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OTTOMAN BUILDING TECHNOLOGY: A BRIEF SUMMARY

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In the context of the historical continuity of construction traditions, we can consider Istanbul, the center of Late Antiquity, Byzantine and the Ottoman periods, and its immediate surroundings to be a techno-cultural focal point. Istanbul's central role has been a significant factor in the spread and development of architectural forms and techniques unique to Ottoman geography.

The subject of how monumental Ottoman structures were built arouses curiosity; in a context ranging from the design stage to the process of obtaining materials, from laying the foundation to covering the dome. In addition, logistics are also vital points of interest beginning with the production of primary building materials such as stone, lumber, and iron are produced at significant distances from where the structures are built. The dimensions of the material, which was defined according to the place it would be used in the structure, were sometimes shaped during the production stage at the source of the material, and sometimes the raw material would be transported from where it was found and could be processed at the construction site according to the requirements.

Models of the Kaaba on display in the Kanuni Mausoleum. J. Pardoe, *The Beauties of the Bosphorus; by Miss Pardoe, Author of "The City of the Sultan," illustrated in a Series of Views of Constantinople and its Environments, from original Drawings by W.H. Bartlett*, London, George Virtue, 1838, 27.

The use of iron, especially in masonry structures, was a field of surprising importance for the pre-industrial period, not only in the context of Ottoman architectural technology but throughout the world. Following the conquests of Edirne and the Balkans, the strategically importantant material iron was integrated into the structures of buildings at an increasing rate beginning from the second half of the 15th-century. However, there were significant transportation problems involved in delivering the iron produced in southwestern Bulgaria. Since this region is inland and away from the once established trade routes, it was imperative to devise transportation routes to supply iron from there, either through land or a combination of land and sea transportation. For example, we know from surviving documents that iron was sometimes brought to Istanbul using only the land route in the 16th-century. Some of the iron used in the Süleymaniye Mosque had been transported by wagons from Samokov to Istanbul in 46-47 days. Furthermore, we know from a document that when wagons were not available, iron was sent on camels, with a load of three kantars [kantar = 56.449 kg] per camel.

The technical knowledge Ottoman builders relied on appears to be quite extensive and diverse. It is not possible to attribute this accumulation of knowledge to a single origin. However, there is data suggesting an unbroken continuity extending from Antiquity to the Classical Ottoman Period. Through archival documents, period testimonies, and technical structure analyses, we can display that Ottoman architecture, like all Ottoman culture, is related to a vast geographical region and historical period ranging from Europe to Inner Asia, from the Romans to the Ottoman era.

The preliminary technical preparations before construction began by surveying and drafting a rough sketch of the area to measure the construction site. This process, called mesaha [land survey] in Ottoman Turkish, was commonly performed by architects. However, some documents state that apart from architects, occasionally, people called mühendis (engineer in modern Turkish) and rarely technicians called a mesahacı (land surveyor) also made the surveying. A special measuring rope called “iki ucu mühürlü urgan” (rope sealed on both ends) was used for horizontal measurements. This rope was made of silk specified as 75 terzi zirаı (tailor’s cubit) long, which had knots marking the units.[1] A tool called havayi terazi (miners triangle), or commonly called terazi (levelling instrument) for short, was used to measure vertical heights.[2]

After the construction site was measured, the project for the given area was prepared. It’s safe to say that only drafting the plan was emphasized during the design process. In turn, it is also known that models of important and complex structural buildings were built. Until the late 18th-century, Ottoman architects utilized a unique modular system to draft construction plans. Similar techniques have also been used in Iran, Central Asia, and India. The principle of this system was to divide the paper on which the project would be drawn into squares by evenly spaced horizontal and vertical lines. The Ottomans made this square grid as a light relief on the paper surface with a tool called a mıstar tahtası. Although this technique is not practiced in other Islamic countries, using an inked square grid is widespread in Iran, Central Asia, and India. The advantage of using squared paper is that it allows one to draw without calculating scale ratios. In other words, the architect first determines how many zira (cubit) each grid unit will correspond to and plans the drawing accordingly.

