Chapter 2
Selected Elements of the Dome Building History

The development that was taking place over centuries in the field of the stability of wooden structures and constructions can be analysed by observing the changes occurring in the wooden building trade. Since wooden structures are specific models of geometrically invariable bar structures.

This is applicable both to wooden structures, allowing to build stone and brick structures, and structural systems characteristic of wooden domes. A hypothesis may be formulated that the creation of wooden domes was preceded by the development of scaffoldings for the building of stone domes. In the historical process of the effective use of wooden structures, associated with domes, transformations of architecture, structure and understanding of statics, also the production of structural elements, the methods of their connection and building technologies are noticed.

The prototype of the dome was created already in very remote times when man started building shelters in form of a hut from branches. These first structures—a couple of branches embedded in soil and bound above—have accompanied us from the very beginning of the civilization.

The proven form and structure of a hut from branches also happen to be an inspiration for contemporary architects. In 1986, in Visegrád, a dome from tree stems was built. The author of the project was Imre Makovecz, a Hungarian architect from Budapest. On the basis of the work by Natterer [1], a figure was compiled, Fig. 2.1, presenting its structure. The facility has a span of circa 11.5 m and a height of 9.0 m. The natural appearance of the dome ribs emphasizes the rationalism of the structure and the beauty of the minimalist form.

In the civilizations of the East and the West, domes were built to distinguish the given facility from among other building structures. The sacral and prestigious facilities were crowned with a dome in order to achieve a strong urbanistic accent.

They were built on roofs of the centres of authorities, religious cult and culture. In building structures of a special destination, having extensive meeting rooms, a

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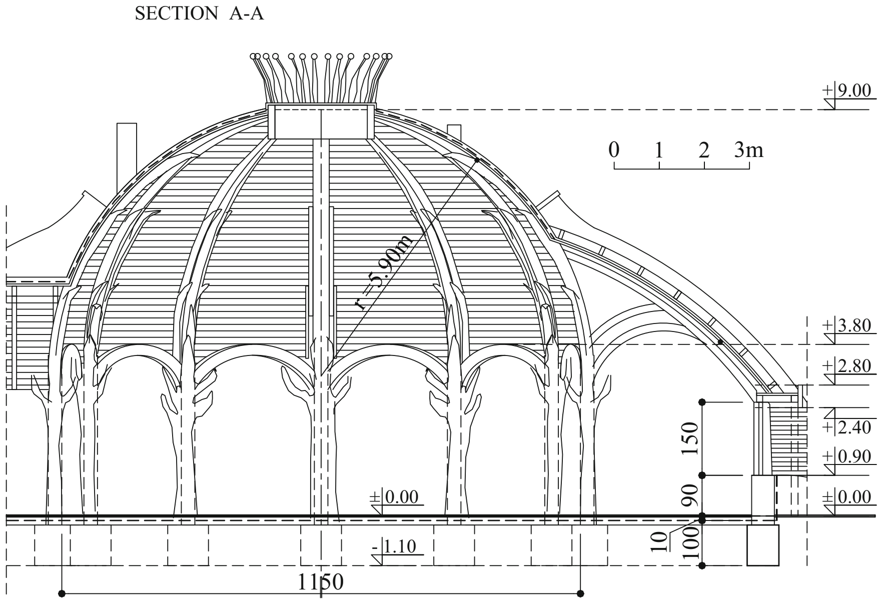

Fig. 2.1 A "hut-like" dome built in 1986 in Visegrád according to [1]

dome was used as a unique, known at that time, roof covering without intermediate supports. The palate of the dome was applied to arrange an exceptionally scenery of the representative interior. It was often covered with paintings with views from the biblical heaven.

Domes are characterized by a minimum outside surface in relation to the volume of the interior. The two-curvature of the dome surface fosters the reduction of materials in relation to the cubic volume of the facility and limits the destructive environmental effects. Its shape ensures the reduction of the load by wind and facilitates a quicker drying of the surface, and the distance of the structure of useful surfaces impedes the formation of fire. This is confirmed by the domes of various historical facilities existing to date.

Depending on the geographical position, in various proportions, the first materials used for the construction of domes were stone, clay and wood. The availability of stone in the Mediterranean area and its greater durability affected its use in the building structures of Egypt, Greece and Rome.

The timeless building facilities of Egypt were formed from stone. Stone, having a high resistance to compression, has a many-time lower resistance to extension and is susceptible to brittle breaking. Hence a huge quantity of pillars in constructions supporting the ceilings of the temples of Egypt where the clear distance between the pillars similar to their diameter is noticed.

