount the use of molds and emphasize the significance of thick mortar between bricks. This mortar is crucial in shaping the triangular prisms precisely and compensating for stylistic imperfections caused by dividing and trimming the bricks (Figure 17d).

While brick appears to be the primary building material used in the zone of Turkish triangles, a closer examination of certain structures, such as the Molla Arap Mosque, the Yalıayak Masjid and the Tahtakale Bath, reveals a hybrid use of both brick and stone. In these examples, craftsmen deliberately incorporated long and flat rough cut stone pieces or rounded rubble stone alongside bricks, either irregularly distributed within the triangular units (Figure 15c, 15d) or arranged in specific horizontal courses (Figure 15e, 15f). These stone elements were often integrated into the brick courses, not necessarily for aesthetic precision (as these areas would later be plastered), but rather for practical reasons such as material availability or constructional convenience. For example, in the Karagazi Bath in Tire, while brick is commonly observed on the surface areas of the transition zone-where the inclination toward the dome is relatively low-stone appears to have been predominantly used in the plane triangles at the corners, where the corbelling projection is more pronounced (Figure 15f). In some instances, the flat stones may have served to anchor the triangular units more firmly into the wall mass, enhancing structural integration.

The integration of stone materials is particularly evident in the corbelled parts, suggesting that these stones were deliberately positioned within the inner courses to stabilize the units and align with the brick layering. Therefore, it is appropriate to consider the belt of Turkish triangles as a structurally hybrid system in certain applications, where brick is predominant but stone is used as a reinforcing or stabilizing element as seen in the wall section of the Molla Arap Mosque (Figure 15c). This hybrid construction strategy also implies that masons employed flexible techniques rather than a strictly uniform method.

Before delving into the construction of the belt of Turkish triangles, establishing the relationship between the walls and the dome is necessary. In the critical corner regions, where load transfer from the dome to the walls is most crucial, the triangular units play a vital role in safely distributing these loads by elevating the height of the transition region (Figure 18). As the dome opening expands, the height of the transition zone increases accordingly. An observed ratio of 1/4 to 1/5 exists between the height of the transition zone, featuring the belt of Turkish triangles, and the size of the dome opening.

Figure 17. **(a)** Beçin Yelli Mosque (Yurt Haberleri, n.d.), **(b)** Hekim Bath in Tire (Author, 2007), **(c)** Karagazi Bath in Tire (Author, 2007), and **(d)** Tahtakale Bath in Tire (Author, 2007).