1 In a provision, it states that a measuring rope of 70 tailor’s cubits, that is 56 architects’ cubits, was sent to measure real estate property, and a measuring rope of 55 tailor’s cubits, that is, 45 builders’ cubits, was sent to measure vineyards and orchards. Therefore, if the tailor’s cubit is established at 58 cm, the difference between the length of the rope used for measuring the real estate -40.6 m- and the rope used for measuring vineyards and orchards -31,9 m- is approximately 2 cm, which indicates the difference between an architects’ cubit and a builders’ cubit.

2 It is well documented that this type of measurement was made for the construction of waterways since it was necessary to profile the route.

Unfinished *muqarnas* workmanship in the corner of Mehmed III Mausoleum.
Photo by Gülsün Tanyeli.

Naturally, the primary raw material needed for construction is "stone." Organic limestone, called küfeki, was extracted from quarries near Istanbul and Edirne and was the building material of choice in structures built in both cities for centuries due to being readily available and also because it is easy to work with. In Anatolia and the Balkans, easy-to-process stones (preferably lime-based) extracted from local quarries were used. In particular, it is possible to say that all of the monumental buildings of 16th-century Istanbul were built with küfeki extracted from quarries in present-day Bakırköy, Yeşilköy, Bahçelievler, and Haznedar districts. The available documents suggest that there is a certain degree of standardization in stone sizes; the thickness and depth of the stones used in various structures do not change by much. Therefore, beginning from the 17th-century, it would not be necessary to make volume or surface measurements and be enough to specify only the length of the stone to pay for it and its workmanship. The way the stone was processed must have also made it unnecessary to measure dimensions other than the length of the front face: it is certain that only front faces of the stones were finely crafted at quarries, and the backs were left only roughly shaped. Therefore, during construction, it was necessary to perform operations such as fitting and burnishing in place. For example, in the Süleymaniye Külliye, the length and width of stones called kalıp (mold) were measured and defined as large and small. For the most part, the thickness of these stones used in massive patterns, such as a foundation or a pedestal, was designated in the documents as "as extracted." The depth of stone to be used in the walls was also variable depending on the thickness of the wall. Finally, according to the position of the stone, for example, at the corners, the thickness of the stone in the transverse, that is to say, its depth when placed horizontally increases.

Green dacitic tuff stone called odtaşı was preferred in the foundations of structures in Istanbul and in the construction of structures that needed to be heat resistant such as fireplaces, hypocausts, etc. It is known that the odtaşı used for the Süleymaniye Külliye were either extracted from the Kavak Pier in the Karamürsel region or salvaged from the ancient ruins of İzmit (Nicomedia). An archival document roughly specifies the dimensions of the odtaşı reported to be located on the foundation of old walls as "eight karış [handspan] long, five karış wide, two-and-a-half karış deep."

In the 16th-century, there were two important sources of obtaining the marble required for building structures: mining from quarries and reusing stones salvaged from ancient structures and ruins. The Ottomans almost exclusively used white marble in their buildings. The primary reason for this is that the white marble quarries on Marmara Island were located close to Istanbul, which was undoubtedly the largest consumer center.[3] Some of the marble-like materials and all of the granite and porphyry had been salvaged from old structures. This is a fairly common practice both in Europe and in the Eastern Mediterranean at that time. Salvaged marbles and stones were always reworked and reshaped, thus losing their recognisability. Columns were also shortened or shaved down to adapt to new structures. It would be safe to say that the Ottomans did not need to produce columns until the middle of the 16th-century. The best example of this is that even the columns used in the sultan's most important buildings were salvaged. For example, the columns of the courtyard of the Üçşerefeli Mosque consist of six column drums made of Marmara marble. These are most likely ancient column drums that were shaved and reused. There are six green porphyries (verde antiqua), one pink Egyptian granite, two gray Kestanbol granite, and nine Marmara marble salvaged columns in the courtyard of Bayezid II Mosque in Edirne. Doubtless, their quarries were not operational at the time. In addition to being used as building blocks of walls, the reused material was also utilized as arch stones, jambs, door stone slabs, and flooring. Therefore, using antique ruins as a depot of rough materials has naturally made screening the immediate environment especially important. Because it is not economical to haul heavy and inexpensive materials to be used as structural elements in vast quantities from remote locations. However, when the inventory in Istanbul and the surrounding area were exhausted in the middle of the 16th-century, it became necessary to either concentrate on mining quarries or move a little further away from Istanbul. The technique used to extract marble and stone from quarries has not changed much since the Roman period. In the Ottoman marble processing practice, producing semi-processed construction elements at the quarry site is preferred over coarse blocks. Jambs, stair treads, column capitals, etc., are made at the quarry according to the sent measurements and delivered to construction sites because these are elements that are processed or decorated on the structure after all the rough construction is finished.

