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The Constructional Characteristics of a Crypt's Dome Roofing. The Case of the Katholikon of the Holy Monastery of Docheiarios, Mount Athos, Greece

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Abstract

This research paper investigates the architectural and constructional characteristics of the dome roofing over the Crypt of the Katholikon (Main Church) at the Holy Monastery of Docheiarios. The study, initiated by the National Technical University of Athens and later continued by Frederick University Cyprus, focuses on the unique construction methods of the domes, particularly their erection without formwork. The Crypt, built as a fortified, concealed space above the Liti area to protect monks and relics during pirate raids, features seven compartments with domes, exhibiting three distinct vaulting variations adapted to spatial and defensive constraints. Through detailed geometric documentation and constructional analysis, the study reveals the builders' innovative adaptations to challenges, such as concealment needs and structural stability, including the use of convex curvature and reinforced nearly-flat dome sections. The findings emphasize the necessity of preserving and carefully restoring the wooden components in any future conservation efforts, recognizing their integral contribution to the dome's resilience and the overall architectural integrity of the Katholikon.

Keywords: brick domes without formwork; constructional analysis; embedded wooden beams; monastery's crypt; Mount Athos, Greece.

Introduction

The Holy Monastery of "Docheiarios" was established around the late 10th century on the western shore of the Mount Athos peninsula and was dedicated to Agios Nikolaos. In the early 11th century, the Monastery was relocated further north, to its present site, due to destruction caused by pirate raids. A significant renovation of the structure occurred in the early 12th century, during which a larger "Katholikon" was constructed and dedicated to Archangel Michael. (NTUA, 2008)

More than four centuries later, in 1554, the Katholikon sustained damage of an undetermined extent due to significant seismic activity. Between the years 1562 and 1568, it underwent a complete renovation, funded by Ioannis-Alexandros Lapusneanos, the ruler of Moldavia.

The main aim of this paper is to highlight the critical role of embedded wooden beams within the dome structure, which provide essential static and dynamic load-bearing support, a system that has preserved the domes through centuries of seismic activity, but has recently suffered deterioration.

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The Monastery complex, measuring approximately 90 by 65 meters, continues to exhibit the characteristic defensive layout, typical of Byzantine monasteries of that period (Fig. 1, 2). This layout features elongated buildings along the perimeter, with the Katholikon situated at the center of the courtyard and a fortified tower positioned at the highest point.

The steep slope of the terrain, on which the Monastery is constructed, results in a height difference of approximately 50 meters between the perimeter buildings located on the eastern and western sides.

Upon approaching from the sea, one first encounters the two-story defensive tower known as the "Arsana" (port's tower) and then, after an uphill route on foot, visitors arrive at the four-story fortified tower, which serves as the sole entrance to the Monastery. The entrance passage directs individuals to the southern side of the Katholikon, situated in the center of the enclosed courtyard. The entrance to the Katholikon is located to the west, accessible after passing the covered "Exonarthikas" (outer narthex). This significant interconnecting covered area of the Monastery provides access to the "Esonarthikas" (inner narthex) and subsequently to the "Liti", through which one enters to the main area of the Church, facing the imposing Iconostasis in front of the Holy Sanctuary. (Fig. 3)

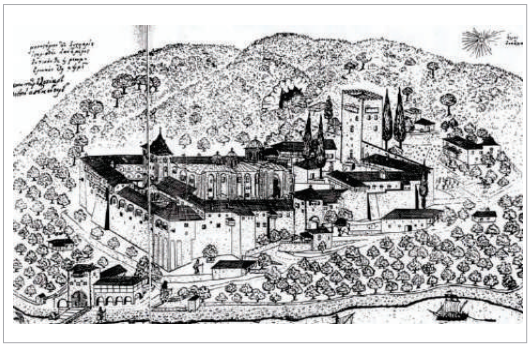


Fig. 1

A detailed sketch by Monk Barsky, created in 1744, provides a general "aerial" view of the Monastery, which closely resembles its present condition. (Mylonas, 2009)

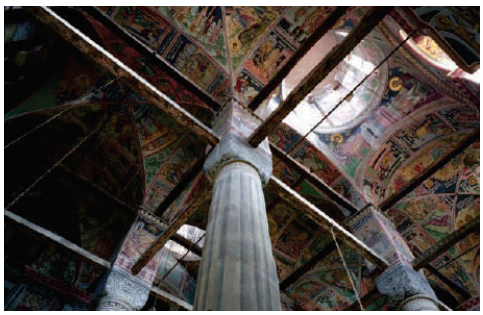


Fig. 2

View of the Monastery from the defensive tower to the east. The Katholikon (main church) is situated in the center of the surrounding complex, which includes the monks' cells. (NTUA, 2008)



(1)



(2)



(3)



(4)

Fig. 3

(From above left to the right) (1) The defensive tower (Arsanas) at the small port. (2) The room just before the Main Church ("Liti"). (3) The Main Church. (4) The Sanctuary Niche with the Panagia Platytera. (NTUA, 2008)

Previous Research

In 1995, the National Technical University of Athens (NTUA), under the direction of Professor Panagiotis Touliatos as the Scientific Coordinator, commenced a research program focused on the documentation, constructional analysis and damage assessment of the Monastery complex. This program was terminated in 2004 and the findings from the research conducted up to that point were subsequently published in an anniversary edition (NTUA, 2008). (Fig. 4)

The Katholikon features floor plan dimensions of approximately 41 by 13 meters and is composed of a series of interconnected spaces, including the Exonarthikas, Esonarthikas, Lyti, Main Church Area and the Holy Sanctuary. Its section exemplifies the characteristic, of all Byzantine monuments, "Imantosis" which is a full-circumferential binding system comprising multiple superimposed layers of interconnecting wooden beams. Although some researchers (Ousterhout, 1999) claim that these wooden ties had generally a secondary role, it is now documented that this was the primary securing system of the structure in order to withstand the frequent earthquakes (NTUA, 2008).

