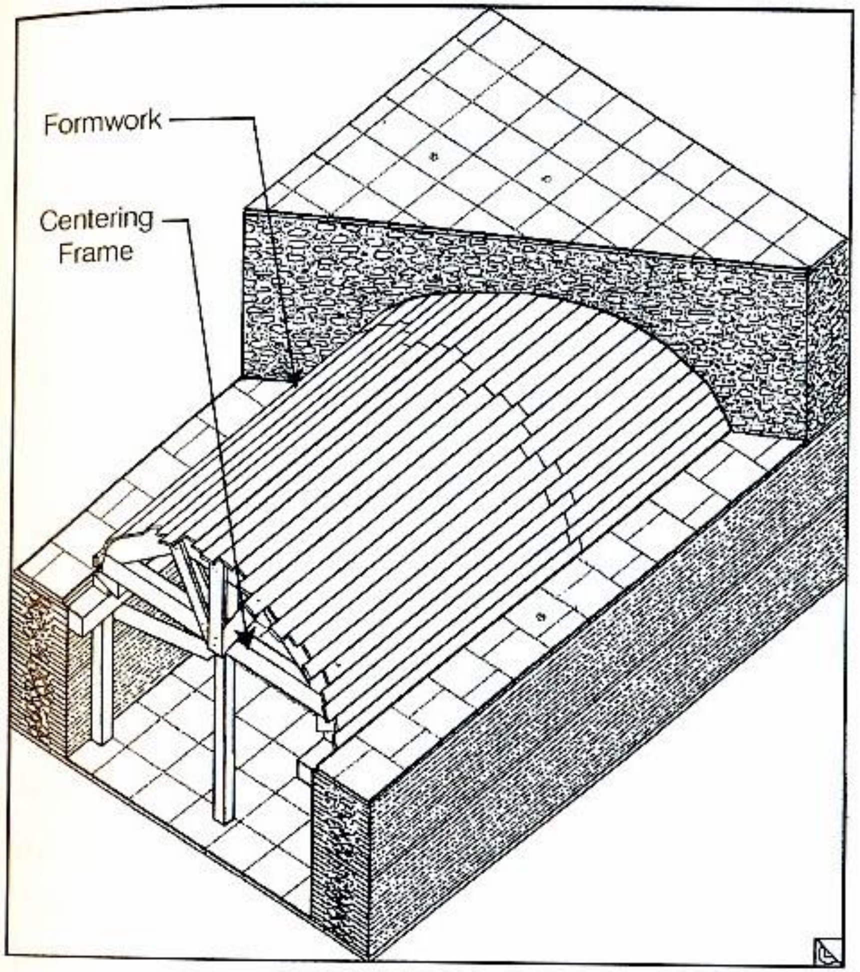
“A spectacle of marvellous beauty” domes and other histories

Domes and other histories



8. Reconstruction of wooden centering for concrete barrel vault.

The construction of the most impressive Roman vaults was dependent on the builder's ability to erect large wooden centerings capable of taking the weight of the concrete.

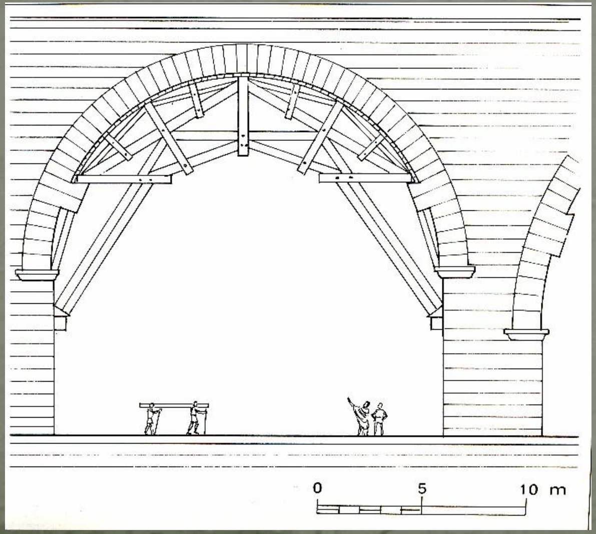
The basic structure for the centering of vaults and domes consisted of a number of arch-shaped frames connected by formwork boards.

Domes and other histories

We know that centering was a technique used throughout Roman construction as evidence remains in the ruins today.

There are many holes (putlog holes) in the sides of buildings that suggests that these were used to hold beams to support platforms needed for scaffolding .

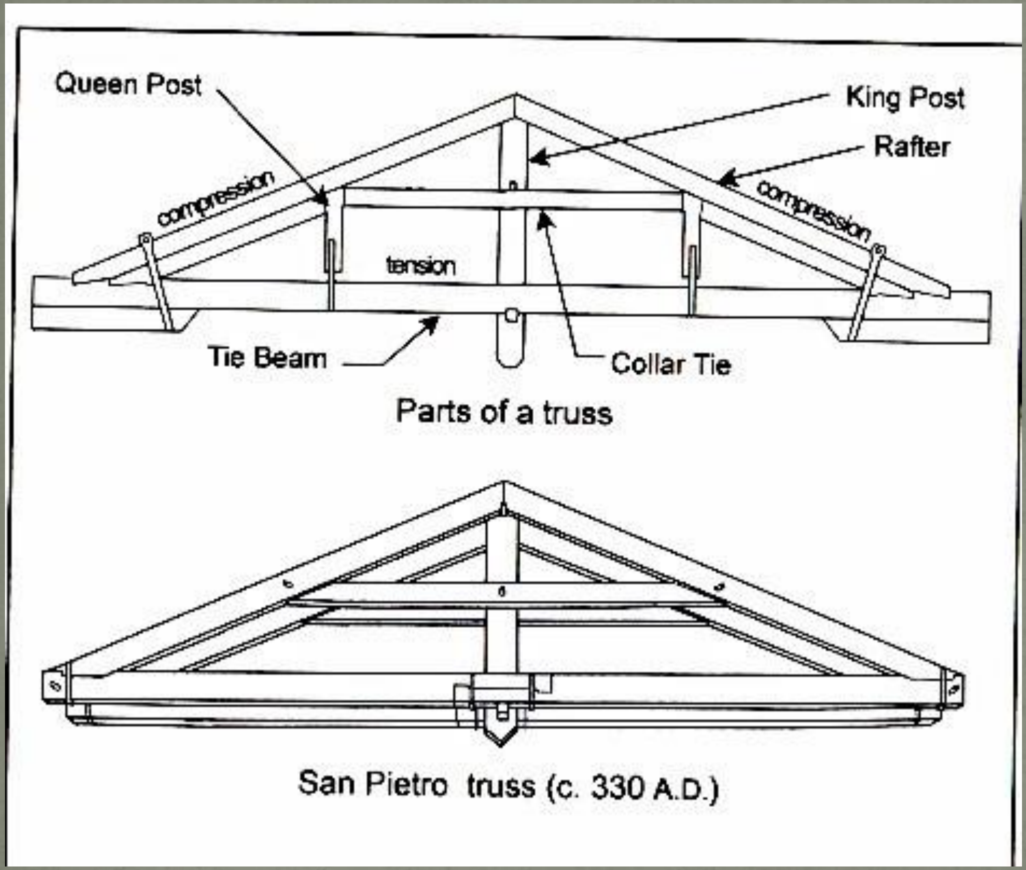
Domes and other histories



Further evidence is that on arches still standing today projecting stones can be seen in the arch. These projecting stones is where the formwork for the arch would have rested and are convenient for when any repair work on the arch must be done.

The Romans perfected a technique known as flying centering, "a kind of formwork erected not from the ground up but from the springing points of the planned arches or vaults" .

Domes and other histories



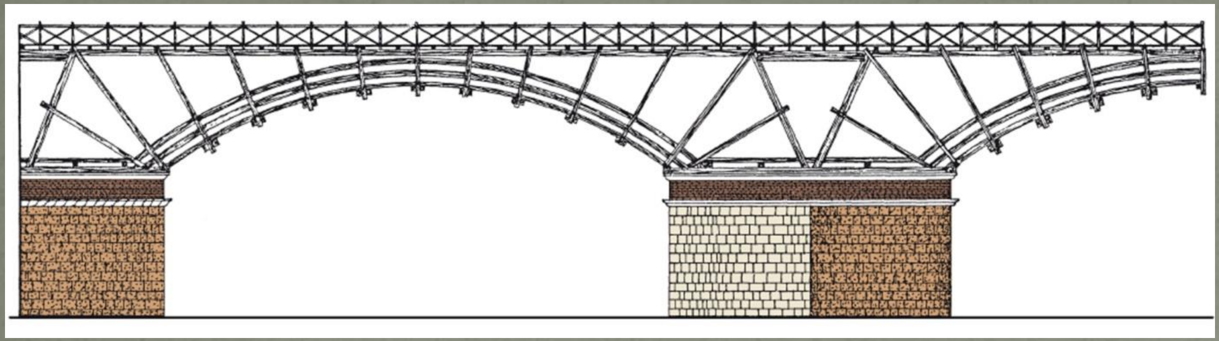
The development of triangle truss made possible the construction of large scale wooden structures.

A truss is a structure created of a minimum of three beams forming a rigid triangle . It had the advantage over a simple beam of spanning great distances using a number of smaller timbers.

Domes and other histories

The depiction of Apollodorus's famous bridge over the Danube on Trajan's Column demonstrates a complex understanding of trussed construction in the early second century A.D.

Domes and other histories



The structure was 1,135 m. long (the Danube is now 800 m wide in that area), 15 m wide, and 19 m. high.

Apollodorus of Damascus used wooden arches, each spanning 38 m, set on twenty masonry pillars made of bricks, mortar, and pozzolana cement.

