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# Structural evaluation of the dome of Küçük Ayasofya - Sts. Sergius and Bacchus

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## Abstract

The church of Sts. Sergius and Bacchus, or Küçük Ayasofya Mosque as it is now called, is a Byzantine monument of 527-536 A.D. in İstanbul. It is the first fully centralized architectural form used in the Byzantine Capital.

An ongoing structural study supported by the Research Fund of Yıldız Technical University is aimed at providing a better understanding of the structural history to contribute to the preservation problem of this early Byzantine edifice. As the investigation proceed, new perceptions about the structure are coming to light.

The geometrical and structural evaluation of this sculptural dome is the principal focus of this paper.

## 1 Introduction

Küçük Ayasofya Mosque, the former Church of Sts. Sergius and Bacchus, is an important edifice of Byzantine architecture constructed during the early reign of Justinian between 527-536 A.D.. It is consisted of an octagonal nave enlarged by four semi-circular niches surrounded by two storey ambulatory on three sides forming an irregular square hall, a rectangular narthex on the west and a projecting half hexagonal apse on the east (Figure 1b). This church contemporary to St Sophia is of great importance as the first fully centralized form of the Byzantine Capital.

This monument, mainly studied by art historians, has always been evaluated to have similarities with the contemporary single focal domed monuments as Sts. Sergius and Bacchus Leon at Bosra (Figure 1a), St. Vitale at Ravenna (Figure 1c) and Palatine Chapel at Aachen (Figure 1d). They are best examples of enlarging a space of a single central dome by other roofing systems. As it is

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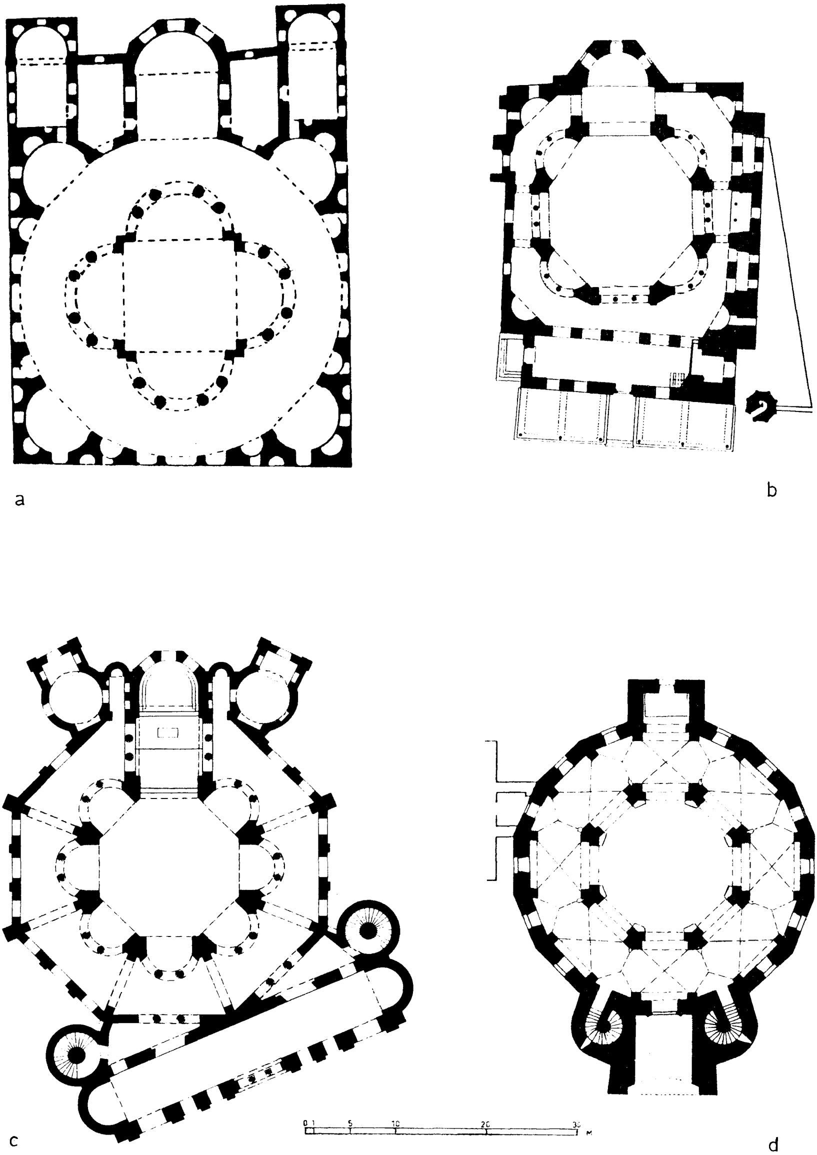


Figure 1 Churches in centralized plan forms

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seen in their plans, the arrangement of piers, the niches and galleries around the central nave resemble similarities. When taken structurally, especially in the formation of their central dome, they exhibit quite different characters. The structural characteristics of the church at Bosra of 511 A.D. can not be stated for nothing survives of its original structure [3]. In St Vitale at Ravenna of 532-547 A.D., the central nave enlarged with niches between each pair of eight piers has a dome of a semicircular profile above an elevated drum. The transition of the dome to the octagon is through eight pendentives supported on piers linked by arcades. The palatine Chapel at Aachen of 777-794, which the upper parts have been twice restored [2] has a dome made up of groin vaults which give it a tapered appearance. These monuments might carry inspiration from each other in using a centralized form. But structurally they are different.

