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Domes in architecture

Introduction

Architecture structures are a form of presentation of significant message of the period when they were built. Architecture of centers of power, religious cults or culture is the synthesis of knowledge about communities that built them. Ecclesiastical and prestigious structures were often crowned with domes to develop a prominent structural landmark. In Eastern and Western civilizations, domes were built in order to emphasize the prestige of the structure and develop representative interiors of representative buildings. The construction designs of domes reflect the technical knowledge and culture of specific epochs.

Selected elements of the history of construction of domes

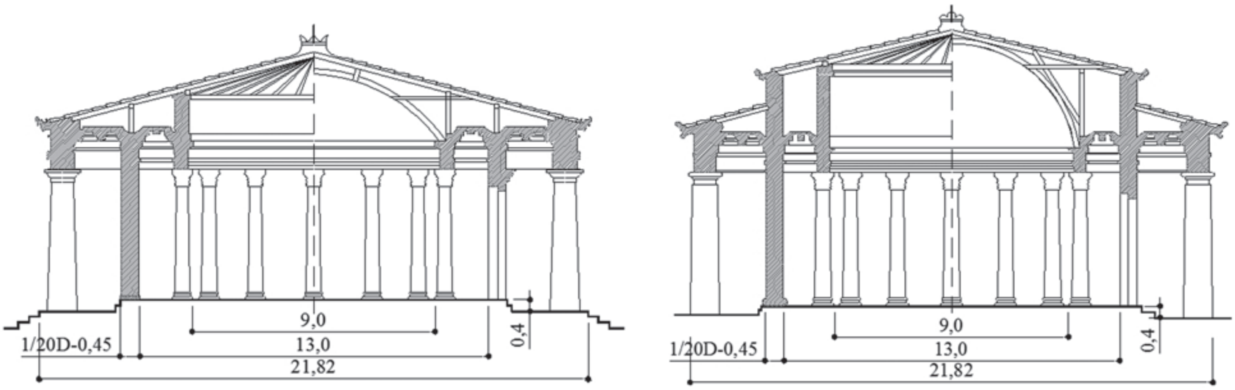

Fig. 1. Reconstruction variants of the roof on the Aeschylus' Temple in Greece according to [2]

Depending on geographic location, in different proportions, the first materials which were used to build domes included stone, clay, and wood. Due to its availability in the Mediterranean region and its greater durability, stone was applied in construction of monumental structures in Egypt, Greece, and Rome.

Ancient Greece contributed to building its innovations which made the most of the best properties of stone and wood. In Greek temples, the walls were built of stones whose thickness was 1/20 of the distance between the walls. Such proportions were achieved for instance in the temple of Aeschylus in Epidauros, designed by Theodoros from Samos which was built around 370 B.C. The small thickness of stone masonry walls indicates that they supported light timber roofs. The distances between walls and piers show that they could not have been simple beam

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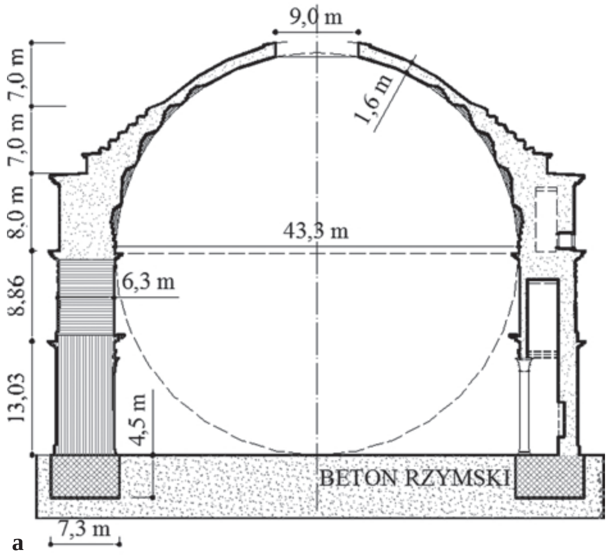


