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PART 1 - Construction history and survey of historic timber roofs

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Cover illustration: Lattice roof trusses in the nave of Jät church, Småland, Sweden, 1225–1226 by Robin Gullbrandsson. © Robin Gullbrandsson (2022)

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THE GENESIS OF TIMBER TRUSSES: "UNEXPECTED" AFFINITIES BETWEEN ROOFS CARPENTRY IN ETRURIA AND PHRYGIA DURING THE ANTIQUITY

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Abstract

The genesis of wooden trusses is a very controversial issue as the archaeological data, scarce and incomplete, are not very explicit.
Indirect pieces of evidence of roof carpentry organized according to a truss system seem to have been found in the Mediterranean basin, at least since the Iron Age. However, these are isolated cases that probably did not have a decisive influence on the evolution of the roofs in the immediately following eras.
Full awareness of the potential and systematization of the truss system occurred in Roman areas, and only in Late Antiquity such an organization of the roof structure started to be notably widespread, especially in the basilicas.
In the process of conceptualizing the trusses, a considerable contribution is to be recognized to the Etruscan and Phrygian civilizations. Besides having in common an advanced development of timber structures, these societies show diverse "coincidences" in material culture. In fact, for both populations, relying on the iconography of figurative products, the articulation of the widely used roof carpentry is comparable to a truss, at least in the essential members and in their arrangement.
The contribution also provides information, with particular regard to that of construction nature, about the oldest existing wooden carpentry, dating back to the Early Phrygian period and belonging to the roof of the burial chamber of the "MM" tomb of the ancient city of Gordion (currently the village of Yassıhöyük, in Anatolia).

Keywords

Timber truss, Antiquity, Etruscans, Phrygians, History of the construction.

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1. INTRODUCTION AND METHODS

The need to absorb the thrust deriving from a sloping roof, functional to respond to the correct flow of rainwater, must have been one of the construction problems to be solved in the evolution from the first makeshift shelters of prehistoric times to the most definitive homes.

The solutions, of an empirical type, adopt, in general, two different structural "philosophies": counteract the rotation of the pitched roof through the mass of the vertical structure or, alternatively, create a system of members organized according to a truss, which transfers the internal forces in a "closed" flow path with no pushing component. A third possible "way" has been left out, that is, adopting some constraint with high stiffness between the two inclined elements, a complex condition to achieve in the historical context of this contribution.

The genesis of wooden trusses is a little-explored topic in the literature with often conflicting and oscillating opinions between an older dating that considers their use as early as the sixth century BC in the Magna Graecia context [1, 2] and a more "cautious" position that recognizes an extensive use of trusses at least since the Hellenistic age [3, 4].

However, both hypotheses have raised many perplexities as they rely on inferences deriving from indirect and uncertain data and inevitably lead to formulating divergent theses [5-8]. In fact, although there is episodic evidence of trusses since the Iron Age, for example, the one engraved on the stele of San Vitale in Bologna, dating back to the eighth century BC [5, 9], a full awareness of the potential and the systematization of this system took place within the Roman realm. Only during the Late Antiquity, there was a notable spread, especially in the basilicas, of such an organization of roof carpentry [5, 6, 7, 8].

The slow and gradual conception process of the truss took advantage, among the various contributions, of the Etruscan and Phrygian material culture. Despite belonging to very distant geographical areas, these civilizations show "curious" links, perhaps apparent, and share a high degree of advancement around the wooden structures with possible early construction of roof structures similar to trusses with regard to the stresses transferred among the members.

The study, part of broader research on the origins of wooden trusses in the Mediterranean basin, relied on sparse archaeological evidence and, above all, on indirect shreds of evidence such as the iconography of figurative products that reproduce roofs.

The picture outlined is based on powerful interpretative "tools", in some cases neglected by the literature of the sector, which are the laws of statics and construction rationality used in the execution of the roofs of buildings during the Antiquity.

2. RESULTS

2.1. ETRURIA AND PHRYGIA IN ANTIQUITY

The hypothesis of an Anatolian origin of the Etruscans and of the Orientalizing cultural phenomenon that developed in Italy between the eighth and sixth centuries BC [10] was proposed, among the most authoritative sources, by Herodotus (Stories, I, 94, 5-7) with a wide echo in the Antiquity.