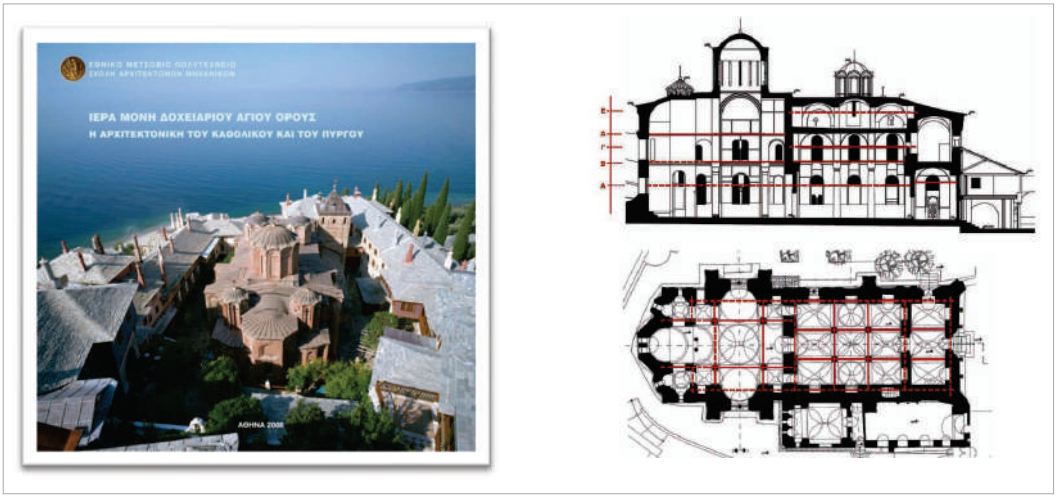


Fig. 4

(Left) The cover page of the anniversary edition of the National Technical University of Athens. (Right) The successive, vertical levels of "bindings" with the wooden supports. (NTUA, 2008)

The New Research Programme

Among the unresolved issues stemming from the research conducted between 1995 and 2004 was the necessity to analyze, study and restore the damaged dome structure over the "Liti" area. In 2011, Frederick University Cyprus (FU) accepted an invitation from the Holy Monastery, along with a proposal from Professor Touliatos, to undertake a new research project focused on the constructional analysis and restoration of the upper dome structure over the "Liti" of the Katholikon.

The new research was conducted by the Department of Architect Engineers, with Professor Panagiotis Touliatos serving as the Scientific Coordinator, Associate Professor Marios Pelekanos acting as the Main Researcher, and Architect Argyris Fellas responsible for the three-dimensional visualization of the dome structure.

The geometrical documentation conducted in 2011 was based on the general survey of the complex, which was prepared by the National Technical University of Athens during the years 1996 to 2004. This initial survey was subsequently enhanced with more precise measurements and observations for the upper dome structure above the Liti, which has since been referred to as the "Crypt".

The newly acquired detailed measurements facilitated a more in-depth analysis of the dome structure, resulting in the identification of four notable characteristics:

(a) Dome building methods without the use of formwork,

(b) The presence of three distinct variations of domes, designed to serve the need to conceal the Crypt,

(c) The presented negative curvature in certain parts of the dome structure, and

(d) The nearly flat curvature of the four domes located at the corners of the roof.

The Crypt

The Crypt was constructed during the comprehensive renovation of the Katholikon in 1558. It is evident that the frequent pirate raids, that the Monastery suffered at that times, forced the monks to establish a fortified defensive structure capable of safeguarding both lives and sacred artifacts. Concurrently, a fortified tower was erected at the highest western end of the complex.

The sole access point to the Crypt is via a very narrow passage located within the 2-meter-thick northern wall of Liti. This passage, which has been strategically designed for defensive purposes, leads to the entrance of the Crypt situated to the northwest. (Fig. 5)

