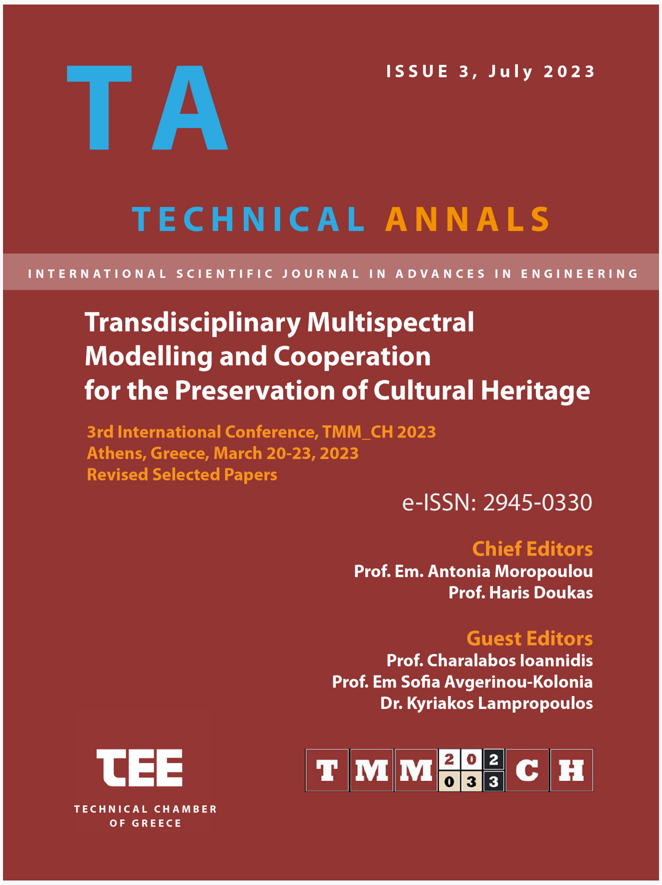
Technical Annals

Vol 1, No 3 (2023)

Technical Annals



Digital documentation of three largest subterranean structures of Hagia Sophia: The passage under the esonarthex, the vaults under the atrium and the hypogeum

Hasan Fırat Diker

doi: [10.12681/ta.36068](https://doi.org/10.12681/ta.36068)

To cite this article:

Diker, H. F. (2023). Digital documentation of three largest subterranean structures of Hagia Sophia: The passage under the esonarthex, the vaults under the atrium and the hypogeum. *Technical Annals*, *1*(3). https://doi.org/10.12681/ta.36068

Digital documentation of three largest subterranean structures of Hagia Sophia: The passage under the esonarthex, the vaults under the atrium and the hypogeum

Hasan Fırat Diker [1[0000-0002-3156-3127]]

[1]Fatih Sultan Mehmet Vakif University, Beyoğlu, Istanbul, Turkiye
hfdiker@fsm.edu.tr

Abstract. The terrestrial scanning project of Hagia Sophia's subterranean structures took place in 2020. This field study enabled the creation of a three-dimensional point cloud model capturing the underground tunnels and structures. Subsequently, in 2022, a more detailed documentation of the older hypogeum within Hagia Sophia was conducted. This study particularly focused on the three largest subterranean structures on the site. The first of these is the passage beneath the esonarthex, delineating a structural transition between the Theodosian and Justinian periods, spanning from the fifth to the sixth centuries. Notably, the discovery of a previously unnoticed column base on the floor of this structure prompted an update to the plan of the Theodosian atrium. The second focus lies on the vaults beneath Justinian's atrium, requiring an architectural visualization update since Schneider's documentation in 1941. These subterranean structures define the boundaries of the no longer physically existing Justinian atrium, and the debris within them awaits excavation to provide further insights. The last structure examined is the hypogeum dating back to the 4th century. This structure underwent a more detailed redocumentation following a partial clean-up and has been digitally visualized.

Keywords: Hagia Sophia; subterranean; atrium; vault; hypogeum; tunnel

1 Introduction

Once precise metric measurements of a structure are obtained, they become invaluable tools for restoration and maintenance endeavors. Moreover, the process of gathering data enables the utilization of 3D information in various formats, making history and architecture more accessible to a wider audience [1]. Undoubtedly, the subterranean aspects of Hagia Sophia warranted such scrutiny. While the monument's superstructure had been digitally scanned numerous times, the architectural visualization of its subterranean elements had been neglected. The fieldwork for the terrestrial scanning project of the subterranean structures at Hagia Sophia took place between June 29 and July 16, 2020. This groundbreaking project marked the inaugural digital documentation of Hagia Sophia's subterranean realm, which spans a total length of 936 meters. Consequently, a comprehensive three-dimensional point cloud model of the underground channels and other subterranean structures was acquired and documented [2]. This documentation and visualization initiative raised awareness about the current state of

Hagia Sophia's subterranean structures, leading the Istanbul Preservation Board to order their cleaning on October 13, 2021. The cleaning process, which began in the hypogeum on November 15, 2021, was paused on December 14, 2021, due to challenging seasonal conditions and the necessity for a more comprehensive, long-term excavation process. Following the partial clean-up by the end of 2021, an improved environment was established, enabling better visualization of the space. Subsequently, in January 2022, the hypogeum, older than the current Hagia Sophia, underwent a more detailed redocumentation. This study primarily centers on Hagia Sophia's three largest subterranean structures: the passage under the esonarthex, the vaults under the atrium, and the hypogeum. These remarkable spaces interconnect via subterranean tunnels traversing beneath and around the structure, delineated on the plan by their section lines (see Fig. 1).