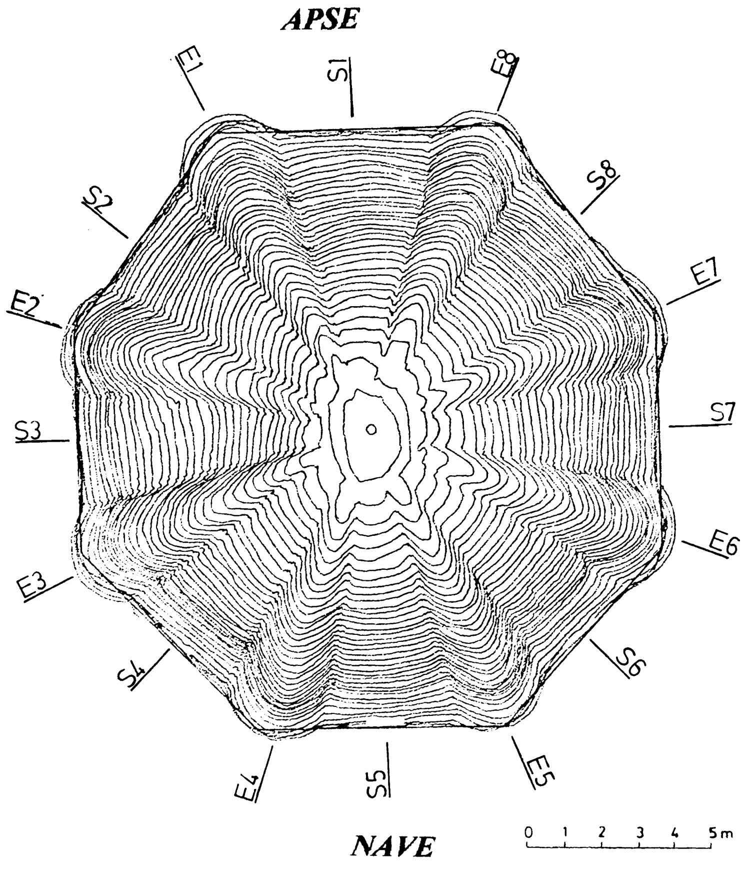


Figure 2 Photogrammetric map of the dome

## 2 Photogrammetric Survey

The photogrammetric survey of the dome is carried out to understand and record the actual state as accurate as possible. To make drawings of such a complicated dome in a classical measuring way was impossible. Because the dome wasn't high enough, the photogrammetric pictures are taken down to the windows middle height levels. The section to the base is extended in classical geotechnical methods.

As seen in the contour map of the inner surface of the dome in figure 2, the curvature is flat at the top and steep at the bottom part. Approxsimately the height of the dome from top to the window tops is 4.5m and to the base is 7.5m. In drawings of the dome map, its taken from top down 3m at 10cm intervals and from there down 0.7m at 20-30cm intervals and from there down to the window tops at 50cm intervals in y-coordinate. It is easy to see the irregularities of the curvature in the drawings which sensitively reflect the characteristic of the dome profile. Because the aim is to examine the dome surface geometrically, determining the seasons for those irregularities are not attempted at this point.

The dome is made up of two types of surfaces where one is concave and take place over the piers, the other is flat and have window openings at the bottom (figure 3). Since the ondulating form of the dome can be noticed externally, the thickness of the dome is assumed to be equal everywhere. The profile curvature of the intrados may represent the middle surface of the dome.

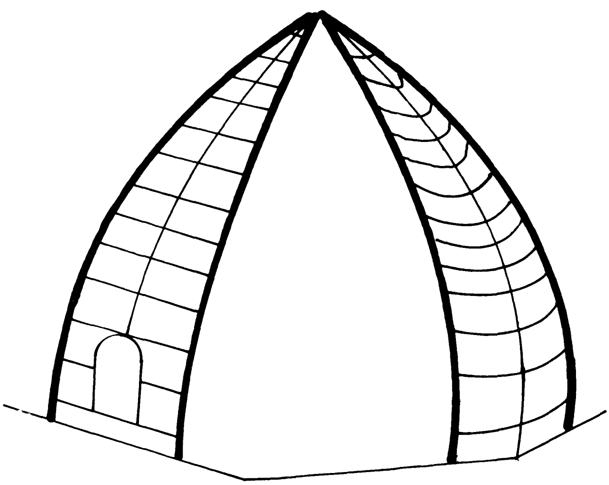

Figure 3 Dome surfaces

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# 3 Geometry of The Dome

For the geometrical investigation of the dome, profiles of the intrados are taken from each concave slices and flat slices as seen in figure 2. These are named as S1...8 for the flat part and E1...8 for the concave part. Except the few curves taken from the deformed parts of the dome, almost all the curves show the same curvature. Figure 4 shows the profiles S4 and E5 from center to base. The studies on finding the curvature of the profiles go on.