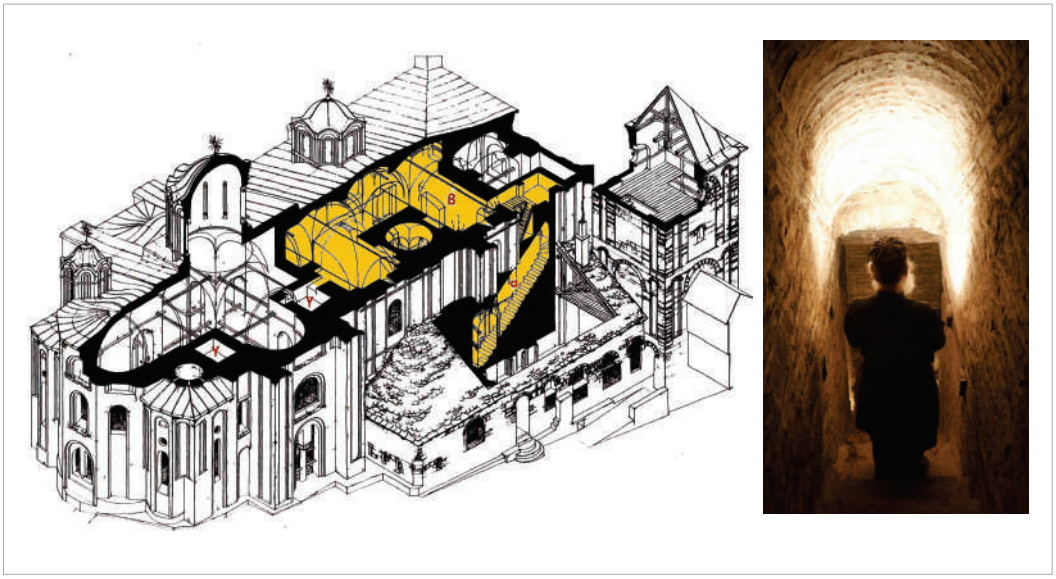


Fig. 5

(Left) Axonometric Section indicating the Crypt. (Right) The only passage to and from the Crypt, within the thickness of the north wall. (NTUA, 2008)

The Crypt was constructed directly above the Liti and consists of nine smaller sections. Its design is based on the existing layout of the underlying Liti, which includes four central pillars. The central northern and central southern sections accommodate the two very tall domes of the Liti.

This architectural endeavor is regarded as highly successful, as the primary objectives of the builders were to ensure that the Crypt was both functional and secure, while also remaining inconspicuous to potential raiders, whether from outside or within the Katholikon.

In 2011, water leaks from the lead covering layer resulted in significant corrosion of the entire structure, leading to extensive decay of its wooden components. In certain areas, where wooden beams were integrated within the stone structure, the wooden beams had virtually disintegrated.

The dome structure exhibited extensive cracking, necessitating the immediate implementation of temporary support for the entire structure, using wooden scaffolding. This observation underscores the critical structural role played by the wooden beams embedded within the domes. (Fig. 6)

During the 2011 survey, more comprehensive measurements and observations were conducted to enhance and elaborate upon the general plans and sections established in the previous survey. It was promptly noted that the existing survey plans, elevations and sections required further enrichment through the development of an accurate model of the distinctive domed structures situated above the Liti.

Fig. 6

(Above) Cracks and damages to the upper vaulting of the Crypt, due to the extensive decay of the wooden elements. (Below) Cavities of the vaulting, where wooden beams have been totally destroyed due to decay. (Photos: P. Touliatos, M. Pelekanos)



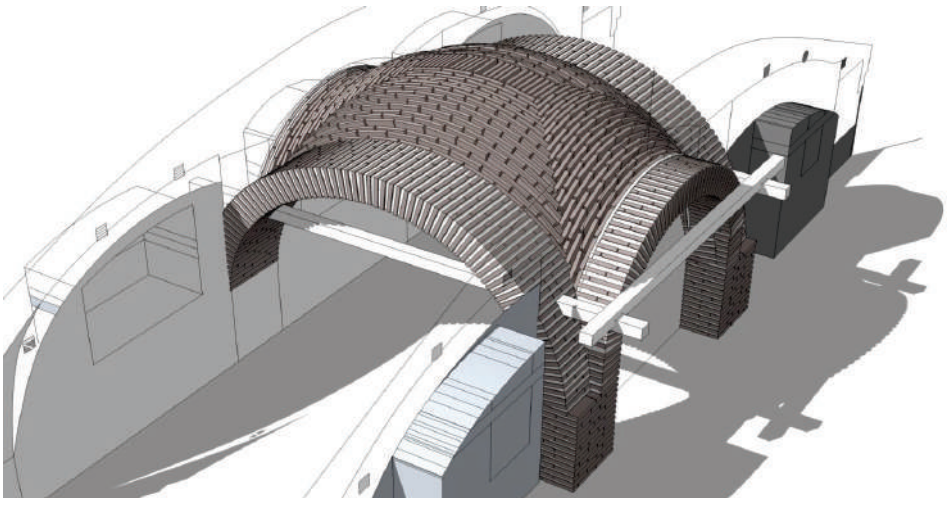
Consequently, computer-aided design technology was employed in an effort to virtually "reconstruct" the domes in a three-dimensional digital format. (Fig. 7) However, in order to achieve an electronic reconstruction of the structure, it was imperative to first analyze and comprehend the actual construction methods employed. It was noted that the seven individual domed structures had been constructed without the use of formwork, in contrast to the intermediate arches. The research prompted the team to investigate vault construction systems that do not use formwork.