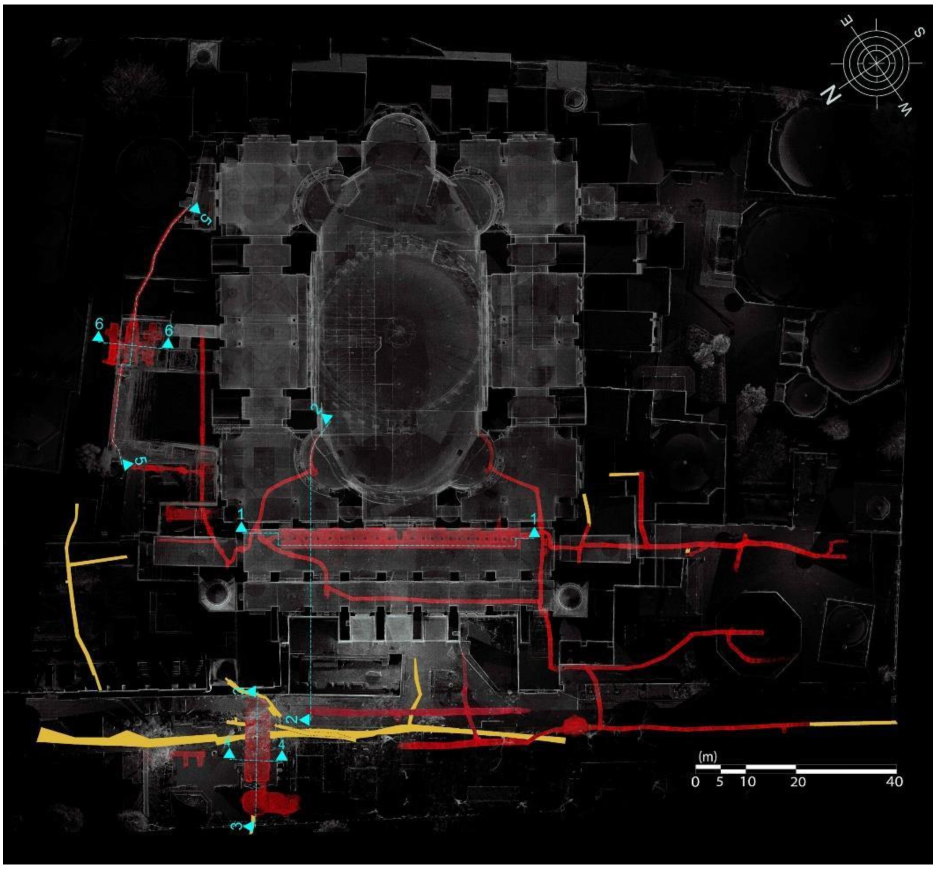


Fig. 1. The plan of Hagia Sophia's subterranean structures features section lines delineated as 1-1 and 2-2 for the passage under the esonarthex, 3-3 and 4-4 for the vaults under the atrium, and 5-5 and 6-6 for the hypogeum. In this representation, the superstructure scanned by the University of Calabria is depicted in grey, while the subterranean structures scanned via laser technology are highlighted in red. The areas that were measured manually are indicated in yellow.

2 Materials and Methods

The scanning process utilized a Faro Focus S 150 Terrestrial Laser Scanner for the passage under the esonarthex and the vaults under the atrium. Equipped with an eight-megapixel HDR camera, this scanner adeptly captured detailed imagery, providing natural color overlays to the scan data, even in low-light underground conditions. Optimal parameters were applied for scanning, including a resolution of 1/8, Quality set at 3×, a scan duration of 03:27 minutes, and a scan size of 5120 × 2133 points. Data processing was performed using Faro Scene software, generating orthographic photographs of the scanned areas.

For the hypogeum, a Leica BLK360 Camera Laser Scanner was preferred regarding its small size and easy use with the properties of 6 mm accuracy in 10 meters, com-pact size (165 mm tall × 100 mm diameter), weighing just 1 kg. This scanner, capable of capturing 360,000 points per second within a 60 m radius, was advantageous for maneuverability in low and narrow spaces, including other underground tunnels.

However, the initial digital documentation of the hypogeum using the Leica BLK360 Camera Laser Scanner required an update due to low resolution, unnatural colors, and unclear structural edges (see Figs. 2-3). Furthermore, rainwater accumulation on the floor negatively affected this documentation. Subsequent to a partial cleanup that involved draining rainwater using a water pump, a more conducive working environment was established. This prompted a different approach for redocumentation opting for an image-based modeling technique rather than using the laser scanner. A 24-megapixel NIKON D5200 camera equipped with AF-S DX NIKKOR 18-105mm f/3.5-5.6G ED VR lens was employed to capture 958 internal and 596 external photographs at 300 dpi. Agisoft Metashape Professional program version 1.5.2 facilitated the creation of a three-dimensional imaging space, resulting in a more refined redocumentation of the hypogeum compared to the 2021 documentation. Despite debris obstructing visibility of the actual height and original floor, future visualization steps post-complete hypogeum cleaning will facilitate a comparative analysis of the structure's true height.

These surveys concentrated on assessing the current condition of the chosen subterranean structures. However, they were not georeferenced or coordinated with the existing scattered surveys of Hagia Sophia due to the preliminary nature of the study. The intention is to re-visualize these subterranean structures after cleaning and to georeference them with the ongoing latest digital visualization of Hagia Sophia's superstructure.

Fig. 2. Section 5-5: Southeast- northwest cross-section showing the middle chamber of the hypogeum and the channels running at its southeastern and northwestern ends.

