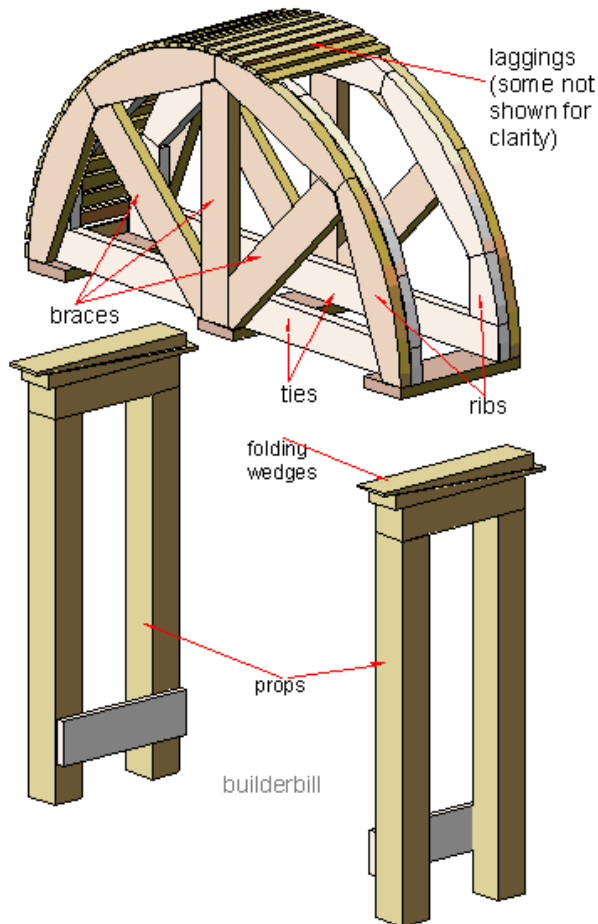


# **“A SPECTACLE OF MARVELLOUS BEAUTY” DOMES AND OTHER HISTORIES»**



# DOMES AND OTHER HISTORIES

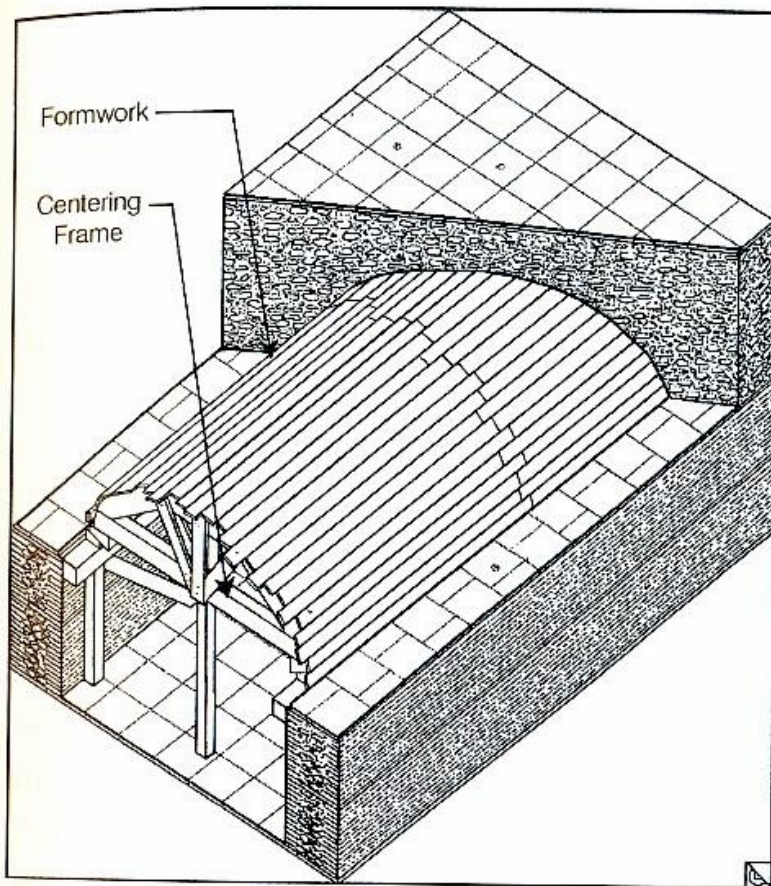


The construction of the semicircular arch relies heavily on the use of **centering** or **scaffolding** in order to create the correct form.

This **formwork** is necessary for both stone and concrete arches in order to support the tons of weight .



# DOMES AND OTHER HISTORIES



8. Reconstruction of wooden centering for concrete barrel vault.

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 in the sides of buildings** that suggests that these were used to hold beams to support platforms needed for scaffolding .



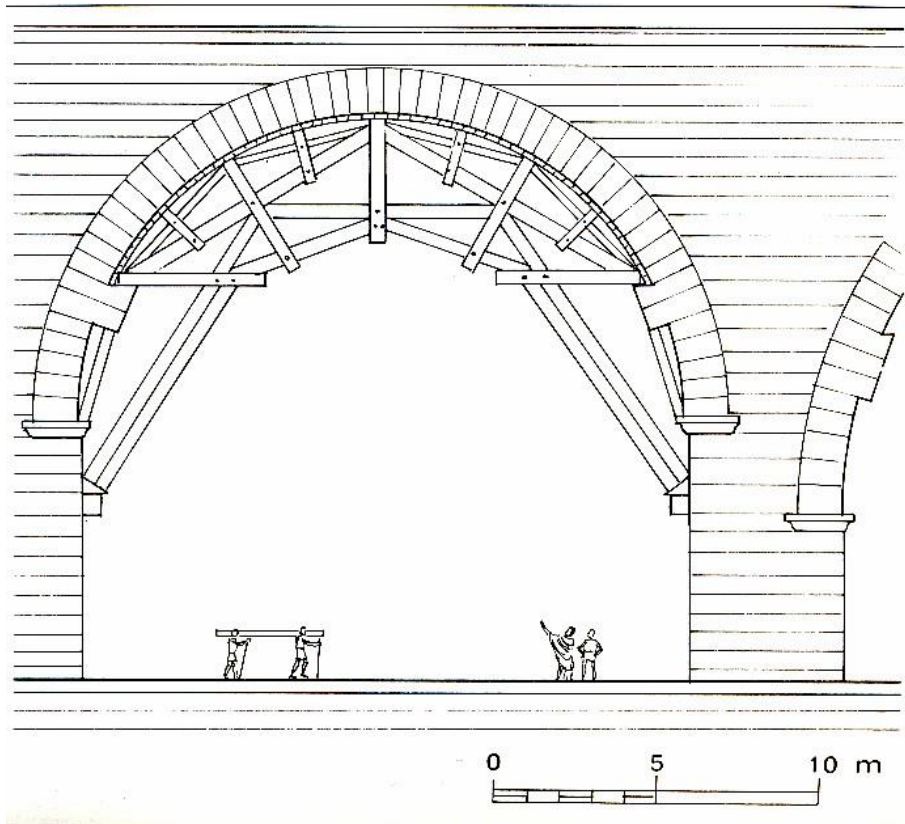
# DOMES AND OTHER HISTORIES



Pont du  
Gard,  
France.