The Ancient Greece contributed technical inventions that were using the favourable properties of stone and wood in building trade. Stone walls were built in the temples of Greece, the thickness of which amounted to 1/20 of the clear spacing of supports. Such proportions were achieved, for instance, in the Aeschylus temple in Epidaurus, built in ca. 370 BC to the design by Theodorus from Samos [2]. The slight thickness of masonry, stone walls allows to presume that light, wooden roofs were resting on them. The spacing of walls and pillars shows that it could not be simple beam roofs. The clear spacings of supports indicate a truss system or an arch system.

Kuznetsov A.W. in his work [2] described two potential variants of a light roof structure, matching the slim fragments of the walls of the Aeschylus temple from the 4th century BC, which is shown in Fig. 2.2. The author supplemented the Kuznetsov's figures by the dimensions, as specified by himself, of the load-bearing walls burdened by the roof structure: wall thickness and spacing between walls. The roof covering of the temple was based on two rings. The skewback of the central roof covering rested on the internal ring, based on columns. Two masonry vaults and the temple roof rested on the internal wall and the outside colonnade. Those vaults, beside their own weight and that of the roof, probably transferred the strutting caused by the central roof covering, maybe by the dome.

Such solution method of the temple structure would give evidence that Greeks had the knowledge of the polygon of forces and the skills how to use it in the designing of building structures.

The engineers of Rome, using the load capacity of stone to compression, propagated semi-circular arches of a high eminence. They used wood sparingly, just for bent and stretched structural elements.

The development of stone domes in the ancient Rome is associated with the growing demand for prestigious facilities with representatives large-surface halls. With higher dimensions of dome-roofed rooms, the use of full masonry domes was related to a high consumption of material. The illustration of the huge mass of material used for the dome is the hall with the statue of Venus in Rome [3] (Fig. 2.3). Worth noticing in the facility shown in Fig. 2.3a is the execution of the spherical roof covering using the sphere division into caissons having the rhomboid form. The author estimates that the weight of the masonry canopy amounted to more than 7000.0 kg/m^2 of the dome's projection.

Despite the enormous weight, domes from concrete, stone and brick were built due to their durability so that they could outlast wars and barbarian invasions. This ensured the perpetuation of patterns and fostered their imitation. It contributed to the creation of many masonry domes in the south of Europe.

Romans used the static properties of domes. By slightly lifting the dome peak, they approached the dome profile to the chain curvature. In Rome, in 125 AC, it was probably the builder Apollodorus from Damascus [4] who managed the works at the erection of the highest axially symmetrical dome—the Pantheon. The construction of the dome was made from the Roman concrete. Its section and dimensions are shown in Fig. 2.4a. The facility has a diameter of 43.30 m and a height of 43.89 m. The thickness of the walls to support the dome totals 1/6–1/7 of its diameter—Fig. 2.4 [2]. Over 1300 years, the dome of the Pantheon was the largest dome of the Western European civilization. The search for lighter solutions