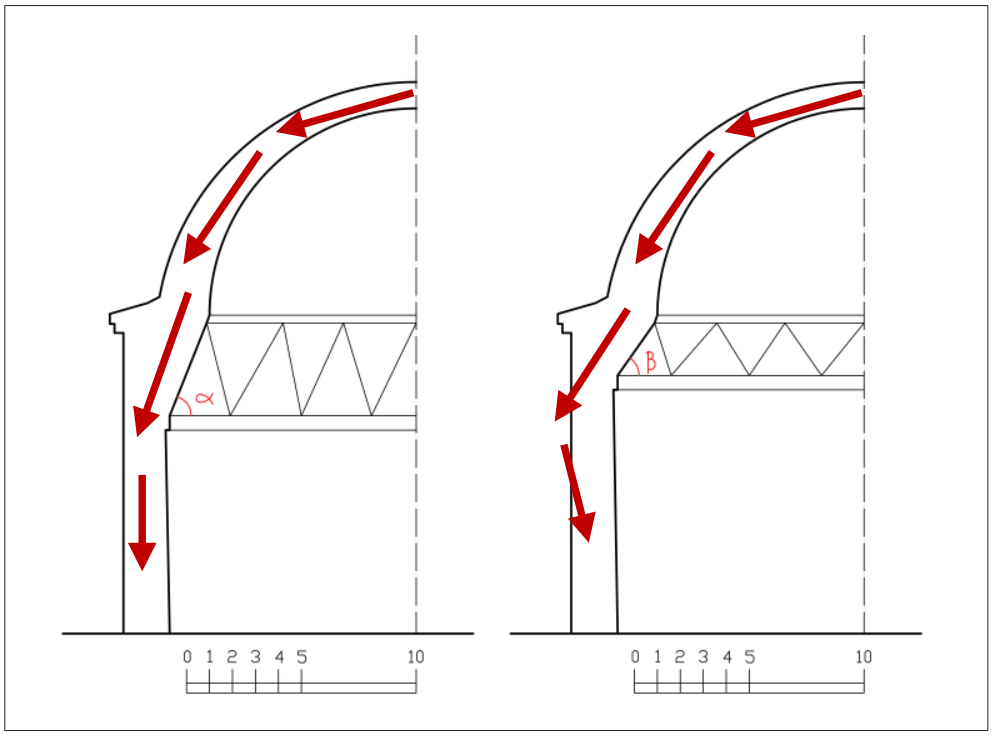


Figure 18. The belt of Turkish triangles with different heights and load transfer (Design by Author).

It should be noted that borders, consisting of two or three rows of bricks positioned to protrude a few centimetres above and below the transition zone, indicate the use of scaffolding during construction (Figure 17a, 17b, 17c, 17d). While the border between the wall and the triangular units ensures a smooth surface for the transition zone, the border on the triangular units facilitates the transition from the polygonal base formed by the belt of Turkish triangles to the circular dome base (Figure 9, 10, 17, 19).

Plane or prismatic triangles are constructed using the corbelling system, employing bricks and thick mortar between them. While there is limited information about the method used in constructing triangular units, Kolay (2017) states that the process begins at the corners due to their structural significance. The resulting triangular units are connected to each other at the midpoint of the transition zone. Şimşek (2010) suggests that when the distance between the walls and the base of the dome is large and the height of the transition zone is low, triangular molds are created in the corners that protrude the most. In such cases, there is no need for a formwork as the middle point of the wall is approached.

Undoubtedly, starting from the corners is crucial to minimize construction errors, considering the role of corners in load transfer for the dome and the necessity of addressing corner areas as a distinct design problem. With consecutively facing triangular units in the belt of Turkish triangles, it is essential initially to construct the triangles located at the corners and along the wall base, as their early stabilization enables the central units to be placed securely. Subsequently, elevating the triangles together using the corbelling system becomes possible. When laying the brick rows of triangular units, it's crucial to shape the material to extend into the wall as much as possible, ensuring a firm fusion with the wall. In certain applications, such as the Molla Arap Mosque, the placement of long flat stones between the rows of bricks reinforced the fusion of triangular units with the core of the wall in the transition zone (Figure 19b). Following the construction of the triangular units, a border section is created with several rows of bricks to achieve a smooth circular base before progressing to the dome.

Additionally, it should be noted that in some Turkish triangular transition zones, an amphora or pipe application may be encountered. Whether they are flat triangles, as seen in the Beçin Yelli Mosque (Figure 19a), or prismatic triangles, as observed in the Molla Arap Mosque in Tire (Figure 19b), amphoras with a diameter of about 20-30 cm are placed in the middle of the triangular units with their open mouths on the surface. Kolay (2017) discussed the use of hollow amphoras or cubes, called *lightening cubes*, to reduce the weight of a building. Atay & Gül (2020) also noted that amphoras can be used in various areas such as super structures, transition elements and flooring to lighten the load of a building, as well as for acoustics or ventilation.

After completing the construction of the transition zone, the front faces of the bricks are trimmed where necessary, according to the folding angle of the triangular units. Finally, the application is completed with plaster, paint, or

Figure 19. **(a)** Beçin Yelli Mosque (Yıldız, 2025), and **(b)** Molla Arap Mosque in Tire (Author, 2007).

decoration. Plastering also serves to conceal craftsmanship faults on the surfaces.

In some applications, the embossed decorative motifs seen on the surface of the belt of Turkish triangles could have been achieved with moulds during plastering. On the other hand, extraordinary surface treatments, such as a single row of projecting bricks placed in the direction of the edge lines of the triangular units during plastering, can be encountered, as seen in the İsmail Bey Bath in İznik.