# DOMES AND OTHER HISTORIES

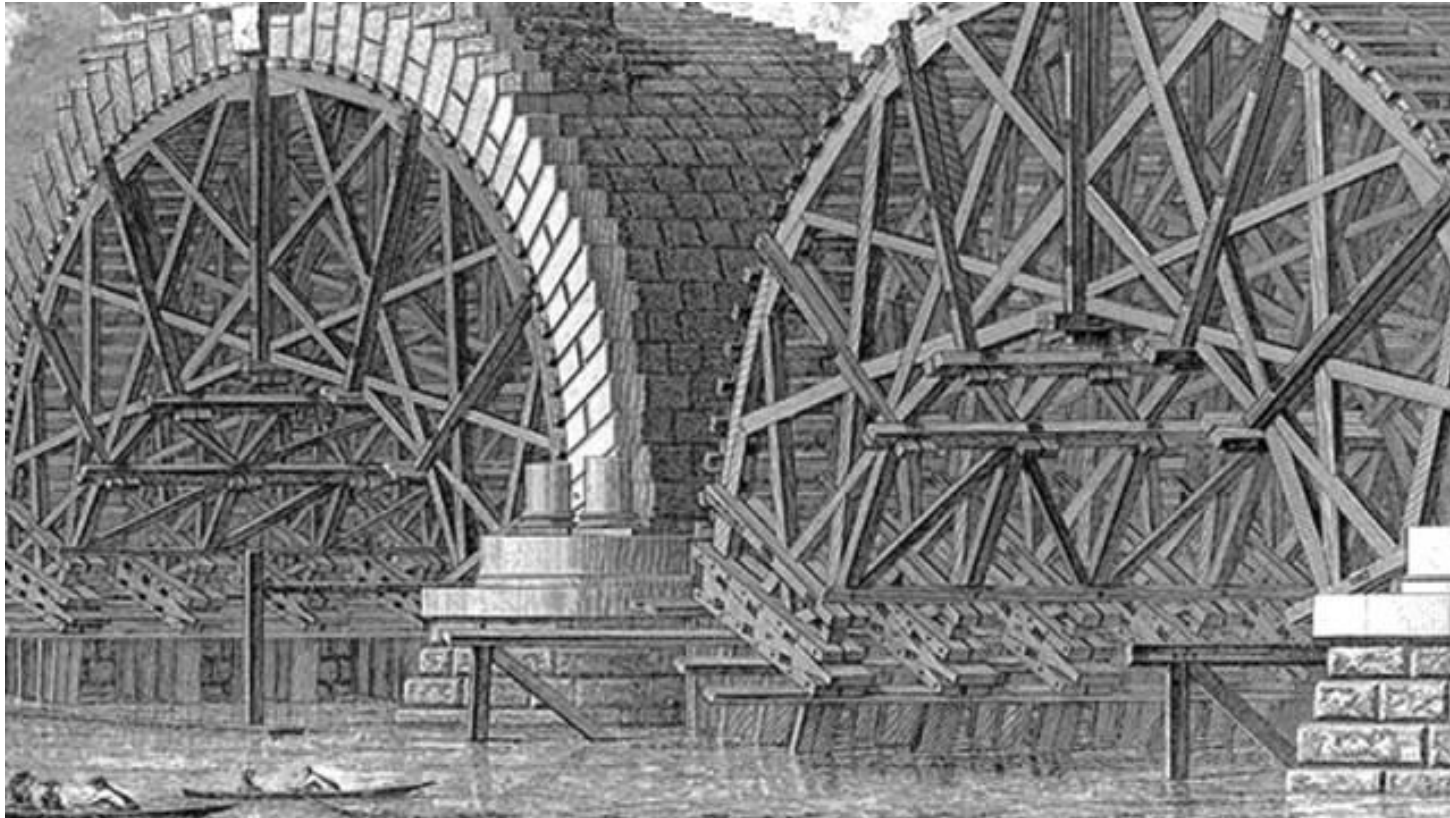


Further evidence is that on arches still standing today **projecting stones** can be seen in the arch. These projecting stones is where the formwork for the arch would have rested and are **convenient for when any repair work** on the arch must be done.

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



G. B. Piranesi, View of the method of construction of the proposed new bridge at Blackfriars in London, 1766.



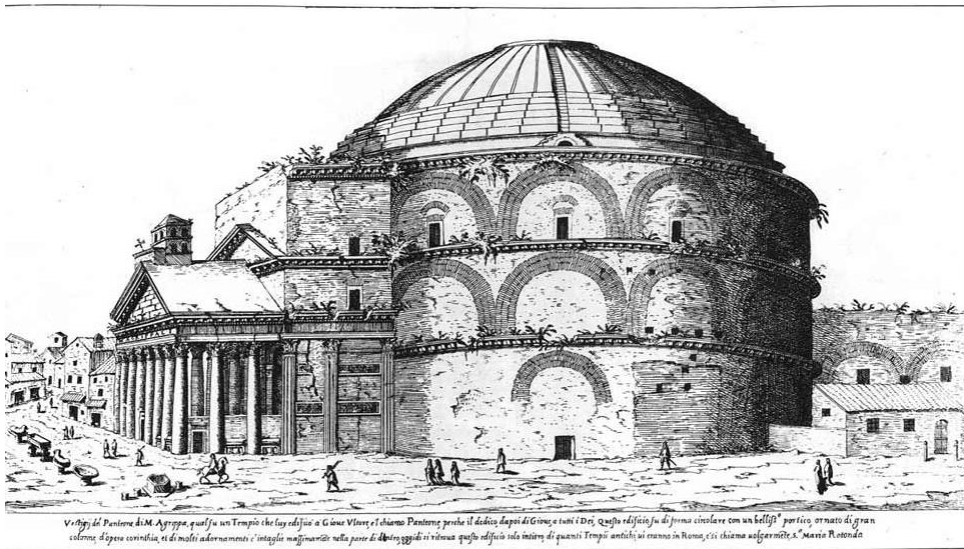
# DOMES AND OTHER HISTORIES



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 independently 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.

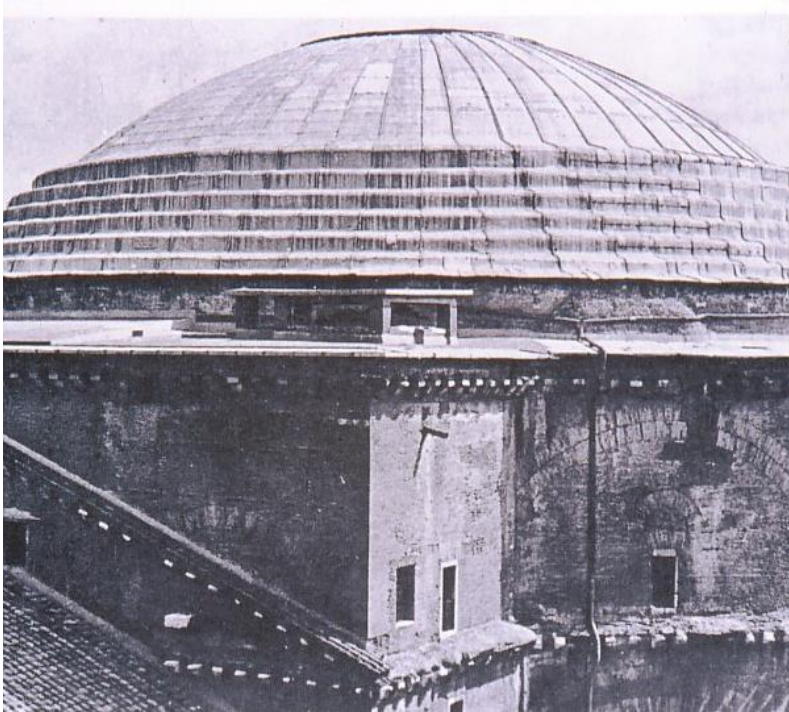


# DOMES AND OTHER HISTORIES

- 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 used the term **«monolithe»** to describe Roman concrete when he raised the issue of **lateral thrust of vaults**. He noted 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**.



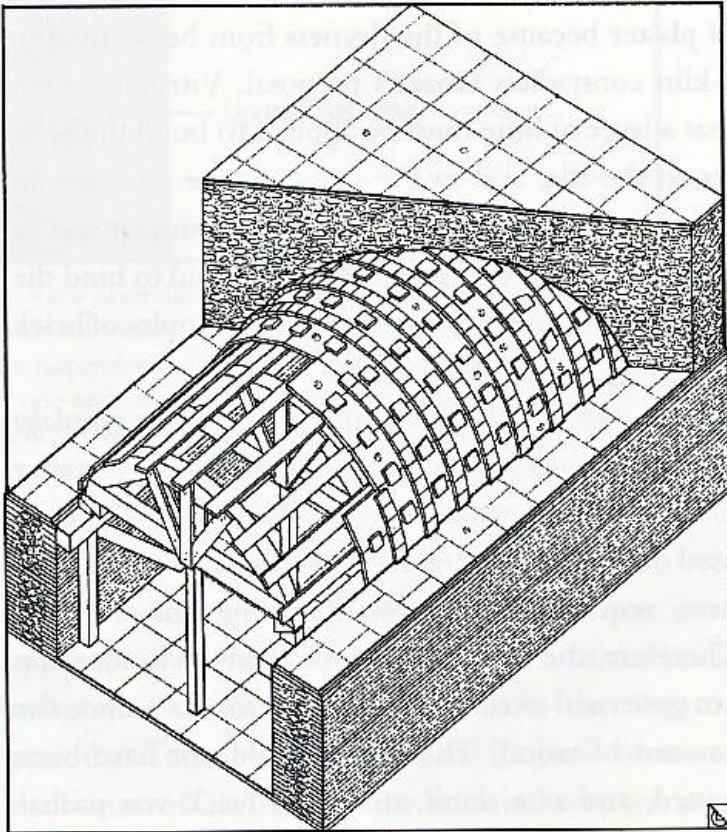
# DOMES AND OTHER HISTORIES



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*.