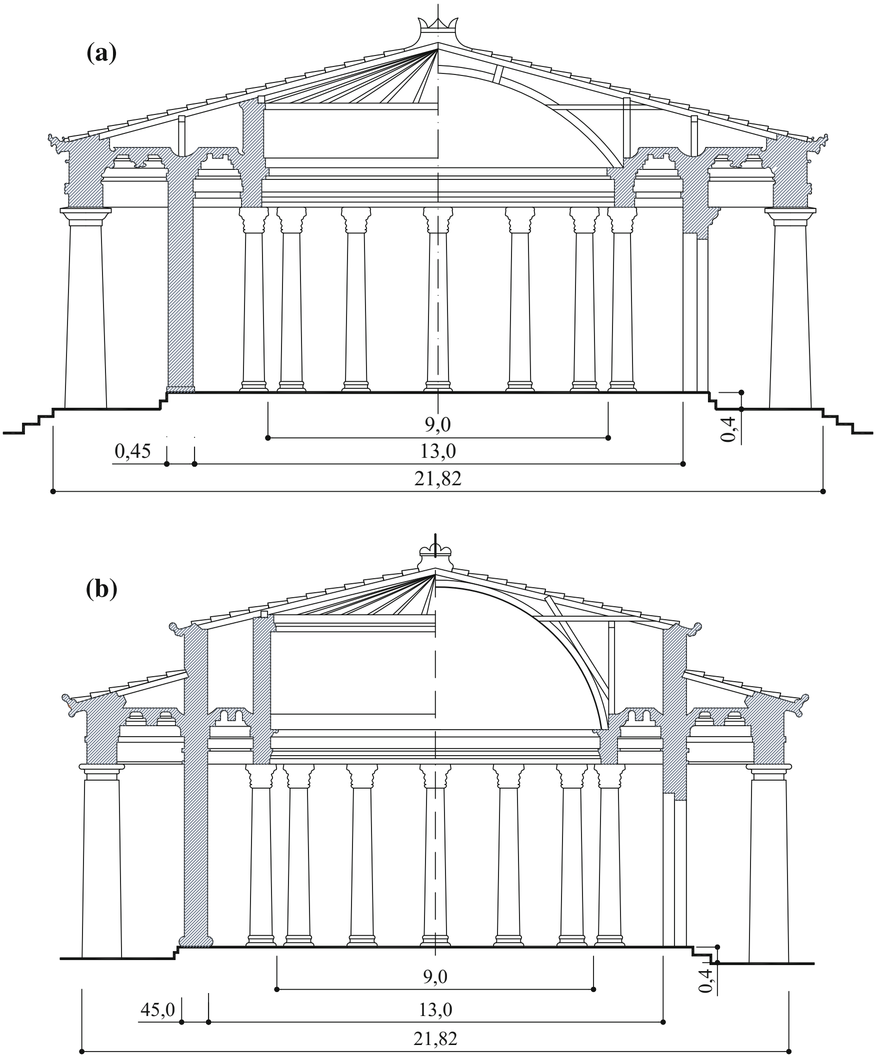

Fig. 2.2 Reconstruction variants of the roof of the Aeschylus temple in Epidaurus, Greece according to [2]

in the masonry dome structures and the need to use wooden scaffoldings to build the domes lasted for thirteen centuries.

In 1412, builders stared to proceed with the resolving of the crowning of the Santa Maria del Fiore Cathedral in Florence with a dome [5], the building of which had been started in 1296. The dome of an internal diameter of ca. 42.0 m had been planned on an octagonal tambour of a 17.0 m long side, ending at the height of 55.0 m above the cathedral floor level.