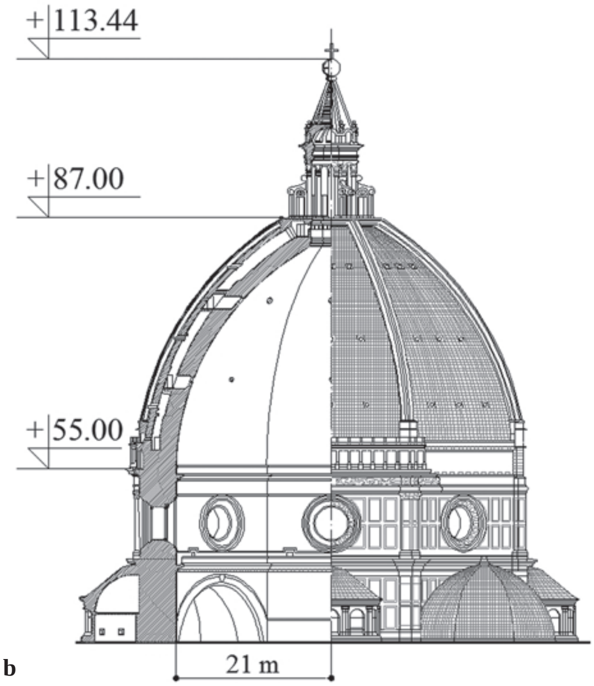


Fig. 2. Largest domes of the Mediterranean civilization:
a) section of the Pantheon dome in Rome from 125 AD acc. to [2],
b) section of the dome on the Santa Marie del Fiore Cathedral,
in Florence acc. to [1]

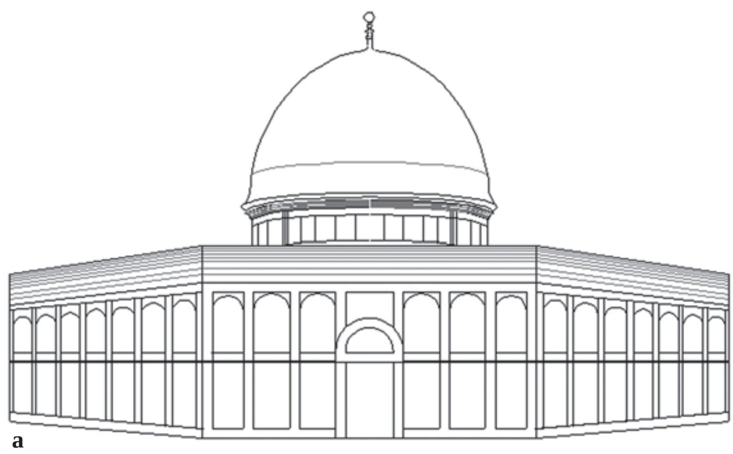
roofs. The distances between piers indicate a system of trusses or arches. Figure 1 shows two variants of the roof on the Aeschylus by A. Kuźniecow [2]. The construction design of the temple's walls and roof can indicate that the Greeks possessed knowledge of the polygon of forces and knew how to apply it in building designs.

The development of stone domes in ancient Rome is connected with the increasing demand for prestigious structures with large representative interiors. Romans could adjust the shape of domes to pressure lines. With greater dimensions of representative rooms, the application of fully stone domes was connected with the use of a lot of materials. That is why the thickness of the walls in the prestigious structures in Rome topped with domes was 1/6 to 1/7 of their diameters [2]. However, due to their durability, the domes were built concrete and stone so they would survive wars and barbarian raids. It resulted in strengthening the patterns and facilitated their repetitions. It also contributed to the development of many masonry domes in the south of Europe.

In ancient Rome in 125, the largest axially symmetrical dome – Pantheon was built under supervision of Apollodoros [1]. The construction of the dome was made of Roman concrete, and the mass of the shell calculated for 1 m^2 of the section was about 6000.0 kg [3]. Figure 2a shows the section of the Pantheon dome and its dimensions.