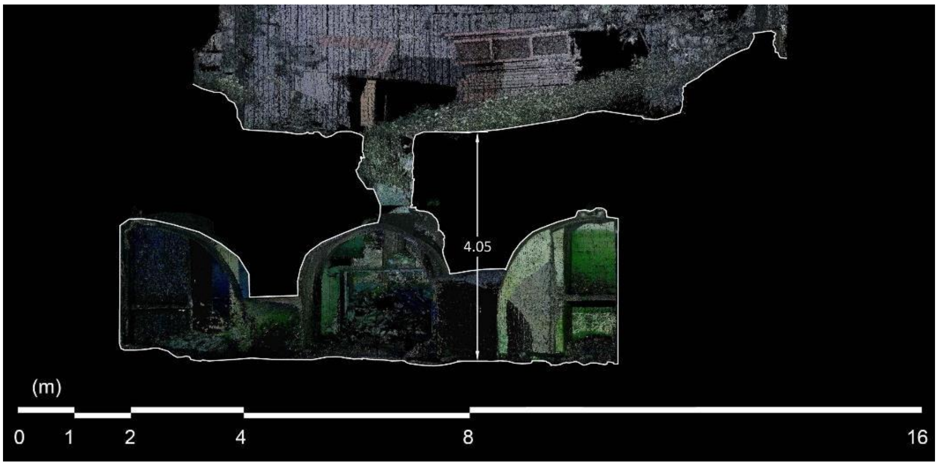


Fig. 3. Section 6-6: Northeast-southwest cross-section of the hypogeum.

3 Results

Given that the initial constructions of the Hagia Sophia complex no longer exist, the study of surrounding and related structures is very important to understand its multi-layered construction history. Therefore, the documentation of the three largest select-ed subterranean structures holds significant importance in unraveling the intricate layers of Hagia Sophia's history. Each documentation intends to offer insights into the original architectural features of these subterranean spaces and emphasizing the necessity for their thorough cleaning before final documentation.

3.1 The Passage Under the Esonarthex

Accessible through an opening west of the Imperial Gate (see Figs. 1, 4), the passage beneath the esonarthex resides approximately 2 meters below the ground floor. Measuring 4 meters in width and spanning 47.50 meters in length, this space runs along a northeastern-southwestern axis beneath the southeastern half of the esonarthex. Its ceiling consists of cross vaults connected in the middle with the 23 masonry piers aligned in row. Notably, three channels extend from each end of this passage, diverging in various directions. Serving as a central nexus, this passage interconnects with the subterranean tunnels extending both within and outside the Hagia Sophia structure. On the other hand, in comparison to the following two subterranean structures, this passage is in good condition structurally and free of debris.

Fig. 4. Section 1-1:Northeast-southwest cross-section of the passage under the esonarthex.

The floor level of the passage under the esonarthex aligns nearly with the remains of the Theodosian Hagia Sophia's portico (see Figs. 1, 5), suggesting a significant connection. This alignment indicates that when constructing the esonarthex and exonarthex of Justinian's Hagia Sophia, much of the Theodosian Hagia Sophia's atrium was incorporated. This passage serves as a defining space, marking a transitional phase between the two monuments from the fifth to the sixth centuries. Presenting the only visible façade of the foundation of the present structure standing on the previous one, the plastered wall of this subterranean structure also provides knowledge for the foundation substructure.

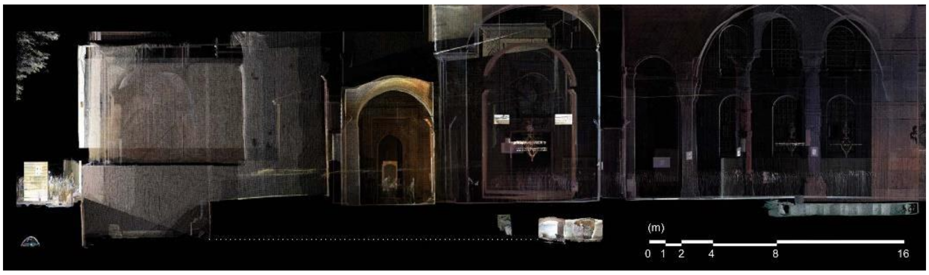


Fig. 5. Section 2-2: Northwest-southeast cross-section extending from the remains of the Theodosian portico to the northern main pier of Hagia Sophia.

The plastered interior surfaces formerly initially suggest that the passage under the esonarthex might have functioned as a cistern [3] (see Fig. 6). However, its connections with channels at lower elevations on the northeastern and southwestern ends refute this function. Instead, this substantial space, believed to be the most voluminous among Hagia Sophia's subterranean structures, appears to have served as an air-ventilation conduit and a transition point to access water lines aligned on its northeast-southwest ends. Notably, there is a column base on the floor of this passage beneath the entry lid, that might have belonged to the Theodosian Hagia Sophia due to its location. While this possibly in situ column base holds promise for shedding light on the reconstruction of the Theodosian Hagia Sophia, no other column bases on the same axis were observed, impeding a definitive assessment. Positioned approximately 1.50 meters from the Imperial Gate, the main axis of the structure, it seems improbable that this base belongs to the interior colonnade of the Theodosian Hagia Sophia's naos (see Fig. 7). Considering a possible column base on the opposite side of the axis, allowing for a total span of only 3 meters, would be insufficient for the beam span of the previous naos. So, this finding suggests that it might have belonged to the arcade of the Theodosian atrium.

Fig. 6. The passage under the esonarthex

Fig. 7. The column base on the floor of the passage.

The Theodosian Hagia Sophia and its atrium have been the subject of various reconstruction proposals over the past century. These proposals aim to recon-struct and understand the layout, architecture, and historical significance of this site. In 1909, Antoniadi proposed an atrium with arcades in four directions, despite lacking archaeological evidence [4] (see Fig. 8). Following the museumization of Hagia Sophia, Schneider commenced excavations within the Theodosian atrium. Despite uncovering the northeastern half of the portico, Schneider only preferred to illustrate the entrance façade (see Fig. 11) rather than proposing a comprehensive atrium plan [5].