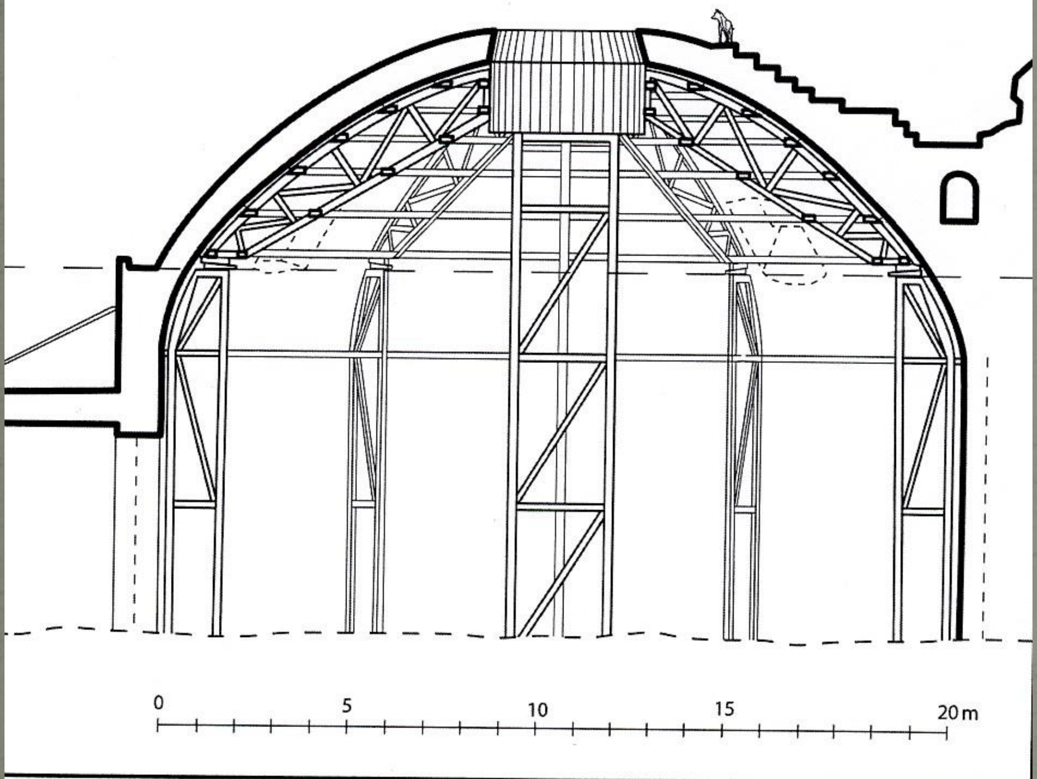
Domes and other histories

- One of the perennial questions regarding the centering of the Pantheon dome is whether it was supported form the ground or if so to what degree.
- At one extreme is the idea of the centering consisting of a virtual forest of supports and, on the other, is the idea of the most minimal "hanging" centering propped against a ring at the oculus with no ground support at all.
- A thir possibility is one that falls somewhere between the two extremes and employs a central tower for support under the oculus.
- In evaluating the proposal, the first question to ask is whether the maximum distance spanned in any of them is within the known capacity of Roman trusses.
- In either , the central tower proposal or the central ring proposal, the centering frames themselves would have been arranged radially in some fashion in order to determine the appropriate form, so the maximum distance any frame would have had to span was the distance from the spring of the dome to the edge of the cornice of the oculus. This comes to about 26 m., which is approximately the same as the span of the Basilica Ulpia trusses.

Domes and other histories

The Temple of Mercury at Baiae (late first century B.C.)

Domes and other histories



emple of Mercury" at Baiae (late first century B.C.). Reconstruction of the centering.

This correspondence is unlikely to have been casual given the close connection in time and techniques between the two projects.

If continuous support form the ground was not necessary, the next question is whether the frames were supported at all from the ground level.

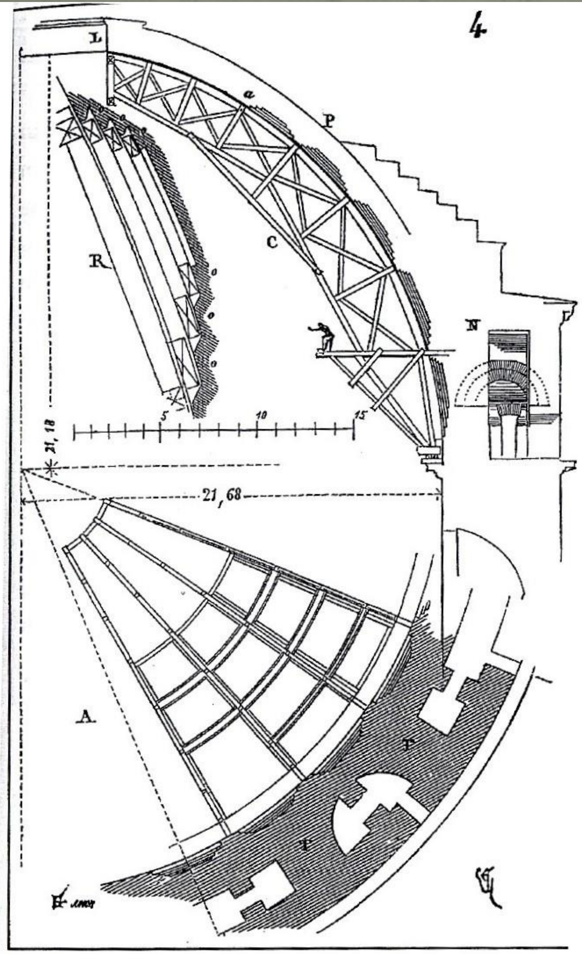
The two possibilities are:

a) a central tower was used as a support against which the frames could rest
b) the radiating centering frames all rested against a central ring at the oculus and balanced each other.

Domes and other histories

One work by Apollodorus does survive, the *Poliorcetica* (c.AD 100), a treatise on siege machines that has been preserved in the corpus of Byzantine poliorcetics (the military art of siege warfare).

Domes and other histories



37. Pantheon (A.D. 118–128). Plan (below) and section (abov
showing reconstruction of centering from Viollet-le-Duc 186
p. 473, fig. 4. "L" marks where ring at oculus is located.

J.J.Rasch has argued that the idea of a large central tower for dome centering was developed in the second century for the Pantheon by Apollodorus, who based the design on the siege towers described in his treatise on siege warfare.

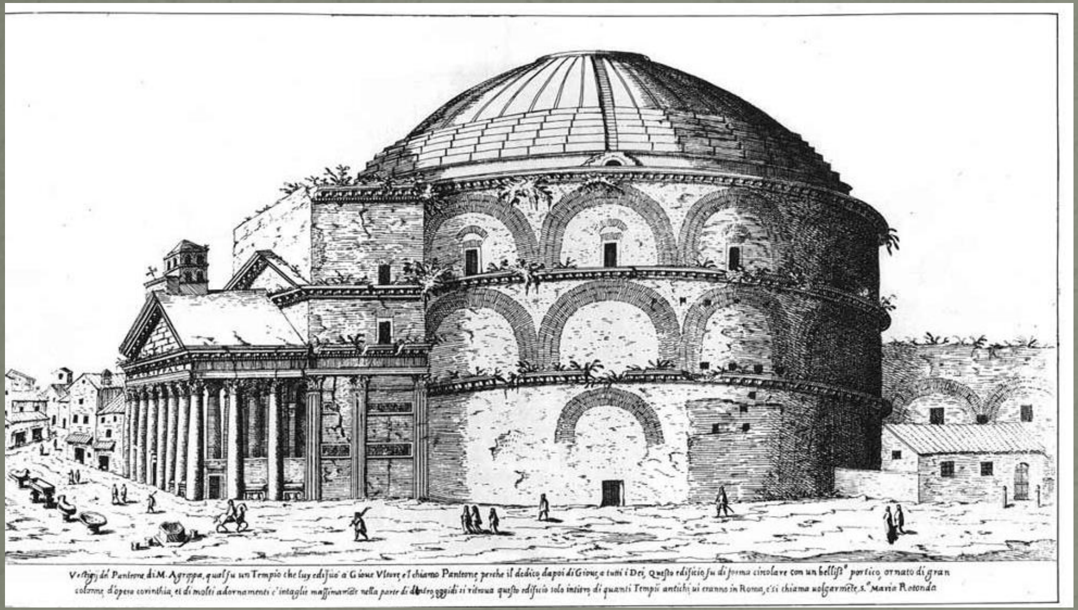
However Apollodorus's siege towers were no doubt modeled on earlier ones developed by Hellenistc Greek engineers.

Vitruvius describes one designed by Diades an engineer of Alexander the Great, that was 53 m high, 10,4 m. at the base, which would hav been large enough to fit under the dome of the Pantheon.

Domes and other histories

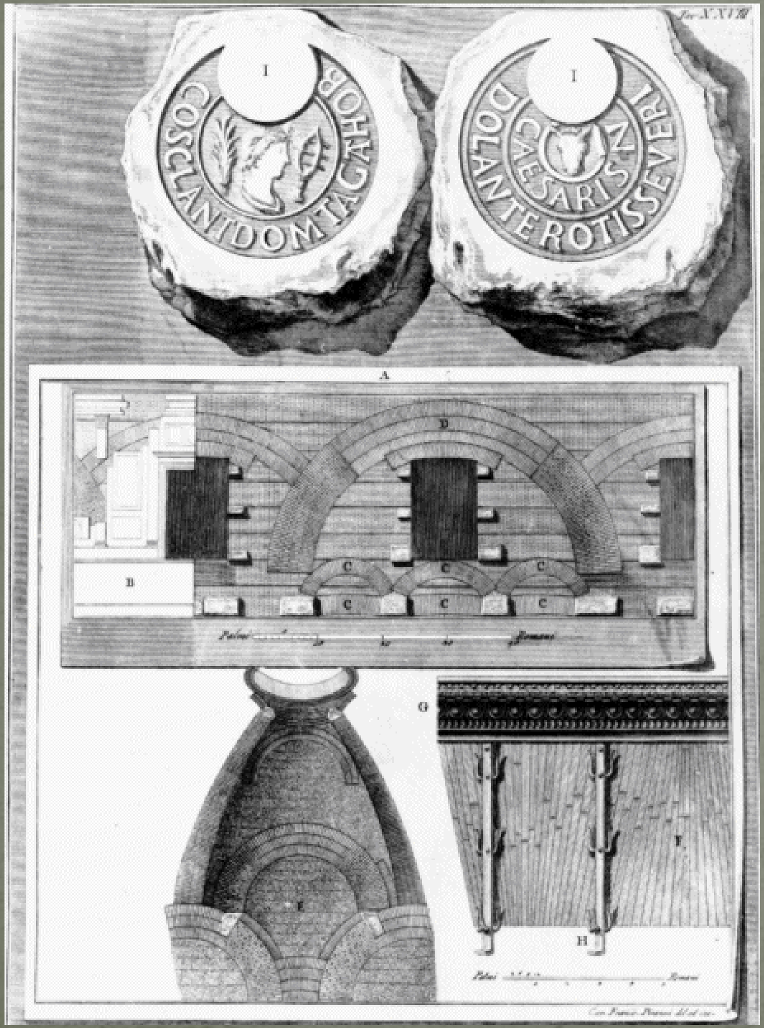
Stone or brick arches built into Roman concrete vaults are called "ribs" but unlike the ribs in Gothic vaulting the Roman ones are usually flush with the intrados and would not have been visible once the vault was decorated.