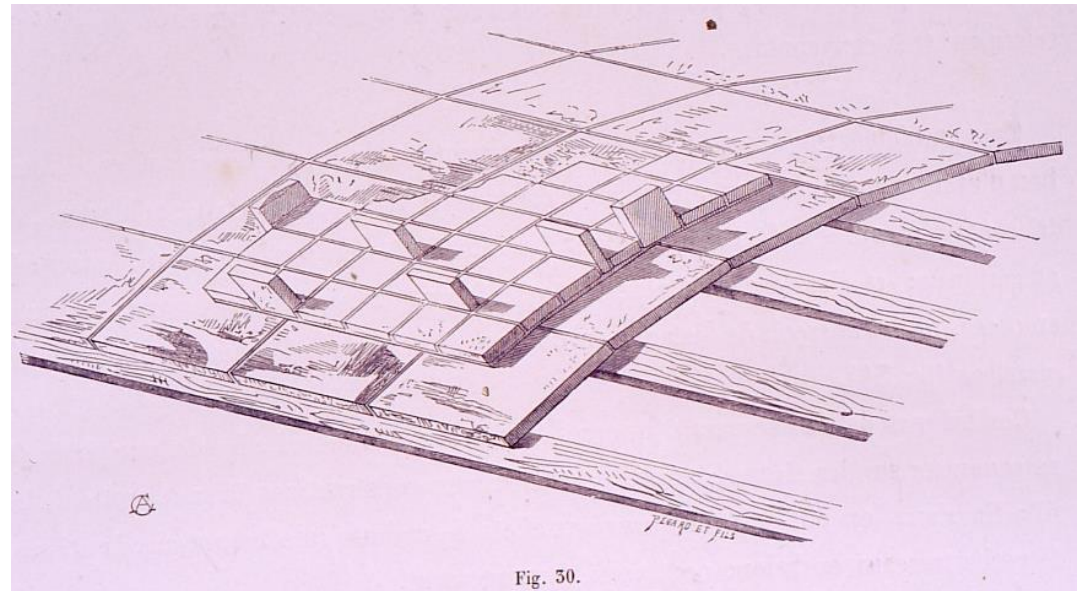
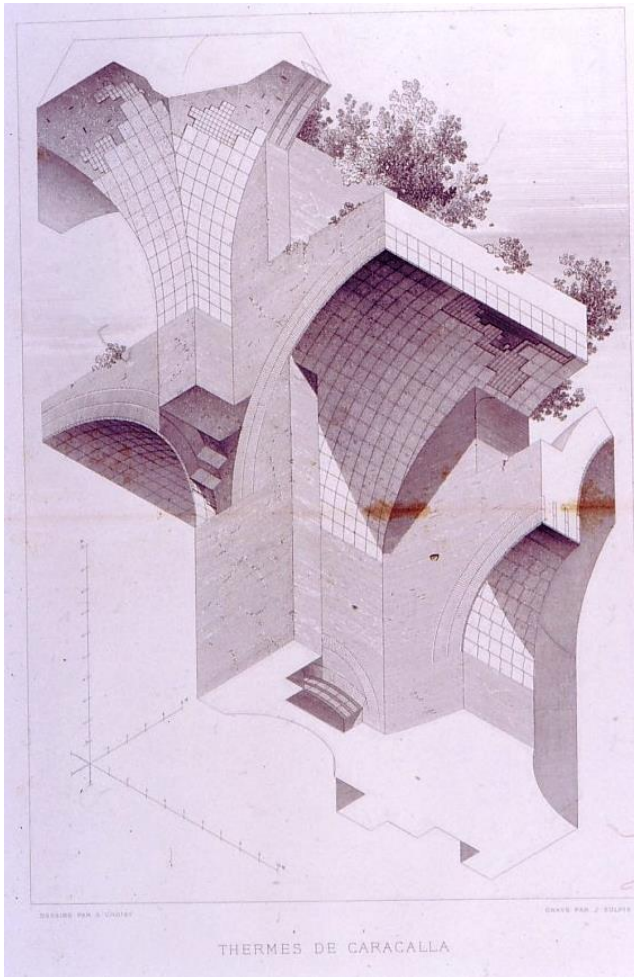
To solve the problem of the formwork adhering to the concrete during the II<sup>o</sup> century a.C. a lining of bricks was placed over the formwork.

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



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

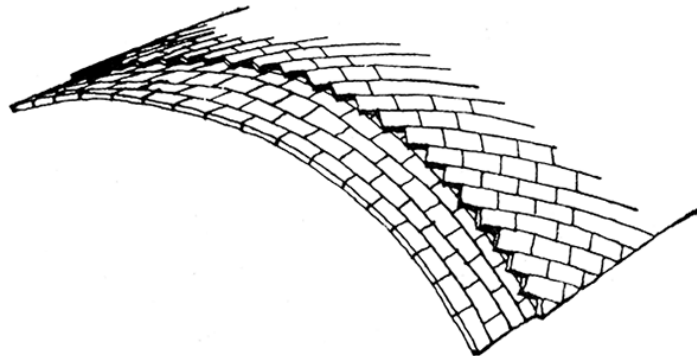
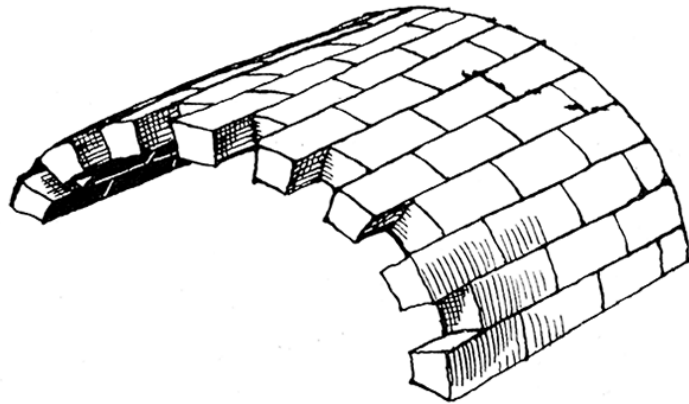


The underground galleries of the Caracalla's Baths.

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



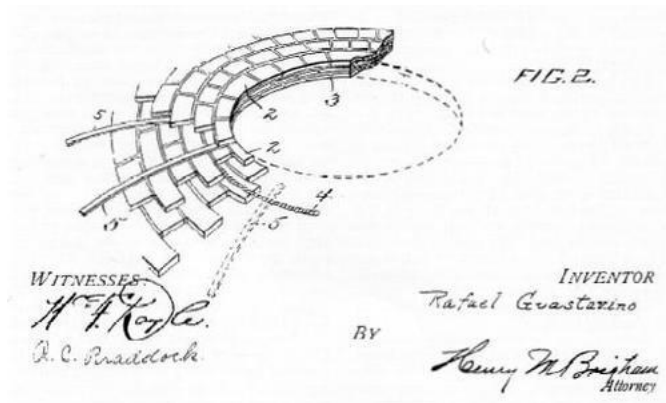
The **tile vault** appears to have been developed by Moorish builders near Valencia, Spain, though it quickly spread to become common throughout the Mediterranean region.

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 20<sup>th</sup> 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.



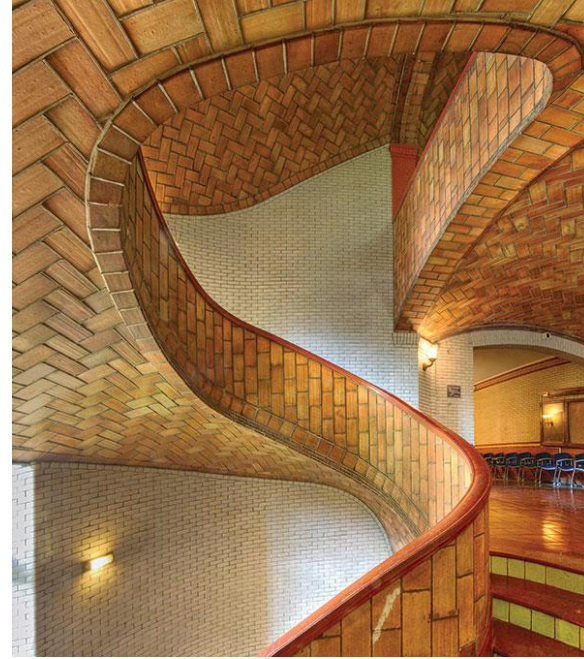
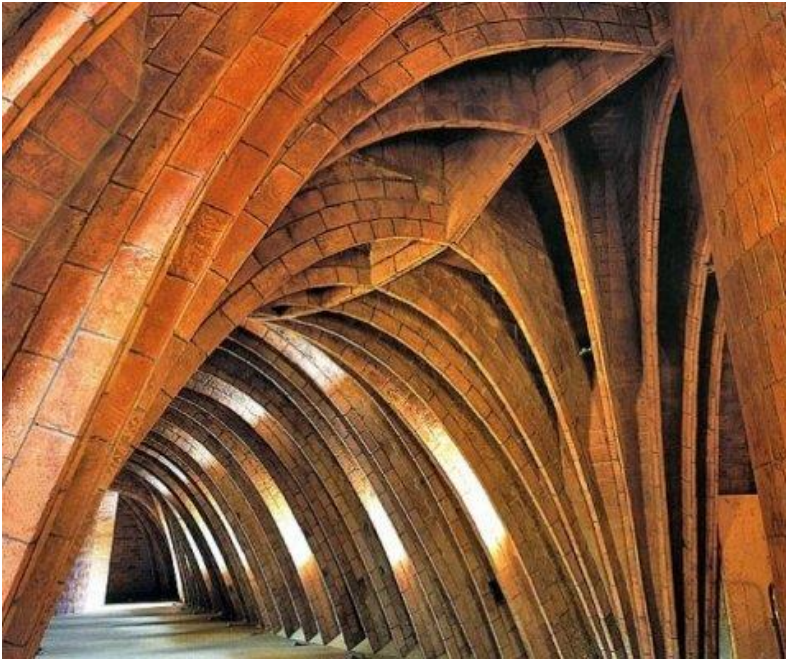
# DOMES AND OTHER HISTORIES



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.