It is known that the production of terracotta, which is one of the primary construction materials, had not yet been completely turned over to the private sector during the 16th- century. Bricks began to be produced by the private sector gradually from the 17th-century onwards. For example, it is understood that some of the bricks required for the Süleymaniye Mosque were bought commercially, some were commissioned to private artisans, and some were cast in state-run brick kilns. The most critical area of terracotta production was the method and process of making large-sized dome bricks. While it was planned to have them built abroad at first, the special molds sent from Istanbul were requested back, and the bricks were produced in miri (state) kilns. We can see that this situation, of how the private sector and state production meet the requirements of large construction sites together, remained largely unchanged until the early 17th-century from the example of the Sultanahmet Külliyesi. However, after this period, demands for terracotta elements were fully met by the private sector.

As for the production of iron, which has been used extensively in structures since the 16th-century, it was processed in two separate ways according to the place of use. The first was the long wrought-iron rods necessary for reinforcing the main mass of structures. These measurements were sent, and these rods were manufactured in the main production centers in the

3 The history of this quarry from Late Antiquity to the period of Selim II (1566-1574) is unknown. However, the quarries of Marmara Island have been operating uninterruptedly since at least 1570.

Balkans, especially in Samokov. Some of the iron materials such as clamps and, mortise and tenons, which are easier to produce, were also wrought in these centers. Some of these materials were produced at the blacksmith forges at the construction site.[4]

Another metal, lead, has been used extensively in the construction of monumental Ottoman structures as a roofing material and to anchor iron elements such as clamps, mortise, and tenons. The lead was delivered as ingots, especially from production centers in the Balkans, to the areas where it was needed. The lead delivered to the construction site was melted in special simple forges and cast into clamp and tenon joints or made into a coating plate through the casting method. Since lead was considered to be a strategic raw material --at least in the 16th and 17th centuries-- its trade was minimal, a state monopoly was established on its production and usage. Therefore, for the construction of large structures, either the state directly undertook the organization or construction owners, who were usually ranking government officials, who could acquire official permission to send their employees to production centers and to make direct purchases and had to personally organize transportation from the mining site to Istanbul.[5]

To determine the boundaries of the area on which the structure will rest, it is necessary to prepare the construction site. For this purpose, it is essential to level the area by excavating or filling as necessary. In Risale-i Mimariye (The Tract of Architecture), which is a 17th-century text, it is stated that Ottoman builders used a rope grid for the implementation of leveling the grounds. After this stage, the excavation begins, which continues until the solid ground where the foundations will be built is reached. Wooden piles are used in places where no solid base can be found. The Ottomans, like the Romans, chose to use short but closely placed foundation piles.[6] After the pile driving process was completed, the pile heads were connected to form a wooden grid. The function of this grid was probably the creation of a leveling floor, that is, zero elevation. The main foundation is built on this level. The material preferred for the grids, as well as the foundation piles, was oak. When the construction of the grid was finished, a mortar which the Ottomans call horasan, whose depth did not exceed 30-40 cm, was poured on it, and the subsequent foundations of the structure were built on this layer.

Without a doubt, lumber was a material needed at every stage of the construction process, starting from the foundation of the structure, except for its use within the structure. The first job that needed to be completed to carry out the stages of construction on the leveled surface is, naturally, the preparation of construction scaffolding and then arch centerings. This allows the load-bearing system to be built. Therefore, a type of scaffolding would be built, which could be raised as the structure was raised. The structure was surrounded with s temporary scaffolding both from the inside and from the outside, which had a horizontal path every three cubits and had roughly cleaned wooden poles with a round cross-section.

