Wooden reinforcements in Byzantine masonry: A rough guide to their position and arrangement[1]

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Introduction

The use of integrated systems of wooden reinforcements has been noted in numerous surviving Byzantine monuments, and it is now rather widely accepted that these must have existed in the majority of Byzantine churches. Most researchers, architectural historians, and architects are more or less cognizant of the possible existence of such reinforcements, or might even already have had some first-hand experience of discovering them in Byzantine buildings. Acknowledged researchers have devoted whole chapters in their work on describing these systems; Auguste Choisy in 1883 in his work "L' art de batir chez les Byzantins" in the chapter 'Les chaînages'[2], Giorgos Velenis in 1984 in his dissertation on the interpretation of exterior decorative elements in Byzantine architecture using the terms 'ζωστήρες', 'ιμαντώσεις' and 'ξυλοδεσιές'[3], Pavel Rappoport in the 1995 translation of his book "Building the Churches of Kievan Russia"[4], Robert Ousterhout in 1999 in the indispensable manual "Master Builders of Byzantium" in the sections on 'Wooden reinforcements' and 'Wooden reinforcements of arches and vaults'[5], and Stavros Mamaloukos in 2005 in a shorter treatise on building technology in Byzantium[6]. Researchers have also already supported that '*the Byzantine use of metal tie bars and wooden tie beams… is probably one adopted from the well-established, albeit hidden, technique developed by Roman builders*'.[7]

Nevertheless, in spite of the aforementioned accounts, our knowledge of the precise use of such wooden reinforcement systems still remains lacking and incomplete. The reason for this is that the discovery of such reinforcing beams is usually incidental, and hence, their study is, out of necessity, fragmentary, as, in most cases,

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[1] This paper presents the initial findings of ongoing research towards a doctoral dissertation at the University of Patras on the subject of 'Wooden structural reinforcements in Byzantine masonry' under the supervision of Assistant Professor Stavros Mamaloukos, to whom I am deeply indebted for his guidance and support, as well as for the opportunity to visit some remote Byzantine monuments, particularly in Turkey. I extend my sincere gratitude to the other two members of my dissertation committee UPatras Assosiate Professor Petros Koufopoulos, and NTUA Professor Elisavet Vintzilaiou. I am also indebted to Dr. Androniki Miltiadou-Faezans, previous Director of the Directorate for Technical Research on Restoration of the Hellenic Ministry of Culture, for introducing me to the subject, and offering me the opportunity to participate in a number of relevant research projects in important Byzantine monuments in Greece.

[2] Choisy 1883, 115-122.

[3] Velenis 1984, 45-65.

[4] Rappoport 1995, 89-109, 133-142.

[5] Ousterhout 1999, 157-162, 192-194, 210-215.

[6] Mamaloukos 2005, 8-17.

[7] Lancaster 2005, 129.

these systems largely remain out of view, intentionally embedded within the masonry by Byzantine builders.

In the case of wooden reinforcements in foundations their discovery and documentation is highly problematic, as it requires extensive systematic excavations, usually allowed only in buildings that have already been razed to the ground. In the case of wooden reinforcements inside walls, their discovery is sometimes possible by careful investigation of the surviving putlog holes, though in many instances these do not necessarily correspond with the wooden reinforcement systems; hence, one must resort to endoscopy in purposely drilled holes, and other non-destructive techniques. In the case of vaulting structures and domes this problem is amplified, as the extrados are almost always out of reach, covered by floors and roofs. Hence, access to these areas is possible only during the construction phase of restoration projects. Finally, as in many cases these wooden elements have deteriorated to the extent that they leave behind only a system of cavities in their place, the application of grouting in modern restoration projects completely fills these voids, thus, sadly, eradicating all traces of these structures forever.

As a consequence, available data on wooden reinforcement systems is severely limited. To perplex matters further, in a number of cases where such systems have been located, either they have not been thoroughly surveyed, documented and studied, or they have been largely ignored, or the voids left in their place have been erroneously interpreted as other building elements (gutters, putlog holes, formwork supports, etc.) One must also note that it may not always be possible to recognize the existence of such reinforcement systems, even in monuments that have been excavated, or the extrados have been exposed, either due to the fact that researchers were not aware of their possible existence, or because of the difficulty of accurately interpreting the exact building elements in masonry that has deteriorated, suffered heavy damage, and is covered with layers of debris and infill, as is often the case in the restoration projects of such weathered monuments.

Methodology

It is not clear whether these wooden reinforcement systems were used in all Byzantine churches, even though they appear over a wide time spectrum, from the 6th to the 14th century, as well as a wide range of geographic locations, from Kievan Rus' in the north to the Peloponnese in the south, and from Italy in the west to Cappadocia in the east. We must also note that, as Velenis and Ousterhout have already astutely deduced '*Clearly, the use of wood was linked to workshop practices, but there is still not enough evidence to draw meaningful comparisons.*'[8] Velenis proceeds into a lengthy and well documented analysis on how different building workshops or teams used a variety of exterior decorative and building elements to hide these wooden reinforcements inside the masonry.[9] Rappoport also differentiates between building

[8] Ousterhout 1999. 192-194.
[9] Velenis 1984. 45-65.

teams based on whether double, single or no wooden ties were used in the churches of Kievan Rus'[10].

This paper will present some preliminary findings of ongoing research towards a doctoral dissertation. Thus, it will draw from an inventory of already recorded monuments (fig. 1), as well as two particular churches in Greece, Panagia Krina on Chios and Parigoritissa in Arta, Epirus, where a more systematic documentation of wooden reinforcement systems was attempted a few years ago. Nonetheless, a number of monuments have not yet been cataloged, and many more deserve more thorough in-situ investigation in the near future. As a result, this discussion might regrettably err more in favor of comprehensiveness, and less towards thoroughness.

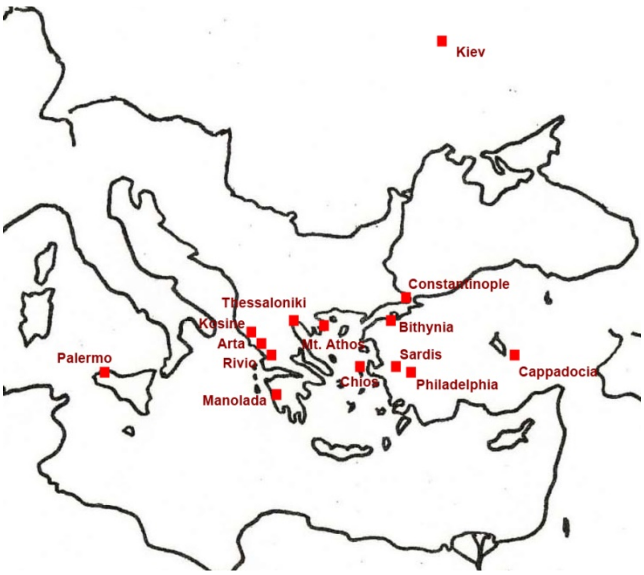

Fig. 1: Map of discussed monuments

As this presentation is aimed at providing a comprehensive, albeit rough, guide to the position and arrangement of such wooden reinforcement systems, there arose the question of how to go about describing the various positions in which they might be found. A systematic account of their possible positions from top to bottom, or vice versa, in a Byzantine church would be the most methodical manner to go. Such a systematic account would also necessarily have to differentiate between the various, distinct typologies in which Byzantine churches fall into. On the other hand, this might not be the most instructive way to go. We must also realize that the actual Byzantine builders would probably not have thought so much in terms of typology, as about the distinct building elements, i.e. columns, arches, vaults, walls, windows, etc., out of which all churches were composed, regardless of their exact typology. Hence, this paper will instead present the positions at which such systems might be found, starting from the most obvious and conspicuous ones, and moving on to the more obscure. This account will only minimally differentiate between typologies, but rather correlate with the aforementioned building elements that compose most Byzantine monuments.

[10] Rappoport 1995. 135.

1. Exposed tie-beams above columns and piers

Fig. 2: Basilica cistern (Yerebatan Sarayı), Istanbul, interior view (Mango 1976, Fig. 95)

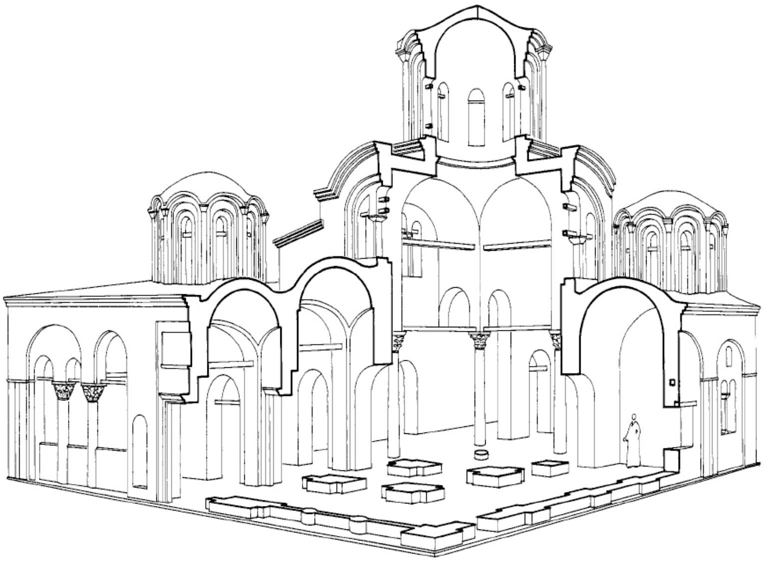

Fig. 3: Hagioi Apostoloi, Thessaloniki, perspective section
(drawing by D. K. McCoubrey in Kuniholm and Striker 1990 / Holy Apostles Thessaloniki)