MODELLING OF THE DIFFERENT GEOMETRIES OF THE BELT OF TURKISH TRIANGLES

When examining the relationship between geometry and construction techniques, despite the existence of extraordinarily complex shapes, it becomes evident that the most prevalent types within the realm of the belt of Turkish triangles include triangular planes, simple triangular prisms known as the belt of Turkish triangles with "badem" and combined triangular prisms (Table 1). In the category of combined triangular prisms, where smaller triangular prisms, known as "göbek", are positioned on the base surfaces of the main triangular prisms, they can be formed either by projecting bricks to create the smaller triangular prisms or by employing a dense plaster containing thick brick and tile pieces. As the construction technique for the belt of Turkish triangles with "badem" is fundamentally similar to that of the belt with combined triangular prisms, the variations between the two primary types-the belt of Turkish triangles consisting of simple triangles and triangular prisms-are meticulously analysed through 3D modelling (Table 5a).

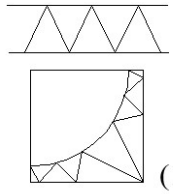
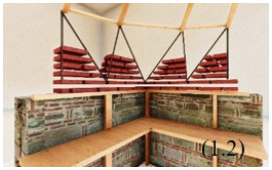
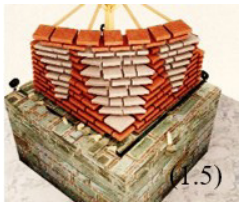
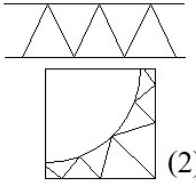
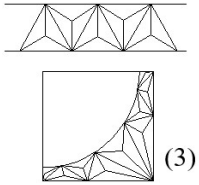
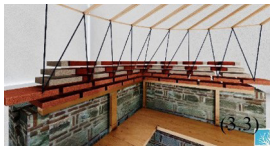
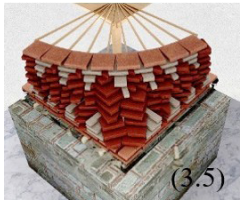
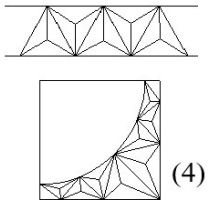
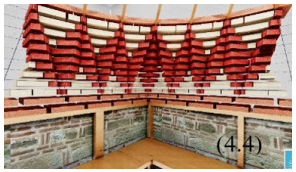
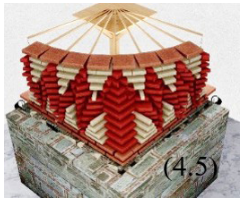
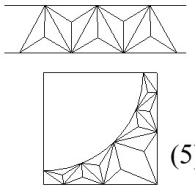
When generating 3D models for the construction technique of the belt of Turkish triangles, certain assumptions were made based on examples in the literature. These considerations encompassed factors such as space size, the height of the transition zone, dimensions of triangular and prismatic units, as well as material size and mortar thickness. In the belt of Turkish triangles, comprising plane triangles, a square space with a side length of 3 meters was utilized, whereas in types with prismatic triangles, a square space with a side length of 3.5 meters was chosen, accounting for the geometry and number of units. In both scenarios, the height of the transition zone was adjusted to be between 1/4 and 1/5 of the opening (3~3.5 m), set at 70 cm. For the material, 30×30×5 cm bricks were employed, a size frequently found in historical buildings and representing an average among various types. 3 cm of mortar thickness was applied between the bricks. Considering the diagonal length of the brick material, the base of each triangular prism was established at 40-45 cm.

To unveil the geometry of the belt of Turkish triangles before construction, the top level of the wall and the initial level of the dome are determined using timber scaffolding. The scaffolding serves a dual purpose by adjusting the beginning of the transition zone and establishing the centre of the radius and the springing level of the dome. Following this, a border consisting of two or three rows of bricks projecting towards the space between the wall and the triangular units is constructed to provide a smooth surface for the transition zone. Subsequently, the fundamental geometric contours of the triangular units -such as the vertex, base, and edge- can be easily established between these horizontal levels by creating guidelines with simple marking tools like rope and nails (Table 5b).