The construction of domes without the use of formwork

Domes constructed without the use of formwork possess a lifespan of at least 5,000 years. Vaults built utilizing the "corbelled" system, also without formwork, are known from the Mycenaean vaulted tombs dating from 1500 to 1600 BC. (Fig. 8)

Fig. 7

The virtual reconstruction of the vaulting. (Simulation by FU Research Team)



The same technique, despite the advancements made by the Romans in vaulting through the use of formwork, reappears during Roman times, as demonstrated by the basilica of Aspendos in Asia Minor, dating to the 3rd century AD. (Fig. 9) Evidence suggests that this architectural technique may date back to at least 3000 BC, as demonstrated by the vaulted tombs of the Assyrians in Mesopotamia. (Fig. 10)

Auguste Choisy (1883), while studying Byzantine vaults constructed without the use of formwork, recorded several variations of a method he termed the "pitched-brick technique". Such a variant was also employed in the vaulting of Docheiarios Crypt. Self-supporting arches were constructed alternately around the perimeter of each chamber, and due to the slight inclination of the bricks, these arches were supported by the preceding ones, utilizing strong mortar, which facilitated the gradual upward construction of the distinctive dome. Notably, the work of Spanish architect and academic researcher Santiago Huerta is significant in this context; he emphasized Choisy's contributions to the study of Byzantine vaulting in his publication, "The Geometry and Construction of Byzantine Vaults: The Fundamental Contribution of Auguste Choisy" (Huerta, 2009).

This specific method was similarly embraced by the Byzantines, at least from the conclusion of the 4th century AD, as evidenced by the letter from Saint Gregorios of Nyssa (in Asia Minor) to Bishop Amfilochios: *"...Please take care that, among the craftsmen (who you will send to us), there are individuals who possess the skills to construct without the use of wooden formwork. Because, I heard, that such construction is more stable than the one built using formwork..."* (Harisis, 2003)

It appears that the perception that this construction method is "more stable", led the Byzantines of the 4th century AD to adopt it, particularly in specific instances involving relatively small structures. The same method is still used even today in various regions around the world, including Africa and South America, due to its advantages for a quick and cost-effective construction of vaulted structures. (Fig. 11, 12)

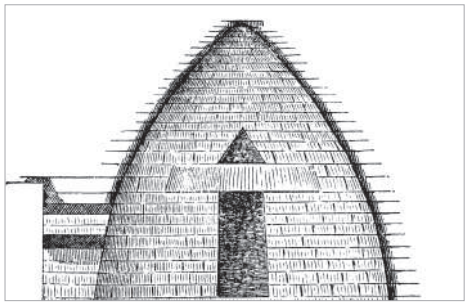


Fig. 8

The Mycenaean Tholos tomb of Atreus (1600-1500 BC) (Rosengarten & Collett-Sandars, 1895)

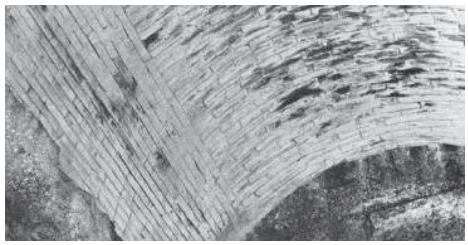


Fig. 9

The vaulting of the Basilica of Aspendos in Asia Minor (3rd century A.D.) (Ward-Perkins, 1958; Huerta, 2009)

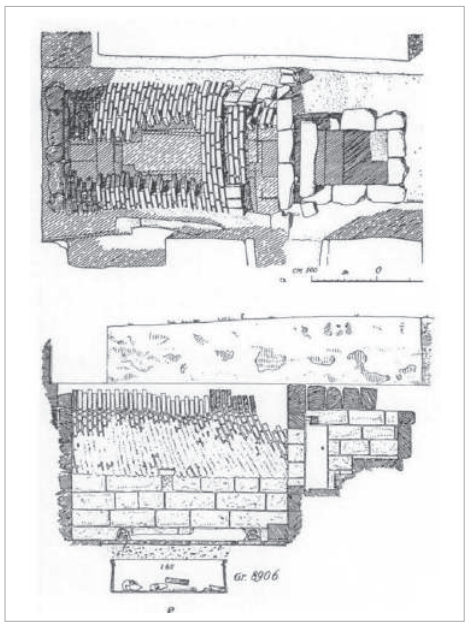


Fig. 10

Assyrian vaulted tombs (Mesopotamia, 3000 B.C.) (Besenval, 1984; Huerta, 2009)

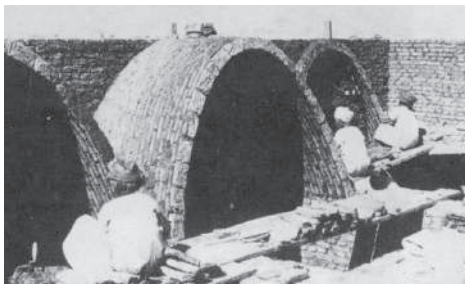


Fig. 11

Traditional vaulting in North Africa around 1940. (Fathy, 1976; Huerta, 2009).

Constructional Particularities of the Dome Structure of the Crypt

The architects, responsible for the design of the Crypt, operated within a framework of various functional and technical specifications and constraints. To comprehend the "design concept" of



Fig. 12

Contemporary vaulting without formwork, in Mexico. (Varun Thautam Architect, 2026)

the domed roof, it is essential to identify their fundamental objectives.

The Crypt was required to: (a) Accommodate a sufficient number of monks and a substantial quantity of relics during a siege; (b) provide the minimum necessary natural light and ventilation for the defenders, while allowing them to remain informed about the situation both inside and outside the Monastery without being detected; (c) be constructed in such a way, that it would not be easily perceived from either the exterior or the interior of the Church; (d) feature a hidden and complex access route, that would place the attackers at a disadvantage; (e) be constructed from stone or brick, to mitigate the risk of sabotage by fire; (f) possess a roof with adequate slopes, to facilitate the runoff of rainwater; (g) be based on the existing underlying structure of Liti; and (h) employ established construction methods, utilize available materials and engage local craftsmen.