Unquestionably the most conspicuous position where wooden reinforcements are routinely encountered in Byzantine churches, but also in other buildings, such as cisterns (fig. 2), is just above free-standing columns or piers. This position might or might not correspond to the springing of arches and vaults, but in this instance we will refer mainly to the latter case. Of course, this position is usually encountered in cross-in-square church types with two or four columns or piers, but these types together with their variations account for a large number of surviving Byzantine churches (fig. 3, 4). From a builder's point of view the necessity of these tie-beams is obvious, as they served to stabilize the columns or the pier masonry, while the structure continued to be erected above them.[11]

In many cases, these tie beams were left in place after construction, and sometimes even decorated further, as in the case of some conspicuous wooden ties in Hagia Sophia (fig. 5)[12], as they continued to serve their function of helping to keep these slender elements in place[13]. In other cases, they were cut off for various reasons, one of them being to allow for a subsequent drawing program to be realized, as in the case of the central wooden ties at the 10th c. Katholikon of Vatopedi Monastery on Mount Athos[14] (fig. 6).

Fig. 4: Panagia Parigoritissa, Arta, Epirus, interior (May 2005)

[11] This position logically also includes the tie-beams at the springing of window arches, but these shall be dealt with separately in section 6 of this paper.

[12] See further, Sheppard 1965. For this paper, wood specimens were taken from both the beams in the west gallery of the Hagia Sophia, as well as the decorative planks covering them. These were carbon dated to 470±70, and 830±70 respectively.

[13] An interesting case of such members left in place, and decorated further, is that of a number of small Byzantine churches in Mani, Greece, such as Hagios Nikolaos at Ochia, Mani (mid-12th c.) and others. Here long marble members, similar in dimensions to wooden tie-beams, are used instead of wooden members. The small dimensions of these buildings do not seem to warrant the use of such difficult to find and carve, long marble members, merely as formwork supports. Furthermore, sources refer to them as «κοσμήτες», i.e. decorative cornices, and together with some massive marble cornices at the base of the central dome drum, they might hold further clues to the relation between marble cornices and wooden beams as tension members in Byzantine buildings.

[14] Mamaloukos 2001. 62-63. *"Only the wooden tie-beams that connect the eastern columns with the bema walls survive. All the other wooden tie-beams were obviously cut off before the execution of the early 14th c. drawing program."*

Fig. 5: Hagia Sophia, Istanbul, decorated tie beam in the west gallery (July 2010)

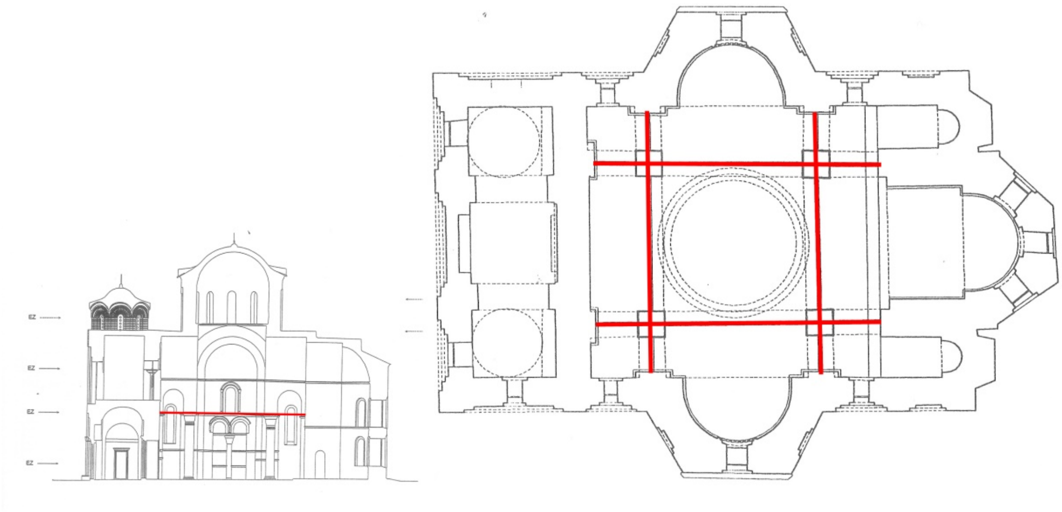

Fig. 6: Katholikon, Vatopedi Monastery, Mount Athos, plan and longitudinal section showing wooden reinforcements at the level above the columns
(Mamaloukos 2001, Figs. 27, 69.2)

It goes without saying that, in order for these tie beams to serve their stabilizing function they would have to be anchored to similar wooden beams embedded within the walls. In fact, in many cases these exposed tie beams over the columns have been found to be part of a system of wooden reinforcements or '*wooden chains* [that] *would brace the building throughout its height, connecting to the system of reinforcement in the vaults and domes. At the same time, wooden chains would allow the masonry enough flexibility to settle without cracking*'[15]. On the other hand, we must not be led to assume that there were necessarily any hard and fast rules. As a matter of fact, a careful recent investigation of the 14th c. Panagia Pantovasilissa in Trigleia confirmed that the exposed tie beams did indeed connect to double rows of

[15] Ousterhout 1999. 194.

wooden reinforcements within the walls at the same level, and that these tie beams extended along the longitudinal axis, but also, perplexingly, that these did not extend along the transverse axis within the church (fig. 7).

Fig. 7: Panagia Pantovasilissa, Trigleia, plan and longitudinal section showing the surveyed wooden reinforcements at the level above the columns
(Mamaloukos and Kamboli 2013)

2. Tie-beams at the springing of arches and vaults

A second, almost equally conspicuous location where such exposed tie beams, connected to respective wooden reinforcements throughout the walls at the same height, are routinely found is at the springing of arches and vaults (fig. 3, 4). In fact, in certain cases this level coincides with the previously described one over the columns or piers. Both Velenis and Ousterhout have already explicitly indicated this level as a location where wooden reinforcements were consistently used.
Ousterhout, in particular, provides a compelling drawing of the plan of the Chora monastery in Istanbul, showing the patterns of wooden reinforcements within walls and across vaults (fig. 8) and states that "*wooden beams were positioned at the level of the cornices, which were in turn connected to the exposed tie beams spanning the arches*"[16].

[16] Ousterhout 1999. 192-194.

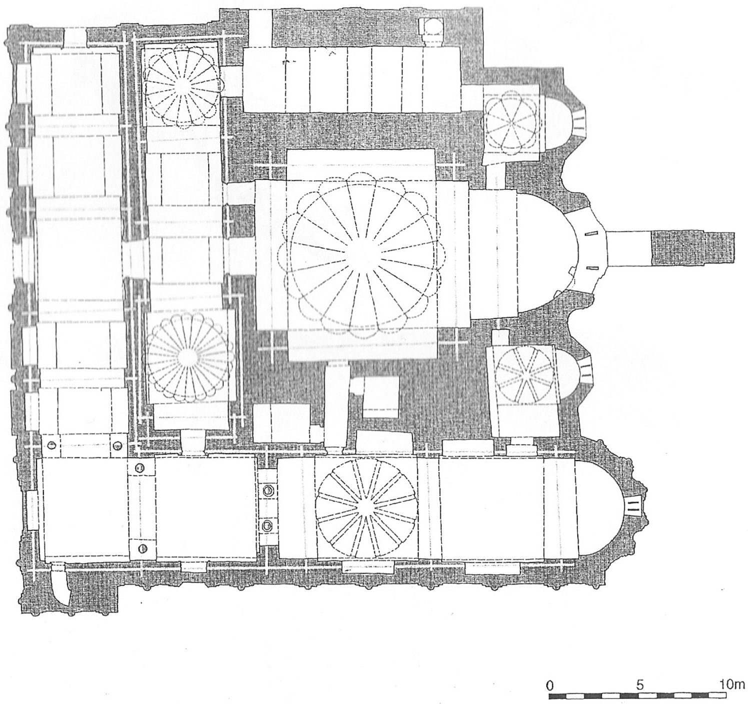

Fig. 8: Chora monastery, Istanbul, plan showing the pattern of wooden reinforcements within walls and across vaults
(Ousterhout 1999, Fig. 83)

Velenis also states that the Byzantines recognized the need for reinforcement at this level in the masonry, and that at first they used continuous marble cornices on the interior and exterior, which when interconnected and embedded deep in the masonry, would function as a tension ring, and were aptly named "ζωστήρες" (a term that roughly translates as 'belts')[17], though later on the term "κοσμήτες" (decorative cornices) was preferred as they gradually lost their tensile function. It also appears that such wooden tie beams were not only used in middle and late Byzantine buildings, but also, in some cases at least, in earlier churches as well, as illustrated by the example of the church of St. John in Philadelphia (Alaşehir) (fig, 9), where the remaining cavities point to the use of such tie beams across vault spans of up to 14 m[18].