Domes and other histories



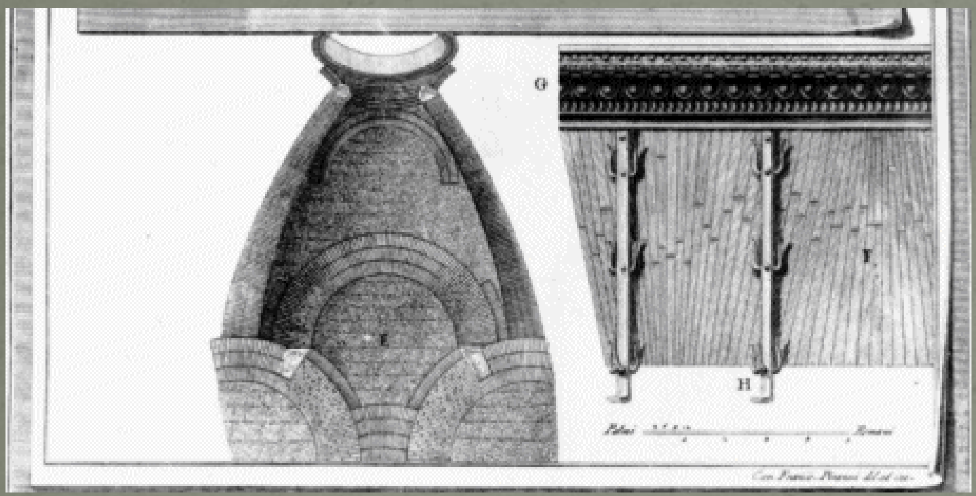
In the past scholars of Roman architecture have disagreed about the role that ribs and relieving arches play within the fabric of the concrete structure. Some have asserted that once the concrete cured, the relieving arches or ribs become part of the hardened mass and no longer act indipendently to divert loads or to reinforce the concrete, whereas others have assigned them a more active role in the channeling of loads through the hardened mass of the concrete even after the curing of the mortar.

Domes and other histories



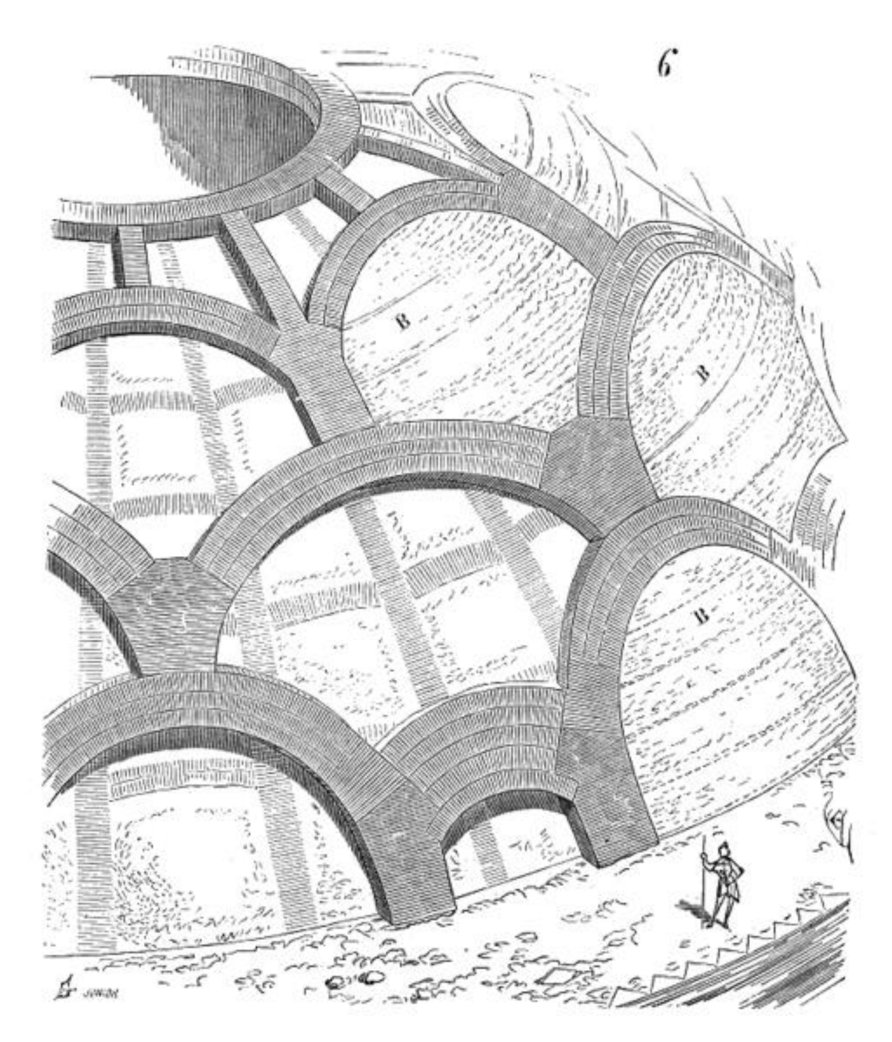
Pope Benedict XIV authorized after the Jubilee of 1750 to repair damage to the interior of the dome, which had been caused by infiltration from rain. During 1756–1758, adjustable scaffolding was put up, and Giovan Battista Piranesi had an opportunity to make firsthand observations. His studies were collated by his son Francesco, which appeared as part of a set of engravings in 1790.

Engraving illustrating brick stamps (top), construction of attic level (middle), brick skeleton for a portion of the dome, and an elevation detail of the oculus (bottom) by Francesco Piranesi.



In the lower third of Piranesi's plate, the perspectival drawing is entitled "Dimostrazione dell'ottava parte della cupola, come si vede quando fu spogliata dell'antica intonacatura".
Above the attic arches Piranesi drew a system of ribs and compartments, which would have numbered eight in all. The engraving conditioned subsequent studies and publications on the Pantheon for over a century, but the web of arches above the first row is mere conjecture.

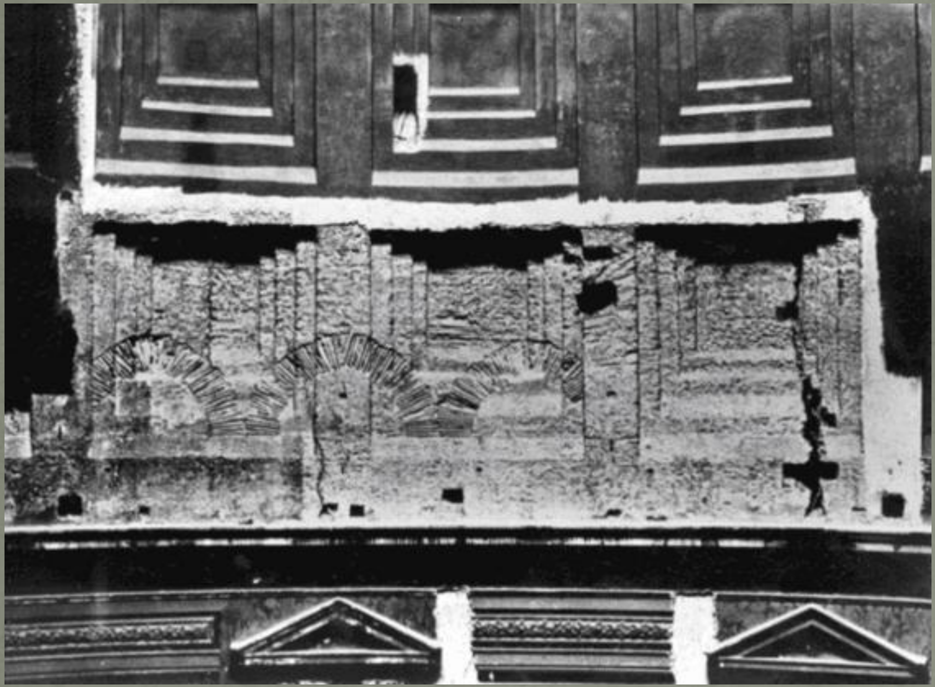
Domes and other histories



Viollet le Duc based his interpretation of the construction tecnique of the Pantheon dome upon Piranesi engravings and conceived a double shell.

In the intrados the radial ribs of the coffers were surmounted by the relieving arches whose function was to enclose the concrete layers.

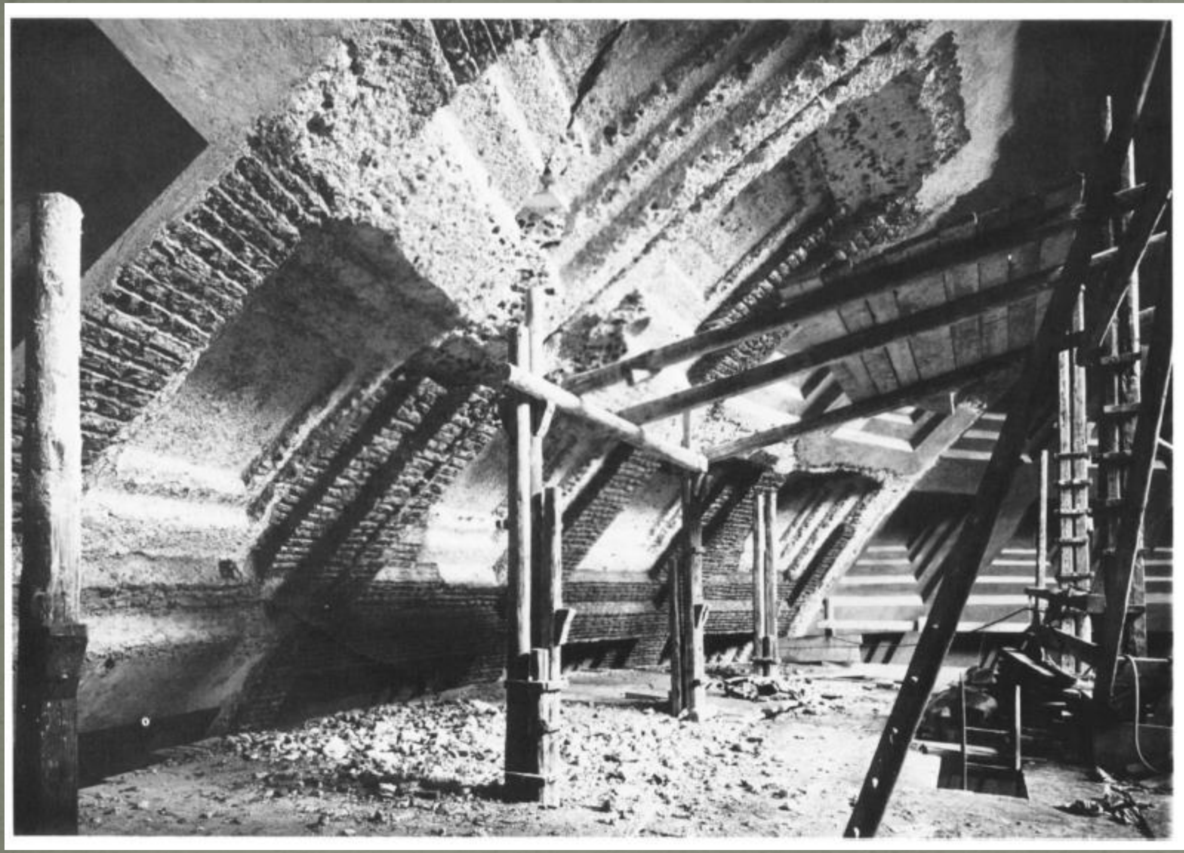
Domes and other histories



In 1892–1893, the Italian government commissioned repair work to some coffers near the springing of the dome, on the right of the main altar. In charge of operations were Giuseppe Sacconi and Luca Beltrami.