This thesis of some links between the Etruscan civilization and Anatolia has sparked a heated debate since the nineteenth century. Although in the last century the academic Etruscology, under the authoritative push of Pallottino, believed that the problem of Etruscan origins had been solved, the question reopened recently. In fact, the discussion has come back alive thanks to a new "point of view", mainly generated by studies on the genetics of ancient populations. Therefore, the position that based the origins on the – not quite fast – evolution of an indigenous people in the Villanovan era, which led to the birth of the Etruscan *ethnos* in substantial continuity, is enriched with further contributions. The latter interpretation admits the possibility of modest phenomena of immigration that may have affected the territory of central Italy at the end of the Bronze Age [11].

It is always and in any case incorrect to "enclose" the Etruscans in a sphere of singularity as a phenomenon that is extraneous to the surrounding world. In fact, the diffusion of religious and fantastic motifs from the East, during the Orientalizing phase, in other areas of the Mediterranean basin – for example, in Greece, in a sort of *ante-litteram* globalization –, in addition to the ornamental and figurative taste, is not to be considered secondary [12]. Despite this, the congruence among cultural factors, even related to construction, in the Etruscan and Phrygian civilizations seems so evident that it still influences modern opinions [10]. For example, a particular expertise in metalworking is known in both civilizations. During the Iron Age, Phrygia's territory stood out as Anatolia's most prominent metal producer [13]. A similar development can be assumed for woodworking. In this regard, Vitruvius (*De Architectura*, II, 1, 4) attributes a continuity with the territory of Phrygia in the use of wooden structures for houses, indirectly recognizing some *ab antiquo* knowledge linked to timber carpentry. Profound knowledge is evidenced by the finesse and complexity of numerous wooden finds discovered in the Early Phrygian period (ca. 950-800 BC) tombs.

Similarly, in Etruria, a privileged condition for the presence of metalliferous resources (iron, copper, lead) gave a considerable impulse to the birth of advanced metallurgy; evidence can be found in the bronzes, gold, and silvers of the Orientalizing tombs of Caere, Vulci, Vetulonia, and Palestrina, whose decorations, in some cases, recall those made for the royal Tomb of Gordion, the ancient capital of Phrygia.

Furthermore, the concordances concerning aspects of the religious and funerary sphere are perspicuous. The grandiose Etruscan hypogea tombs imitating the house and the splendor of the grave goods evoke, in fact, oriental origins. Moreover, the 6th century BC cube and aedicule tombs of Etruria give the impression of a direct correlation with the rock facades of the sanctuaries of some areas of the Anatolian territory, datable between the 8th and 6th centuries BC. These artifacts faithfully imitate the shapes of real buildings, including the roof, in the most minute details.

2.2. THE WOODEN ROOF CARPENTRY

The graffiti engraved on the front of the Megaron 2 in the Phrygian citadel of the ancient Gordion, depicting buildings dating back to the 9th century BC [14], is of remarkable interest for the genesis of wooden trusses.

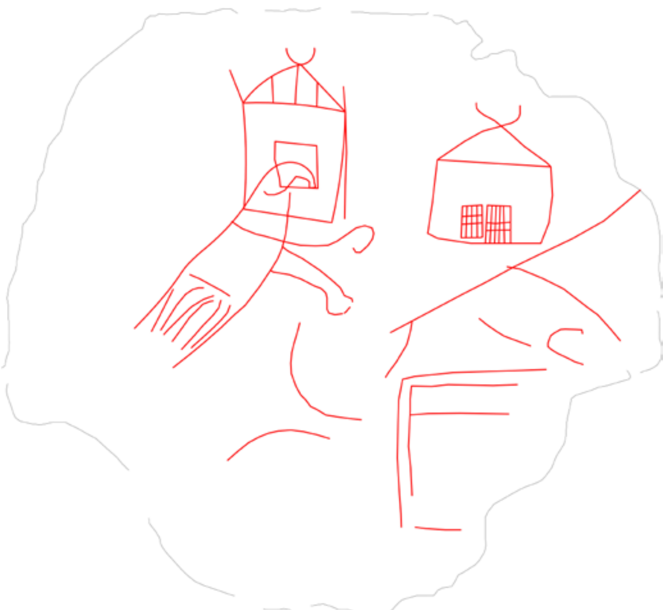

Fig. 1. *Graffiti engraved on the front of the Megaron 2 in the Phrygian citadel of the ancient Gordion. (Redrawn by the author from Berndt-Ersoz, S (2006) Phrygian Rock-Cut Shrines: Structure, Function, And Cult Practice, Brill Academic Pub).*

The sketched lines reproduce the front of buildings with pitched roofs, whose high slope leads to the hypothesis of using a thatched covering, according to archaeological evidence [15]. The hut depicted on the left of figure 1 is particularly interesting for its details. The structure, probably made of wood, comprises frames whose posts continue beyond the base of the roof.