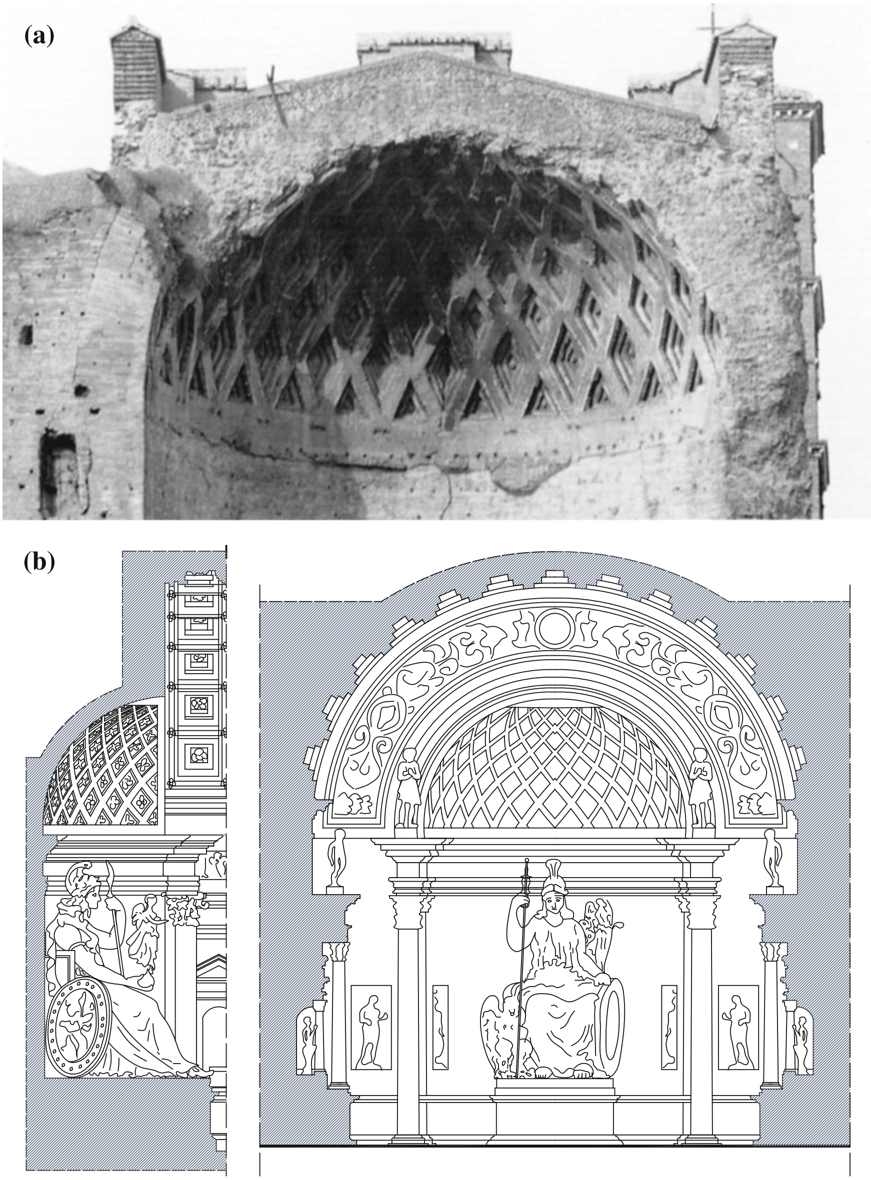

Fig. 2.3 Dome of the Diana Temple of 135 AC. **a** contemporary view of the dome from the inside [3], **b** reconstructed section of the historical interior (figure developed on the basis of the sketch by the German architect Josef Bühlmann of the facility reconstruction project; Die Architektur des Klassischen Altertums und der Renaissance; 1913, Verlag; München, Deutschland)

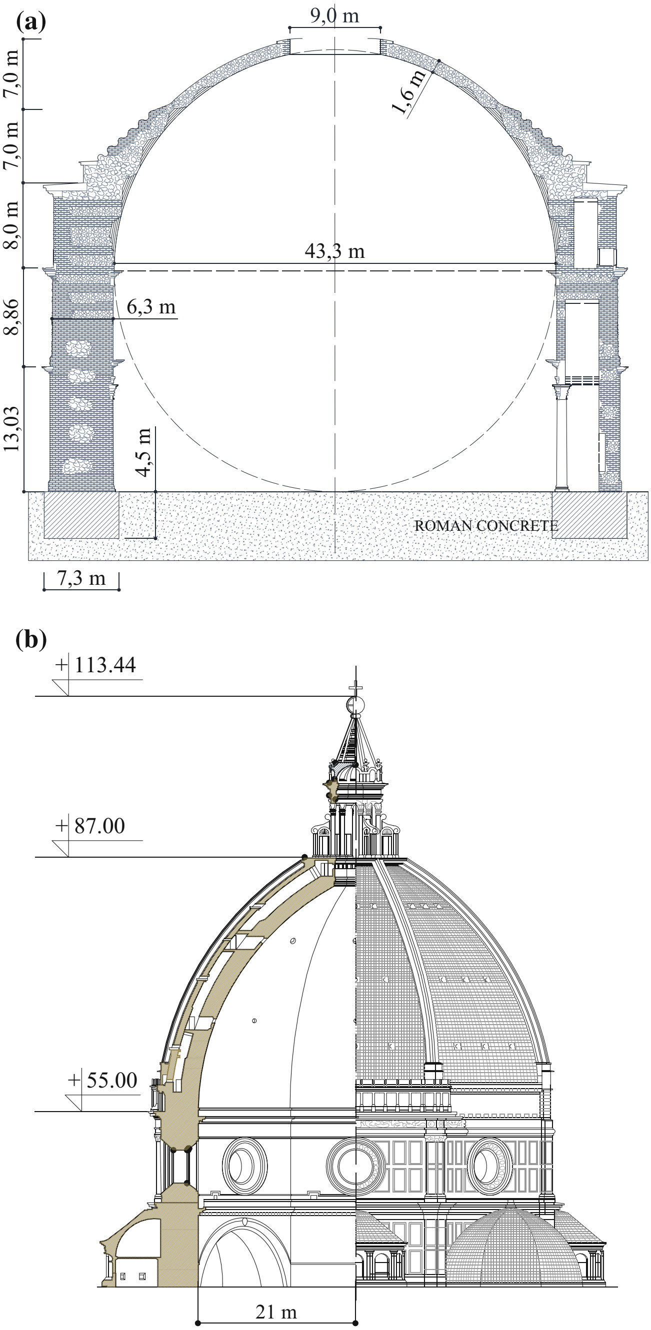

Fig. 2.4 The largest domes of the Mediterranean civilization, **a** section of the dome of the Pantheon in Rome to [2], **b** section of the dome of the Santa Maria del Fiore Cathedral in Florence according to [5]

The attempts to position a scaffolding under the heavy, masonry two-shell canopy of the dome demonstrated how difficult it was to build a sufficiently resistant scaffolding having the wooden construction only known in that time. The task to maintain two massive masonry shells exceeded the technological capacities of the epoch.