Beltrami discovered that the arches at the springing of the dome do not follow its spherical curvature but rise vertically.
In fact, he made an opening for inspection in the concrete at the level of the second row of coffers .

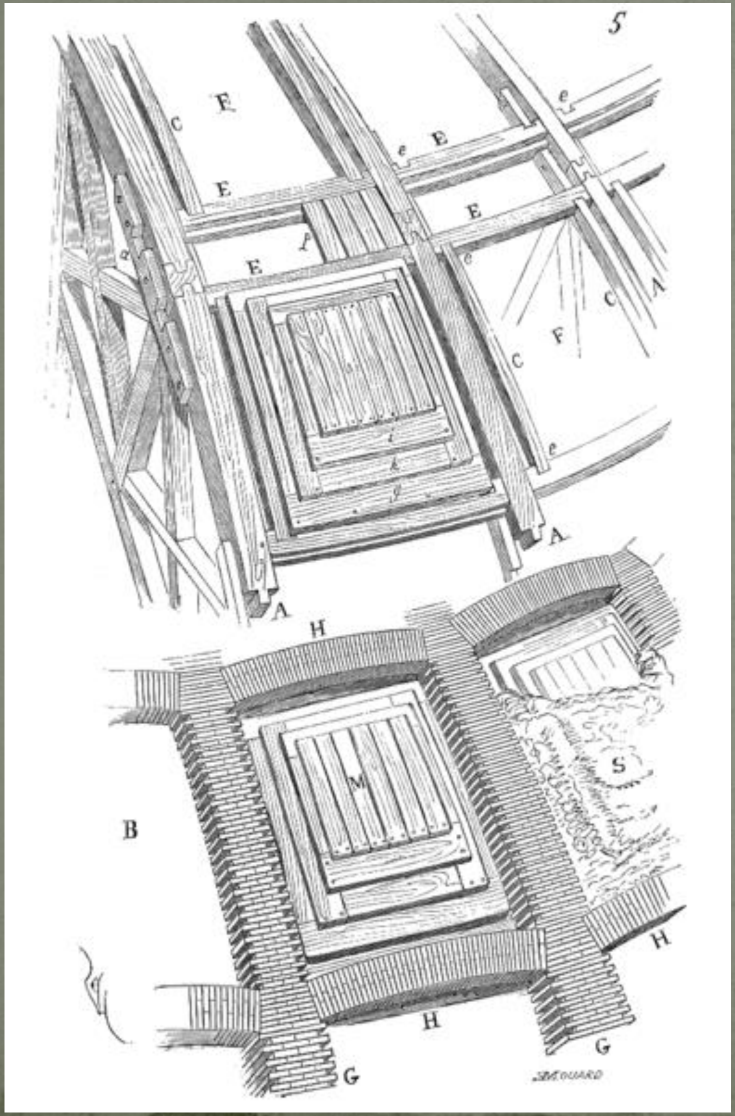
Domes and other histories



The upper coffers of the Pantheon dome with the brick ribs. Whatever use the brick ribs served during the construction, perhaps in shaping the coffers, they delivered no diagonal thrusts.Once the building cured these ribes were part of the dead weight , all thrusts in the structure being vertical.

Photographs taken during the repair works (1892-93) show the ribs of the coffers without the plasterwork. Some are faced in brick, others appear to be concrete, but this aspect does not seem to have been adequately investigated .

Domes and other histories



Viollet le Duc two hypothesis for the construction of Pantheon coffers, the centering wooden frames or brick ribs enclosing the wooden formwork.

Domes and other histories

- The concept of the monolithic concrete vault is based on the idea that Roman concrete, due to the use of the volcanic ash, pozzolana, was so strong that it acted as a «monolith», or a rock, and therefore transferred no lateral thrust onto its abutments.
- Auguste Choisy himself uses the term «monolithe» to describe Roman concrete when he raises the issue of lateral thrust of vaults. He notes that «It is, apparently, one of the great advantages of monolithic vaults that they can be supported without any auxiliary abutment».
- He then concludes that the Romans could see the danger in relying too much on the monolithic nature of the material because they took measures to counteract the potential lateral thrust by adding buttresses.

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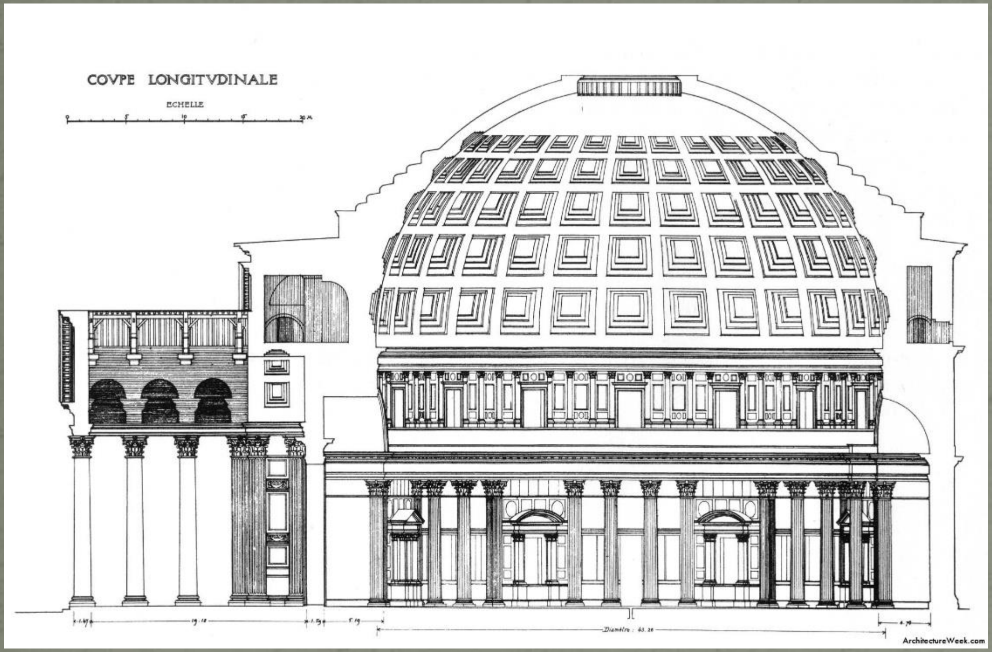
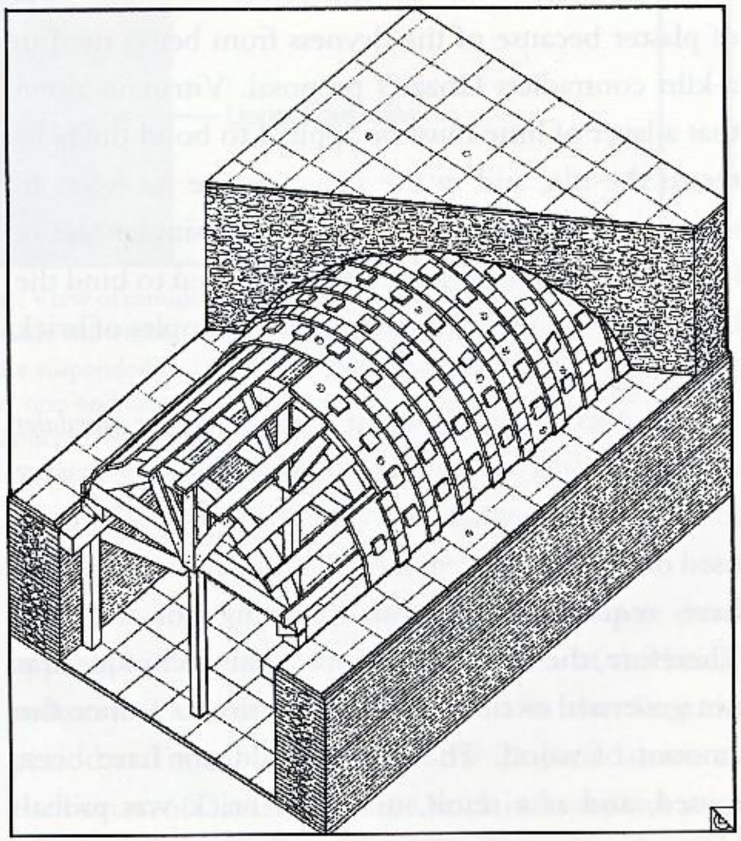
Domes and other histories



Once Choisy had explained why buttressing was necessary, he then examined its use in light of his theory of economy of construction. His conclusion was that the Roman architects cleverly arranged their structures so that buttressing elements were integrated into the design of the building rather than being attached to the exterior (such as the step rings on the Pantheon's dome).

Domes and other histories



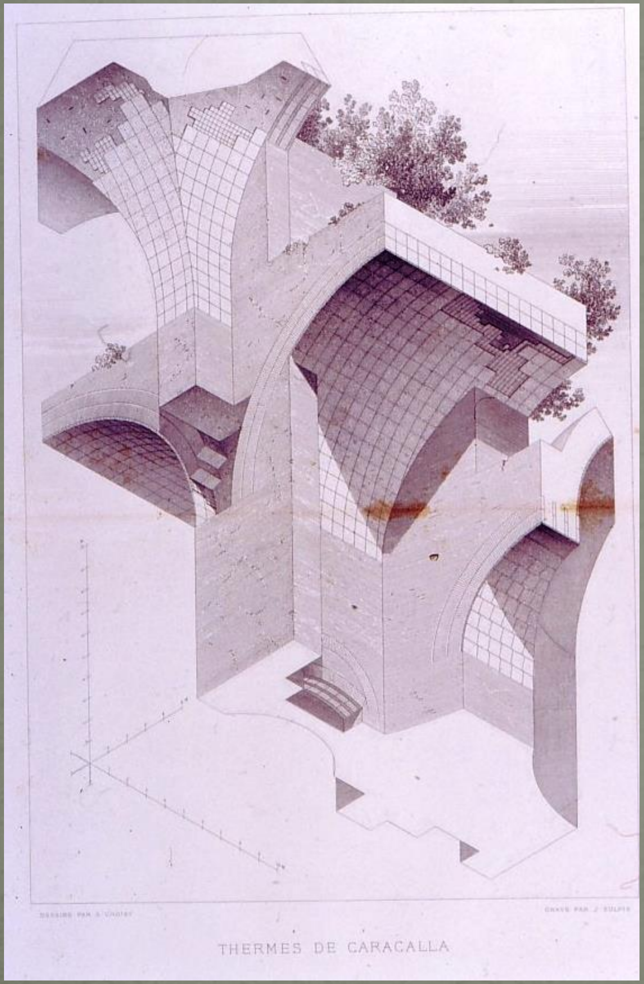
17. Reconstruction of centering for barrel vault using brick linings of *bipedales* and *bessales*.