Subsequently, Kleiss and Mainstone presented two distinct proposals for the Theodosian Hagia Sophia's plan. Kleiss's proposal [6] (see Fig. 9) suggested an atrium with arcades in four directions, resembling Antoniadi's concept. But, this proposal evaluated the Schneider's finding as the southeast wing of the atrium and moved away the atrium in the northwestern direction. So according to this proposal, the position of the mentioned column base would place in the middle of the previous structure's naos, causing a discrepancy. Finally, Mainstone accepted the Schneider's findings as the entrance portico and the northwestern wing side of the atrium and proposed an atrium surrounded with three wings, excluding the southeastern wing [7] (see Fig. 10).

Though this latest proposal appears more plausible than previous ones, the column base in question seems to be located solely in the southeastern wing of the atrium, an aspect overlooked by Mainstone. Therefore, by amalgamating Mainstone's plan proposal with Schneider's façade proposal (see Figs. 10-11), here a new atrium plan layout is proposed. This suggestion integrates elements from both reconstructions, combined with the newly discovered column base mentioned above.

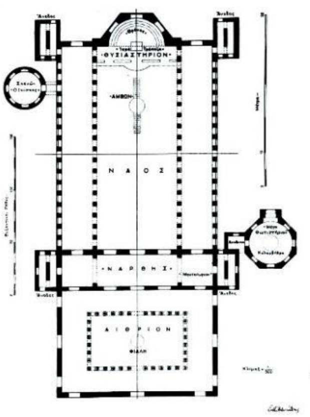


Fig. 8. Antoniadi's plan proposal

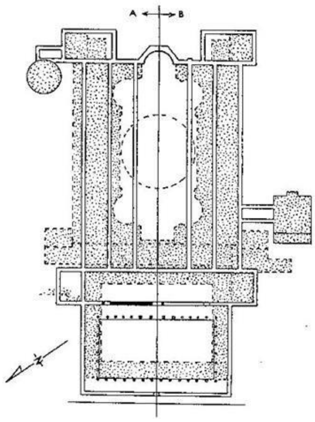


Fig. 9. Kleiss's plan proposal

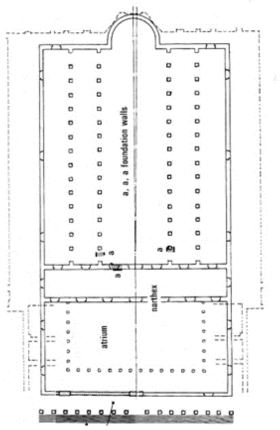


Fig. 10. Maninstone's plan proposal

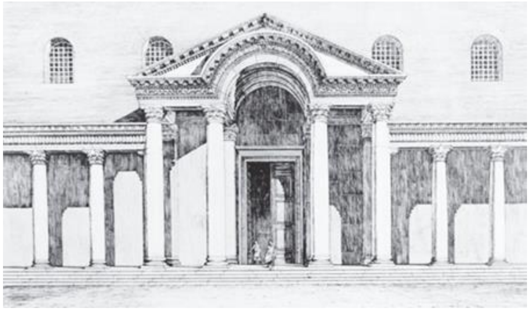


Fig. 11. Schneider's façade entrance reconstruction for the Theodosian atrium

The discovery of the column base within the passage under the esonarthex holds significant implications. This base stands as a pivotal piece of evidence, potentially serving as the sole and conclusive proof of the neglected southeastern wing of the Theodosian atrium, a detail that previously could not be observed by Mainstone. With a diameter of 57 cm compared to the approximately 80 cm diameters of the column bases at the portico, it suggests that the wings of the Theodosian atrium, now absent, were likely narrower than the entrance portico. This unexpected finding has sparked the development of a new proposal for the plan of the Theodosian atrium, possibly indicating the presence of four interior arcades (see Fig. 12). This fresh proposal could potentially enhance new speculative reconstructions of the Theodosian Hagia Sophia (see Fig. 13).