The *tectum* carpentry is drawn as composed of two inclined elements, a vertical prop and a tie-beam – more appropriately, the latter has to be merely defined as the upper closing element of the wooden framing –. This member, in fact, has the primary purpose of integrating the two posts preventing their rotation, a consequence of the horizontal thrust deriving from the wooden rafter. In the construction phase, it is easy to encounter stability problems for the wooden post if subject to the thrust of the inclined roof member without the aid of the top constraint created by the horizontal member. In the tympanum, two other vertical lines are arranged symmetrically with respect to the central prop, acting as queen-posts, helpful in creating an intermediate constraint for the rafter stemming its deflection. This arrangement is similar to what was carved in the cube tomb of the necropolis of Peschiera (Tuscania, VT) and the main chamber of the Mengarelli *tumulus* (Cerveteri, RM). The joint in which the three members – tie-beam, post, and rafter – concur is of complex execution. Hence, it can be inferred that these members were juxtaposed, assuming that the transmission of the stresses, especially tensions, was delegated to metal fittings and vegetal ropes. This configuration is plausible, considering a relatively high inclination of the thatched covering with low values of the horizontal component of the thrust and, therefore, of the tensile stresses in the horizontal member. It is a reasonable hypothesis that the connection between the two rafters benefited from a scissor-type joint, with recesses made in both members. This geometry allowed to keep the two inclined elements on the same plane in order to center both rafters on the chord. The prop is essential to withstand and transfer to the horizontal member loads deriving from the *acroterion* depicted on the ridge, which, in both the graffiti, is made by continuing the rafters beyond their junction.

The Etruscan marker of an inhumation tomb, found in the necropolis of San Vitale near Bologna and dating back to the end of the 8th century BC, is slightly later [5, 9]. A hut is engraved on this stele, whose roof structure is characterized by a configuration similar to that depicted in the front of Megaron 2. The central post of the hut continues until it intercepts the ridge of the roof, assuming the static role of a king post. As in the Anatolian drawing, the two rafters benefit from two struts which, with the same role as the queen-posts of Gordion, constitute further supports for the rafters, limiting their displacements.

Fig. 2. *Stele found in the necropolis of San Vitale, Bologna (Inv.: 11683, Archaeological Museum of Bologna).*

This organization of the roof carpentry corresponds to what is depicted in the facade identified with no. 9 [15] reproduced into the rock of Kes Kaya (actual Turkey), where, in addition to the two struts, a king post is carved. This last member is the recurring and dominant element in the tympanum compositional scheme and other rock sanctuaries in the Phrygian Highlands. The sanctuary, imitating a real building in detail as in Etruscan funerary architecture, consists of one or more facades. At the entrance, there is a niche in which the divinity statue was placed. The sloping type roof emphasizes an extreme variability with slope values between 18° and 53°. Such morphological features lead to hypothesizing the representation of buildings with different covering. As is known, the thatched covering requires significant slopes for proper rainwater control.

The use of clay tiles, effective in the disposal of rainwater even with a modest slope inclination, is a phenomenon attested in Anatolia only from the 6th century BC [21].

In some examples – e.g., facade no. 16 in Arslankaya [16] and Malta's monument in the Ihsaniye district – the king post highlights a protrusion at both ends. In some artifacts, such as the stele found in Bahçelievler, Ankara, which portrays Kybele and dates back to the seventh century BC, the king-post is represented in the essential morphological characters of a column, with a shaft, capital, and base. In the context of Magna Graecia, similarly, columns are depicted in the tympanum of the southern slab of tomb 24 in Paestum (5th century BC) and, in Sicily, in the *cippus* of Gela, dating back to the 6th century BC [8]. For the Italian term *colonnello* (king post), an etymological derivation from *columna* (column) has been supposed, considering the similar static role exercised by both structural typologies [22]. A possible explanation for this peculiarity could be that the resistant section expands in the transverse plane, near the constraint, in order to stabilize the compressed element and, at the same time, facilitate the transfer of stresses between the members. The presence of construction devices aimed at improving the constraint at the base of the king-post is essential to ensure equilibrium in the construction phase before the installation of the ridge beam. In other words, it could be the reproduction of a connecting cleat arranged transversely to the structural unit, similar to those, for exam-