To solve the problem of the formwork adhering to the concrete during the II° century a.C. a lining of bricks was placed over the formwork.

The lining usually consisted of a layer of bipedales or sesquipedales covering their joints.

When the wooden centering was removed the bricks lining remained adherent to the intrados of the vault.

Domes and other histories



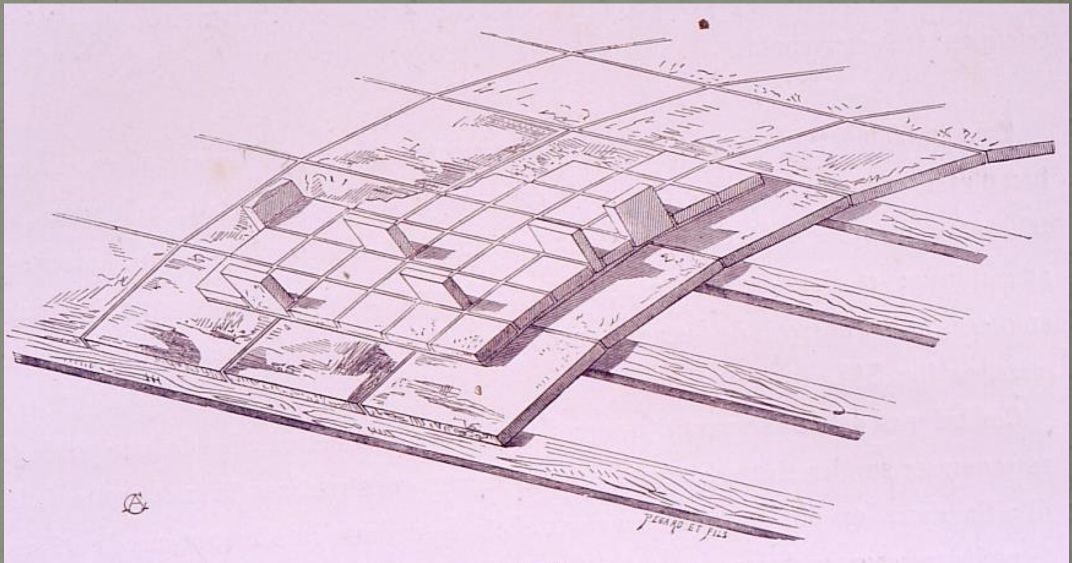


Fig. 30.

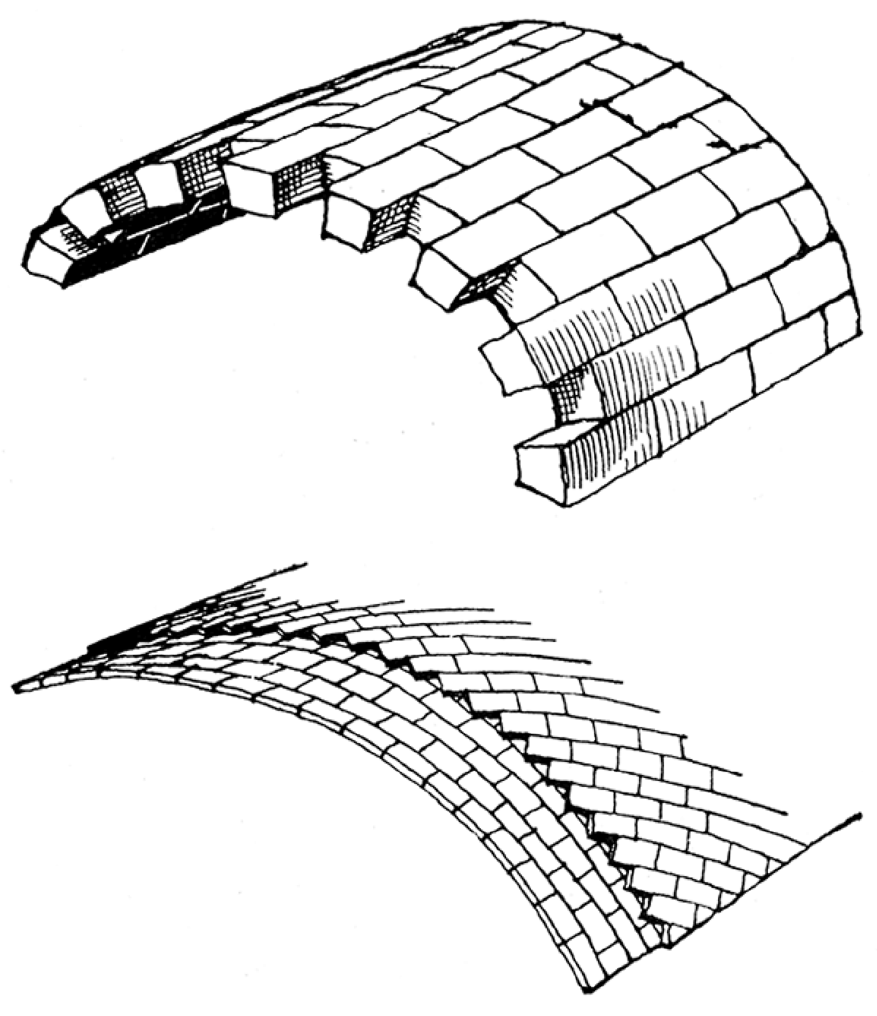
The examples Choisy illustrates, such as those at the Palatine and at the Baths of Caracalla, are ones where the bipedales have largely fallen away

Domes and other histories

The underground galleries of the Caracalla's Baths.

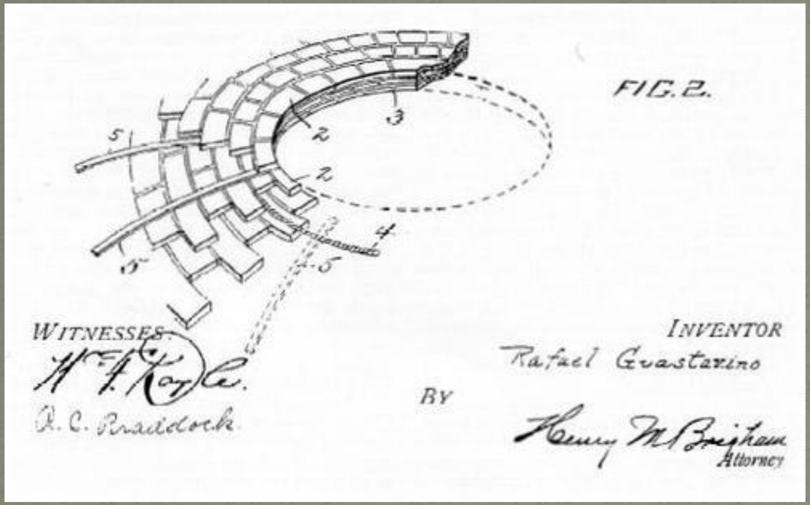
The brick linings were held in place by a layer of fine white lime mortar .
Auguste Choisy also saw a similarity between the Roman brick linings and a technique
used in his day that employed bricks laid flat, which he called volte "alla volterrana" or "volte a foglio" also known as timbrel vaulting today.

Domes and other histories



The tile vault appears to have been developed by Moorish builders near Valencia, Spain, though it quickly spread to become common throughout the Mediterranean region.
The method is known as the *bóveda tabicada* in Spanish and is sometimes called the *timbrel vault* (so-named by Guastavino Sr.) or the *Catalan vault* (so-named by 20th century Catalan architects).
Comparison of the traditional stone vault (top)and the Guastavino tile vault (bottom).

Domes and other histories



Rafael Guastavino and the tile vaulting.

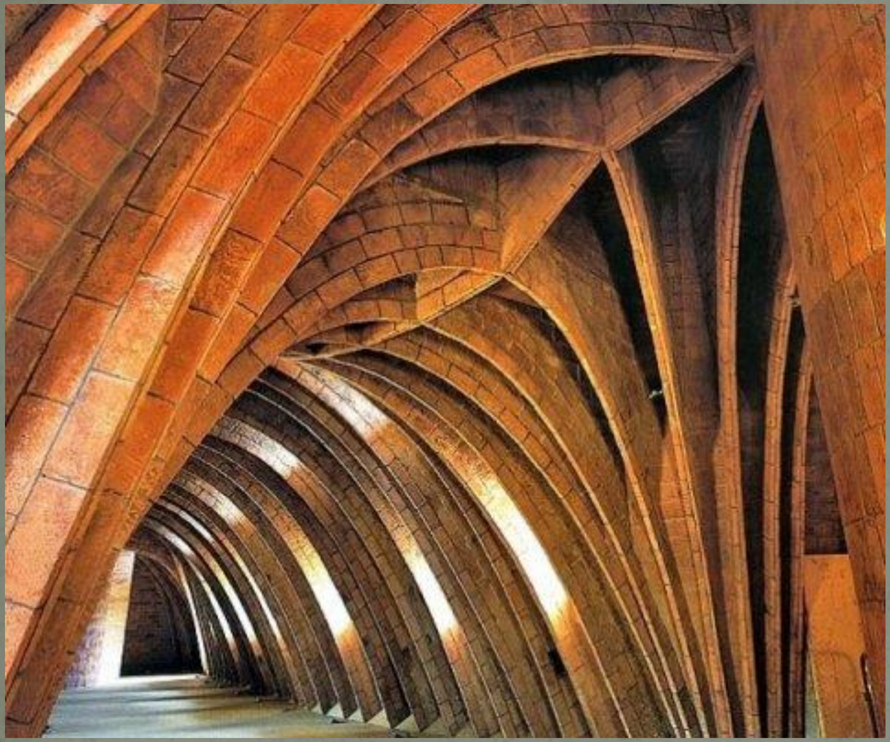
When compared to traditional stone vaulting, tile vaulting uses much less material and can be built much more quickly. Because the thin bricks are laid flat, with their narrow edges in contact, the total thickness of the vault is less than conventional masonry, and therefore the self-weight and corresponding horizontal thrust values are reduced.

In the traditional tile vault, the tiles are joined with plaster of Paris, which sets quickly enough that the interior of the vault does not require any support from below during construction.