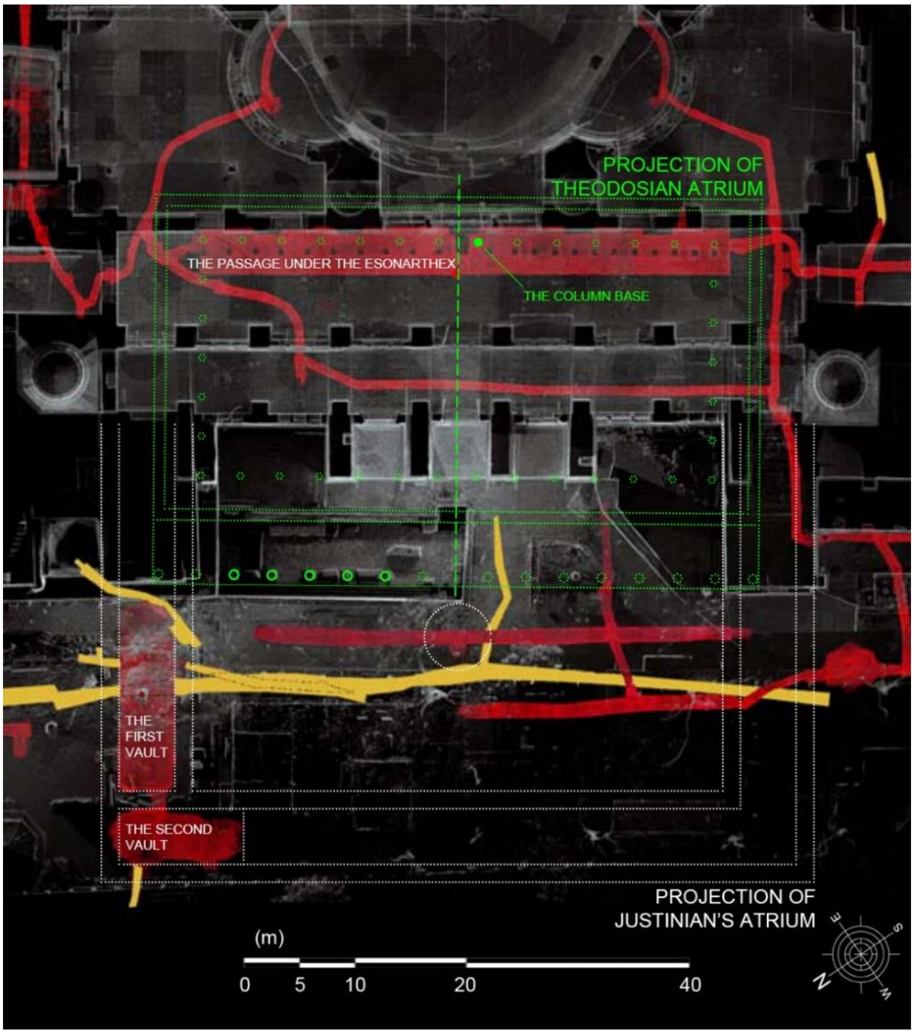


Fig. 12. Reconstruction plan for the Theodosian (in green) and Justinian's (in white) atriums.

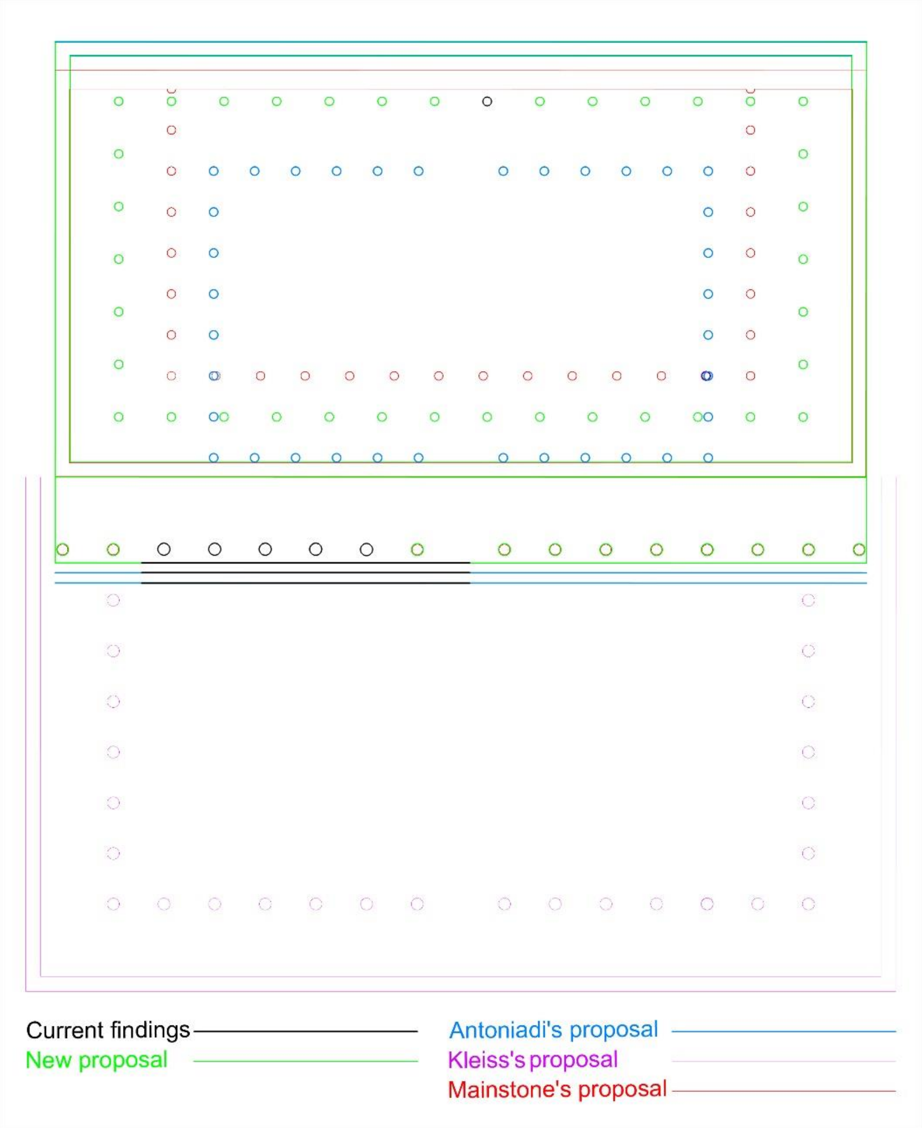


Fig. 13. Scaled comparison of the current proposal for the Theodosian atrium plan with the previous ones

3.2 The vaults under the atrium

To the northwest of Hagia Sophia, stand two impressive subterranean structures that have been digitally documented (see Fig. 1). The first structure, which boasts a rectangular plan and remains unplastered, is accessible from the southeastern edge of its barrel vault. Notably, a chestnut tree has breached its vault, causing structural damage over time (see Fig. 14). The second vault also follows a rectangular plan, and these two vaults together form an L-shaped configuration.

Following the conversion of Hagia Sophia into a museum in 1934, Schneider was granted per-mission to excavate the remnants of Theodosian Hagia Sophia [8]. Notably, the marble elements from the Theodosian portico, unearthed during the excavation, displayed in the garden's northwestern section of Hagia Sophia. One of these stone elements, situated beside the chestnut tree, has compressed and shaped the lower trunk of it as the tree continued to grow. Meanwhile, another chestnut tree, which grew adjacent to the stone element, has also penetrated and damaged the vault of the first subterranean structure which will be defined below. Since Schneider did not document these trees, it can be inferred that they sprouted after his documentation of the subterranean structures within Justinian’s atrium [5], essentially after the conver-sion of Hagia Sophia into a museum. Hence, these trees on the site are, at most, 90 years old (see Fig.15).