The search for lighter solutions of sail masonry roofs and sufficiently strong timber scaffold needed for their construction lasted for thirteen centuries. In 1412, the construction of the double-shelled dome of the Santa Maria del Fiore Cathedral in Florence (Fig. 2b) [1] began; its outer 75.0 cm thick masonry shell was placed on octagonal drum with its 17.0 m long sides, 55.0 m above the floor level.

Attempts at erecting a scaffold under a double-shelled masonry dome demonstrated how difficult it is to build a sufficiently strong scaffold made of wood – which was



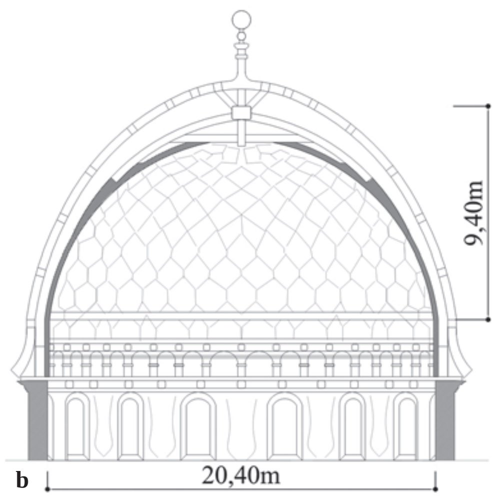


Fig. 3a, b. Dome of the Rock in Jerusalem, built in 687–691 AD acc. to [6]

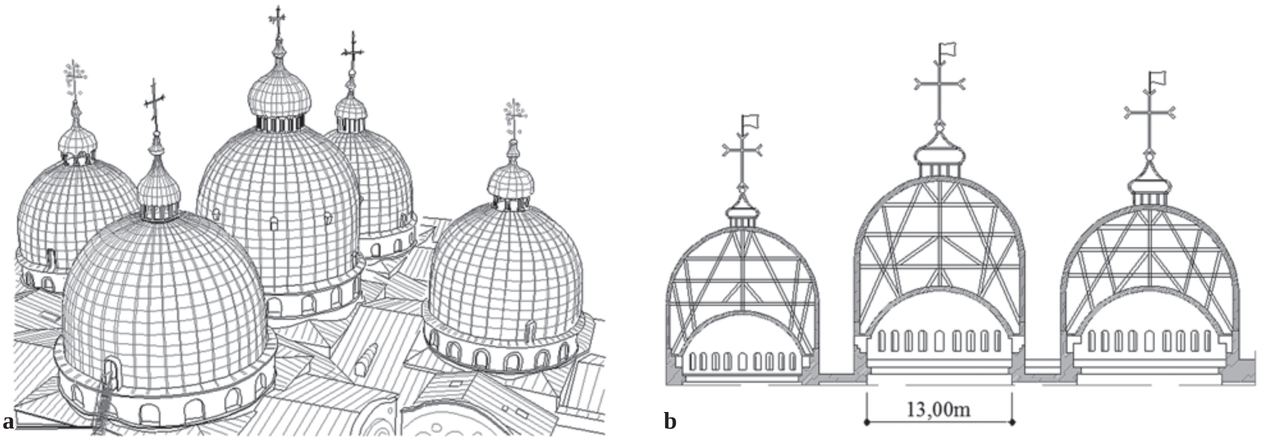


Fig. 4. Venice - Saint Mark's Cathedral, 1063–1031 according to [1]:
a) view of the roof, b) cross section of the three domes acc. to [1]

the only known technology then – to hold the massive masonry dome shells.

In 1542, the double-shelled dome of St. Peter's Cathedral in Rome (42.52 m in diameter and 52.0 m high) designed by Michael Angelo was built. The mass of that dome is about 6800.0 kg per 1m^2 of the section [3].