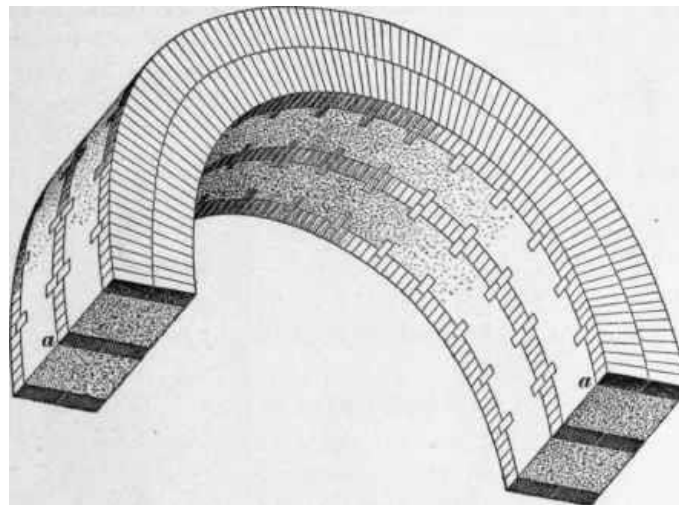
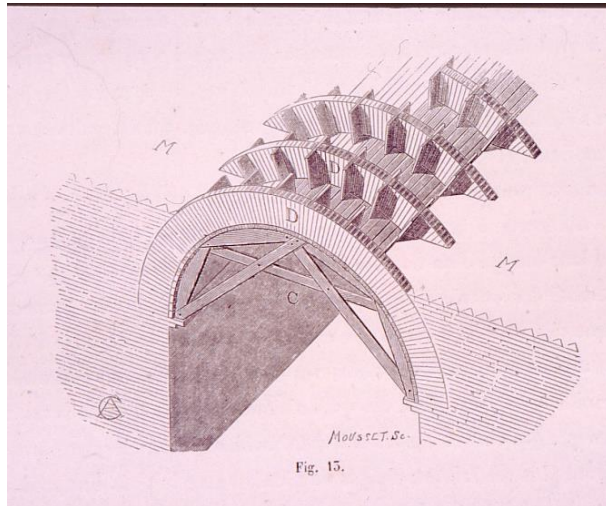
# DOMES AND OTHER HISTORIES



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

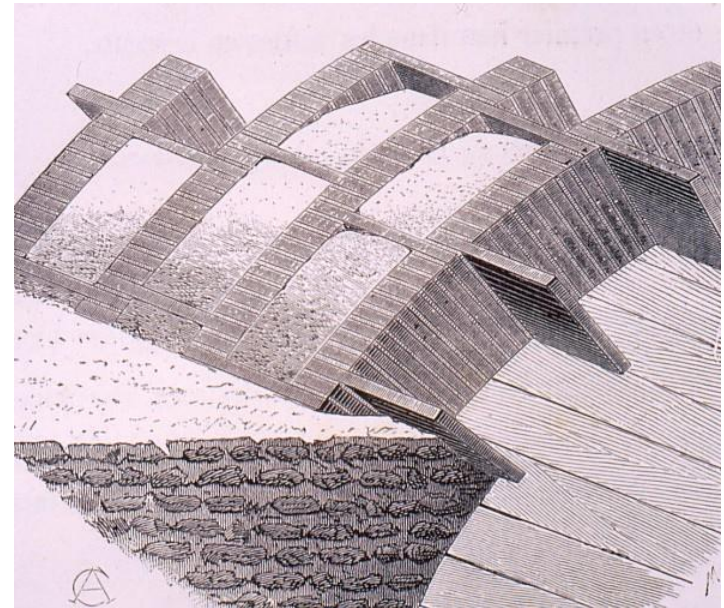
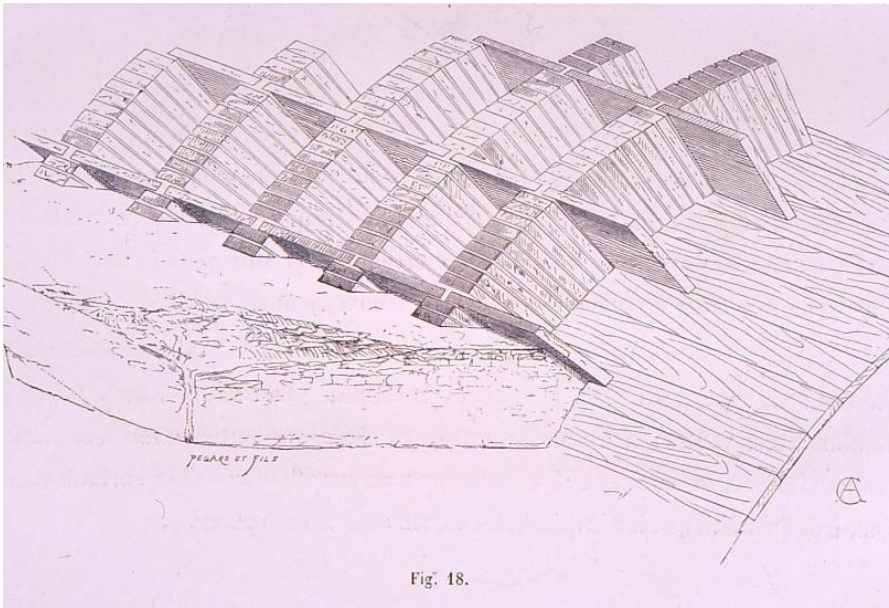


.Starting from his premise that the Romans were trying to be as economical as possible with their materials, **Choisy** interprets the Roman **vaulting ribs**, which often consist of a brick latticework construction as an attempt **to reduce the number and size of centering frames**.

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.



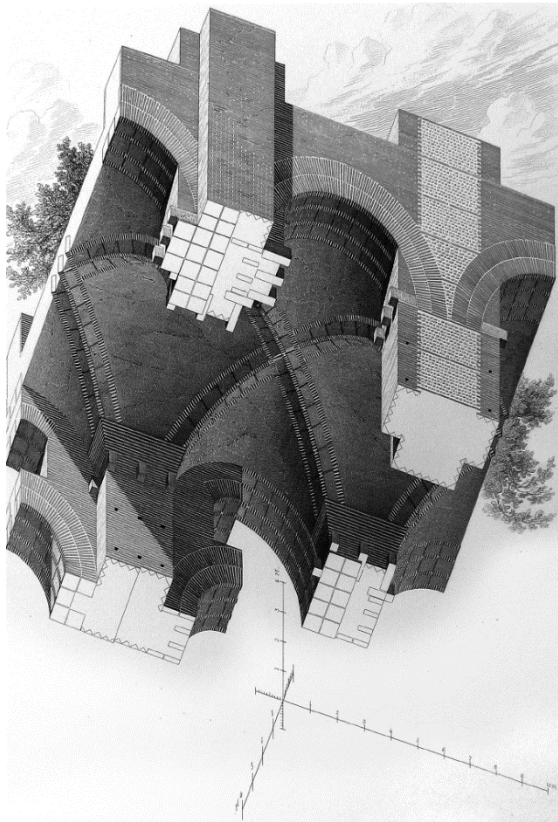
# DOMES AND OTHER HISTORIES



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



# DOMES AND OTHER HISTORIES

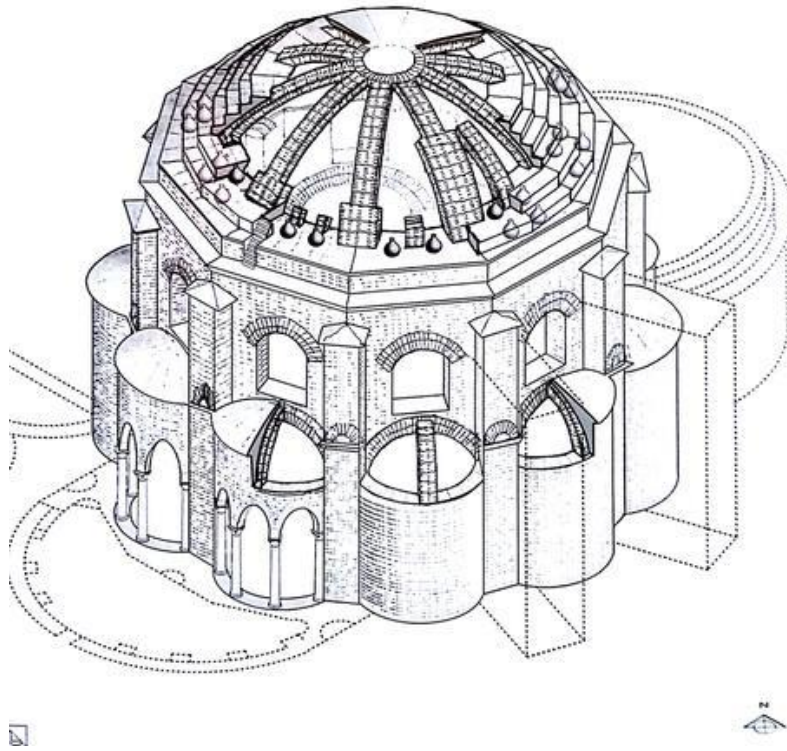


One of the great debates in Roman construction is whether **the ribs** **functioned only during construction** thereby ceasing to play any structural role after the hardening of the concrete, or whether **they continued to play an active role** during the life of the structure.

The Maxentian substructure on the Palatine (4<sup>th</sup> 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.