Fig. 14. View from the first vault under the northeastern wing of the Justinian’s atrium.

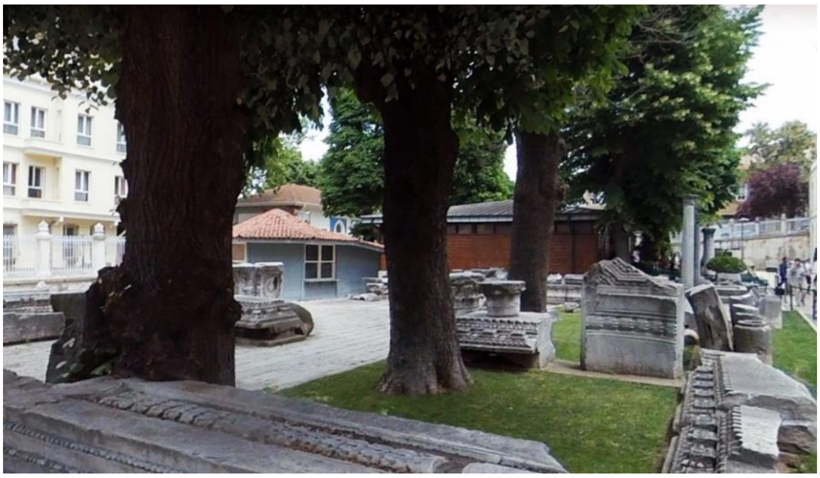


Fig. 15. The tree on the left shaped by the marble element, and the next one penetrating the vault.

The initial vault penetrated by the tree roots measures 5 meters in width and spans a length of 17 meters. But it has gradually filled with debris and soil over time. Consequently, the ground surface and height within the space remain obscured due to this accumulation. Within the masonry of the vault, the bricks are corbelled along their longitudinal sides. The unplastered brickwork starts vertically from the northwest side and gradu-ally inclines towards the southeast. There are also two waterway tunnels intersecting this structure in the northeast-southwest direction that were later blocked.

This vault is linked to another subterranean structure positioned above, with a channel extending northwestward from its western corner (see Fig. 16). This second vault, could be measured 5 meters in width and 11 meters in length with the debris inside. It is covered by a barrel vault and, akin to its counterpart, is filled with debris and soil that was deposited from the courtyard. However, the brickwork of this vault differs from the previous space and features bricks laid both vertically and horizontally. Partial plasters can also be observed on its vault and side walls. Despite Schneider's assumption regarding the continuation of the atrium's substructures beneath the rest wings [5], these presumed spaces were unable to access.

Fig. 16. View from the second vault under the north corner of the Justinian's atrium.

Although Justinian's atrium no longer exists, these two subterranean structures define its northern part beneath the ground. The first vault pertains to the subterranean structure of the northeastern wing, while the second belongs to the subterranean structure of the northwestern wing. The absence of plaster on the surfaces of the first vault suggests that it likely did not serve as a cistern. Instead, it might have functioned as an underground storage cellar, possibly for materials like lamp oil used for the church's chandeliers but not meant to be visible inside.

Conversely, the partially plastered second vault may have served a different cellar function. A comprehensive understanding of the functions of both these vaults awaits further excavation and the removal of accumulated debris. An analysis of materials within the debris and a thorough cleaning of the vaults may offer valuable insights into the functions and specific uses of these subterranean structures within Justinian's atrium (see Fig. 1, 17-18).

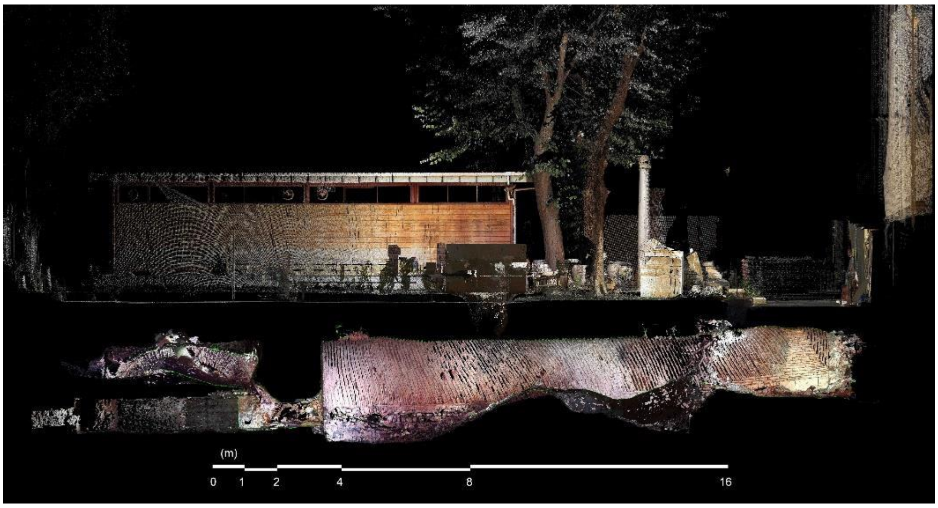


Fig. 17. Section 3-3: Northwest-southeast cross-section depicting the vaults beneath the north-east- ern wing of the nonexistent atrium. (The first vault is depicted on the right, while the second one above the channel is on the left.)

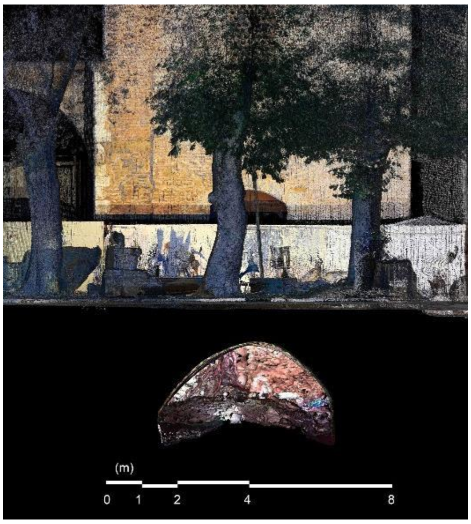


Fig. 18. Section 4-4: Northeast-southwest cross-section of the first vault.