For the architects, the new construction needed to effectively address the aforementioned requirements and objectives. In interpreting the initial stages of the builders' creative thought process, their primary constraint was the underlying support areas. Loads had to be directed either to the perimeter or/and to the four pillars of the Liti located on the ground floor (Fig. 13 (1), 13 (2)).

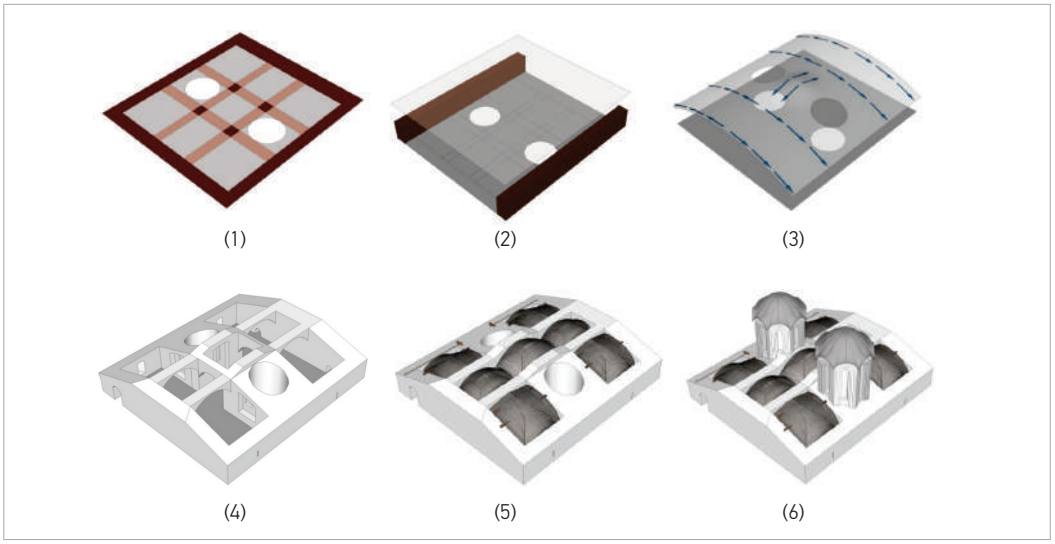


Fig. 13

The construction of the Crypt:

(1) The underlying support areas for the construction of the Crypt.

(2) The low walls on the north and south sides.

(3) The final selected overall shape that achieves low walls on the north and south sides while maximizing the interior space. The simultaneous decisions regarding rainwater flow.

(4) The load-bearing masonry of the Upper Room made of stones and bricks and the creation of the nine compartments.

(5) The load-bearing masonry and the construction of the vaulting in seven of the nine compartments of the Upper Room.

(6) The construction of the domes in the central southern and central northern compartments of the Upper Room.

(Simulation by FU Research Team)

The requirement to attain the desired internal height, aimed at optimizing accommodation and storage, conflicted with the necessity to reduce the height of the northern and southern walls, for concealment purposes. Consequently, a curved roof type shape was selected, which effectively addressed both the need for adequate rainwater runoff and the aforementioned spatial considerations (Fig. 13 (3), 13 (4)).

Nine compartments were established above the corresponding structure of the Liti. Seven of these compartments were covered with the mentioned peculiarly constructed domes, while the other two featured externally visible hemispherical domes with a tall drum (Fig. 13 (5), 13(6)).

The entire structure features a full-circumferential binding system, referred to as "Imantosis", at the highest level of the "Katholikon". The upper surface of the domes has been filled with soil and covered with interconnected lead sheets.



Fig. 14

The domes with the very tall drum managed to provide lighting, ventilation, and acoustic connection of the Crypt with the underlying Liti, without this being noticed by the raiders. (Photo: NTUA, 2008; Section Diagram: FU Research Team).

The tall drum of the hemispherical domes penetrate vertically the Crypt, facilitating the entry of natural light, ventilation and acoustic interaction with the interior of the Church. (Fig. 14)

Furthermore, the narrow openings located in the four corner compartments serve a dual purpose: they not only allow for the influx of natural light and cross-ventilation but also enhance sound and vision contact with the exterior of the Church.

A special provision was implemented at the southeast corner part, where the wall surrounding the narrow slot was widened, to facilitate discreet observation of the sole entrance to the Monastery and to enable timely awareness of the siege's conclusion. This modification resulted in significant structural instability issues in that particular area, which were addressed by incorporating special wooden reinforcements within the dome's structure. (Fig. 15)



Fig. 15

The area around the slot in the southeastern compartment was widened for better observation, as it is located directly opposite the monastery's only entrance. This required the installation of special wooden supports to reinforce that specific area of the vaulting (shown in red colour). (Floor Plan: NTUA, 2008; Reflected ceiling plan and photo: FU Research Team)

The implemented construction method, responding to the objectives and limitations of the project, had to adapt to the conditions of the structure in question. Consequently, despite the limited area of the Crypt, three distinct variations of the typical vaulting construction are present. (Fig. 16)

The first variation, regarded as the most typical, is located in the central section of the Crypt. The construction consists of a dome, built with the aforementioned vaulting technique, which does not employ formwork, and exhibits no notable deviations from standard design. Remarkably, the dome has sustained no damage despite enduring five centuries of existence and experiencing at least six earthquakes with magnitudes ranging from 6.2 to 7.5 on the Richter scale, proving its durability over the years (Kulkarni & Nalawade, 2019).