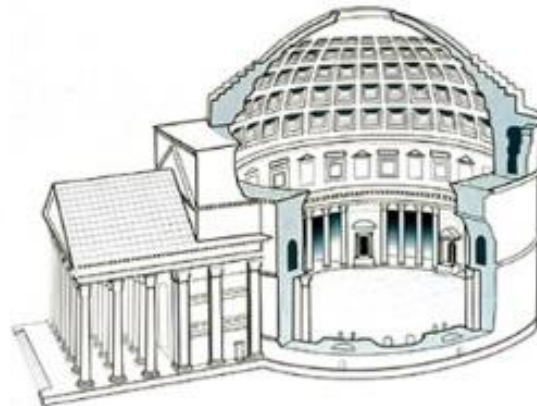
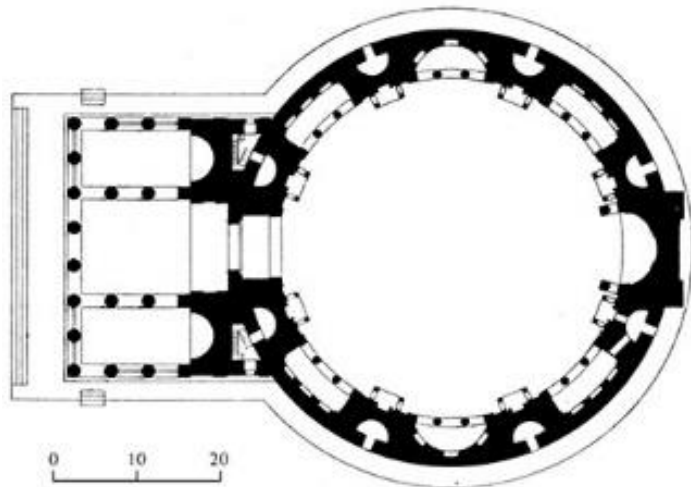
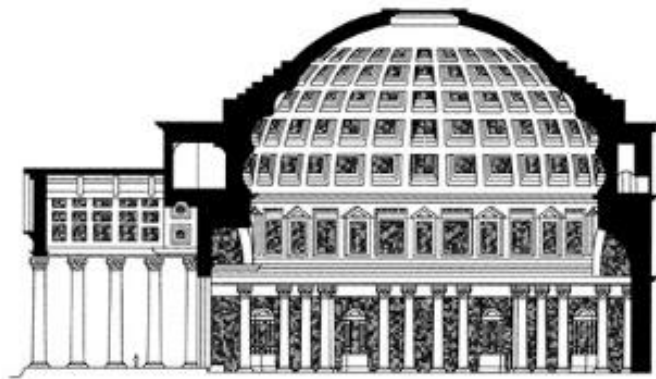
# DOMES AND OTHER HISTORIES



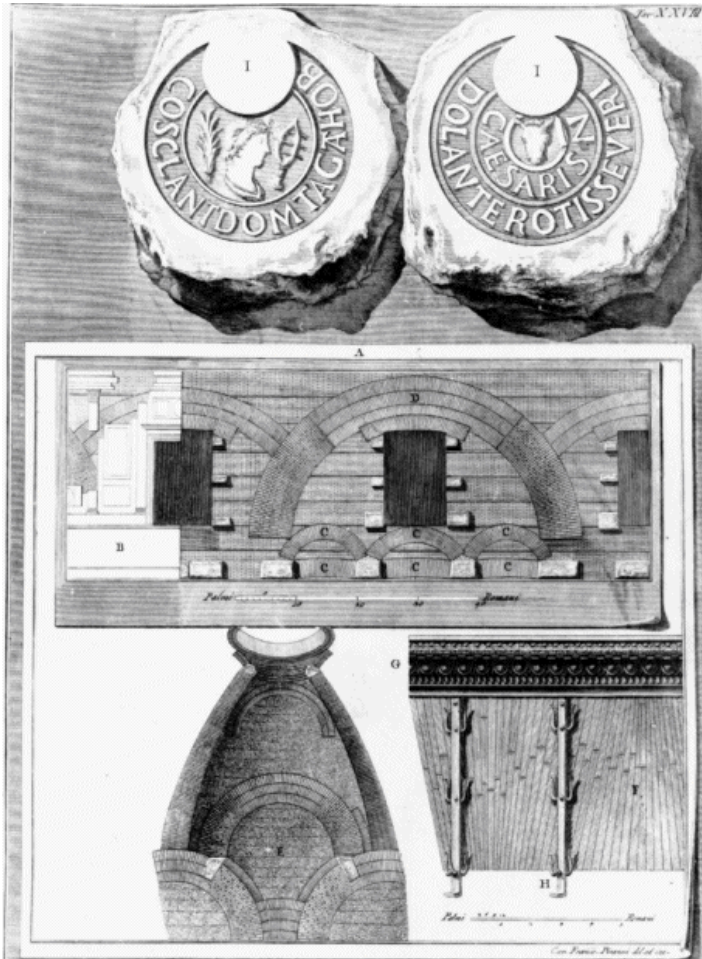
Choisy stated that «**this internal frame was useful during construction only.** It allowed the vault to be built up; but it loses its value and its role as the mass becomes solid; finally, once the mortar consolidated, it ceases to have an independent existence, and does not appear any more in the vault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



# DOMES AND OTHER HISTORIES



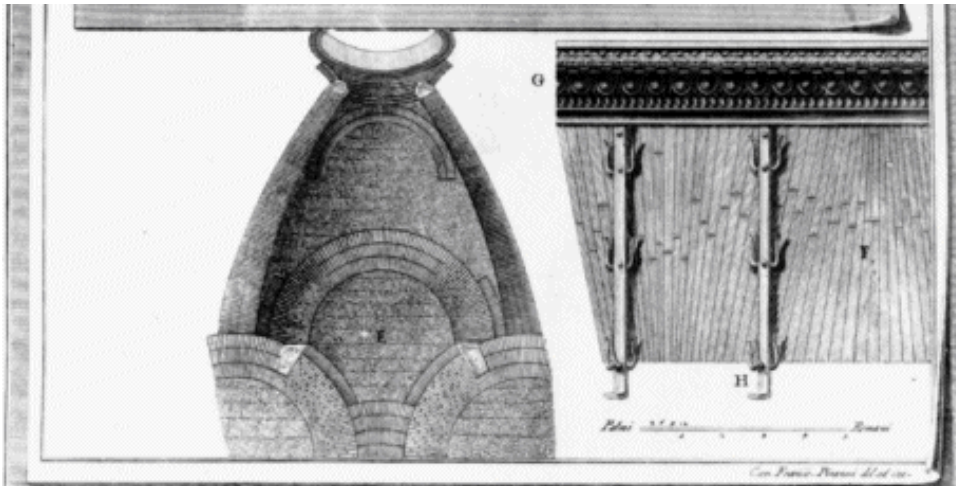
# DOMES AND OTHER HISTORIES



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. 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

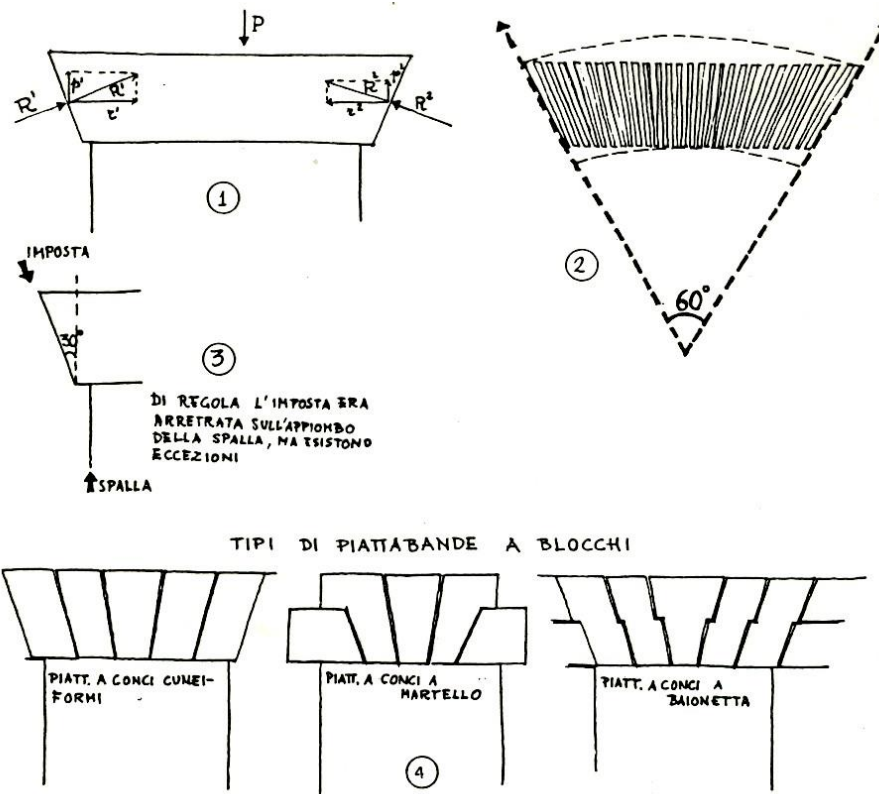


In the lower third of Piranesi's plate, the perspectival drawing is entitled “**Dimostrazione dell’ottava parte della cupola, come si vede quando fu spogliata dell’antica intonacatura**”.

Above the attic arches Piranesi drew a **system of ribs and compartments**, which would have numbered eight in all.