3.3 The hypogeum

The hypogeum is a subterranean Roman tomb situated between Hagia Sophia and the Hagia Sophia Imaret (also known as the "soup kitchen"). Consisting of three chambers interconnected by a passage, this structure is dated back to the 4th century, predating the current Hagia Sophia. Following the conversion of Hagia Sophia into a museum in 1934, this hypogeum was first discovered and documented in 1946 by Muzaffer Ramazanoğlu, the museum director at that time [9]. Ramazanoğlu dated this subterranean complex, noting two distinct layers on the superstructure floor, to the 4th century. Although the hypogeum was republished in 1962 [10], it subsequently faded into obscurity. However, it was rediscovered, along with its pavement floor, during an excavation in 1985 aimed at locating the toilet drain of the guard room attached to the northeastern wall of Hagia Sophia. The guard room was likely constructed on the hypogeum in the first half of the 20th century. The excavation process then proceed-ed by removing the guard room, which was initially intended for repairs. As the excavation progressed, the original pavement of the hypogeum's superstructure was revealed (see Fig. 19). This pavement, composed of white Marmara marbles and Verde Antico marbles even not used together in Hagia Sophia's interior floor, was uncovered. Additionally, a smaller white marble surface, along with its marble baseboard from an earlier period, was found approximately 40 cm below the upper level [11,12]. In this context, the white marble pavement within the lower layer, dated to the 4th century along with the hypogeum, suggests it may have been contemporaneous with the initial Hagia Sophia structure. The pavement on the upper layer, positioned at the level of the lower edge of partially surviving buttresses that constructed from brick and stone, is dated to the 6th century together with the attached buttresses [13]. Following the documentation of the hypogeum's superstructure, the marble pavement was once again covered with soil in 1985 for preservation purposes [11,12].

Fig. 19. Marble floor pavement above the hypogeum exposed after the excavation in 1985.

This structure complex spans approximately 60 square meters and lies approximately 4 meters below the current ground level. Comprising three rectangular-planned spaces, each boasting a long side of about 8 meters, this arrangement features various access points. A circular hole, concealed by an iron lid, permits entry to the central space of the hypogeum from the ground level. Additionally, a gradual transition gap allows access to the southeastern end of the space. These three spaces, aligned in a southeast-northwest direction, run parallel to each other and are linked by an arched passage in the middle (see Fig. 20). The chambers situated in the middle and southwest directions lie beneath the Vizier Garden, while the northeastern-oriented chamber is located under the courtyard of the Hagia Sophia Imaret. Notably, the chamber in the middle possesses a distinctive marble door jamb along its southeastern edge. Within the side chambers, niches known as "arcosolia" were traditionally used for housing the remains of the deceased. However, the arcosolia within this hypogeum currently remain vacant.

Fig. 20. View from the hypogeum in 2020 before the cleaning.

The three chambers of the hypogeum were constructed using bricks and are topped with barrel vaults. These original walls and vaults, although plastered, lack any decorative traces, indicating a probable absence of adornment. Around the 6th century, approximately one-third of the two side chambers were filled with cut stone walls, aligning with the upper level of the superstructure floor [13]. These cut stone walls, constructed along the long sides (northeast and southwest) of the side rooms, were elevated to the upper level by cutting through the vaults of these spaces, excluding the arcosolia in the southeast direction. In addition to the added cut stone walls in the side rooms, other stone walls were later constructed on the northwestern sides of the three chambers during a subsequent period. These foundation walls, believed to have been built dur-ing the erection of the buttress by Architect Sinan in the latter part of the 16th century to reinforce Hagia Sophia, were crafted from rough stones, differing from the other infrastructure built with cut stone.

Two tunnels are connected to the hypogeum from the southeast and northeast. The southeastern tunnel originates from the rain gutter at ground level between Hagia Sophia and the Skeuophylakion, inclining until it terminates at the upper level of the southeastern edge of the middle chamber. Conversely, the other tunnel begins from the upper level of the northwestern corner of the same middle space and extends northwestward. These tunnels likely coincide in timing with Architect Sinan's buttresses, considering their locations (see Figs. 1-3).

The original ceiling height remains uncertain due to the accumulation of mud and debris on the floor. The buried appearance of the door jamb and the muddy floor surface suggest that the original ground level of the structure lies approximately 1 meter lower than the existing mud surface. At the end of 2021, a partial cleanup in the hypogeum removed 3875 kilograms of mud and debris, leaving the remainder (see Fig. 21). Subsequently, following the temporary removal of rainwater from inside the structure using a motor pump, a more favorable environment was created for documentation. As a result, the hypogeum was re-visualized in higher resolution in January 2022 [14] (see Figs. 22-25).

Fig. 21. View from the debris and mud removed from the hypogeum in 2021.

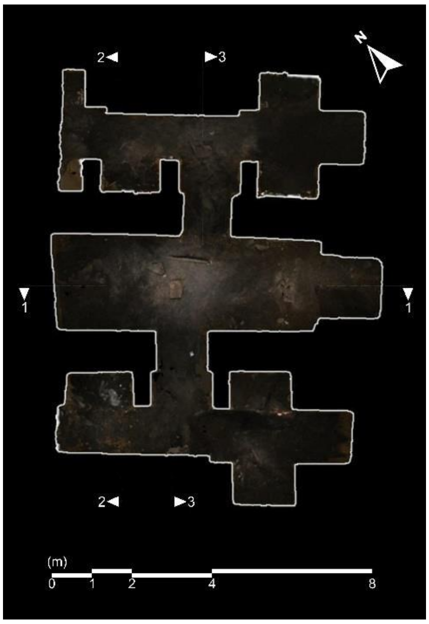


Fig. 22. Plan of the hypogeum

Fig. 23. Section 1-1 of the hypogeum.