The specific dome type exhibits geometric similarities to both the "truncated scaphoid vault" and the "sail vault". This type can be characterized as a truncated scaphoid vault, that incorporates the spherical surfaces of the sail vault, along with cutouts along its perimeter. (Fig. 17, 18)

Fig. 16

The three variations of the vaulting above the Crypt: (1) The central dome (red color), (2) The two outer central domes (orange-brown color), (3) The four corner domes (yellow color). The figure also shows the wooden circumferential binding and the wooden reinforcing beams at a higher level. (Simulation by FU Research Team)



Fig. 17

The shape of the central dome can be geometrically considered to be between a "Truncated Scaphoid Vault" and a "Sail Vault". (Diagrams: FU Research Team)

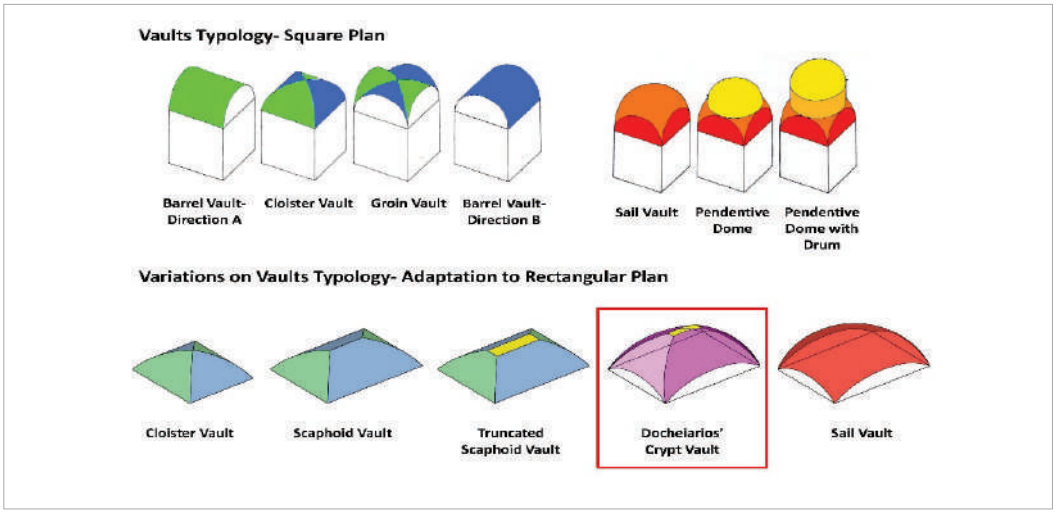


Fig. 18

View of the interior surface of the central dome. (Photo: FU Research Team)



The two adjacent domes, located to the east and west of the central dome, exhibit structural and morphological similarities to the central dome. However, upon closer examination, a notable peculiarity is observed. The bases of these domes, where they intersect with the surrounding arches, display an inexplicable convex curvature. (Fig. 19)

The comprehensive measurements and observations, facilitated by computer simulations, elucidate specific characteristics of the construction process. The necessity of constructing a lower dome forces the builder to initiate the dome's construction between the perimeter arches rather than directly above them.

Consequently, the bricks of the initial arches are positioned almost vertically, and after seven or eight layers, the subsequent arches attain the desired slope, thereby achieving a radial setting. From this point the slope of the superimposed arches adheres to the standard radial alignment,

similar to that of the central dome. This explains why the base of the specific domes present a convex curvature.

From both a static and constructional perspective, the convex curvature of a dome should ideally be avoided, as it may lead to the emergence of bending stresses. Nevertheless, this method was chosen by the builders in order to prioritize more critical objectives, such as ensuring adequate slopes for rainfall runoff and achieving a visually compressed appearance of the overall volume of the Crypt. Notably, despite these considerations, the specific domes, including the central dome, have exhibited no signs of damage, even after enduring significant seismic vibrations over the past five centuries.

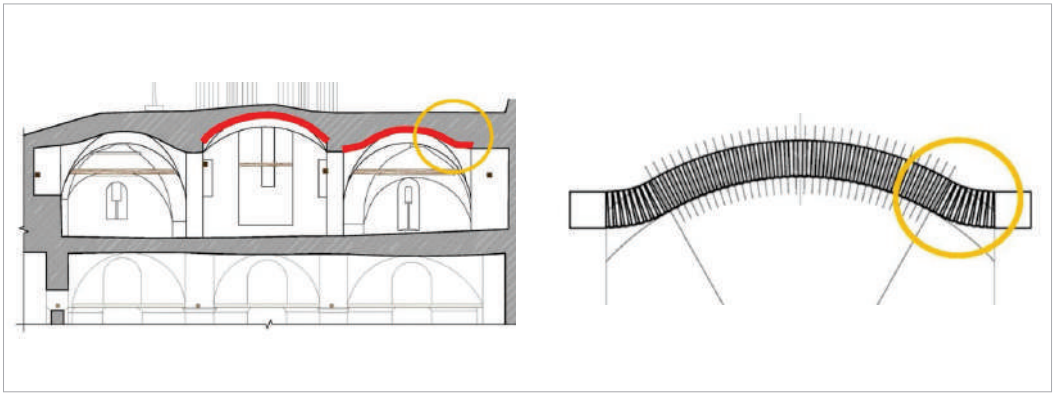


Fig. 19

The presented negative curvature in the formation of the extreme central vaults, due to the need to achieve a lower vault compared to the central one and the particularity of the structural system. (Section plan: NTUA, 2008; Detailed Section: FU Research Team).