In the 7th and 8th centuries, double and triple-shelled domes appeared in Arabian architecture. In the years 687–691, [6] in Jerusalem a dome was built from Lebanon cedar wood as a double-shelled semicircular dome 20.4 m in diameter (Fig. 3).

The unknown constructor of the dome deliberately applied knowledge of possible separation of external and internal loads in order to build a double-shelled dome. The builder of the dome 745 years before the construction of the Santa Maria del Fiore Cathedral in Florence, designed and built a double-shelled dome. Probably this is the very first rod construction where the outer wooden construction bears the weather loads, and the inner one bears its own dead load and interior decoration. The dome's double-shelled construction consists of the outer shell, king-post truss construction, and the inner brick dome braced at the keystone to the outer dome. It is unknown whether this building technology was introduced in this area by the builders from the areas full of forests or these are examples confirming high development of civilization and technical of Arab craftsmanship in the Middle Ages in comparison to medieval w Europe.

As a result of the prestige requirements in Europe and increasing dimensions of masonry domes, their weight exceeded technological capabilities. In order to satisfy the ambitions of wealthy investors it was necessary to apply lighter solutions of dome construction. What appeared was double-shelled masonry domes combined with wooden scaffold needed in the dome construction stage. On the basis of preserved accounts, it was found that the invention of a lighter double-shelled masonry dome with the shells connected with the use of inner wooden construction was known in Europe in the Middle Ages. Examples include the domes from the years 1063–1031, described in [1] (1996), built in St. Mark's church in Venice. Figure 4a and b show the view and section of the dome, the biggest of which in the middle has the 13.0 m long span between the walls. Lighter than the masonry single- and double-shelled, the triple-shelled dome enables the separation of loads. The lower masonry shell bears its own dead load and interior decoration. The upper one, strengthened by the inner wooden construction bears the weather loads.

Figure 5 shows another example of application of wooden scaffold creating the third shell of the dome. This

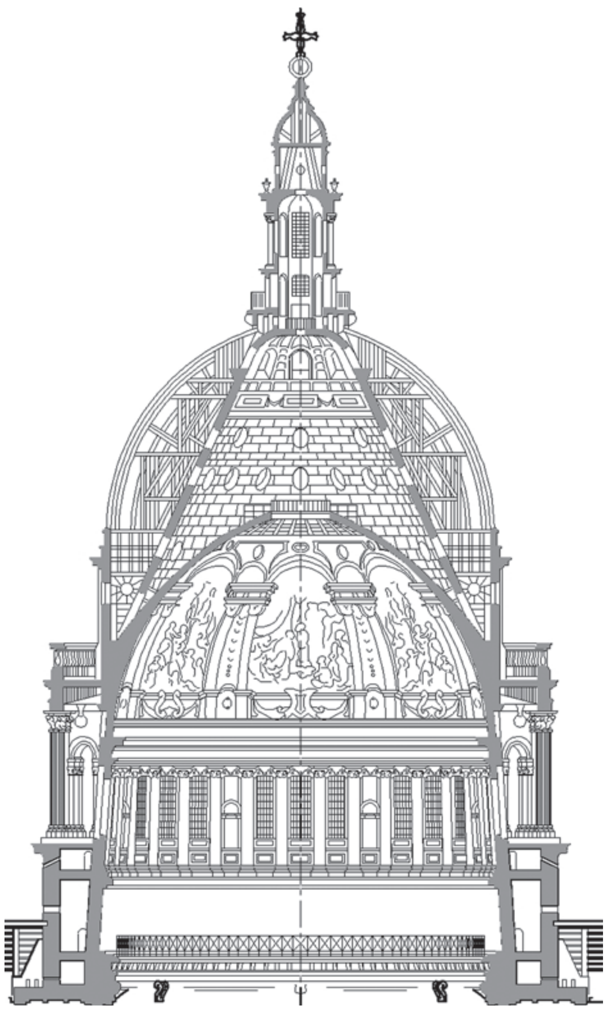


Fig. 5. London – Saint Paul's Cathedral, 1710 acc. to [1]