Components of the load-bearing system that transfer loads from the superstructure to the floor can be considered in two groups; walls and single load-bearing elements. There are several types of wall construction techniques in 16th-century Ottoman architecture. Among them, the inexpensive rubble-work and pitch-faced stone wall patterns were used in structures that were modest in size and importance. In this technique, which was well known since the Romans, the stones were bound with horasan mortar, a mixture of sand,

4 A weight measure used for iron is the *kantar*, but the quantity of this measure varies from region to region. For example, the scale equivalent of one *kantar* in Istanbul is 44 *okka*, while it is 59 *okka* in Samakov, and 180 *okka* in Aleppo.

5 Materials brought by land were hauled on the backs of animals or loaded onto wagons, making it an expensive mode of transportation.

6 Approximately 40,000 foundation piles between the lengths of 3.75-6.00 m. were used for repairing a bridge in 1552.

lime, and brick-tile powder and chips of brick. The implementation of alternating wall techniques/patterns, which had been widely used and had reached a relatively rich visual diversity during the 15th-century, began to waiver during the 16th-century and was used only in second-degree structures of large building complexes, and masonry structures that were built with limited resources. The Ottoman's alternating pattern wall is a double-wythe wall similar to the Romans opus mixtum. In this pattern, almost only the outer wall consists of regular horizontal rows of stones and bricks. The inner wall is built with pitched or rubble stone. Stone and brick chips are filled irregularly with Khorasan in the section that lies between the "wythes" during construction. Khorasan mortar is again the binding element between the rows of stones and bricks that make up the walls.

When a dry-stack joint stone masonry was preferred on the wythe wall, there was not enough mortar to connect the blocks on the horizontal and vertical surfaces of the cut stone pattern, iron clamps have been widely used to attach stone blocks, and molten lead has also been used to anchor them since the end of the 15th-century. The clamps prevent deformations that will occur with the pressure that the wall will make on the wythes as the wall rises since the rubble-stone and horasan mixture filling between the walls would take time to set in. Therefore, it also plays an accelerating role in the production process. Although the variety of forms do not reach the extent seen in Ancient Greece, there are a large number of clamp types described in original documents as "small," "large," "medium," "new," and "kened-i Firengi" [European clamp].

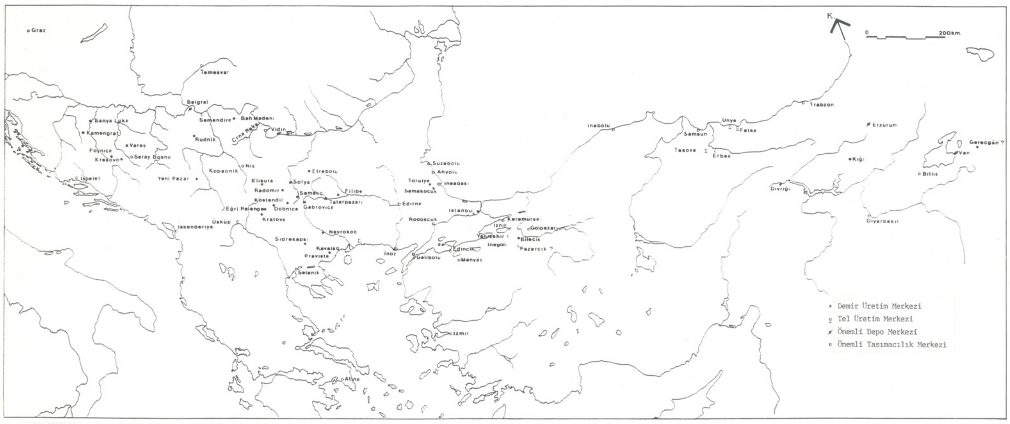
In addition to the clamps, iron pins called zıvana (mortise and tenon) were also used in the pattern with dry-stack joint stone masonry. These pins connect horizontal rows of stones and strengthen the wall construction against shear forces caused by lateral forces. But, the use of pins was not yet a common practice on all walls in the 16th century. The pins provide vertical connection of the outwardly flooded cantilever blocks, which form the fringing erasures in the main building mass to the lower row. On the other hand, it is used in an oblique position on the side surfaces of arch stones or hidden in a horizontal position when stone blocks in the form of vertical panels come side by side. Its use is more common in minarets. This is because the minaret is a slender tower structure with a small diameter in proportion to its height. Turkey is located in a seismic zone, so it must be well reinforced against shearing forces.[7]