Domes and other histories

The research carried out by Antoni Gaudi found his most significant manifesto in the Provisional Schools of the Sagrada Familia (1909).
Gaudi explored the theme of bóveda tabicada from the geometrical and spatial point of view and drew a new and unusual form for roofing and walls. This form, called conoid, is obtained with a double layer of bricks making up a continuous and thin layer.

Domes and other histories



Antoni Gaudi, La Pedrera (Milà, 1905-1912, left) and Rafael Guastavino, tile vaulted staircase of Baker Hall, Carnegie Mellon University, Pittsburgh, 1914 (right).

Domes and other histories

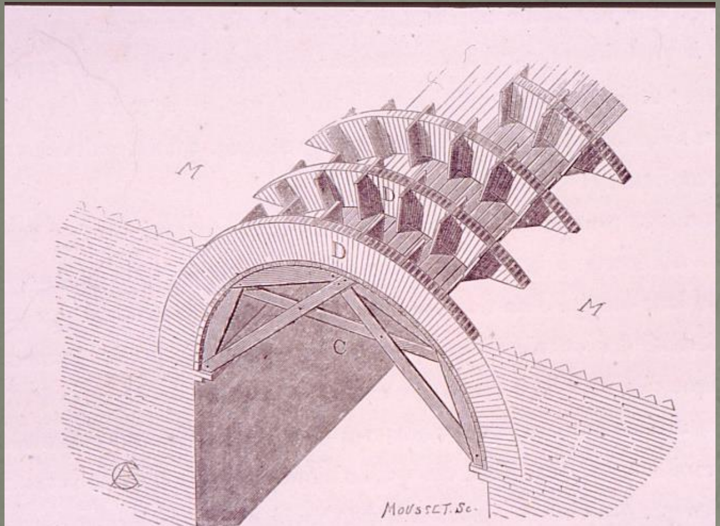
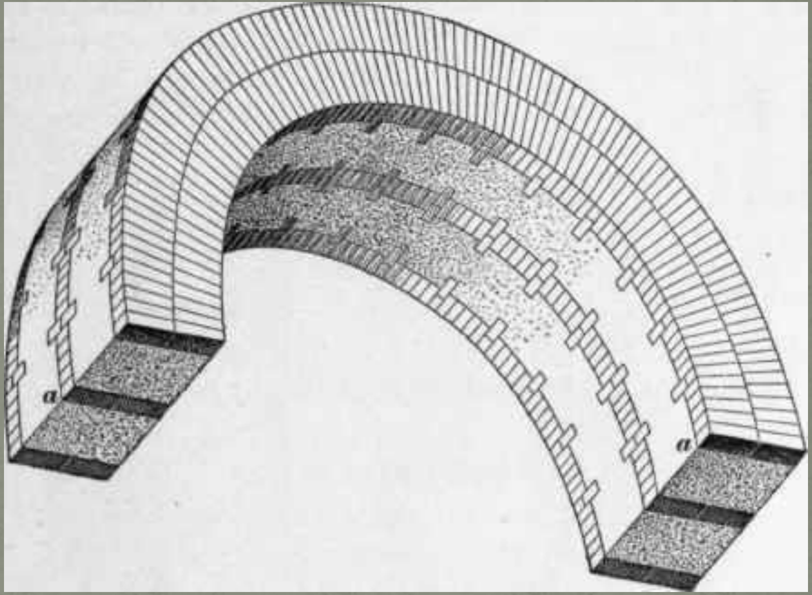


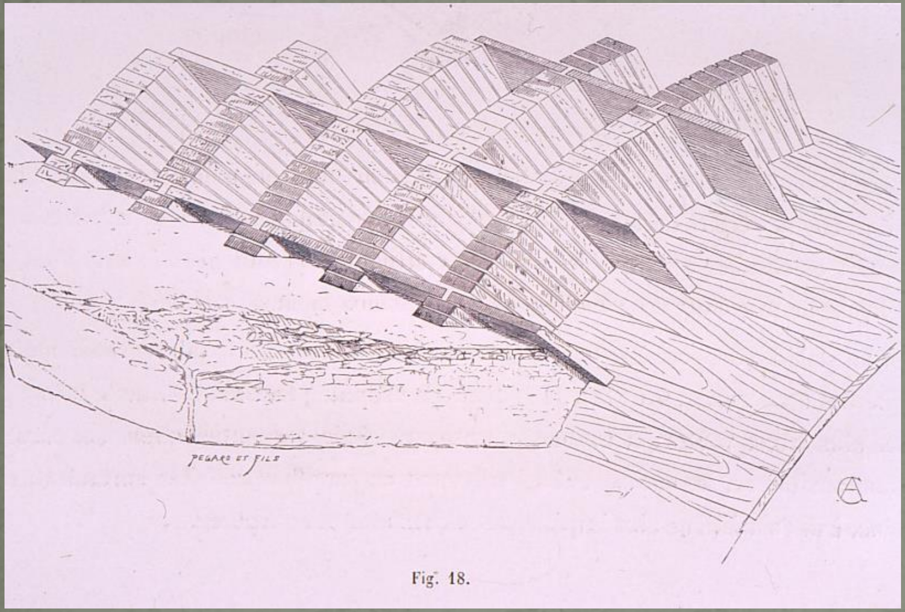
Fig. 15.

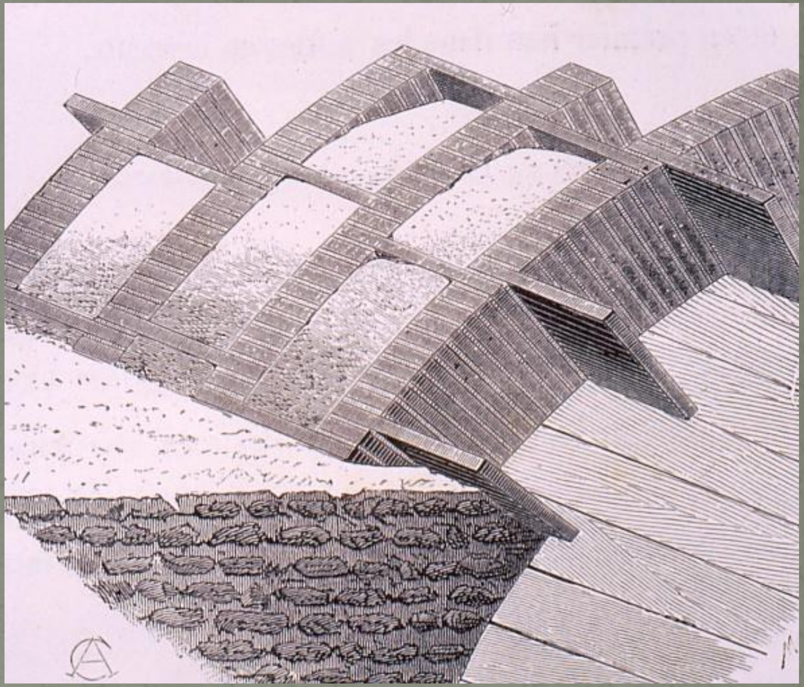


Starting from his premise that the Romans were trying to be as economical as possible with their materials, Choisy interprets the Roman vaulting ribs, which often consist of a brick latticework construction as an attempt to reduce the number and size of centering frames.

By placing the frames under the brick arches, which would be self supporting once complete, they could be much lighter because the brick ribs would take much of the load off the frames.

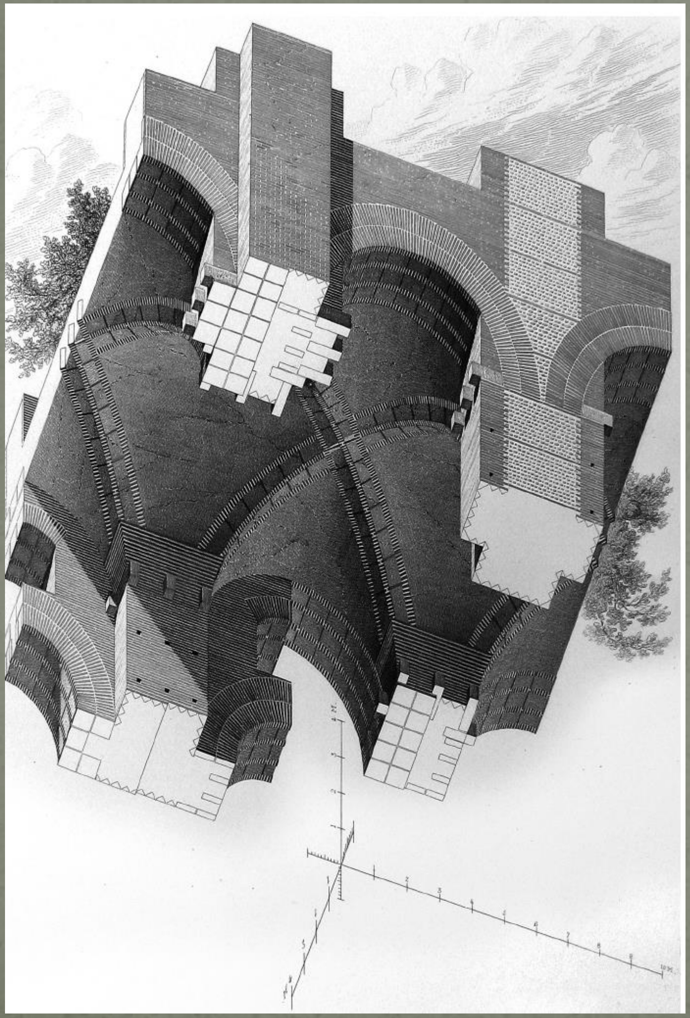
Domes and other histories





Auguste Choisy’s proposal for the way in which lattice ribs were constructed in barrel vaults.