[17] Velenis 1984. 46-47.
[18] We are indebted to Nikolaos Karydis for the excellent reconstruction drawings of this church. One must note though, that while the central wooden element appears to be a permanent tie-beam, as the builders took great care in placing it between massive ashlar blocks, the exact use of the lateral wooden elements is not so clear. Their much weaker anchoring behind a thin brick veneer and the fact that they are at exactly the same level (although, of course, they could have been notched) makes their use as tensile elements in an earthquake problematic. On the other hand, their in-wall part does serve to transfer the load of the whole arch to the tie-beam, and as Karydis states, the arches' wooden centering appears to have started just above their level, and not at the actual arch springing.

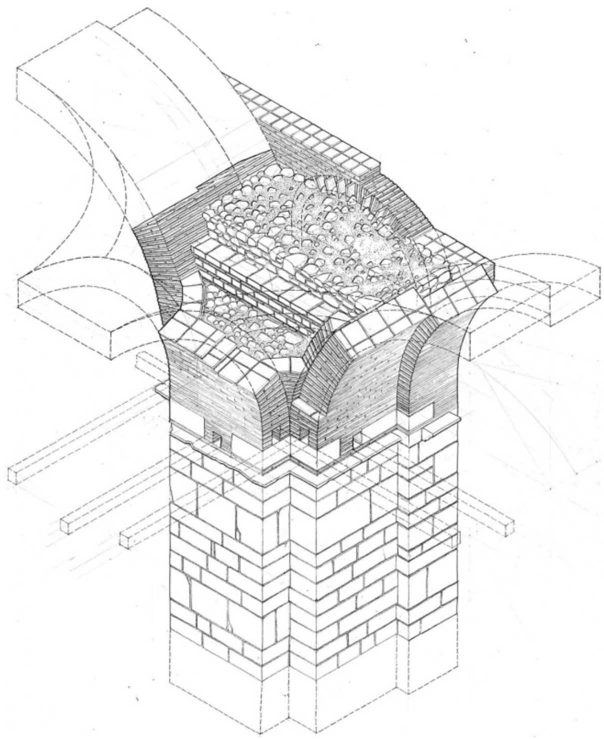

Fig. 9: Philadelphia (Alaşehir), St. John, Northwest Pier, Interpretative axonometric (Karydis 2012, Fig. 7)

It is true that the level of the springing of arches and vaults coincides with the height of interior cornices, however, documented tie beams and most importantly the wooden reinforcements within the walls are actually located, partly or completely, above the level of the cornices. Another important note regarding the cornices is that even in typologies that lack central columns or piers, the corresponding level where a continuous cornice is visible on the interior may well indicate the existence of an integrated wooden reinforcement system at the same height, as is illustrated in the example of 13th c. Panagia Krina church on Chios (fig. 10).

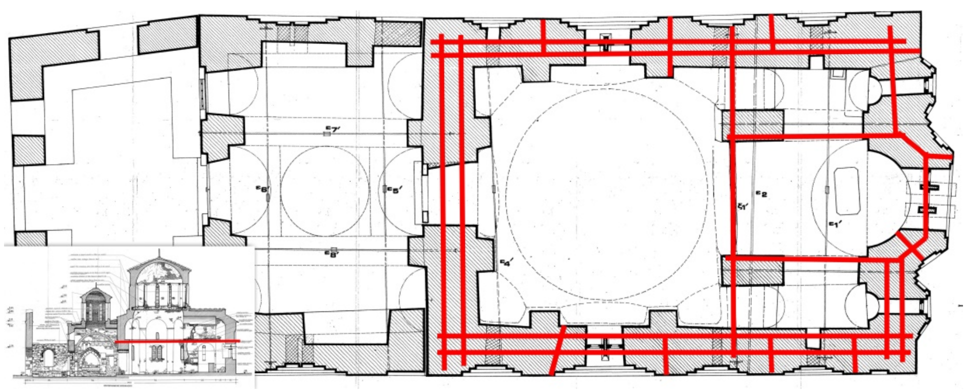

Fig. 10: Panagia Krina, Chios, sketch of the discovered wooden reinforcements found at the level of the first interior cornice
(Vintzilaiou 2006)

Again though, there are no hard and fast rules, as is illustrated by the case of the 13th c. church of Panagia Parigoritissa in Arta (fig. 11). Here, wooden reinforcements within the walls were found to be integrated with the exposed tie beams both at the springing of the lower level arches, and the cross-arm barrel vaults, but neither of the two were found on the upper level arches. Another curious but instructive example is the 13th c. church of Hagios Stephanos at Rivio, Western Greece, where a row of wooden reinforcements at the level of the cross-arm barrel vaults was visible on the exterior, but did not necessarily include exposed tie-beams on the interior (figs. 12, 13). In this case, the small size of the building might not have warranted the use of such exposed beams on the interior, but only embedded around the wall perimeter.

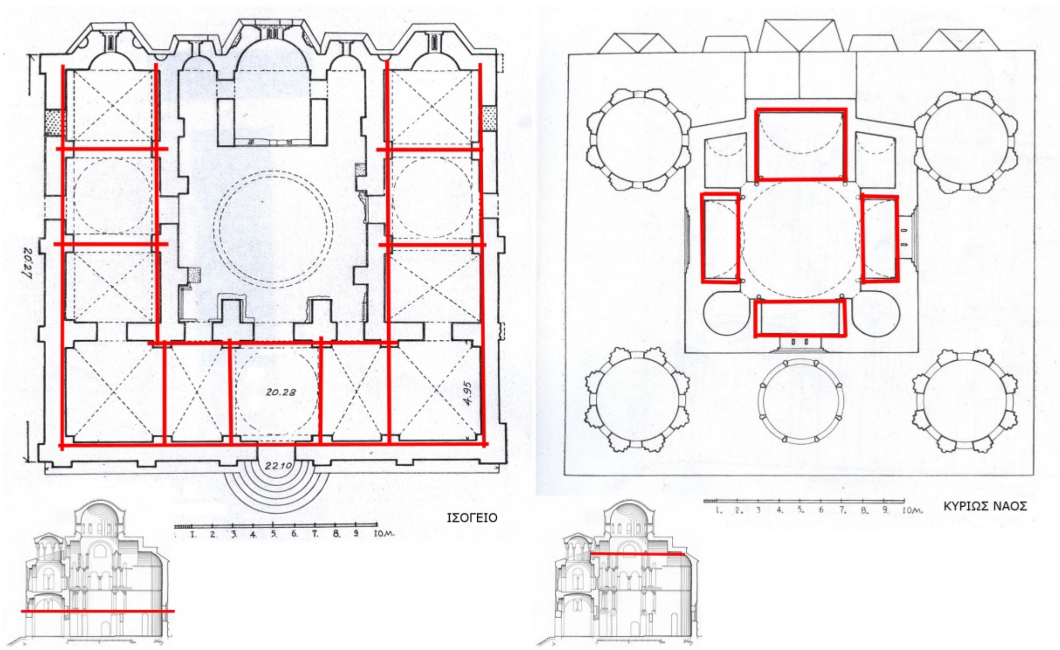

Fig. 11: Panagia Parigoritissa, Arta, sketch of wooden reinforcements found at the springing of lower level arches (left), and the cross-arm barrel vaults (right)
(Miltiadou and Koumantos 2005)

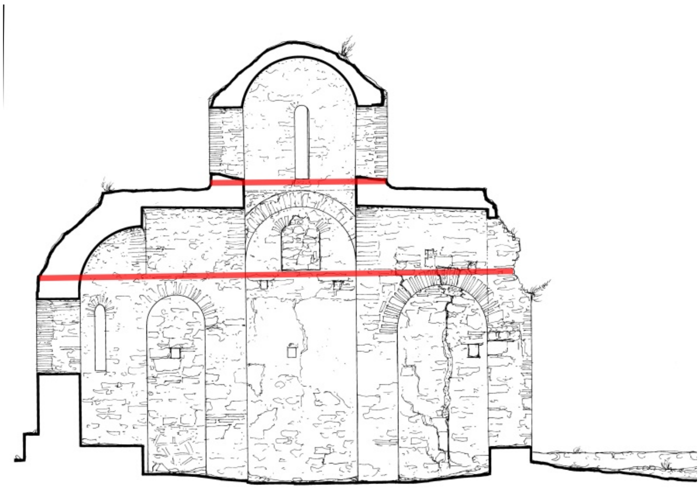

Fig. 12: Hagios Stephanos, Rivio, longitudinal section (before restoration) showing levels of discovered wooden reinforcements
(Mamaloukos and Kamboli 1995)

Fig. 13: Hagios Stephanos, Rivio, , traces of wooden reinforcements at the springing of cross-arm barrel vaults
(Mamaloukos and Kamboli 1995)

Finally, the rule of integrated wooden reinforcements at the springing of arches and vaults also holds for secondary, i.e. lower, arches or vaults as well, as was found in the 11th c. St. George of Peristremma church (Karagedik Kilise) in Cappadocia (fig. 14), where a collapsed pier revealed the, otherwise completely hidden, single wooden beam along the northern bema wall, to which the exposed tie beam of the northeast corner bay was anchored.