Structural elements, called single load-bearing elements, consist of pedestals and columns. The pedestals do not have any structural differences from the pattern with dry-stack joint stone masonry in terms of construction. In classical Ottoman architecture, the load-bearing system was largely worked out with the help of columns and arches. Ottoman columns are massive and monolithic bearing elements. There are very few examples of the practice of making columns in the form of placing drums on top of each other as those were in Antiquity. The use of columns with pedestals is so rare that one might say it was 'never' used. In all observable examples, columns were fixed to the floor and the column capital with iron pins anchored to the pin slots with lead. This practice has been known since Antiquity. However, it is also necessary to mention a difference here; the connection element -metal bracelet (bilezik)- unknown in Antiquity, was widely used in Ottoman architecture.

Almost all types of masonry wall patterns have wooden bond beams that surround the structure at certain elevations. This bond beam system, which sometimes comes as close as about 10 cm of the inner and outer wall surface, usually consists of two elements with a cross-section close to a square and parallel to each other. These elements are horizontally connected to other elements that traverse the wall vertically. In addition, in observable

7 The practice of connecting rows of stones vertically with iron pins found a wider area of application in the following centuries. For example, all the outer walls of the 18th-century structure Nuruosmaniye Mosque (1748-55) were built with clamps and pins.

examples, the bond beams at the corners of the structure are connected through joints and nails. Therefore, it can also be mentioned that they serve as a kind of framework within the masonry. This system was widely used in 16th-century structures. However, starting from the Sultan Selim Mosque in Istanbul (completion:1522-23), it seems that -at least one level of- the structure was stiffened with two parallel iron rods instead of wooden bond beams. This application would develop well towards the end of the same century and evolve into a system of iron reinforcements that strengthen the structure in various ways.



Ottoman Iron Production Centers. Map by Gülsün Tanyeli.

Although the use of iron, directly related to the change in the production technology of iron in the Ottoman lands, as iron tie rod had become widespread to some extent until the beginning of the 16th-century, it is possible to say that it continued to be a valuable material that could only be used in the most important structures. At this point, the Beyazıt Mosque in Istanbul (1501-6) forms a turning point for the era. In the structure, both the courtyard arches and all the piers in the interior are connected to each other and to the walls with iron tie rods. Ottoman architecture had developed the ways of tie rods use that it would continue to use until the 18th-century in the period starting from the end of the early 16th century to the end of the Sinan era. The mosques of Beyazıt, Şehzade (1544-48), and Süleymaniye (1550-57) were the norm and standard-setting examples of positioning of the tie rods in the interior openings of large structures. In all three examples, the piers carrying the main dome were fixed by connecting two tie rods in two directions to the outer walls. The largest cross-sectional tie rods in the structures are these said tie rods. Those at the Beyazıt Mosque have impressive measurements with cross-sections in 10 x15 cm and about 7.5 m in length. Also, in the Şehzade Mosque, the tie rod cross-sections reaching 9x16.5 cm are quite large compared to later applications of the same type. These dimensions prove that Ottoman technology had pushed the traditional technological limits of wrought iron production considerably.[8]

In Ottoman architecture, the replacement of wood with iron and the complete elimination of lumber from masonry construction took nearly a century. The most interesting part of the practice of using metal elements for reinforcement purposes in classical Ottoman architecture is formed by systems called kuşaklama (bracing). These are located within the wall construction and encompass the structure at one or several levels. The bracing systems made of wood, which are located both within the dome and in the building mass on which the dome sits, were also used in other architectural traditions and in Early Ottoman architecture.