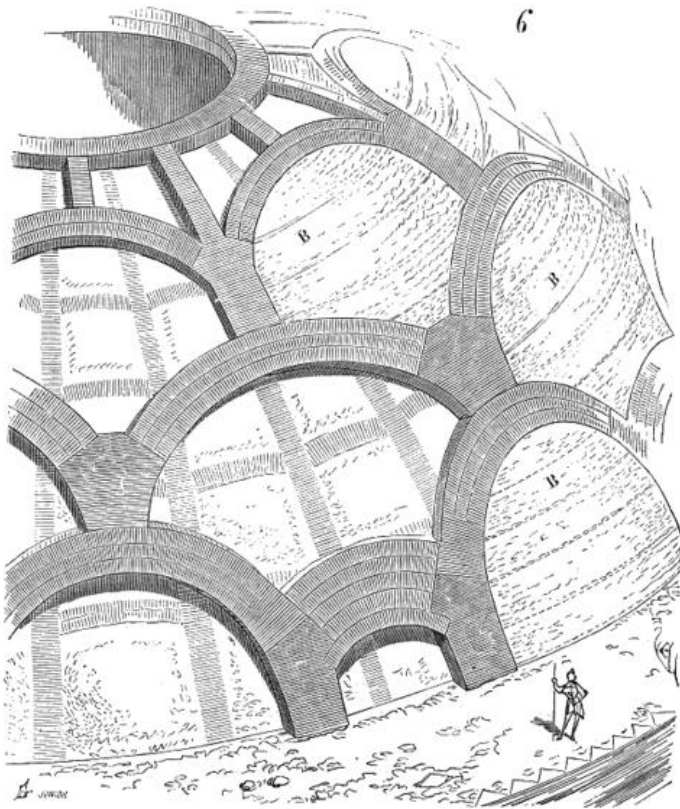
# DOMES AND OTHER HISTORIES



The **flat arch (even lintel arch)** is very common in is not a strong construction. To be self-supporting it must be of such a size that a **segmental arch** of proper radius and sufficient depth can be drawn on its face.



# DOMES AND OTHER HISTORIES

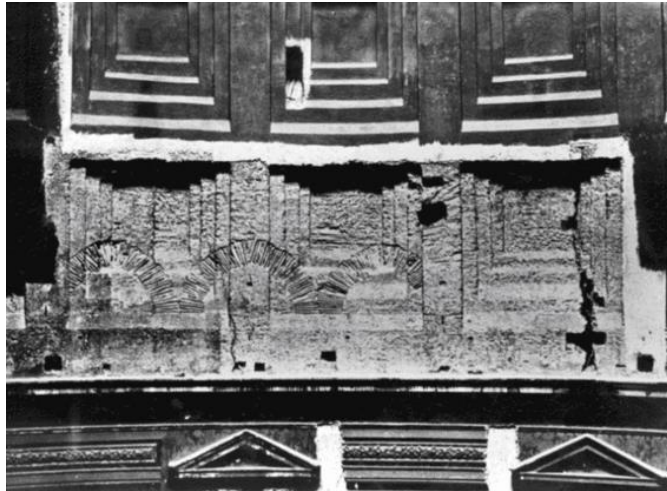


**Viollet le Duc** based his interpretation of the construction technique of the Pantheon dome upon Piranesi engravings and **conceived a double shell.**

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 (bottom).



# DOMES AND OTHER HISTORIES

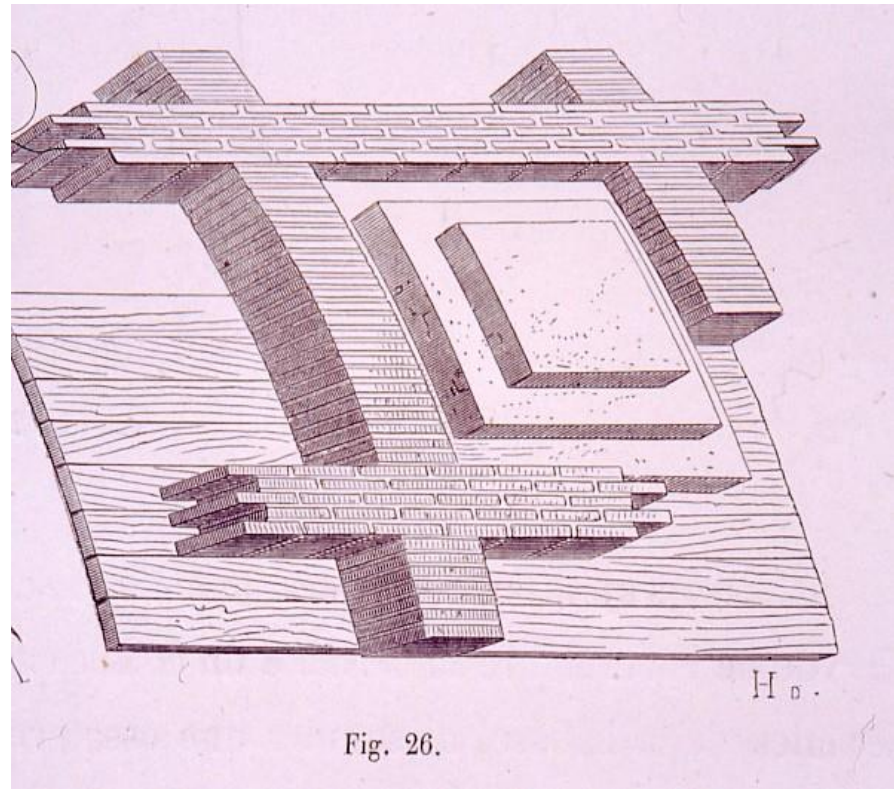


The **upper coffers** of the Pantheon dome with the **brick ribs**.

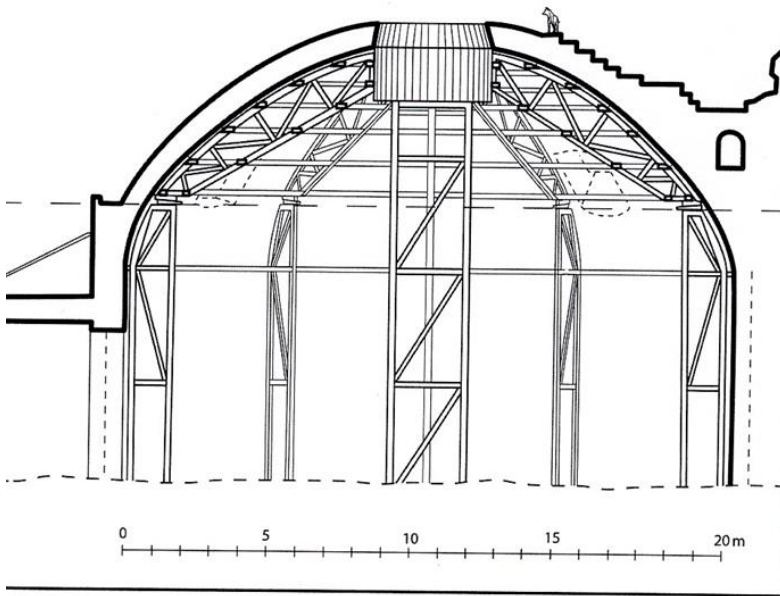
Whatever use the brick ribs served during the construction, perhaps in shaping the coffers, they delivered no diagonal thrusts. Once the building cured these ribs **were part of the dead weight**, all **thrusts** in the structure being **vertical**.



# DOMES AND OTHER HISTORIES



# DOMES AND OTHER HISTORIES



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

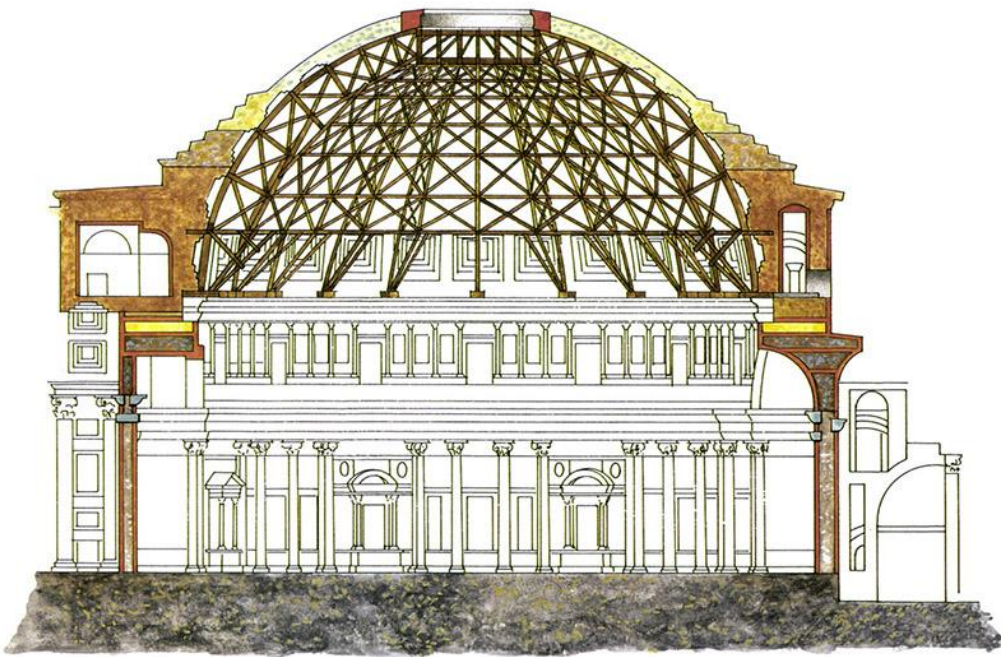
One of the questions regarding the centering of the Pantheon dome is whether it was supported from the ground or if so to what degree.