Fig. 14: St. George church (Karagedik Kilise), Peristremma (Belisırma), Cappadocia, cavities left in the place of notched wooden reinforcements at the springing of the vault in the NE corner (July 2009)

3. Wooden reinforcements at the base of the dome drum

The next level of integrated wooden reinforcement systems we shall turn our attention to, is again very prevalent, and has already been discovered in a number of Byzantine churches. This level is at the base of the dome drum, and again has been described explicitly by Velenis[19], as well as Ousterhout who has reported such systems found during the restoration projects of both the Chora church (Kariye Camii)[20] (fig. 15), and the Christ Pantocrator chapel (Zeyrek Camii)[21] (fig. 16) in Istanbul. Indeed, we are also well aware of the iron reinforcement chain around the base of the dome of the Hagia Sophia, at the same, structurally critical level.[22] Since this is an already rather well known position, we shall describe its position in the two churches we have examined in depth, i.e. Panagia Parigoritissa and Panagia Krina, and discuss some interesting permutations of it in other monuments.

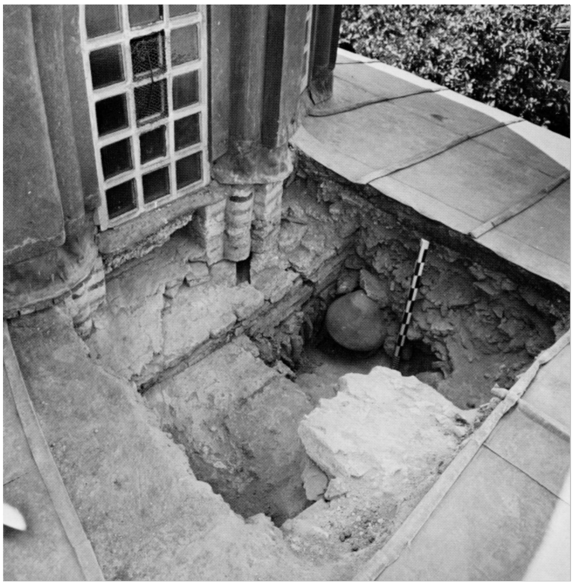

Fig. 15: Chora church (Kariye Camii), Istanbul, extrerior view of the extrados of the Parekklision during the 1980s excavation
(Ousterhout 1987, Fig. 152)

[19] Velenis 1984. 46-47.
[20] Ousterhout 1987. Fig. 152
[21] Ousterhout et al 2010. 63. Fig. 7.
[22] Velenis rightfully remarks that the costly use of iron instead of wood in this case was warranted by the immense loads that this reinforcement chain would have to bear. Velenis 1984. 45.

Fig. 16: Christ Pantocrator chapel (Zeyrek Camii), Istanbul, window reveal of the west central dome, showing the cavities for reinforcement beams at its base (July2003)
(Ousterhout et al 2010, Fig. 7)

In Panagia Parigoritissa a wooden reinforcement chain was located on the interior side of the base of the central dome, hidden behind the plasterwork (figs. 17, 18). It was impossible to ascertain whether a similar wooden reinforcement run along the exterior face as well. We must point out that, contrary to the other two examples, it was located well below the window sills, and also clearly above the height of the stone cornice on the interior.

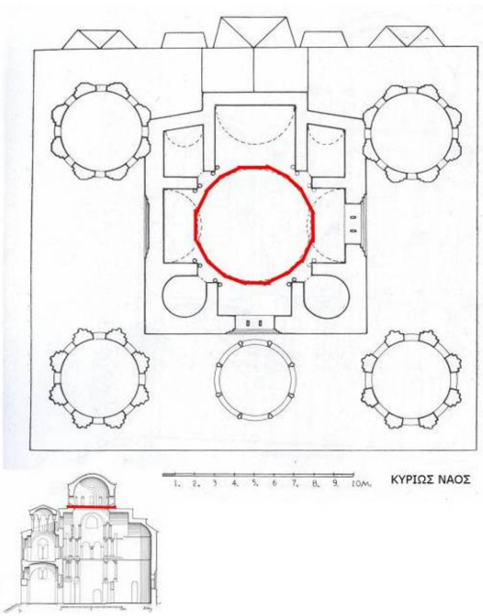

Fig. 17: Parigoritissa, Arta, sketch of wooden reinforcements at the base of the central dome drum
(Miltiadou - Koumantos 2005)

Fig. 18: Parigoritissa, Arta, interior view showing wooden reinforcement at base of the central dome drum
(Miltiadou - Koumantos 2005)

In Panagia Krina, during the restoration project, two rows of wooden reinforcements were discovered at the base of the central dome drum, one flush with the exterior face, and another on the interior just below the window sills, but at a distance from the interior face (figs. 19, 20). It is noteworthy that at this height, the wooden elements accounted for over fifty percent of the thickness of the masonry wall. This was not the only wooden reinforcement system of the dome drum base, however. Another one was later discovered about 30 cm below it, this time reinforcing the sensitive area of the rectangular pedestal base of the drum, and which corresponded to the spherical surface raising the base of the dome over the supporting conches (figs. 21, 22). In Panagia Krina this level of wooden reinforcements was laid out in a single row, in an octagon, or truncated rectangle.

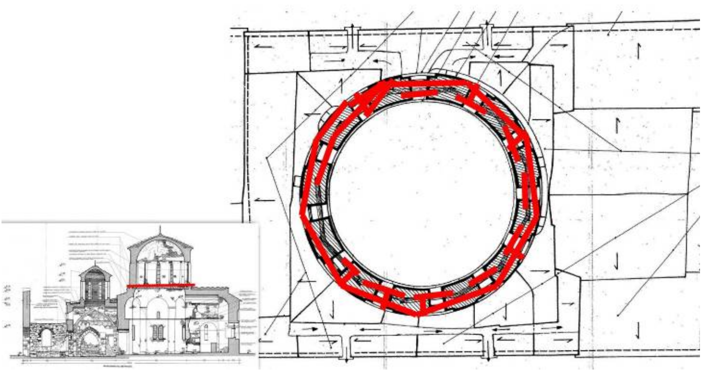

Fig. 19: Panagia Krina, Chios, plan of wooden reinforcements at the base of the dome drum (Vintzilaiou 2006)

fig. 20 Panagia Krina, Chios, exterior view showing the position of wooden reinforcements at the base of the dome drum (Vintzilaiou 2006)

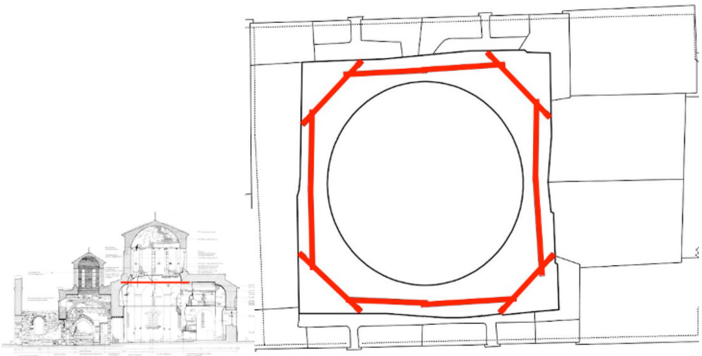

Fig. 21: Panagia Krina, Chios, plan of wooden reinforcements at the rectangular base of the central dome (Vintzilaiou 2006)

Fig. 22: Panagia Krina, Chios, exterior view showing position of wooden reinforcement at the rectangular base of the central dome (Vintzilaiou 2006)

In other monuments though, such as the 13th c. church of Hagios Stephanos, in Rivio, Western Greece, where the level of the rectangular pedestal base coincides with the base of the drum, only one level of wooden reinforcements was found, laid out not in a circle around the drum, but rather in a single-row rectangle around the base (fig. 23, 24)[23].

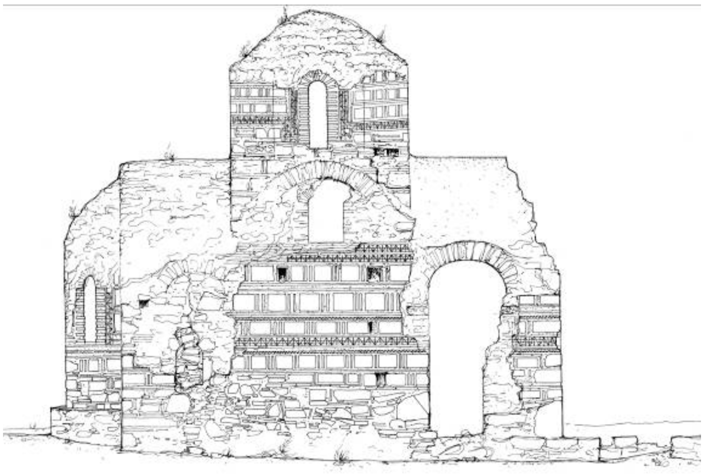

Fig. 23: Hagios Stephanos, Rivio, south elevation (before restoration)
(Mamaloukos - Kamboli 1995)

Fig. 24: Hagios Stephanos, Rivio, , traces of wooden reinforcements at the base of the dome drum
(Mamaloukos - Kamboli 1995)

On the other hand, in the church of St. Mary in Mary, Kosinë, Albania, a similar to the above, Despotate of Epirus church (fig. 25, 26), two quite different arrangements are found simultaneously on the same level; a circular wooden ring on the interior above the cornice, and a double row of rectangular arranged reinforcement beams visible on the exterior within the rectangular pedestal base of the drum. These two arrangements might also be interconnected, but that would require additional in-situ investigation to ascertain.

[23] Mamaloukos et al 1995.