The last, and perhaps most significant, particularity is observed in the compartments located at the four corners. In these areas, there were heightened restrictions and limitations. The expertise and deep knowledge of the builders enabled them to adapt a well-established construction system to meet specific conditions. The limitations were clearly defined:

(a) The necessity to minimize the additional height at the northern and southern elevations,

(b) The need to maximize the available internal hosting volume,

(c) The presence of irregular and unusual floor plan dimensions, and

(d) The requirement to minimize the additional weight of the soil needed on the roof prior to the installation of the lead sheets.

The aforementioned constraints resulted in the construction of an unusual vaulted structure, essentially a half-dome, but with geometric curvatures of a dome at its lowest point and a flat "slab" at its highest. (Fig. 20)

In this particular way, the craftsmen addressed the project's requirements, however, upon recognizing the structural inadequacy of the upper section, they reinforced it by incorporating wooden beams within the structure of the dome. (Fig. 21)

The specific horizontal wooden beams are not associated with the overall wooden binding of the structure, as they are positioned at a different level and do not extend continuously throughout the Crypt. Their primary function was to accommodate the tensile-flexural stresses at the uppermost, nearly flat, section of the specific dome type. These beams were essential, primarily for static stability rather than for managing dynamic stresses, a role that is fulfilled by the overall wooden binding system located at a lower level.

The computer simulation reveals how this specific type of dome was constructed. The wooden beams were positioned prior to the commencement of dome construction, including both those integral to the overall binding system (lower) and those that reinforced the nearly flat part (higher). (Fig. 22)



Fig. 20

The lower part of a corner compartment presents regular curvatures and structure. The upper part has the same structure but almost zero curvature, essentially making it an almost flat "slab." (Simulation: FU Research Team)



Fig. 21

Cross-section of the computer model, showing the placement of the wooden horizontal elements in relation to the vaulting, at the upper part of the roofing of a corner compartment. (Simulation: FU Research Team)

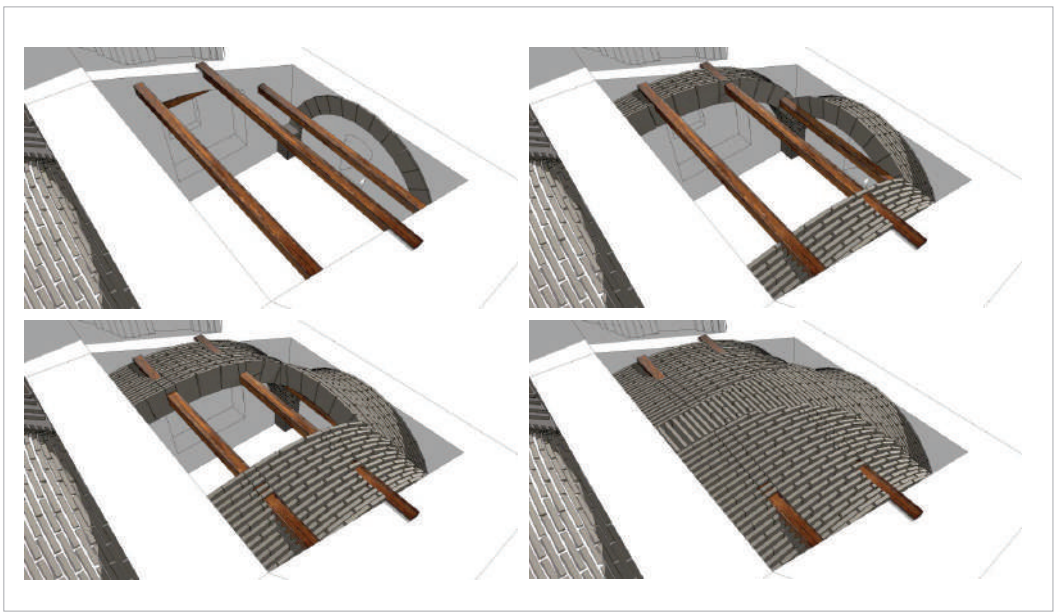


Fig. 22

Simulation of the construction of a corner dome, showing the successive assembly of the self-supporting arches, starting from the perimeter and progressing upward toward the center. (Simulation: FU Research Team)

Starting from the outer wall, an arch constructed of bricks was erected, with a slight inclination, using strong mortar measuring approximately 3-4 cm in thickness. This arch is self-supporting, within its own plane, due to its geometric configuration, which terminates on both sides on strong walls. Out of its plane, this first arch is supported by the surrounding masonry, where the bricks are also positioned with a slight inclination. Then, the two lateral arches are constructed in a similar manner, with one side terminating against the opposite wall and on the other side resting upon the bricks of the first arch.