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 **"flying" centering** propped against a ring at the oculus with no ground support at all.

A third possibility is one that falls somewhere between the two extremes and employs a **central tower for support under the oculus**, as in the Mercury Temple at Baia.



# DOMES AND OTHER HISTORIES



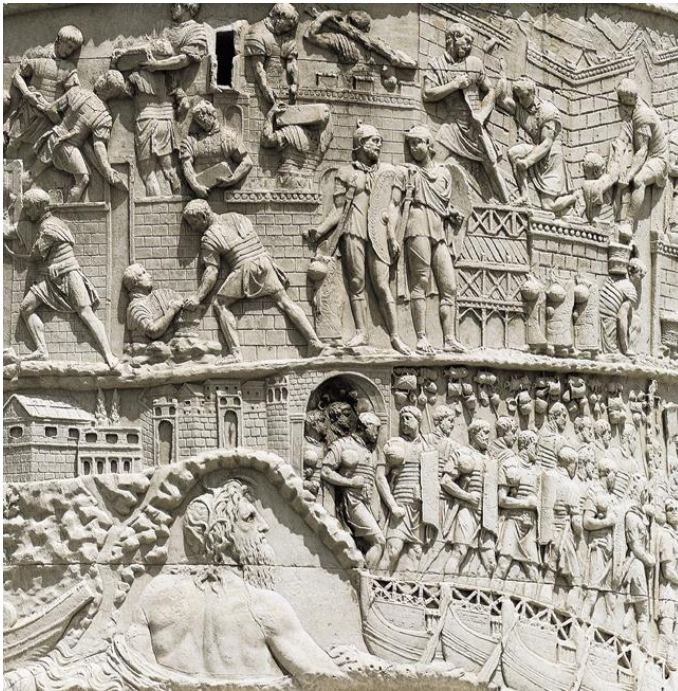
This comes to about **26 m.**, which is approximately the same as the span of the Basilica Ulpia trusses.

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 proposals the **centering frames** themselves would have been **arranged radially** in order to determine the appropriate form, so the maximum distance that 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**.



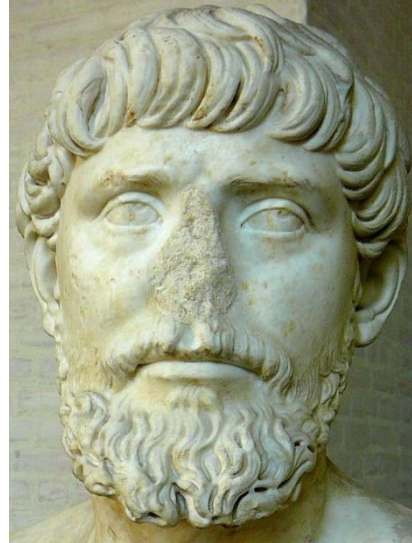
# DOMES AND OTHER HISTORIES



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



One work by **Apollodorus does survive**, the ***Poliorketica*** (c.AD 100), a **treatise on siege machines** that has been preserved in the corpus of Byzantine poliorcetics (the military art of siege warfare). Rasch has argued that the idea of a large central tower for dome centering was developed for the Pantheon by Apollodorus, who based the design on the siege towers described in his treatise.



# DOMES AND OTHER HISTORIES



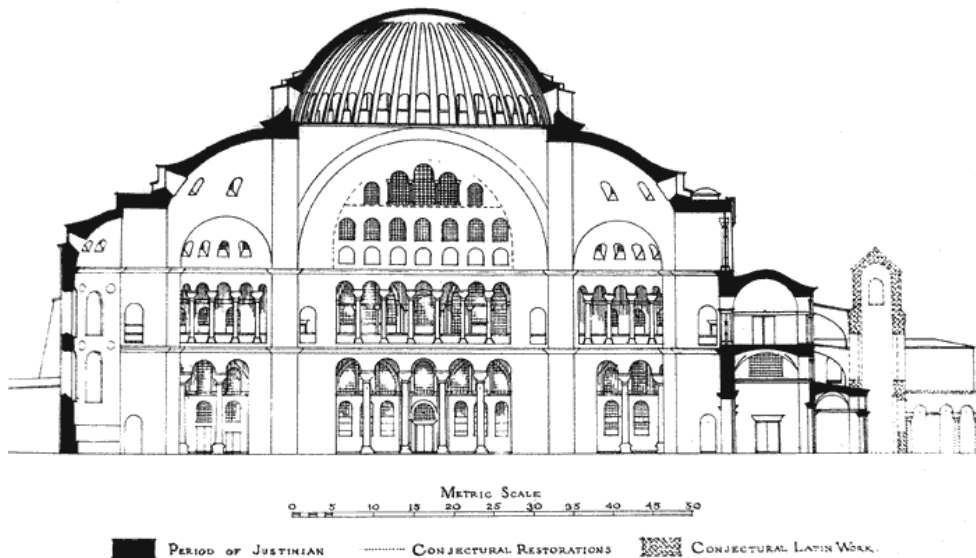
# DOMES AND OTHER HISTORIES



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

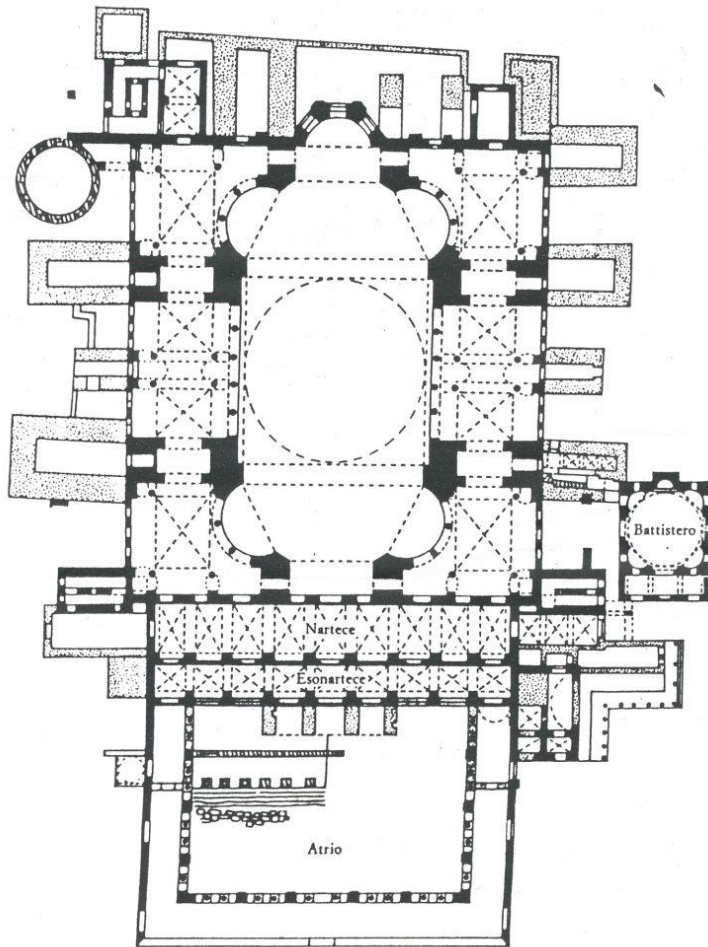


The central dome rests on a circular base, which is formed by four main arches and pendentives.

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.