Fig. 25: St. Mary, Kosinë, Albania, view of wooden reinforcement ring at the base of the drum on the interior (September 2014)

Fig. 26: Mary, Kosinë, Albania, view of wooden reinforcements at the base of the drum on the exterior (September 2014)

Yet another permutation of such a system can easily been seen, even today, in the 6th c. Red Church (Kizil Kilise) in Cappadocia[24] (fig. 27, 28). Here, the octagonal dome drum rests on the square main church walls via squinches. In this case, a double row of wooden reinforcements was laid at the base of the squinches, which in this manner coincide with the base of the dome drum. This is a particularly interesting, albeit perplexing, example, as it is an early Byzantine church, no traces of other wooden reinforcements are to be found in the rest of the church, the wooden elements are completely exposed, even though they are embedded in the masonry, and finally it is an ashlar masonry monument, as opposed to the majority of brick or rubble masonry churches discussed in this study.

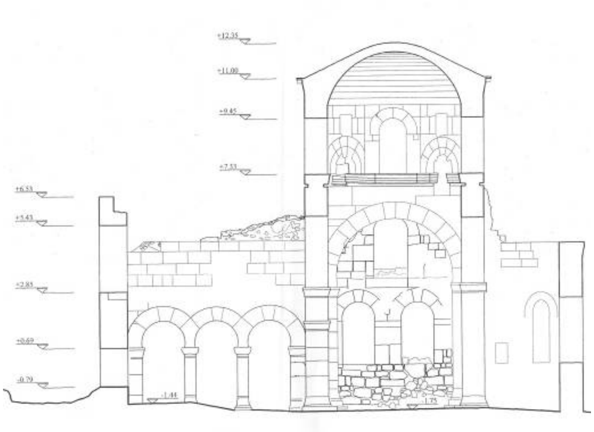

Fig. 27: Kizil Kilise, Cappadocia, longitudinal section showing the position of double wooden reinforcement at the base of the dome (Agaryilmaz 2007)

Fig. 28: Kizil Kilise, Cappadocia, interior view showing traces of the wooden reinforcements at the base of the dome drum and squinches (July 2009)

[24] Agaryilmaz 2007.

An almost identical wooden reinforcement arrangement has been encountered in the 12th c. church of St. Mary of the Admiral (Martorana) in Palermo (fig. 29), a church just beyond the western end of the Byzantine world, and some six centuries later. Here, the dome drum includes the squinches that make the transition from the square main church walls, to an octagonal drum, and then to the round dome. As Ćurčić reports[25], two distinct levels of continuous wooden reinforcements were discovered during the restoration works: the lower one was composed of four pairs of beams, a pair above each of the main arches, i.e. at the base of the four squinches, presumably linked to each other, and the higher one a continuous wooden chain hidden behind decorative planks at the springing of the dome.

Fig. 29: St. Mary of the Admiral (Martorana), Palermo, view of the interior showing the transition to the dome
(http://www.globeimages.net/data/media/186/chiesa_della_martorana_palermo.jpg)

4. Wooden reinforcements at the crown of the dome drum

The latter example points to the next level of integrated wooden reinforcements, again in the structurally sensitive area of the dome drum, that is commonly found at the crown of the dome drum walls. Even as far back as 1883, Choisy pointed out this area in a drawing of the Pammakaristos Chapel (Fethiye Camii) in Istanbul (fig. 30).

[25] Kitzinger and Ćurčić 1991. 38,106,107. The church of St. Mary of the Admiral is included here, though it is not strictly speaking a Byzantine church, both as an indication of the geographic dissemination of the use of integrated wooden reinforcement systems, as well as an interesting example of the adaptation of these systems to different church typologies.

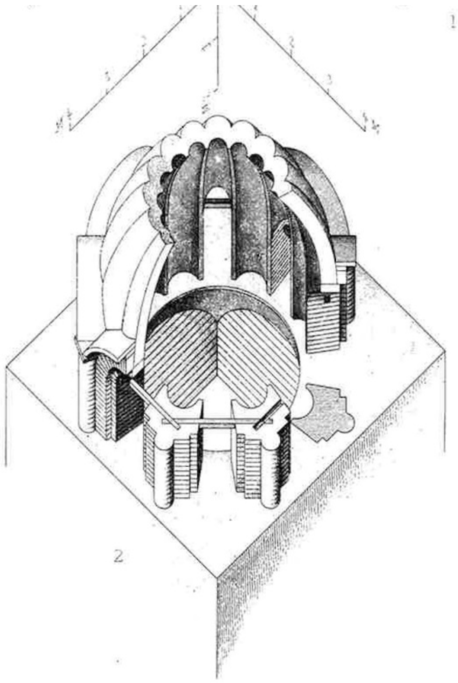

Fig. 30: Pammakaristos chapel (Fethiye Camii), Istanbul, axonometric section showing wooden reinforcements at the crown of the dome drum
(Choisy 1883, pl. XX)

Also in Panagia Krina on Chios island, wooden beams were visible at the springing of the window arches of the dome drum, and endoscopic investigation in the masonry piers between them confirmed that they form a continuous tension ring around the base of the dome (fig. 31, 32).

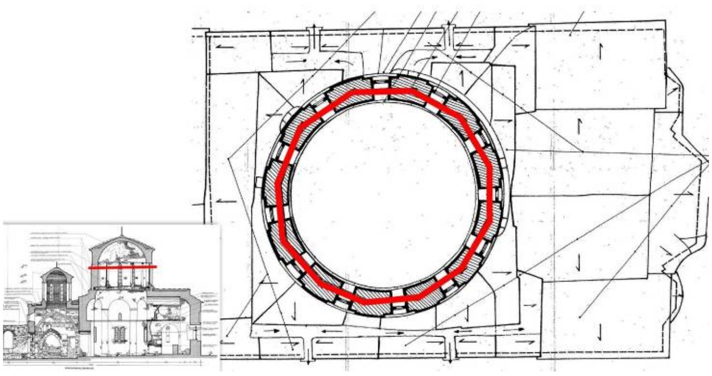

Fig. 31: Panagia Krina, Chios, plan of wooden reinforcements at the base of the central dome
(Vintzilaiou 2006)

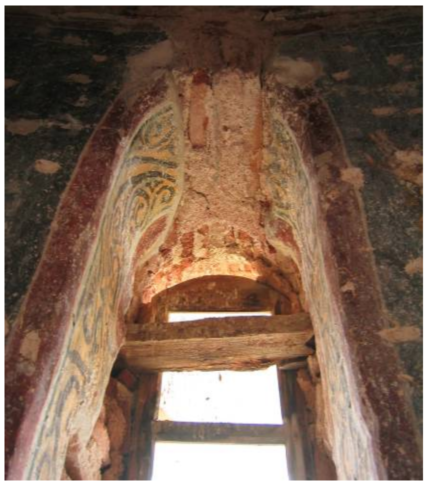

Fig. 32: Panagia Krina, Chios, interior view of central dome drum window, showing wooden reinforcement at the springing of the window arch
(Vintzilaiou 2006)

These reinforcements are almost always found to be composed of a single row of wooden beams, and sometimes a second level might be found in the same area as in the case of the tall windows of the central dome of Hagioi Apostoloi in Thessaloniki (fig. 3). On the other hand, in the churches where the windows do not extend up to the level of the springing of the dome as in Panagia Parigoritissa (fig. 17,18), such reinforcements are not visible, and more research is needed to confirm their existence.

5. Wooden reinforcements below the window sills

Moving on to the rather more obscure levels of wooden reinforcement systems we shall turn our attention to the area below the main window sills, roughly at a height of 1,50 m above the floor. This is also the height where the first row of putlog holes start to appear, and in some cases the scaffolding beams embedded therein appear to have been linked to an integrated, and extensive double row reinforcement system, as was found in Panagia Krina (fig. 33). Here the whole system was thoroughly documented and surveyed, through a multitude of putlog holes and remaining transverse wooden elements, on the exterior and the interior of the church. The system was highly symmetrical, and was interrupted only by the main entrance doorway.

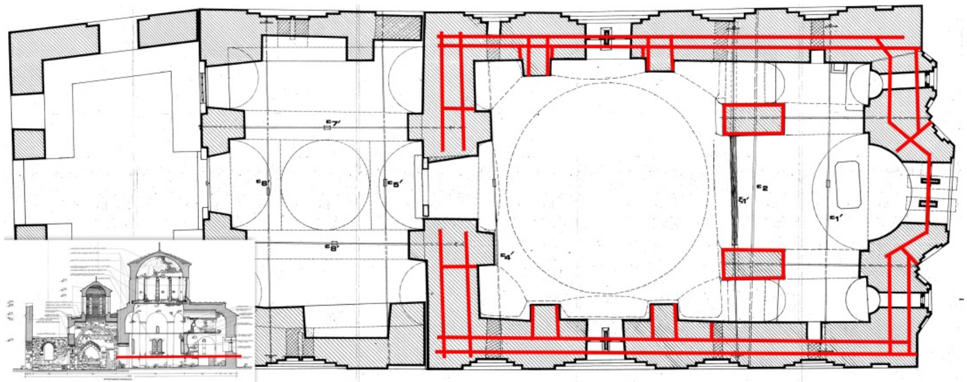

Fig. 33: Panagia Krina, Chios, sketch of the discovered wooden reinforcements found at the level just below the sills of the main church windows (Vintzilaiou 2006)

In the church of St. George (Karagedik Kilise) in Cappadocia where '*some of the putlog holes appear in the stone courses with a notch cut into the stone*'[26] it was found that these putlog holes were indeed rather shallow and isolated from the single row wooden reinforcement running along the center of the masonry wall, just 10-15 cm below (fig. 34, 35). This wooden reinforcement is visible in two partly collapsed areas along the south façade, and hence we must assume that it ran continuously throughout the church walls at this height. Indeed, it might further be assumed that the churches that have wooden reinforcements higher up their structure, in all probability also possess structural reinforcements at this height as well.