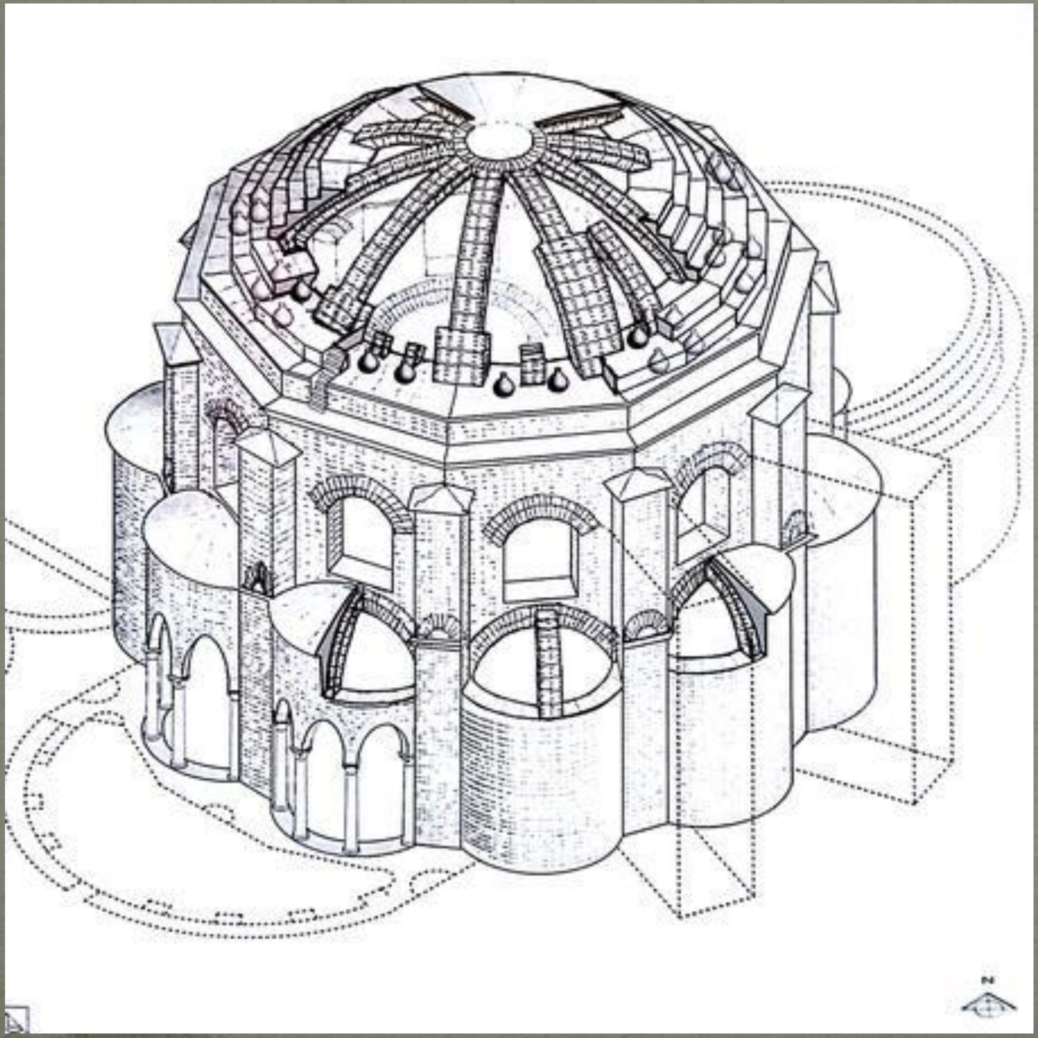
Domes and other histories



One of the great debates in Roman construction is whether the ribs functioned only during construction thereby ceasing to play any structural role after the hardening of the concrete, or whether they continued to play an active role during the life of the structure.

The Maxenthian substructure on the Palatine (4° century a.C.).

Domes and other histories



The decagonal dome of the “Temple of Minerva Medica” has numerous lattice ribs running along the meridians, but some of the ribs do not extend all the way to the crown.

Domes and other histories

Choisy stated that «this internal frame was useful during construction only. It allowed the vault to be built up; but it loses its value and its role as the mass becomes solid; finally, once the mortar consolidated, it ceases to have an independent existence, and does not appear any more in the vault but as an integral part of the whole».

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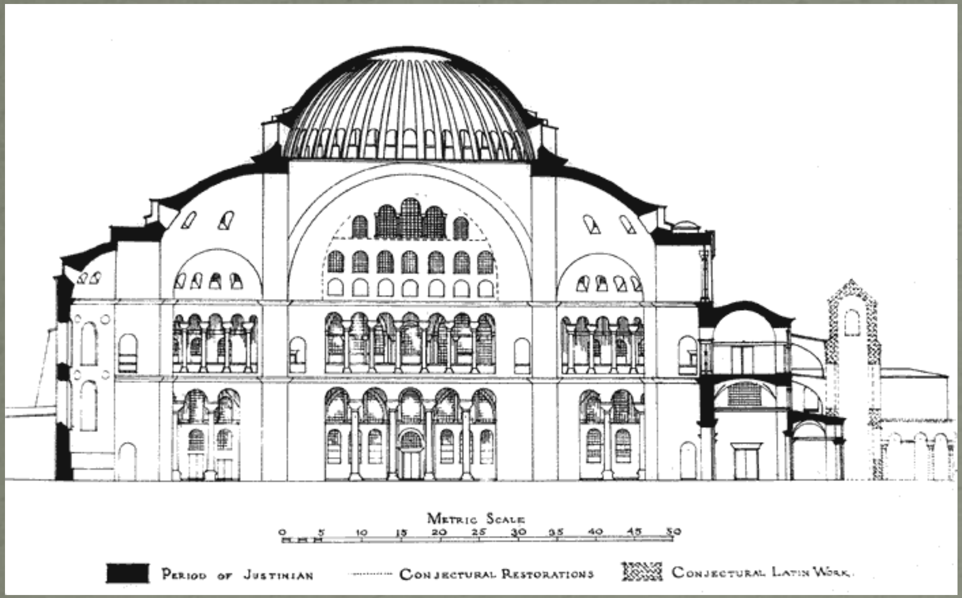
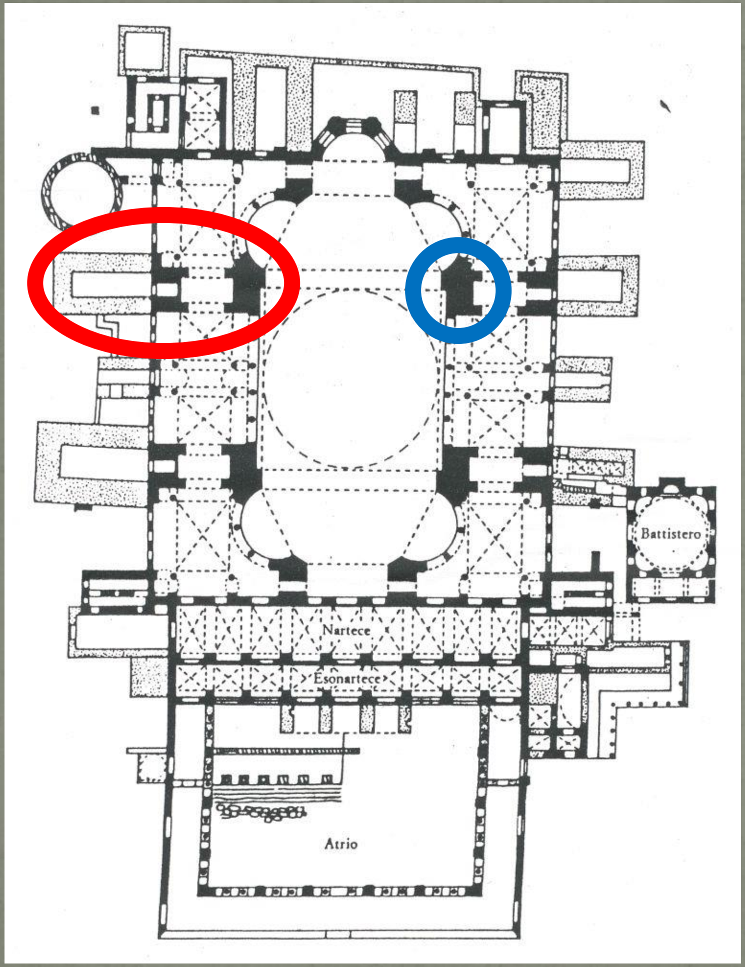
The church of Hagia Sophia in Constantinople was built in 6th century during the reign of Justinian.
The construction lasted in a fairly short time in comparison with its huge scale, only five years and ten months between 532 and 537. The architects Anthemius of Tralles and Isidorus of Miletus established a unique structure, by means of combining architectural and structural innovative arrangements, which astonishes in the very first sight even today.

Domes and other histories



The central dome rests on a circular base, which is formed by four main arches and pendentives.
It rises about 56 m. from ground level) and has a diameter of 31 m. The massive piers in the central space support the main arches and pendentives in order to transfer loads to the foundations.