As the construction of the belt of Turkish triangles primarily involves the symmetrical repetition of quarters, it is sufficient for the builder to organize the triangular or prismatic units based on the quarters of the space, with the corner part remaining in the middle. The fundamental contours of the triangular units, including corners and edges, could be determined by dividing the border at the lower part of the transition zone and the scaffolding passing through the upper part of the transition zone into four, eight, or more parts, depending on the geometric form of the belt of Turkish triangles. Guide ropes can then be drawn between these divisions, and the triangular or prismatic units, comprising rows of bricks, can be constructed following these guidelines (Table 5b).

In the plane triangular type, two different corner solutions exist. In the case of an upward-facing plane triangle (base at

Table 5. Construction technique of the belt of Turkish triangles via 3D models (Designs by Author); (a) two main geometric types and different corner solutions, (b) establishing scaffolding and the geometry of the triangular units, (c) beginning of construction with triangular units with their bases on the wall, (d) knitting triangular units opposite to the triangular spaces in between, (e) knitting straight and inverted triangular units all together to the end and (f) core of the transition zone

	(a)	(b)	(c)	(d)	(e)	(f)
The belt of Turkish triangles with plane triangles	 (1)	 (1.1)	 (1.2)	 (1.3)	 (1.4)	 (1.5)
	 (2)	 (2.1)	 (2.2)	 (2.3)	 (2.4)	 (2.5)
The belt of Turkish triangles with "baklava"	 (3)	 (3.1)	 (3.2)	 (3.3)	 (3.4)	 (3.5)
	 (4)	 (4.1)	 (4.2)	 (4.3)	 (4.4)	 (4.5)
	 (5)	 (5.1)	 (5.2)	 (5.3)	 (5.4)	 (5.5)

the top) at the corners (Table 5(1)), the construction commences with triangular units whose bases rest on both sides of the corner part and extend along the transition zone up to a certain level (Table 5(1.1), 5(1.2)). Consequently, the triangular units with bases on the walls act as moulds for the triangular units in between, with their tips touching the wall and bases facing upwards, providing support to keep them standing (Table 5(1.3)). When constructing the triangle facing upwards in the corner, a full brick is initially placed in the corner of the wall, forming the peak of the triangle in the corner. Subsequently, the shapes of the bricks are broken or cut and adjusted accordingly, taking the triangles on both sides of the corner as a reference and ensuring no gaps on the inner surface of the wall. As the triangular units facing upwards reach the level of the mould triangles, the construction of all triangular units is carried out simultaneously until the transition zone is completed (Table 5(1.4), 5(1.5)).

If there are two downward-facing plane triangular units in the corner (Table 5(2)), the positioning of the units is simpler compared to the first application, requiring less brick shaping. When the horizontal rows of bricks forming these two triangular units in the corner are constructed using a corbelling system following the reference lines, the dome skirt is already reached (Table 5(2.1), 5(2.2)). The crucial aspect here is to fill the corner part, which is not visible from the front but remains empty inside, by perfectly completing the remaining space with full bricks using a corbelling system. After knitting the other downward-facing triangles in a similar manner, it is time to knit the upward-facing triangles (Table 5(2.3)). It is observed that those closest to the corners undergo the most folding to the right and left. This change in angle or direction on the surface can be achieved by removing excess triangle pieces from the front parts of the brick material depending on the position of the triangles (Table 5(2.3), 5(2.4), 5(2.5)).

In the case of the belt of Turkish triangles, featuring an upward-facing triangular prism in the corner region (Table 5(3)), the construction process follows a sequence akin to that of the triangular planes. However, a notable distinction emerges: in positioning the endpoints of the diamond shapes formed by the surfaces of two adjacent triangular prisms on the wall, it becomes imperative to initially construct the bases of the downward-facing triangular prisms (Table 5(3), 5(3.1)). These triangles, with their bases on the wall, are typically built with a 5-10 cm recess within the wall. This helps both adjust the centre of gravity of the triangular prisms during load transfer and helps the "badem"s stand out more clearly (Table 5(3.2), 5(3.3), 5(3.4)). In the corner region, the precise alignment of two bricks is essential, ensuring that their corners align with the guideline. The careful placement of bricks to form the "badem"s in the upper rows involves meticulous attention to ensure alignment with the reference lines and the absence of gaps between these shapes and the adjacent triangular units (Table 5(3.3), 5(3.4), 5(3.5)). As the "badem"s progress and reach their widest surface length, nearly horizontal in orientation, across one or two more rows, depending on the transition zone's height, the subsequent step involves crafting the plane triangular surfaces of the upward-facing triangular prisms. In these constructions, the spaces that appear between the diverging "badem"s signify the areas to be filled with these triangular units, completing the intricate geometry of the structure (Table 5(3.4)). This sequential process ensures a snug fit and cohesion between the various elements, enhancing the overall stability and aesthetics of the design.