[26] Ousterhout 1999, 192.

Fig. 34: St. George church (Karagedik Kilise), Peristremma (Belisırma), Cappadocia, continuous wooden reinforcement below the window sills (July 2009)

Fig. 35: St. George church (Karagedik Kilise), Peristremma (Belisırma), Cappadocia, closeup of wooden reinforcement and putlog hole below the window sills (July 2009)

As is partly evident from the last example, though this horizontal position is not always accompanied by windows per se, it is a critical horizontal level on which integrated wooden reinforcement systems consistently appear, as in the 11th c. church of St. Abercius at Kurşunlu (Elegmi), Bithynia (fig. 37), and the 10th c. Katholikon of Vatopedi Monastery[27] (fig. 6).

On the other hand, the window sills, regardless of the exact height on which they appear, are an area where wooden elements, otherwise embedded in the walls, might be readily discoverable, as was the case in the church of Panagia Pantovasilissa in Trigleia (fig. 7).

[27] Mamaloukos 2001, 62-63. *"The lower level of wooden reinforcements was located at a height of approximately 1.20 m above the floor."*

6. Wooden reinforcements at the springing of window and doorway arches

Moving up from the previous level, the next level where Byzantine builders would have utilized the stabilizing properties of wooden reinforcements would obviously be the springing of the arches of the windows and doorways. Naturally these wooden beams are visible at this point, as they were in Panagia Krina (fig. 36), where several holes were drilled in the masonry between the widows at the same height, and examined with an endoscope to verify whether these beams formed a continuous reinforcement system. Unfortunately, even though one would expect to find a similar system at about this height as well, judging from the regularity of the rest of the levels, no evidence of wooden members or left-over cavities was to be found.

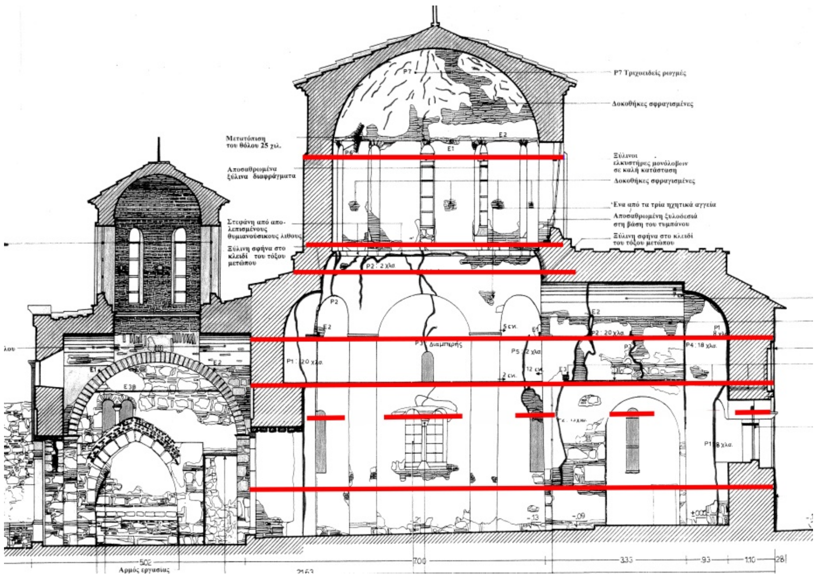

Fig. 36: Panagia Krina, Chios, sketch of discovered wooden reinforcements on different levels including beams at the window arches

Nevertheless, a possible solution to this seeming discrepancy was revealed in the 11th c. church of St. Abercius at Kurşunlu (Elegmi), Bithynia (fig. 37). Here the exposed beams at this height were actually to be found in the springing of the arches of the side doorways. As none of the wood elements has survived, their exact positions and connections are to be seen in the cavities left in their place. Interestingly, in this case, the exposed, single wooden beams at the springing of the arch were connected, via a transverse wooden element, to a double row of wooden reinforcements within the walls some 10-15 cm above the level of the springing, in a staggered manner. As a matter of fact, this system of wooden reinforcements ran exactly above the arches of the windows, which are somewhat lower than the doorways.

Fig. 37: St. Abercius church, Kurşunlu (Elegmi), Bithynia, staggered connection between exposed beam and built-in wooden reinforcements (three more wooden reinforcement systems, one below and two above, are also discernible) (March 2013)

Fig. 38: Zeyrek Camii, exonarthex, windows in north wall with surviving wooden beams at mid height
(Ousterhout et al 2010, Fig. 18)

Thus, returning to Panagia Krina, we could hypothesize that a similar system of continuous wooden ties could be present within the walls, in this case somewhat lower than the exposed window beams, at a height that corresponds with the regular placement of reinforcement systems along the height of the church (fig. 39). Unfortunately, this hypothesis cannot be proven, as in the meantime all masonry cavities have been filled with grout in the course of the, now completed, restoration project of the church.[28]

A pertinent side note here would be that wooden reinforcements can sometimes be found, not only on the window sills, or the springing of window arches, but at mid height of windows as well, especially in triple windows under an arch. Available examples, are few, and belong to otherwise correlated churches as well, such as St. Abercius at Kurşunlu (fig. 37), and the north wall of Zeyrek Camii in Istanbul (fig. 38)[29], but nevertheless they must be noted here.

[28] It is also unfortunate that all comparable evidence of wooden reinforcements has been similarly obliterated in the 11^{th} c. church of Nea Moni on Chios island, a monument that we know served as the prototype for Panagia Krina.

[29] Ousterhout et al 2010.

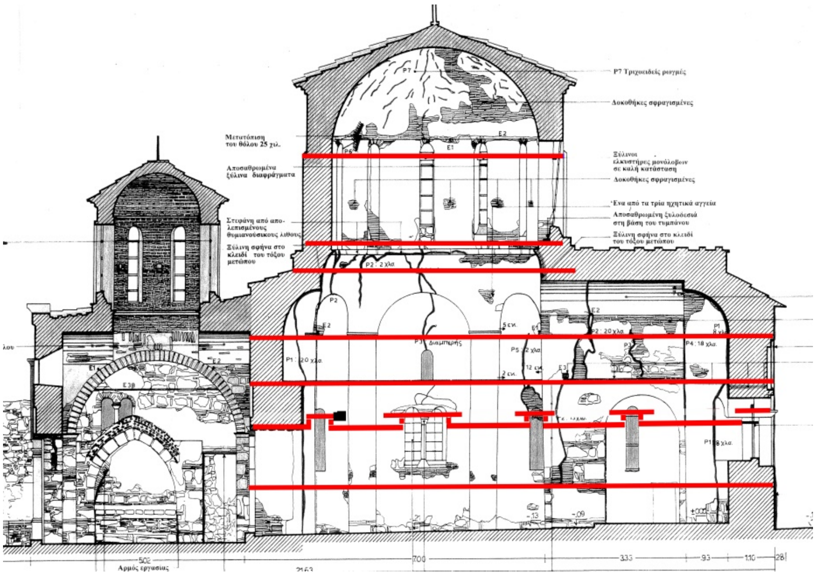

Fig. 39: Panagia Krina, Chios, sketch of discovered wooden reinforcements on different levels, including possible staggered level of continuous reinforcement at the window arches

Lastly, another example of the use of wooden reinforcements at this height is given from Çanlı Kilise in Aksaray, Cappadocia (fig. 40, 41) where again the wooden beams visible at the springing of the window arches do, in fact, continue within the walls at the same height, though in a single row, and at the exact same height throughout the church.

Fig. 40: Çanlı Kilise, Aksaray, Cappadocia, continuous wooden reinforcement at the springing of the main window arches, interior looking north (July 2009)

Fig. 41: Çanlı Kilise, Aksaray, Cappadocia, continuous wooden reinforcement at the springing of the main window arches, east façade (July 2009)

7. Wooden reinforcements in the foundations

One of the most obscure parts of Byzantine churches where builders might regularly have used wooden reinforcements is the foundations. Evidence from this part of monuments is really hard to locate, as it usually requires both the building's previous collapse, and the execution of a meticulous excavation. Thus, all relevant data presented here will, alas, be derived from the limited bibliography on this matter. An important note here is that this category, in reality, includes two distinct levels, one below the foundations, and one at the very base of the walls; however, since the evidence is limited and the aim of this paper is instructive rather than analytic, these two levels will be treated as one here.

The largest body of gathered evidence on the use of wooden reinforcement systems in the foundations comes from the book of Pavel Rappoport on Kievan Rus' churches. Rappoport refers to dozens of monuments in the area from the 10th up to the 12th century, where '*groundsels*' had been used in the foundations, and offers a multitude of information, photos (fig. 42), and drawings (fig. 43) on their exact arrangement, depth and construction details of the foundations, even records of the type of wood found[30], and alludes to the fact that these foundations were in most cases found to exceed the soil freezing depth[31]. The data presented in his book definitely derives from much more detailed studies of individual monuments, which unfortunately remain largely inaccessible due to the language barrier and lack of relevant translations.