Iron reinforcement elements that carry masonry floors, stairs, and

8 For example, it is clear that the production of tie rods of the dome suspension arches of the Selimiye Mosque, extending as long as 17 m, is much more complicated than the construction of clamps, mortise, and tenons.

covering systems form another group called "beams." In the 16th-century, the non-vaulted mahfil floorings of almost all of the large mosques were a type of brick jack-arch flooring, which were carried with iron beams. This type of flooring can be seen in the open in examples such as Kadırga Sokollu (completion: 1571-72) and Cerrahpaşa Mosque. They can also be seen in many areas of the Harem of the Topkapı Palace, which, by order of the sultan, was rebuilt using iron instead of wood after the fire of 1665. Interestingly, the fire justified the construction of iron-reinforced flooring, which was older than all known European examples. It is interesting to note that the iron-reinforced jack-arched floors of the early industrial age in Britain were also built out of fear of fire.

Ottoman architecture continued to develop in terms of iron reinforcement elements and bracing from the 17th-century until the beginning of the 19th-century. However, the new architectural and metallurgical breakthroughs occurring in Western Europe with the onset of the Industrial Age would leave the corresponding Ottoman technology obsolete. The new methods of using iron would dominate the Ottoman world in the second half of the 19th century, albeit with a bit of delay.

Conclusion

It is impossible to say that the technical knowledge that the Ottoman builders relied on was the product of a single origin-tradition. For this reason, it is necessary to draw a pluralistic explanation framework. Data suggest an unbroken continuity extending from Antiquity to the Classical Ottoman Empire, especially in some fields. For example, it seems that urban water systems are directly related to Roman practices that have been saved from oblivion thanks to a big city such as Istanbul, which had not lost its vitality during the Byzantine era. It is not easy to make similar remarks in other areas. For example, the similarities observed between the basic Roman construction techniques and those of the Ottomans cannot be easily explained by the mediation mechanism provided by Byzantium. As another example, it can be said that the batardo [cofferdam] and the pile foundations, which were used to build in water and on weak soils, were already forgotten in the last centuries of Byzantium. At this point, the Istanbul shipyard's (which functioned as a technical connection center with Italy, especially Venice) role in pile foundation and construction on the water side and on weak soil should not be overlooked. In fact, the expertise of shipyard officials was still used in such matters even at the beginning of the 19th-century.

On the other hand, the issue of the role the Iranian-Central Asian cultural area (which has constantly supported Anatolia with its qualified workforce since the early centuries of the Turkish era) has had on Ottoman production technology is also among the questions awaiting an answer. In the field of stucco craftsmanship, the influence of said region on the Ottoman geography is incontrovertible. It is undoubtedly more accurate to think that the opposite applies to rough construction. The way Iranian-Central Asian builders thought about and implemented the supporting and covering elements of a structure was completely different from that of the Ottomans. It's safe to say that they weren't much interested in the topic of building deep foundations and of pile driving techniques. On the subject of metals, which is of vital importance to a classical Ottoman monumental structure, it seems impossible to even find enough data for comparison in other Islamic traditions. In terms of the structural use of iron, Ottoman practices show similarities with the Italian and Western European practices. It is also not certain whether this similarity is the result of a direct relationship or not. However, elements such as iron bracing rods should be listed among the technical equipment that the Ottomans owe to Italy.

It should also be taken into account that all of this technical knowledge varies immensely depending on the region and period of an empire spanning three continents. For example, we cannot claim that Bosnia and Erzurum or Crimea and Baghdad are the components of the same techno-cultural tradition.

In summary, the above-mentioned explanations apply only to what can be called the “central tradition” consisting of Istanbul, Edirne, the Eastern Balkan region, and Anatolia west of the Trabzon-Sivas-Antalya line. In short, there are still many unresolved issues awaiting clarification regarding the local variations and origins of Ottoman architectural technology.

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Gülsün Tanyeli received her master's and doctoral degrees from ITU. After working at Istanbul University and the Turkish Historical Institute, she started her academic life at ITU Faculty of Architecture in 1984 and continues to do so at the same institution. From 1994 to 2012, she served as a member of the Board for the Protection of Cultural and Natural Assets in Adana and Nevşehir. Her publications and projects and implementation work mainly involve archaeological sites, monumental structures, and old industrial facilities. She is a member of the National Committee of ICOMOS Turkey.