The investment project was saved by the idea by the architect Filippo Brunelleschi. In his project, he proposed to build an ogival, two-shell ribbed dome that would be a scaffolding for itself [5]. The idea was innovative and in order to prove its feasibility, F. Brunelleschi built, without scaffoldings, a dome in the Ridolfi's Chapel in the San Jacopo sopr'Arno Church [6].

Brunelleschi F. applied in the construction of the dome of the Santa Maria del Fiore Cathedral eight meridional main ribs and sixteen intermediate ribs, two ribs between the main ribs each. The building of the dome was started in 1420. The constructing of the ribs and the two shells was scheduled to follow in several stages. Each stage of the erection led to the closure of the dome curvature. The completion of each stage was the execution of a horizontal, latitudinal rib to stiffen meridional ribs. The circumferential closure of main and intermediate ribs secured the meridional ribs against twist. Brunelleschi F. made masonry canopies between the ribs as two-shell canopies. The outside canopy protected the inside one against weather effects. The backup facilities of the construction yard was arranged on the horizontal ribs, including a canteen for workers. Two masonry shells rested an octagonal tambour. Brunelleschi F. designed strings of steps and ramps between the masonry shells. The traffic of workers and the transport of materials was carried out over there. Brunelleschi F. developed the structural system of the dome canopies, gutters and drains, inter-connections of the masonry canopies in order to provide the stability of the dome, even during an earthquake. The space between the shells has been, until today, sufficient for the routing in plumb line between the masonry canopies of the dome [6].

During the construction, it turned out that the heavy stone could be used at the dome's base up to the height of seven metres. Lighter materials were used higher, such as porous travertine or brick. The building technique of the shells was described by Brunelleschi F. in his "Rapporto" in 1426. Probably, this was an oriental plot imported by Brunelleschi F. to Europe. This technique consisted in making in the wall of parallel, spiral ribs raising obliquely. Bricks were laid, I quote: "not flat, but upright" so that they protruded from the canopy—Fig. 2.5c. Meridional, inclined spirals of bricks to pressurize and stabilize the bands of bricks were laid in parallel, ensuring a higher coherence and resistance of masonry shells.

The dome of the Santa Maria del Fiore Cathedral was constructed for sixteen years and the building process was completed in 1436 (Fig. 2.4b). Thus, the construction of the cathedral lasting for 140 years was finalised. For one hundred and twenty years it was an expression of the top achievements of the technology of building masonry domes until the creation of the Saint Peter's Basilica in Rome.

The models and the drawings of auxiliary scaffoldings and equipment needed during the construction of the cathedral have outlasted until our times in the Uffizi Museum in Florence. Brunelleschi F. designed many innovative and efficient