By alternately building the self-supporting lateral brick arches, progressively decreasing in length, on the three walls, the dome

ascends in height while gradually incorporating the wooden supports into its structure. A thorough constructional analysis, which encompasses a comprehensive understanding of the building process, is essential for interpreting these distinctive characteristics of the corner compartments. (Fig. 23, 24)

Last, but not least, emphasis should be placed on the aforementioned method of constructing domes without the use of formwork, a practice that is significantly less demanding in terms of energy and materials. Additionally, it is evident that these construction techniques utilized locally available materials and passive design strategies, requiring minimal energy input (Cascone et al., 2023; Fokaides, 2025; IHBC, 2020).

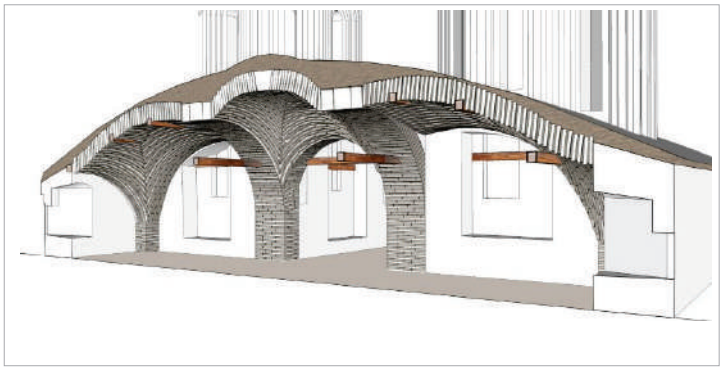


Fig. 23

Section in the three-dimensional computer model along the north-south direction. The wooden tie-beams are visible at the lower level, and the wooden beams that reinforced the upper part of the roofing of the corner compartments at a higher level. (Simulation and section: FU Research Team)

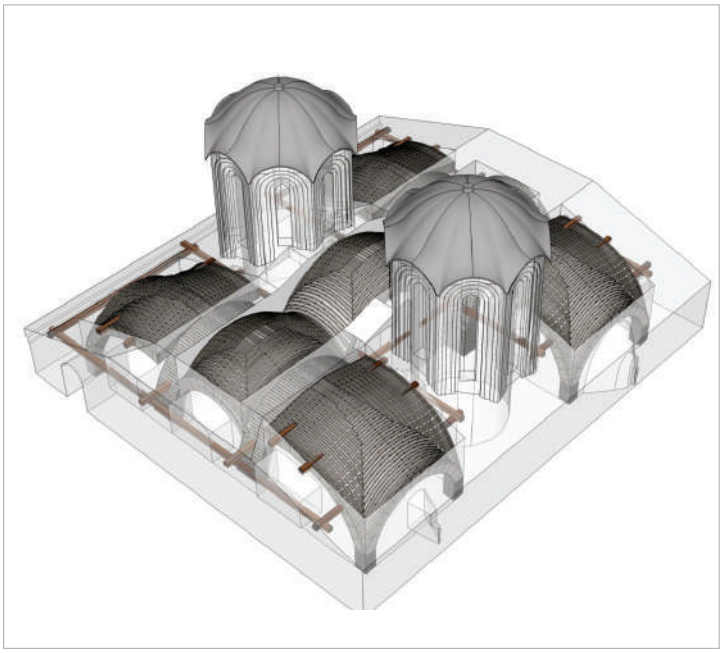


Fig. 24

Computer simulation of the entire structural system of the Crypt, showing the wooden parts integrated within the body of the vault structure. (Simulation: FU Research Team)

Conclusions

The dome roofing of the Crypt of the Katholikon at the Monastery of Docheiarios presents important particularities, which came to the surface through the documentation and constructional analysis of the monument over the past 2 decades. This research was initially undertaken by the National Technical University of Athens, Greece and subsequently by the Department of Architect Engineers at Frederick University in Cyprus.

The architects of the Crypt tried to address the specified requirements and objectives, which included concealment, functionality and security. They recognized that this decision posed significant construction challenges for what was, at that period, a well-established dome type.

The construction of domes without the use of formwork is a technique that has been practiced for at least 5,000 years. This particular method of dome construction was also well-known to the Byzantine builders and was used in relatively small domes, benefiting from its advantages of a faster, safer and more cost-effective building process.

Like nearly all significant historical structures, these distinctive domes were constructed using well-known traditional techniques and locally sourced materials, which are inherently more sustainable compared to contemporary industrial materials. Materials such as stone, brick, wood, and lime plaster were typically obtained and crafted locally, resulting in minimal embodied energy during the original construction.

The builders tried to deal with the specific particularities, limitations and weaknesses of the construction through innovative methods. In certain sections of the structure, they implemented variations of the basic dome construction system, by incorporating additional wooden reinforcements. This unique and composite structure effectively withstood centuries of both static and dynamic loads, owing to the robust interaction between the vaulted structure and the wooden reinforcements. However, this resilience was compromised in recent times, due to the decay and deterioration of the timber components.

The constructional analysis of the dome roofing of the Crypt of the Katholikon at Docheiarios Monastery reveals that the wooden components integrated within the stone body of the structure are a primary and cooperating load-bearing element, effectively supporting both static and dynamic loads.

The current endeavor to restore the dome structure must consider the five-century effective role of these wooden components and ensure that their replacement is conducted in a manner that is compatible with the original design. The tool of Constructional Analysis significantly contributes to understanding its role and utility in these contexts. The forthcoming study, on the restoration of this specific section of the monument, must duly consider the aforementioned characteristics of its constructional system as a foundational element of its restoration proposals.

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Use of Artificial Intelligence Tools

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