[30] In all cases where it was analyzed, it was found to be mostly oak, and sometimes pine. Rappoport 1995. 46, 139-141.

[31] Rappoport 1995, 104.

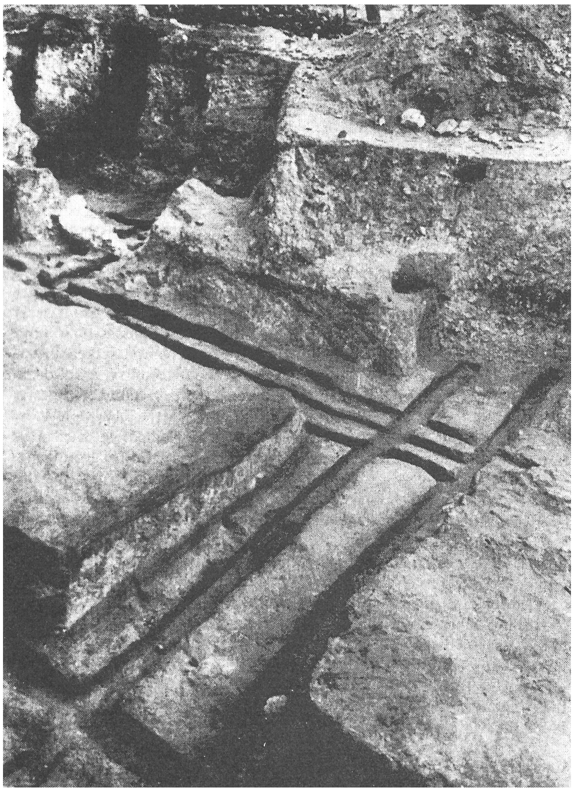

Fig. 42: Church in the campus of the Institute of Arts, Kiev, traces of groundsels under the foundations
(Rappoport 1995, Fig. 47)

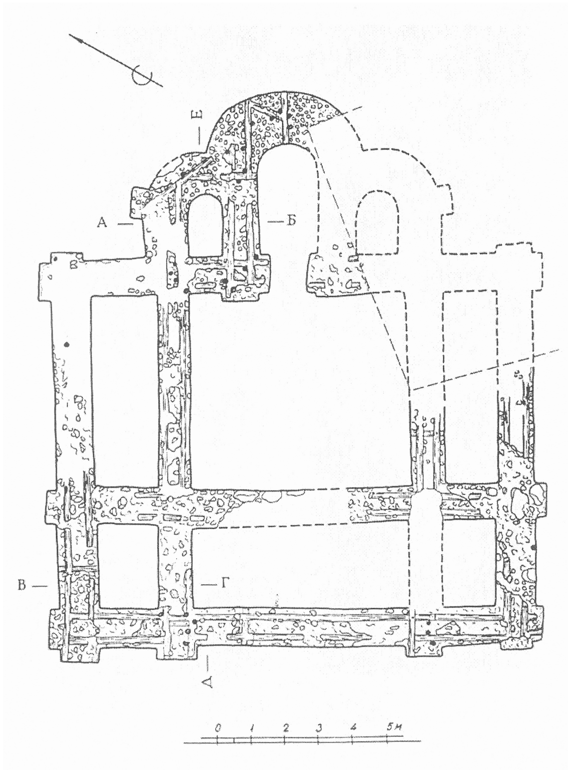

Fig. 43: Church of St. Andrew in Pereiaslavl', plan of the excavated foundations
(Rappoport 1995, Fig. 49)

Nevertheless, it is clear from Rappoport's data that, wherever they were used, wooden reinforcement systems under the foundations were laid regularly in a grid around and inside the whole building (fig. 44)[32], and only later started to be isolated under load bearing members, until their use was eventually discontinued. Ousterhout[33] also refers to an interesting example of a rather expeditious use of isolated wooden elements to bridge over tomb cavities in the foundations of an excavated funeral chapel at Didymoteicho, Northern Greece.

Judging from these specimens one might be tempted to link the use of wooden reinforcements in the foundations with ground freezing conditions, but such a notion will have to be discarded as an identical system has been excavated in church E at Sardis, Asia Minor (fig. 44)[34], a location with a much milder climate. We must note, though, that in this case, the wooden reinforcements were discovered at the crown of the foundation walls, i.e. at the base of the walls, and that the foundations of church E partly lay over the foundations of an older basilica; hence the use of a wooden grid might also have been called for to avert differential settling, and provide a stable building base.

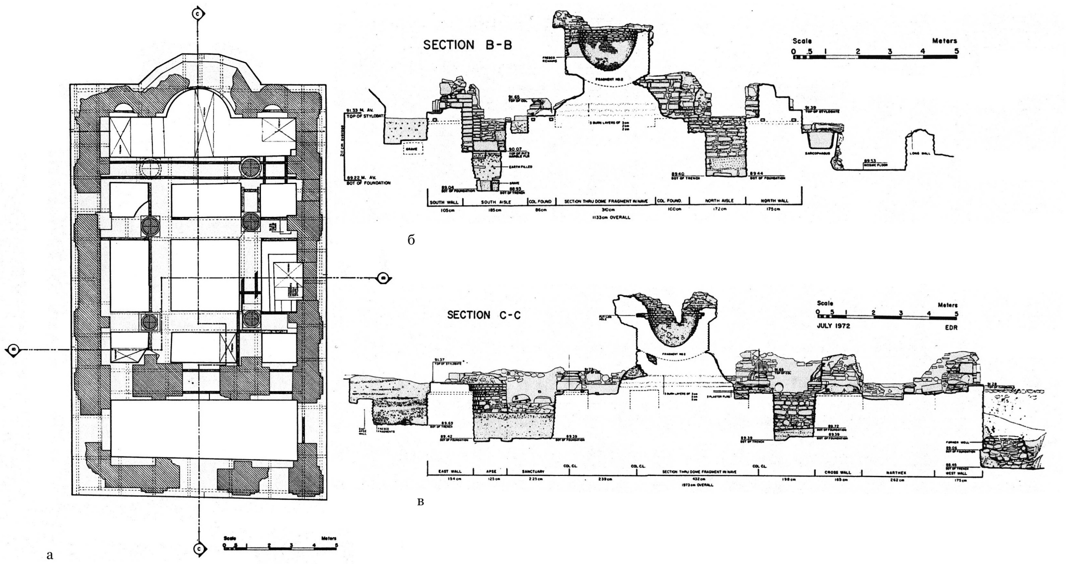

Fig. 44: Plan and sections of the foundations of church E at Sardis, showing wooden beams at the top of the foundation walls (Buchwald 1977, Figs. 4, 5, 6)

Finally, another instance of the use of an integrated wooden reinforcement system at the base of the walls[35] has been discovered in the ruins of the middle Byzantine church of Hagios Demetrios Esfigmenou ("Katholikon of Old Esfigmenou

[32] Note the similarities on the obliquely set wooden beams around the bema with those found in Panagia Krina (fig. 8, 29).

[33] Ousterhout 1999, 161.

[34] Buchwald 1977. Ousterhout 1999. 158, 161.

[35] Yet another recent discovery of such wooden reinforcement systems over the foundations was discovered in the old, 11th or 12th c. Katholikon of Stomio (Tsagesi) Monastery near Larisa, Greece. Cf. Mamaloukos et al 2010.

Monastery”) (fig. 45) on Mount Athos[36]. In this church, a similar system was located also at a higher level, at the window sills, but unfortunately the recorded evidence is very limited.

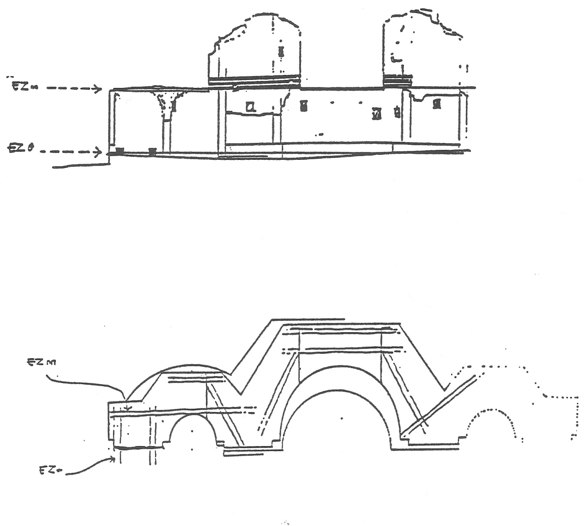

Fig. 45: Plan and section drawing of the church of Hagios Demetrios Esfigmenou, “Katholikon of Old Esfigmenou Monastery”, Mount Athos , showing position of wooden beams at the top of the foundation walls (Mamaloukos 2001, Fig. 104)

8. Wooden reinforcements in vaulting

Finally, the use of wooden reinforcement systems within the masonry of the complex vaulting of Byzantine churches is without a doubt the most obscure instance of their use. There are almost no bibliographical references, and the collected data is severely limited. We shall present here two striking examples, both from Western Greece, the 12th c. church of Palaiopanagia in Manolada, Peloponnese, and the 13th c. church of Panagia Parigoritissa in Arta.