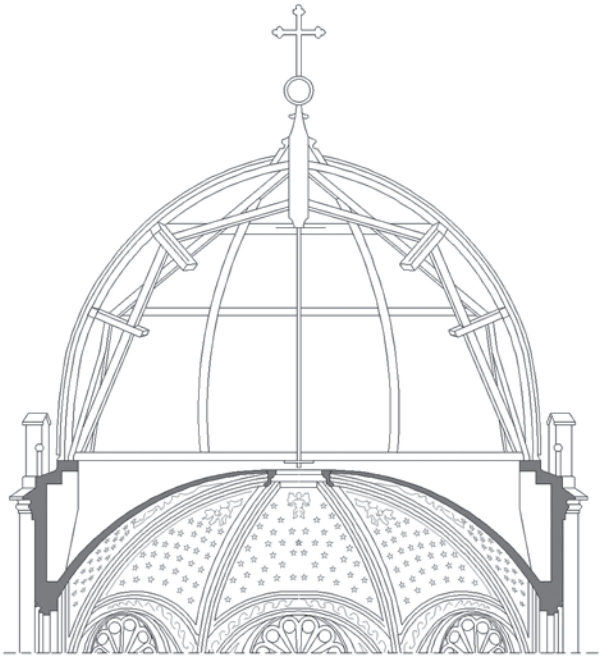


Fig. 6. Stüler's Dome in Berlin acc. to [6]

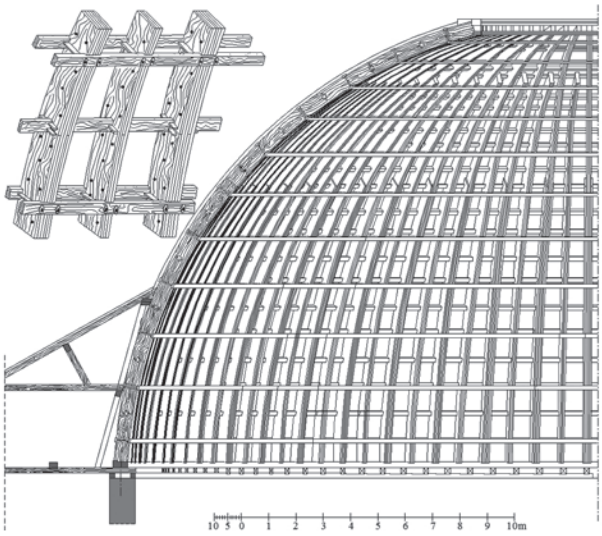


Fig. 7. View of the dome construction by Möller G. acc. to [6]

is the triple-shelled dome built on the tower of Saint Paul's Cathedral in London [1]. After the earlier tower roof was destroyed by fire, the rebuilders were afraid to erect a traditional masonry dome on the building whose structure was weakened. Designed by the astronomer Christopher Wren, the new dome of Saint Paul's Cathedral in London was built in about 1710. Two slender masonry domes braced to the third outer dome on post and beam scaffold were built. After the construction was completed the outer scaffold was left as a shell protecting the two inner domes against wind. The masonry domes of Saint Paul's Cathedral: the semicircular one and the conical one (Fig. 5) jointly transfer the vertical loads. The conical dome bears the load of the lantern, transferring the vertical forces to the ring beam which is the same for both inner shells. The lower dome transfers its dead load and rich architectural detail demonstrating the structure's prestige and function.

External scaffolds protecting double-shelled masonry domes were built in many multi-shelled domes in Baroque and later.

In the first half of the 19^{th} century, the German architect Stüler A.F. replaced the post and beam construction protecting masonry domes with a system of trusses. Figure 6 shows such a solution applied in construction of the wooden outer dome of the church designed by Stüler A.F. in Berlin. The transformation of the external scaffold into a system of meridian trusses with parallel braces was a breakthrough.