Certainly, these sections, characterized by the mirrored symmetry of the triangular units leaning against the wall at the base, can be completed progressively until the transition zone's construction is finish (Table 5(3.4)). It is very important not to overlook that the bricks that make up the triangular units or "badem"s need to be cut or broken in order to fit into place. Additionally, joints, especially on the interior of the wall, should be overlapped as staggered as possible to ensure that each unit integrates with each other and with the core of the wall (Table 5(3.5)).

In the case of two downward-facing triangular prisms in the corner, a "badem" is positioned between the corner of the wall and the dome (Table 5(4)). Similar to the previous application, the construction begins with knitting triangular surfaces with their bases on the wall, accounting for the height of the transition zone and the "badem"s to be inserted in between (Table 5(4.1), 5(4.2)). The spaces between the triangular units are filled with "badem"s, guided by reference lines, making it considerably easier to elucidate the geometry of the "badem"s in the corner compared to the previous type (Table 5(4.3)). This ease arises because, when a full brick is positioned in the corner and the rows are elevated using the corbelling system, the "badem" naturally emerges (Table 5(4.3), 5(4.4), 5(4.5)). If the "badem" with flat surface are in the corner (Table 5(5)), the construction sequence remains similar to the previous one (Table 5(5.1), 5(5.2), 5(5.3)). The only distinction is that the straight edges of the bricks are laid at the corner using the corbelling system instead of the corners on the front (Table 5(5.4), 5(5.5)).

It's important to note that both the outer and inner layers of the wall or drum, consisting of the transition zone with the belt of Turkish triangles, are built together (Table 5(1.4), 5(2.4)). The outer part of the drum, taking the form of an octagon or polygon, is typically completed using the alternate wall technique, similar to the main walls, and the core section is filled with a mixture of rubble and mortar. The part that inclines the most inward at the corners is supported by a buttress on the outer surface of the drum.

It is necessary to underline some important points regarding the construction of prismatic units (Table 5(3), 5(4), 5(5)); the arrangement and forms of the bricks differ from the previous plane triangular applications. Here, the edge

surfaces of the bricks are utilized to form the base surfaces of the prisms (Table 5(3.2), 5(4.2)), either against the wall or the dome, while the brick corners are employed to shape the other triangular surfaces in between them. Essentially, this process creates "badem"s by using the corner part of a full-size or smaller brick (Table 5(3.3), 5(4.3)). Consequently, two consecutive edges of the same brick form two folded triangular surfaces of the "badem" (Table 5(3.4), 5(4.4)). The inclination or projection of these "badem"s varies based on their position within the transition zone. Furthermore, the shapes of the bricks themselves also change, influenced by both the "badem" and the adjacent triangular units (Table 5(3.5), 5(4.5), 5(5.5)). It is important to highlight that the size of the brick utilized in the transition zone has a direct impact on the size of the resulting triangular prisms. This ensures that the longest horizontal length of the "badem" does not surpass the diagonal length of a full brick size. If this ratio isn't maintained, particularly in corners with the widest openings, issues may arise where the bricks forming the "badem"s don't effectively integrate with the core of the wall. This could lead to difficulties in properly closing the surfaces, causing the "badem"s to shift apart. Consequently, in the belt of Turkish triangles consisting of triangular prisms, the precise positioning of triangular units in close proximity to each other is crucial to avoid such complications and ensure structural integrity (Table 5(3.4), (3.5), (4.4), (4.5), (5.4), (5.5)).

The construction of the outer drum portion of the transition zone follows a consistent method. Together with the Turkish triangles, the outer wall shell of the transition zone is built simultaneously with an infill core composed of rubble and mortar. As a result, both the inner Turkish triangle zone-featuring the triangular units-and the outer wall or drum are structurally integrated in a rigid state (Figure 20).