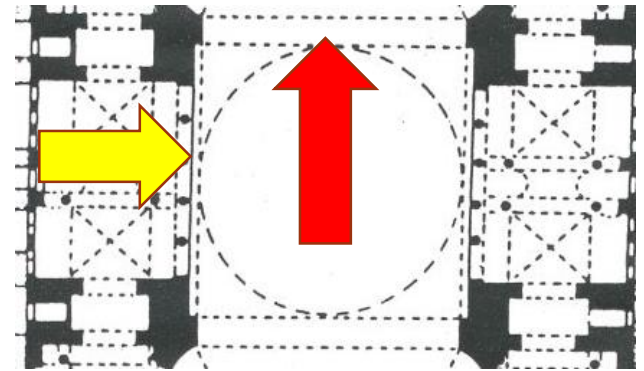
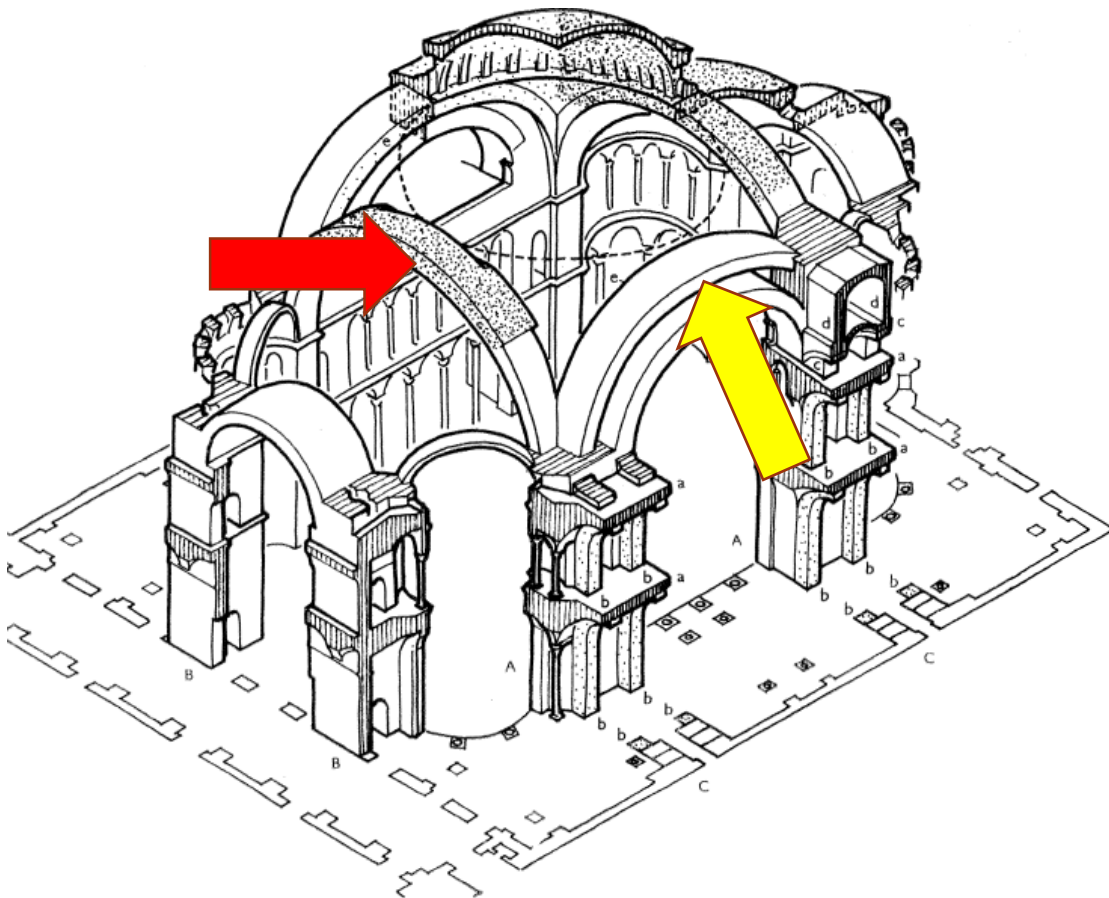
# DOMES AND OTHER HISTORIES



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.



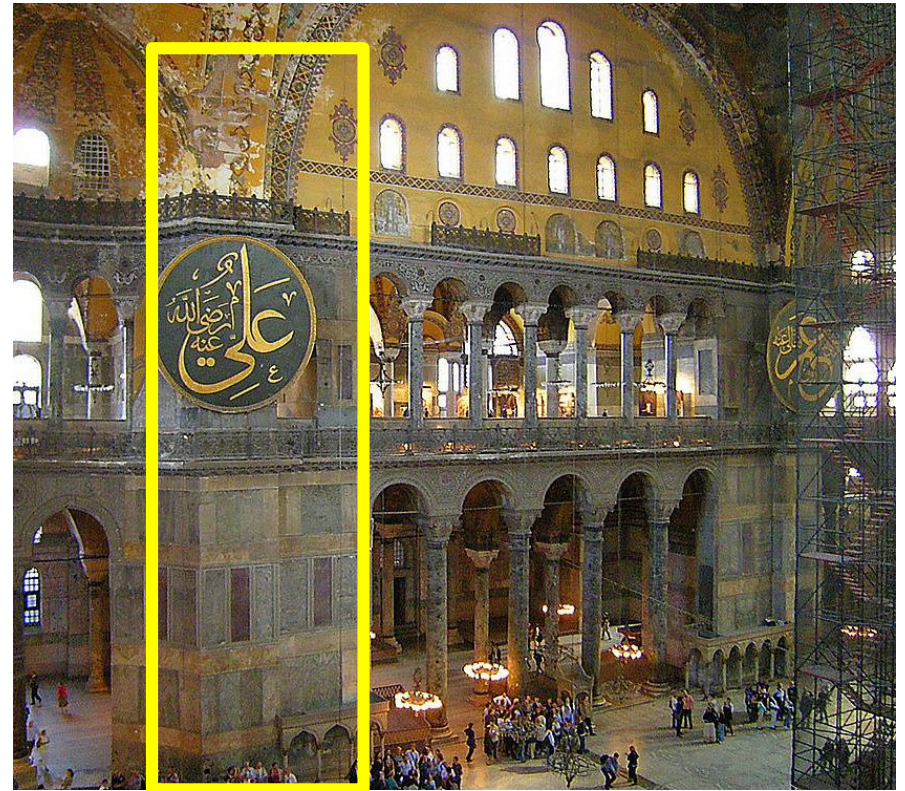
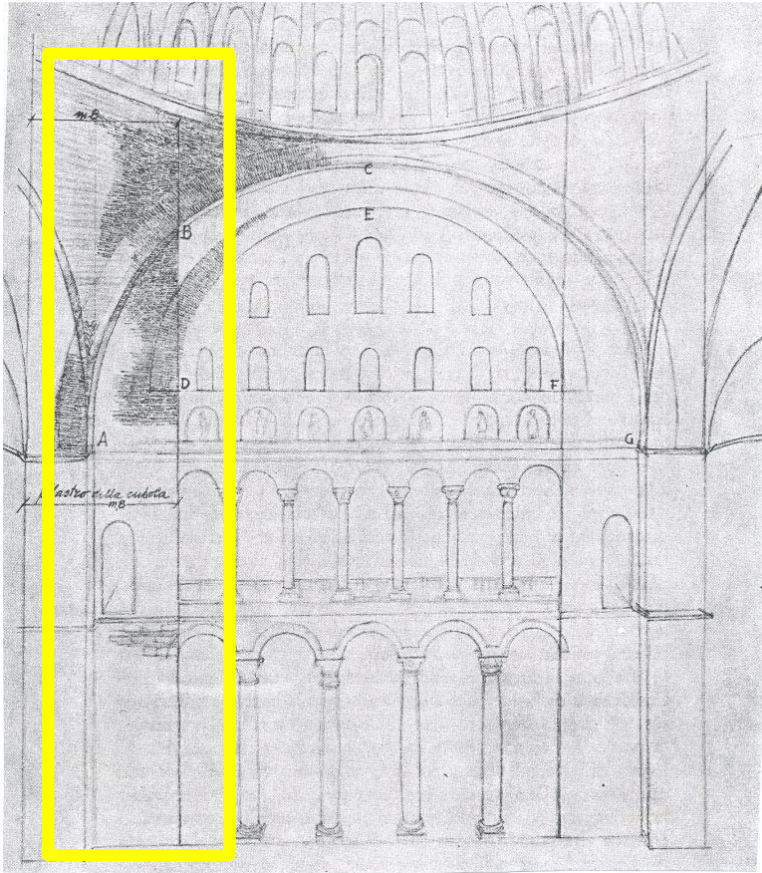
# DOMES AND OTHER HISTORIES



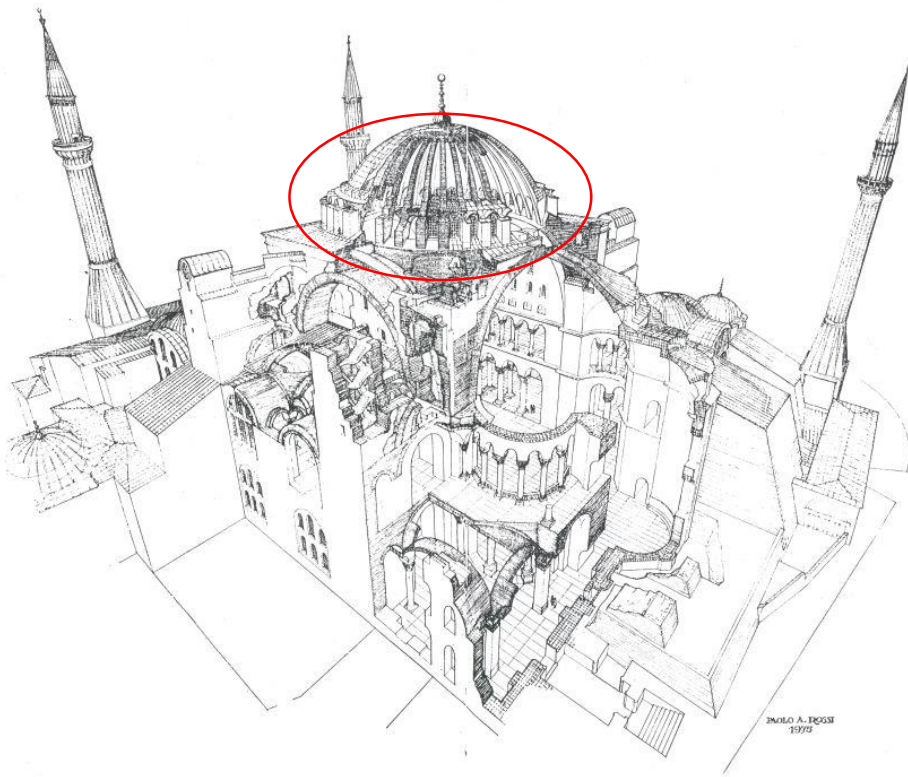
Main arch (east and west ) = 31 meters (red arrow).  
Minor arch (embedded in the wall), 22 meters ca. (yellow arrow).



# 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 openings of the drum.



# DOMES AND OTHER HISTORIES