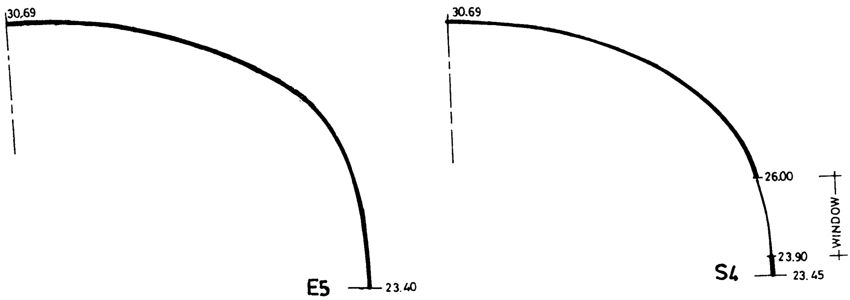


Figure 4 Profiles of the dome

As it is seen in the photogrammetric map, the 16 sided dome is formed by alternatively arrangement of two types of translational surfaces, generated by the motion of a plane curve generatrix, parallel to itself along another plane curve directrix, that lies in a plane at right angles to the generatrix (figure 5).. The flat parts of the dome are cylindrical surfaces where the horizontal straight line is the generatrix and profile curve is the directrix. The concave parts are of elliptic paraboloid surfaces where parabola is the generatrix and profile curve is the directrix ( figure 3).

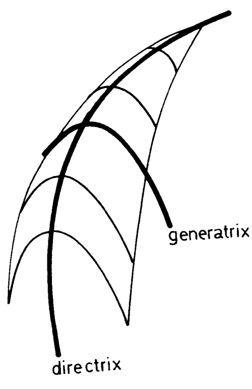


Figure 5. Translational surface

# 4 The Structural Evaluation of The Dome

In such brick masonry buildings as Küçük Ayasofya Mosque, the deficiency of tensile strength of the masonry limits the span of the structural elements. The total strength has to depend more on the compressive strength of the materials rather then mortars for such joints become loosen with time.

The shape of the surfaces determines the bearing mechanism of the systems. In a cylindrical surface the loads along the profile curve are distributed in arch mechanism. In longitudinal direction, the top parts are in compression while the bottom parts are in tension. In the formation of the dome, these surfaces are arranged as if forming a groin vault, but laid apart from each other. Their bottom parts where the longitudinal stresses become tensile are pierced by arched window openings to change the tension stresses to the arch mechanism ( figure 6 ).The elliptic paraboloid surface in between the cylindrical surfaces are arranged at the tops of the piers forming the octagonal nave. In this doubly curvature surface, the loads are transmitted to the boundaries through arch mechanism in two axes. This way a very efficient surface for masonry construction was achieved. The shapes of the two types of surfaces must be organized so properly that it didn't need any salient rib at their intersections. In the horizontal termination of the lower part of the elliptic paraboloid surface, which is in inclined position, a wall of the pier in the form of a low drum was constructed to buttress the arch forces of the surface.

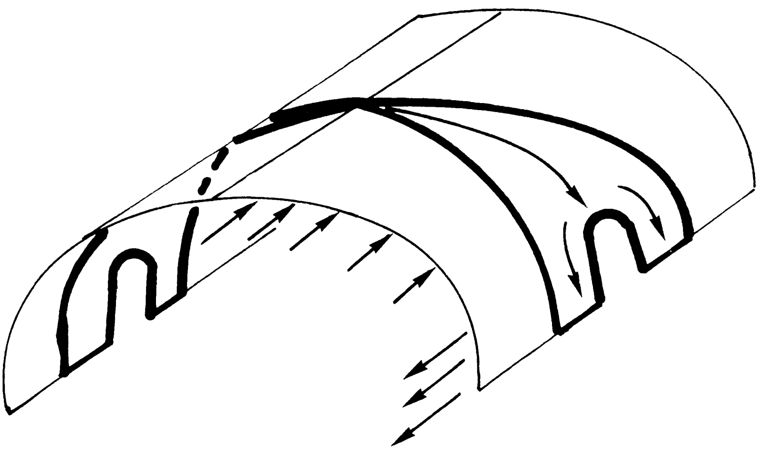

Figure 6

## 5 Conclusion

The structure of the 16 sided dome of Sts. Sergius and Bacchus of 6th century is outstanding with its geometry and its architectural sculpture. With the fully centralized plan form, it proposes a new way of designing a religions building. With the dome geometry, it displays invention and architectural ability. It was designed and built when nothing comparable was around. Formation of masonry dome using elliptic paraboloid surface was a technical innovation.

The geometrical layout of the dome of the church of Sts. Sergius and Bacchus explains its stability to numerous changes and earthquakes the edifice had experienced during its life time. The structure form is not arbitrary. It shows that the architect or architects of the church must have been masters of geometry and mechanics.

The reasons for why such a geometry or dome formation found no follow in masonry structure needs to be searched.

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