CONCLUSION

The structures with the belt of Turkish triangles, which served as a popular transitional element from the Seljuk to the Classical Ottoman Period spanning the 12th to the 15th centuries, boast a history of nearly three centuries. When evaluating the literature on the belt of Turkish triangles, it becomes evident that existing studies predominantly concentrate on the two-dimensional formal properties of the triangular units constituting the belt of Turkish triangles. These studies partially touch upon materials and construction techniques.

In this particular study, an extensive examination of various examples of the belt of Turkish triangles from the Seljuk Period to the Ottoman Period was conducted. Unlike previous works, this research not only delves into the formal and geometric features of the belt of Turkish triangles but also, for the first time in the literature, categorizes and

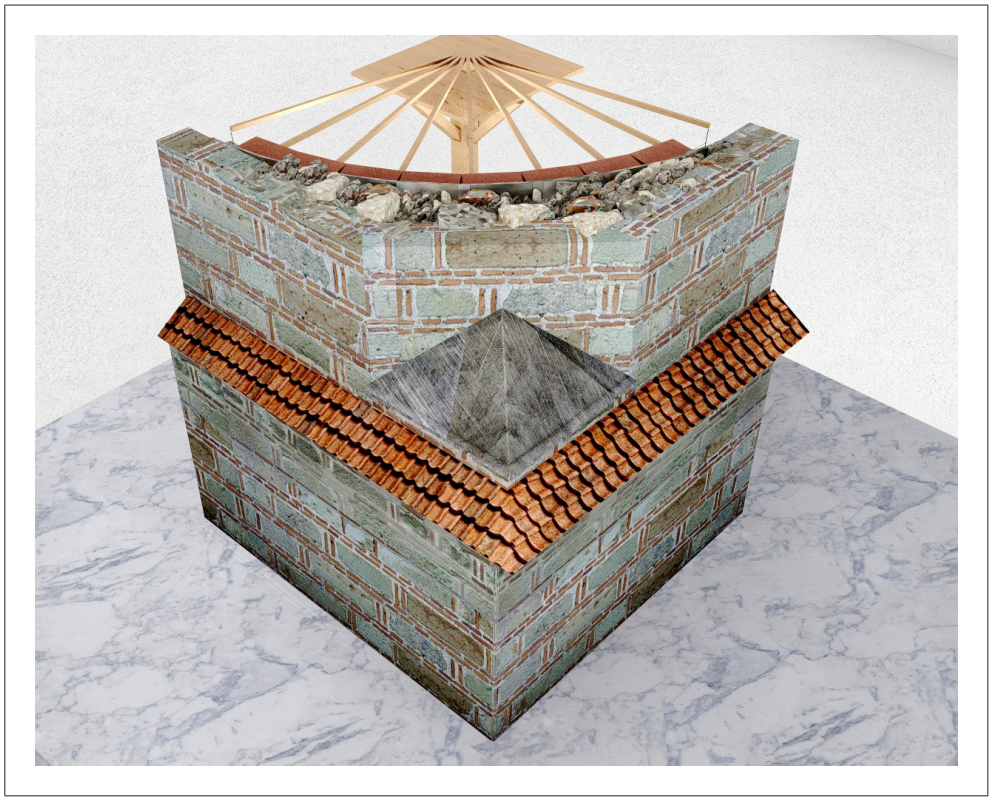


Figure 20. 3D Modelling of transition zone with the belt of Turkish triangles.

presents the ways the belt is utilized in the transition between different plan types and domed top covers. It further explores the relationships between the interior and exterior surfaces and analyses how the belt reflects on the facade, encompassing all possible variations.

Furthermore, the study explores in detail the materials and construction techniques employed in the belt of Turkish triangles, showcasing its diverse geometric shapes. This examination is based on data obtained from numerous field studies, coupled with insights from existing literature. The construction techniques of all geometric and formal types used in the belt of Turkish triangles are elucidated through the creation of three-dimensional models.