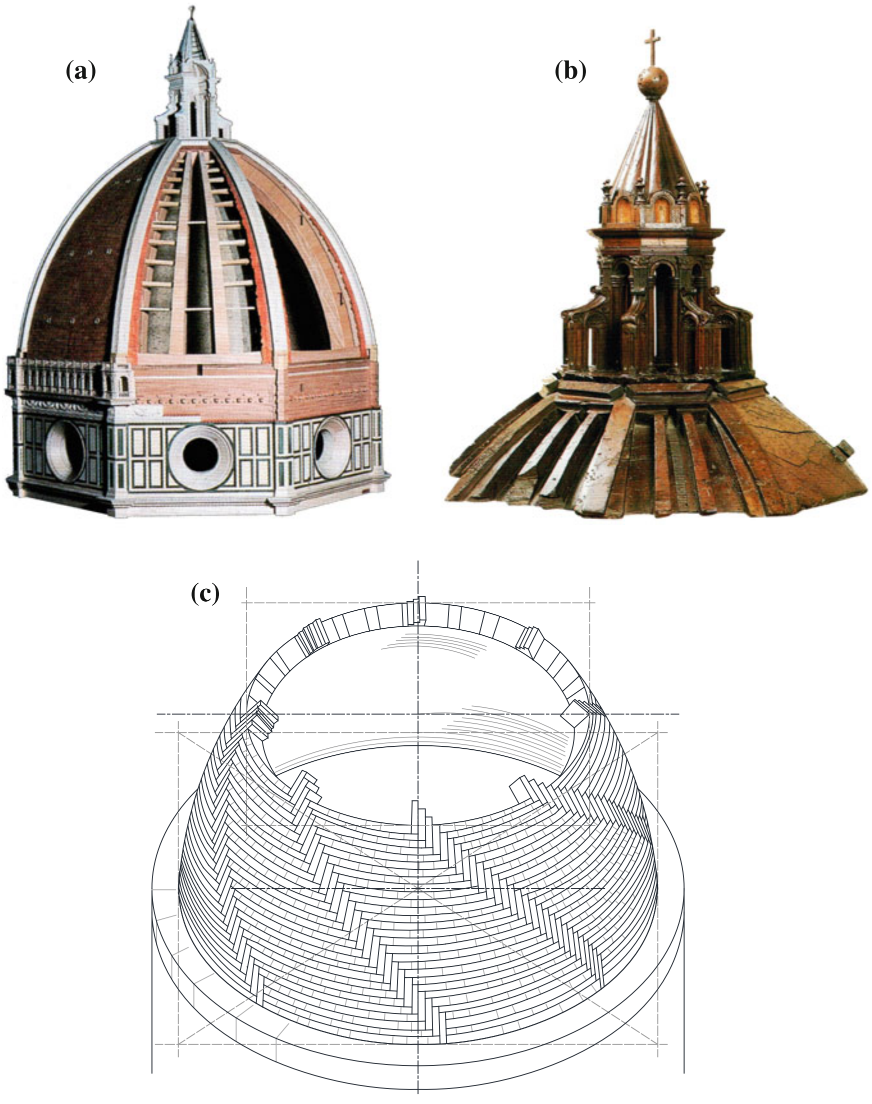

Fig. 2.5 Exhibits of the Uffizi Museum in Florence: **a** wooden model of the dome of the Santa Maria del Fiore Cathedral, **b** wooden model of the lantern to crown the dome, **c** drawing of the brick motif of the dome's masonry shell made on the basis of drawings by Brunelleschi [6]

construction machines, and he even designed, and his own expense, a barge (for which he was awarded with a patent) to convey heavy marbles on the Arno river [7]. We do not know the criterion for the choice of wood. It is known that they were designed sparingly, with a large knowledge of wood statics and features. Of interest is the opinion of another eminent creator of the Renaissance, Leone Battista Alberti, formulated on the occasion of the inauguration of the cathedral on 25 March 1436. Alberti L.B., full of admiration, wrote, “Whosoever could be so envious and unwilling so as not to praise Pippo, the architect, seeing here such an enormous structure, aerial, able to cover with its shadow all the peoples of Tuscany, made without the support of arch centres and a great amount of wood” [6].

In 324 AC, Emperor Constantine ordered the erection of the basilica in honour of Saint Peter in Rome. The building of the facility was started, the extension and improvement of which lasted for 1200 years when Michelangelo joined the project.

Basing on the sketches by Bramante D. (from 1505), he designed the basilica on the plan of the Greek cross, crowned in the centre by a dome having a double canopy. The Saint Peter’s Basilica in Rome was built in 1506–1626 in the shape known to us. The form and structure of the Basilica changed along with the architects striving for the expression of the papal prestige by the architecture. The work started by Bramante was finally determined by Michelangelo and its construction according to his concept was completed after his death. In 1588–1590, the masonry, two-shell dome of the Saint Peter’s basilica, having a diameter of 42.52 m and a height of 52.0 m, was created. The weight of the dome totals 6800.0 kg/m^2 of its projection [8].

The domes of: the Diana Temple, the Pantheon, the Santa Maria del Fiore Cathedral, the Saint Peter’s Basilica, are characterized by an enormous weight of the shell and the structure. The accomplishment of such facilities was possible on the rocky soils of the southern Europe.

Proven scaffolding systems of wood were required for their construction. The constructing of resistant scaffoldings to maintain stone and brick structures contributed to the development of geometrically invariable wooden structural systems and statics of bar structures. An essential role was also played by the constructing of wooden models of the facilities projected, required by the founders. The ease of making wooden models of structures and the possibility to adjust the system in order to provide the geometrical invariability of the structure assisted the difficult investment process.

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