Fig. 24. Section 2-2 of the hypogeum

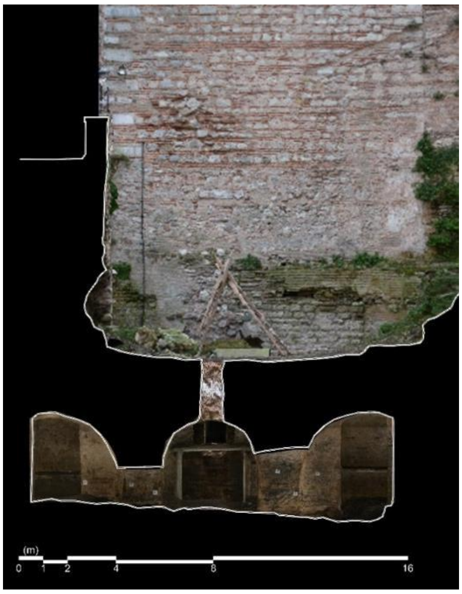


Fig. 25. Section 3-3 of the hypogeum.

4 Discussion

The selection of the three largest subterranean structures within Hagia Sophia for this study was based on their connections to other tunnels and their significant historical importance to the monument. The scan data collected from these structures greatly contributed to understanding their spatial relations with the current superstructure, revealing insights into their original architecture and past functions. However, this documentation also exposed infrastructure issues such as ceiling cracks, humidity problems, and the accumulation of mud and debris within these spaces.

Initiated in 2020, this documentation process highlighted the urgent need for a comprehensive approach to manage Hagia Sophia's subterranean structures. This holistic approach includes general cleaning, maintenance, repairs, documentation, and an archaeological perspective. As a result, the Ministry of Culture and Tourism has placed comprehensive cleaning and preservation efforts for these spaces on its agenda. The visualizations presented in this study advocate for immediate and thorough cleaning, documentation, and preservation. The implementation of archaeological cleaning processes would enhance the accuracy of documenting and dating these structures. Additionally, analyzing cleaned surfaces and archaeological materials found within the debris will significantly enrich the depiction of Hagia Sophia's multi-layered historical features. This study aims to raise awareness of the importance of documenting other historical subterranean structures associated with Istanbul's current aboveground areas.

References

1. Teruggi, S., Grilli, E., Fassi, F., Remondino, F.: 3D Surveying, Semantic Enrichment and Virtual Access of Large Cultural Heritage. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences VIII-M-1, 155–162 (2021).
2. Diker, H. F., Esmer, M.: Preliminary Evaluation of the Terrestrial Laser Scanning Survey of the Subterranean Structures at Hagia Sophia. Preservation, Digital Technology & Culture 50(2), 65-84 (2021).
3. Dirimtekin, F.: Ayasofya iç nartex’in altındaki mekan [Archwise space under inner narthex of Saint Sophia]. In: İstanbul Arkeoloji Müzeleri Yıllığı [Annual of the Archaeological Museums of Istanbul]. no: 3, pp. 15–17, eng. pp. 50–52. İstanbul Matbaası, Istanbul (1961).
4. Antoniadi, E. M.: Ekphrasis tes Hagias Sophias. (originally published Leipzig/Athens 1907–1909).: Volume 1, pp. 7, pl. 2. Ekdoseis V. Gregoriades, Athens (1983).
5. Schneider, A. M.: Die Grabung im Westhof der Sophienkirche zu Istanbul. In Istanbuler Forschungen, no: 12, pl. 1. Zweigstelle Istanbul des Archäologischen Instituts des Deutschen Reiches, Berlin (1941).
6. Kleiss, W.: Beobachtungen in der Hagia Sophia in Istanbul. 15, pp. 168–185. Istanbuler Mitteilungen (1965).
7. Mainstone, R. J.: Hagia Sophia. pp. 141.Thames & Hudson, Slovenia (2001).
8. Diker, H. F.: Ayasofya ve Onarımları [Hagia Sophia a Its Repairs]. pp. 150. FSMVU pub., Istanbul (2016).
9. Ramazanoğlu, M.: Sentiren ve Ayasofyalar Manzumesi (L’ensemble Ste Irène et les di-

verses Ste Sophie). pp. 12-13. Istanbul (1946).

10. Dirimtekin, F.: Ayasofya şimalindeki Vezir Bahçesi denilen yerde bulunan bir hipogee [A hypogeum found in so called the Vizier Garden at northern of Hagia Sophia]. In İstanbul Arkeoloji Müzeleri Yıllığı [Annual of the Archaeological Museums of Istanbul]. no: 10, pp. 30–36. İstanbul Matbaası: Istanbul (1962).
11. Koyunlu, A. Bir buluntu ışığında I.II.III. Ayasofya'nın döşemeleri ve konumu (Die boden-belaege und der errichtungsort der I.II.III. Hagia Sophia im lichte einer ausgrabung). In Ayasofya Müzesi Yıllığı [Annual of the Hagia Sophia Museum]. no. 11, pp. 139–156. Istanbul (1990).
12. Koyunlu, A. Ayasofya Restorasyonu Genel Sorunları [General Problems of Hagia Sophia Restoration]. Yapı (105), 47–54 (1990).
13. Dark, K., Kostenec, J.: Hagia Sophia in Context. pp. 21, 61-63. Oxbow Books, UK (2019).
14. Diker, H. F.: The Story of the Architectural Documentation of Hagia Sophia's Hypogeum. Open Archaeology 9(1), 1-23 (2023).