When evaluated in terms of form, despite the limited use of pendentives and squinches, the belt of Turkish triangles made a significant impact on its period with its flexible design that facilitated the transition from spaces with regular geometries, such as squares, rectangles, and polygons, to irregular geometries like trapezoids and ultimately to the dome. Additionally, the belt of Turkish triangles, which envelops the dome's drum like a horizontal band, has evolved over the centuries through trial and error processes into a visually rich array of forms, ranging from simple triangular surfaces to the prismatic and complex Turkish triangular belts known as "badem" and combined triangular prisms, as well as various combinations of these. Therefore, the flexible structural solutions and aesthetic contributions provided by the formal richness of the belt of Turkish triangles have played a significant role in its widespread preference in various building types, such as mosques, madrasas, baths, and tombs.

When evaluated in terms of materials, the transition zone-formed by the sequential arrangement of triangular or prismatic units facing upward and downward is primarily constructed using brick. In some cases, a hybrid technique is employed that integrates both brick and stone, while stone alone is rarely used, typically arranged using a stacking method. The brick can be utilized in standard sizes, such as whole, half, or quarter units, to reveal the shape of the triangular or prismatic units, or it can be used in irregular forms by breaking the edges to fit the designated placement. Since plaster is generally applied to the transition area, the full form of the units is revealed through thick joints, while precise craftsmanship is not necessary in shaping the brick material.

When evaluated in terms of construction techniques, the height of the transition area is adjusted in proportion to the dimensions of the space to ensure that the loads from the roof are evenly transferred to the walls. Subsequently, the organization of the units that form the transition area is determined by guide strings attached to wooden scaffolding, which define the finishing point of the wall and the starting line of the dome. While a more flexible adjustment is possible for the number or dimensions of units in simple triangular surfaces, in prismatic triangles, the number of units is directly related to the size of the bricks. Specifically, while the face surfaces of the bricks are used in simple triangular surfaces, in prismatic triangles, the corners of the bricks are utilized to achieve "badem"s or combined triangular prisms. Therefore, the widest part of the "badem" should not exceed the diagonal length of the whole brick.

The construction of the transition area begins at the corners, as the corner regions are more inclined and the triangular or prismatic units positioned side by side bend at more pronounced angles compared to the central units. Instead of constructing the transition area in pieces with corners and surfaces, once the corner sections reach a certain height, the neighbouring units are also raised to the same level, gradually completing the transition area. This allows triangular units that only touch the wall at their apex and expand upward to be supported by adjacent triangular units that are positioned in the opposite direction, ensuring that the transition area is completed securely. Additionally, any potential conflicts that may arise within the bricks of two neighbouring units can be easily resolved by cutting or breaking the bricks.

When the transition area is completed, a polygonal base is formed based on the number of units. To fill the gaps between the circular base of the dome and this polygonal base, a border consisting of an average of two to three rows is applied in between. This allows the dome base to be positioned perfectly on a complete circular plan.

In conclusion, the belt of Turkish triangles is a structural element that requires meticulous adjustments in its construction due to its various formal applications, in other words, it demands skilled craftsmanship. Although the use of the belt of Turkish triangles diminished after the 15th century with the increasing importance of constructing spaces with relatively larger spans for structural reasons, it was utilized in countless buildings for an average of three centuries. The structures from the Seljuk, Beylik, and early Ottoman periods represent a significant portion of our cultural heritage, and it is essential to preserve them and pass them on to future generations. Unfortunately, some of these structures have faced neglect, resulting in damage or even collapse. When restoration becomes necessary, a meticulous analysis and understanding of the material, construction techniques, formal characteristics of the building and safeguarding their historical integrity for posterity are crucial.

For this reason, it is hoped that this study, revealing the formal/geometric features, material usage, and construction techniques of the belt of Turkish triangles, serves as a guide for restoration studies and as a pioneer for further research in this field.

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NOTES

[1]This study adopts the term *belt of Turkish triangles (Türk üçgeni kuşağı, in Turkish)* due to its generic descriptive capacity, which allows for a typologically inclusive discussion without being limited to a single geometric definition. Its presence in recent scholarly literature also supports its continued use. It should also be noted that numerous terminologies have been used to describe the belt of Turkish triangles both in Turkish and in English. Many of these terminologies are derived from the shape of the units comprising the belt.