The principle of construction of domes introduced by Stüler A.F. was also applied by other architects (Weinbrener F.), which popularized in Western Europe building of dome structures based on scaffolds used to build masonry vaults which, however, already featured separate load bearing meridian and parallel elements, typical of domes. Instead of posts and beams, the scaffolds often used meridian trusses with parallel braces, with the curvature formed by centerings adjusted to the radius of the domes. The timber centering, which was used for centuries in wooden scaffolds, was the element which was most developed in this construction technology.

The system of meridian and parallel ribs, which was gradually improved in timber protecting domes, resulted in the development of simple and economical constructions of ribs built from timber centerings.

Figure 7 shows one of the first such domes – dome designed by G. Möller with the diameter of 33.5 m which was built in the middle of the 19^{th} century for a catholic church in Darmstadt, Germany. The dome by Möller G. is the first wooden dome described in [6] (1900) with minimalistic ribbed construction. This is the result of the evolution of timber scaffolds used to build vaults and masonry domes which lasted for two thousand years. The timber centering which is the external element of the scaffold supporting the masonry dome became an independent load-bearing rib of the dome. Its supporting scaffold was eliminated. The division of the construction into meridians and parallels resulted in a clear distribution of forces in the dome and facilitated static calculations of load-bearing elements.

Möller's idea was improved in the following designs of structures topped with domes.

Conclusions

Domes are the works of architecture which present the technical culture of the times when they were constructed. The form of domes developed over centuries along with the structure best suited for them. Depending on the building material which was used, dome constructions were different. The paper presented one of the directions of evolution of timber dome structures. It evolved from the transformation of timber scaffold used to build heavy masonry vaults into a dome load-bearing system. The transformation of the protecting post and purlin scaffold into a system of meridian and parallel load-bearing elements was a breakthrough. At first it was a system of wooden meridian trusses with parallel braces, protecting sensitive masonry domes. As a result of experience gained over the years, the external members of trusses made of centerings were transformed into a load-bearing system of ribs typical of a spherical form of the dome.

The minimalistic ribbed construction made of timber centerings developed over time into various load-bearing systems of domes made of solid wood.

References

[1] Heinle E., Schlaich I., *Kuppeln aller Zeiten aller Kulturen*, Stuttgart, Deutsche Verlags Anstalt, 1996.

[2] Kuzniecow A.W., *Tektonika i konstrukcja cientriczeskich zdani,j* Moscow 1951.

[3] Lisowski A., *Projektowanie dome obrotowych,* Biuro Studiów i Projektów Wzorcowych Budownictwa Miejskiego, Warszawa 1955.

[4] Murray P., *Architektura włoskiego renesansu,* Wydawnictwo VIA 1999.

[5] Stierlin H., *Skarby Orientu. Architektura i sztuka islamu od Isfahanu po Tadż Mahal,* Arkady, Warszawa 2002.

[6] Warth O., *Die Konstructionen in Holz,* Gedruct von A. Th. Engelhardt, Lipsk 1900.

Kopuły w architekturze

Architektura obiektów w kulturze Wschodu i Zachodu obejmowała dachy zwieńczone kopułami. Kiedy masa kopuł murowanych przekroczyła możliwości techniczne konstruowania podpierających drewnianych rusztowań, rozpoczęło się poszukiwanie lżejszych rozwiązań konstrukcyjnych. Ewolucja rusztowania stosowanego do wznoszenia ciężkich powłok betonowych i murowanych była jednym z kierunków powstawania konstrukcji kopuł z drewna jednolitego. W toku trwających kilkaset lat doświadczeń przekształcono tradycyjne rusztowanie w konstrukcję z kratownic o układzie południkowym, stężonych równoleżnikowo. Podział konstrukcji na elementy południkowe i równoleżnikowe wpłynął na rozwój statyki i konstrukcji kopuł żebrowych z drewna jednolitego.

Key words: domes, architecture

Słowa kluczowe: kopuły, architektura