The church of Palaiopanagia in Manolada, Elis is dated to the first half of the 12th century. During a restoration project in 1985-1996[37] (figs. 46, 47, 48, 49) where the extrados of the vaulting were exposed and cleared of debris, a dense grid of 2,3 or even 4 parallel, rectangular shaped channels were discovered on the upper parts of the masonry walls, between and around the vaults. These channels appeared to be formed in the building mortar, and were located at the level of the springing of the vaults, encased in the roofing superstructure. In the relevant bibliography, these channels were interpreted as some kind of gutter grid[38]. It is true that without further study of the building itself (which is now impossible, as the roofing has been completely restored and the area sealed), any interpretation on our part must be simple conjecture.

[36] Mamaloukos 2001, 178-179. Fig. 104.
[37] Athanasoulis 2006.,334.
[38] Athanasoulis mentions that similar ‘channels’ had been found in the basilica of Hagios Isidoros in Tragaia, Naxos. Athanasoulis 2006, 349.

Nonetheless, these unusual channels could very well be the voids left in the place of wooden members reinforcing the vaulting at this critical level.

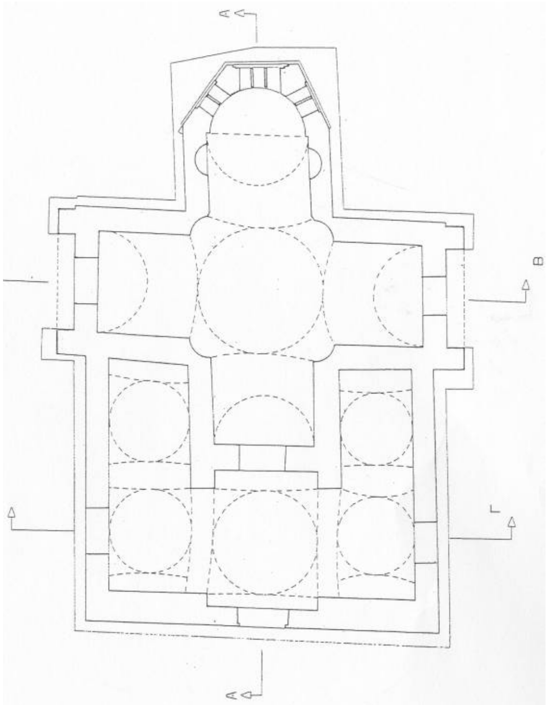

Fig. 46: Palaiopanagia, Manolada, Peloponnese, church plan with vaulting
(Athanasoulis. 2006, Fig. 114)

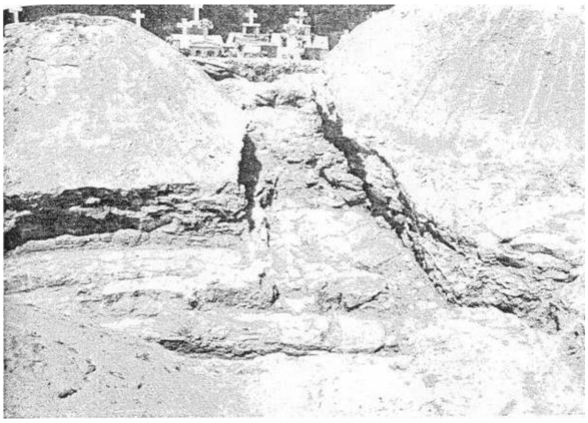

Fig. 47: Palaiopanagia, Manolada, Peloponnese, view of the extrados during the restoration project
(Athanasoulis 2006, Fig. 184.1)

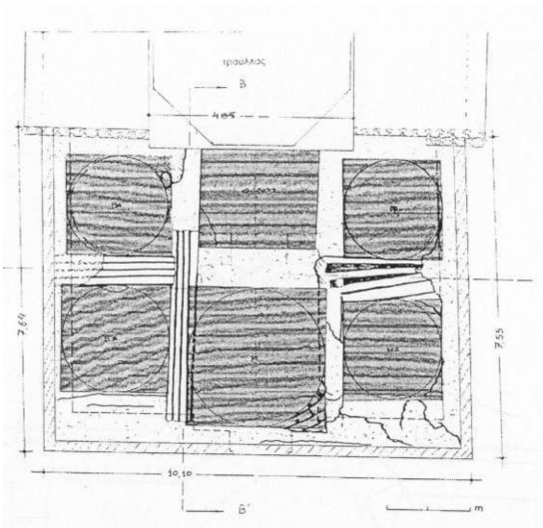

Fig. 48: Palaiopanagia, Manolada, Peloponnese, plan of the extrados
(Athanasoulis 2006, Fig 113A)

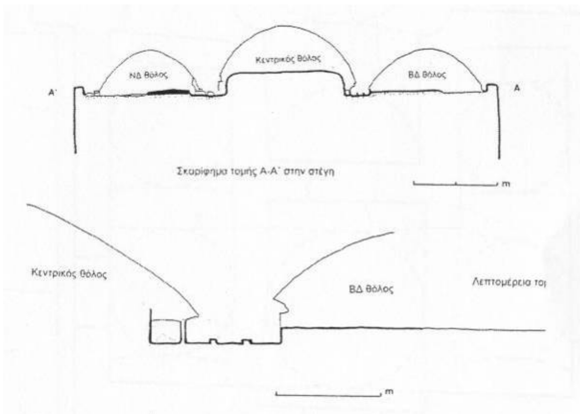

Fig. 49: Palaiopanagia, Manolada, Peloponnese, section and detail of the
(Athanasoulis 2006, Fig 113B,C)

However, the most remarkable area where wooden reinforcements were discovered is in the church of Panagia Parigoritissa, in the floor of the upper level gallery. This floor lies over the ground floor gallery vaulting, and consists of groin and dome vaults, resting on reinforcing arches on the north and south galleries, but without any such arches on the west (fig. 50). Again here, almost no traces of wood remain, but the exact positions and dimensions of the wooden elements were transferred onto the surface of the building mortar in which they were embedded. It must be noted that especially in the dome vaults the wooden reinforcements extended almost throughout the width of the masonry vaulting, in a way substituting the stone building material in these positions. These wooden beams formed an octagon, on which the lowered dome was subsequently built.

This last example is, in a way, striking, until we compare it to the previously described wooden reinforcements at the base of the dome drum. Seen in that light, this octagon resting on four arches and four pendentives is in effect the same system, only this time a dome vault is built upon it, rather than a dome drum.

Fig. 50: Panagia Parigoritissa, Arta, cavities of wooden reinforcements in the dome vaults of the gallery (March 2007)

Conclusions

Even though the preceding discussion opted to present wooden reinforcement systems in a rather unorthodox list, progressing from obvious to the obscure, at this point it will be instructive to also list them in a more orderly fashion, from the bottom to the top. Hence, we have the following possible levels:

a. Below the foundations
b. Over the foundations, at the base of the walls
c. Below the window sills, or at an approximate height of 1,50 m from the floor
d. At the springing of main window and doorway arches
e. Above columns or pier

f. At the spinging of main arches and vaults
g. At the base of other vaulting
h. At the base of dome drums
i. At the crown of dome drums

The preceding discussion has also, admittedly, glossed over issues of different usage of wooden reinforcement systems in different areas and time periods of the Byzantine world. It has also only cursorily touched upon matters of different church typologies and vaulting geometries. Presently, not enough data has been collected and analyzed to make meaningful correlations and comparisons, and in any case, that would be the subject of a much longer and detailed treatise. We are not even certain whether the use of wooden reinforcement systems was standard practice throughout the Byzantine world[39], and any offhand generalizations on their usage are often disproved by isolated examples to the contrary. Still the positions proposed above cover the majority of wooden reinforcements that have already been located in Byzantine churches, and will hopefully assist researchers in locating them – or verifying the fact that none exist, for that matter - in the future.

We also cannot be certain whether Byzantine builders used them just to stabilize the building during its initial construction and allow it to settle without cracking, or rather with the intention that they would continue to brace the building against earthquakes in the future. What can be gleaned from the available examples, is that they must have treated them quite like scaffolding, namely in an efficient and expeditious manner that would facilitate the swift erection of complex buildings. In this sense, the care with which wooden reinforcements were embedded and concealed within the masonry would also be proportionate to the scale and loftiness of each building[40]. Lastly, we must not forget that even though this discussion categorized wooden reinforcements according to strict horizontal levels, the builders themselves readily laid wooden elements in staggered configurations when it suit their purposes, or was necessitated by the exact building geometry.

In the end, the ultimate aim of this discussion is to alert researchers and restoration professionals to the likely position of wooden reinforcement systems, so that they may be recognized in future restoration projects, especially before modern interventions obliterate their traces forever. Only a methodical survey and study of these elements will allow us to collect enough data to shed more light onto this rather overlooked aspect of Byzantine building technology.

[39] In 2007 over 50 putlog holes on the exterior of the Katholikon of Hosios Loukas in Boeotia were examined, and none were found to be connected to any wooden ties within the walls. No wooden ties are visible on the interior of the church either, except for those on the smaller arches on the gallery.

[40] This might also be an explanation for the perplexing fact, that in Greece at least, no wooden members are readily visible in some of the most prominent surviving Byzantine monuments such as Dafni Monastery and the Katholikon of Hosios Loukas Monastery.

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