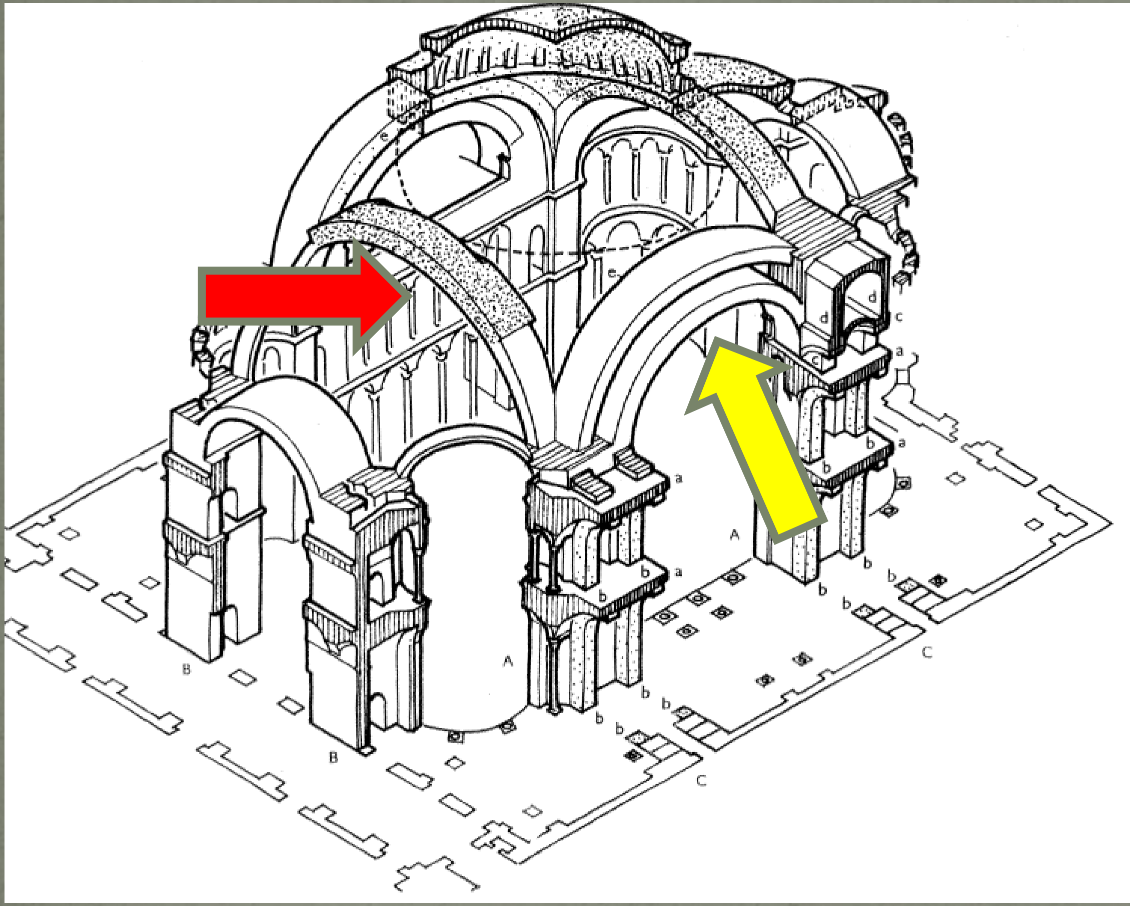
Domes and other histories

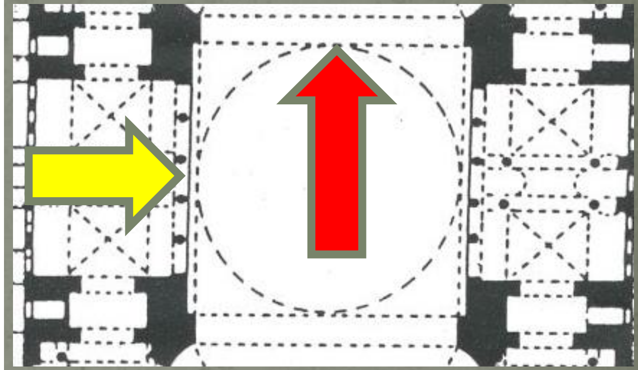


The layout of the monument is a combination of longitudinal basilica and a central plan with a dome (82x73). The buttress piers on the transversal and the secondary piers on the longitudinal direction are attached to the main piers to improve the stiffness of this structural integrity. The primary structural system includes all of these elements.

The interior space extends on the longitudinal axis by two semi domes, which are articulated to the structure from the eastern and western sides. The semidomes and exedrae could also be included in the primary structural system.

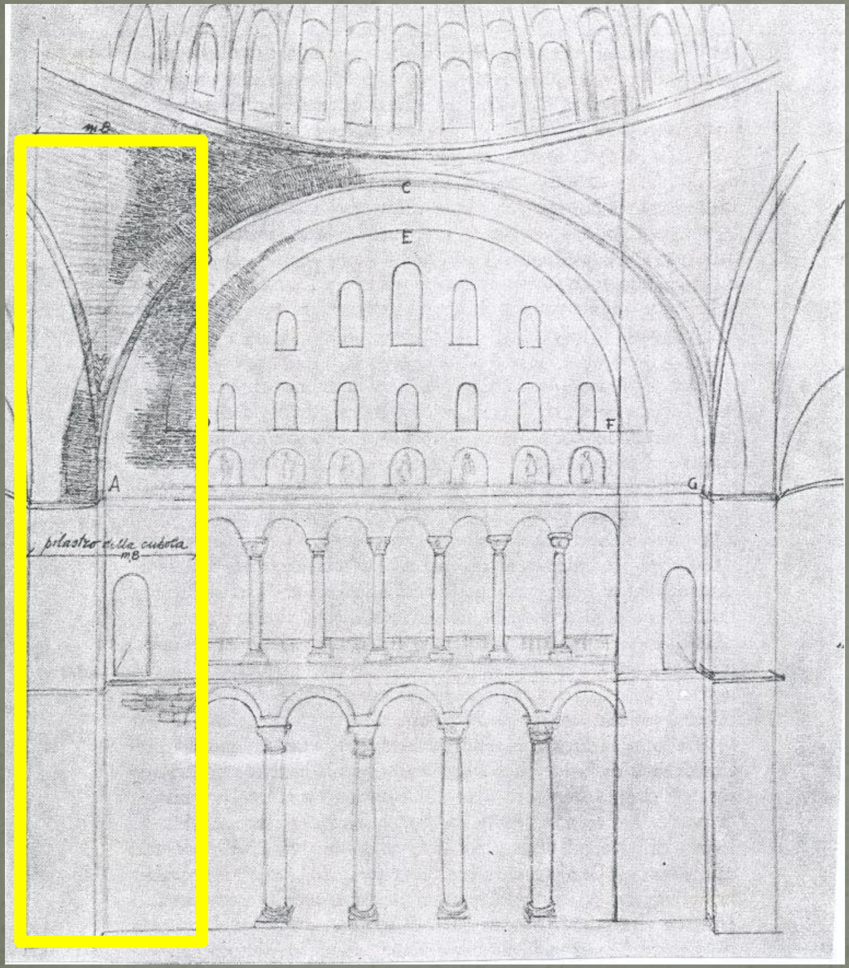
Domes and other histories

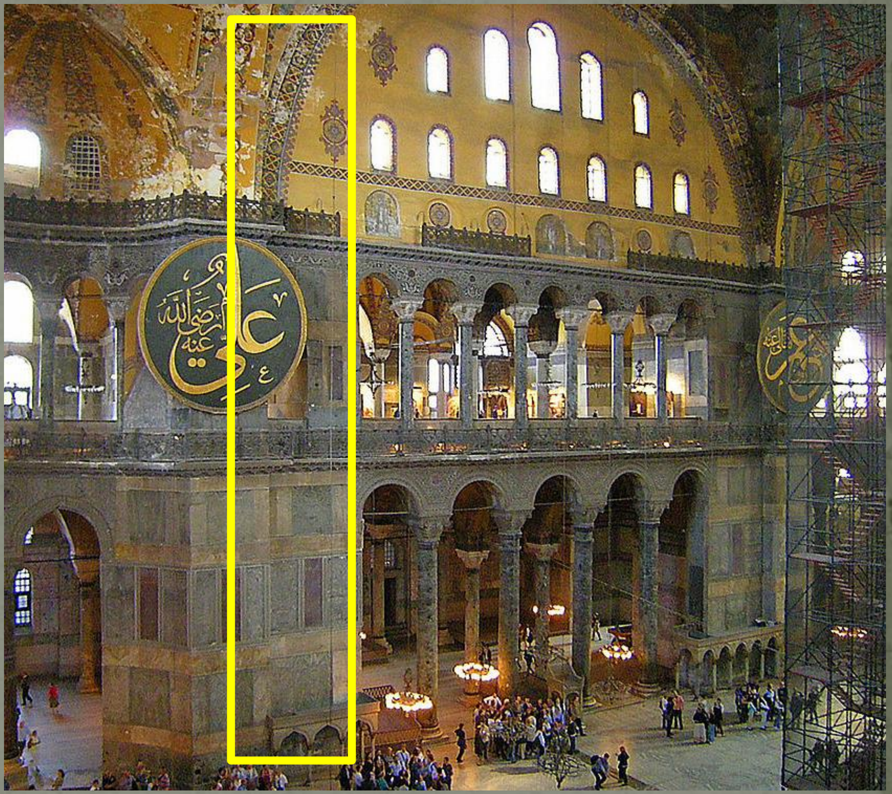




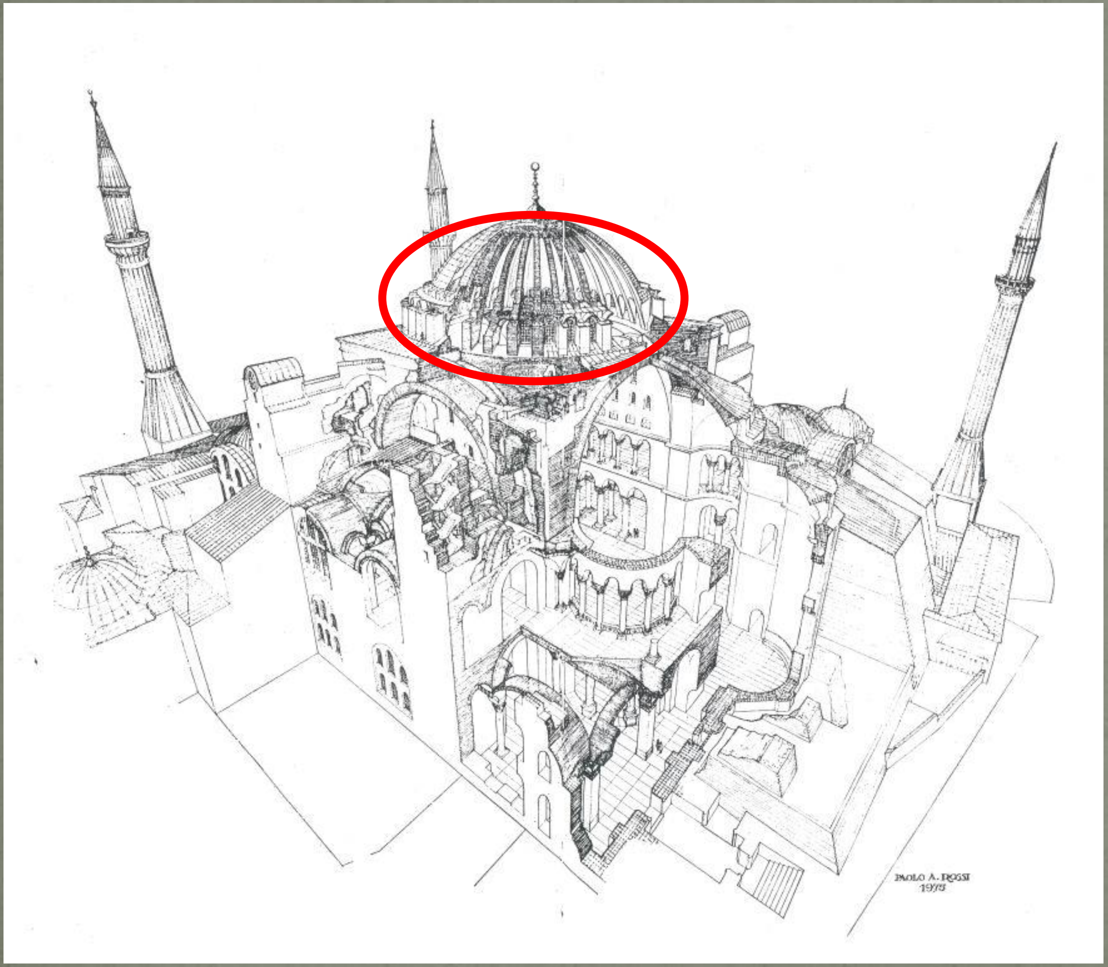
Main arch (east and west) = 31 meters.
(red arrow)
Minor arch (embedded in the wall), 22 meters ca.
(yellow arrow)

Domes and other histories





Domes and other histories



Like the Temple of Minerva Medica even the dome of Saint Sophia had lattice ribs running along the meridians, countered by buttresses flanking the forty openings.

Domes and other histories