In Turkish sources, it is referred to as "üçgenli kuşak" in studies of Seljuk architecture (Kuran, 1969; Batur, 1980). In works describing its architectural features, various other terms are used, such as "üçgen satıhlar" (Söylemezoğlu, 1955; Tansuğ, 1965), "dilimli kuşak", "baklavalı kuşak", "bademli üçgen kuşak", "göbekli baklavalı kuşak" and in Arabic, "müstevi alikalarla mürekkeb kuşak" and "müselles dilimli kuşak" (Ayverdi, 1957; Ayverdi, 1965). Other expressions include "prizmatik üçgenli kuşak", "düzlem üçgenlerden oluşan Türk üçgeni kuşağı", "Türk üçgen(ler)i", "üçgen badem kuşak", and "Türk üçgenleri kuşağı" (Acun, 1985; Kolay, 2017).

Additionally, geometric or symbolic terms such as "müselles-i kürevi" and "müselles-i dilim" are also found (Ayverdi, 1953), along with references to Arabic numerals seven (٧) and eight (٨), due to formal similarities (Uluengin et al., 2001).

In English-language sources, terms such as folded planes, prismatic surfaces, prismatic folded surface (Acland, 1972), belt of triangular planes (Kuran, 2012), and belt of Turkish triangles (Diri Akyıldız, 2018) have been used to describe this architectural feature.

[2]This situation can be determined when the following sources, which are extremely important for the history of architecture and construction technique of transition elements, are examined. See. Ousterhout, R. (1999). Master builders of Byzantium. Princeton University Press, pp. 201-204, Pope, A. U. (1967). A survey of Persian art; from prehistoric times to the present, Vol. II, Oxford University Press, pp. 525-539; Donald Wilber, D. (1969). *The architecture of Islamic Iran*. Greenwood Press, p. 42- 51, and Creswell, K. A. C. (1969). *Early Muslim architecture.* Vol. II, Oxford, pp. 450-463.

[3]The theses written in recent years on this subject can be examined, please see. Kula Say, S. (2007). Erken dönem Osmanlı hamamlarında eğrisel örtüye geçiş sistemleri (Publication No. 222016) [Unpublished Master dissertation, İstanbul Technical University], pp. 1-3; Şimşek, H. (2010). Erken Osmanlı mimarisinde kubbeye geçiş sistemlerinden Üçgenler Kuşağı (Publication No. 313918) [Unpublished Master dissertation, Yüzüncü Yıl University], pp. 31-36; Okçuoğlu, T. (1995). Anadolu Selçuklu mescitlerinde kubbeye geçiş alanının değerlendirilmesi (Publication No. 41668) [Unpublished Master dissertation, İstanbul University], pp. 13-14.

[4]Many international regulations on conservation3, such as the Venice Charter (1964), Charter on the Built Vernacular Heritage (1999), and the Nara Declaration of Authenticity, also underline that the originality, integrity and values of cultural assets should be preserved and transferred to future generations. For the Venice Charter, please see, ICOMOS. (1964). International Charter for the Conservation and Restoration of Monuments and Sites. https://www.icomos.org/images/DOCUMENTS/Charters/venice_e.pdf. For Charter on the Built Vernacular Heritage, please see, ICOMOS. (1999). Charter on the Built Vernacular Heritage. https://www.icomos.org/images/DOCUMENTS/Charters/vernacular_e.pdf. For the Nara Declaration of Authenticity, please see, ICOMOS. (1994). The Nara Document on Authenticity. https://www.icomos.org/en/charters-and-texts/179-articles-en-francais/ressources/charters-and-standards/386-the-nara-document-on-authenticity-1994.

[5]Mihrab is a recessed space in the wall of a mosque where the imam stands while leading prayers (Hasol, 2012; 322).

[6]Diamond shaped surfaces used between triangular shaped surfaces, used to enrich the belt of Turkish triangles are called "badem" or "baklava".

[7]The belt of Turkish triangles with combined triangular prisms refers to "göbekli Türk üçgeni" in Turkish. While explaining the usage of this type of the belt of Turkish triangles in the sources, the terminology of the "göbekli Türk üçgeni" is encountered. Please see, (Ayverdi, 1957; Ayverdi, 1965).

[8]The "halvet" is a single basin bathing cell in baths (Hasol, 2012; 197).

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