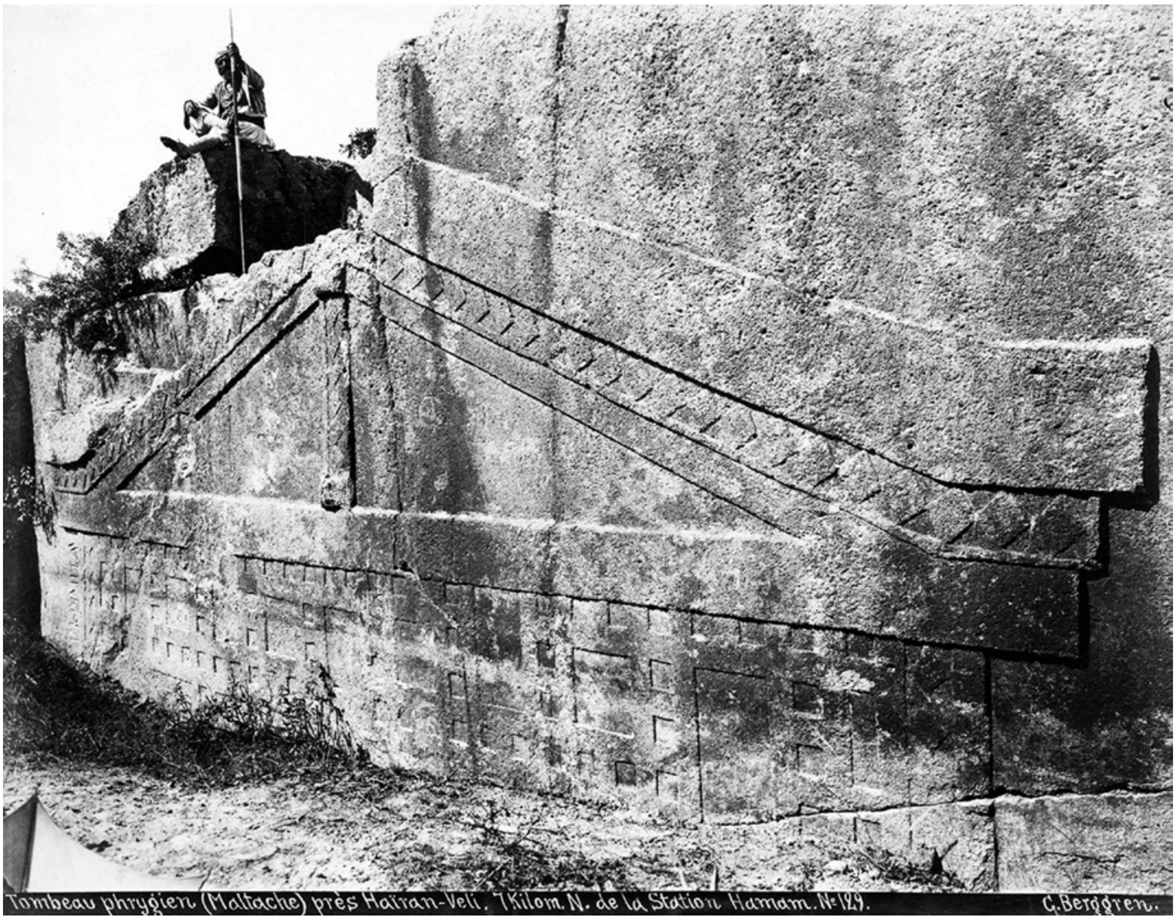

Fig. 3. *Malta's monument in the Ihsaniye district. (G. Berggren's photo, 1889).*

ple, that join the king-post to the ridge-beam belonging to the trusses of Saint Catherine of Sinai – the oldest known surviving trusses – dating back to the 6th century AD.

This solution is a structural device that evokes what has been recognized by recent studies [9, 19], regardless of possible symbolisms, in the iconography of the wall paintings of some Etruscan tombs – for example, those of the necropolis of Monterozzi at Tarquinia (VT) and of Pianezze 2 tomb at Grotte di Castro (Vt) – executed during the Orientalizing period.

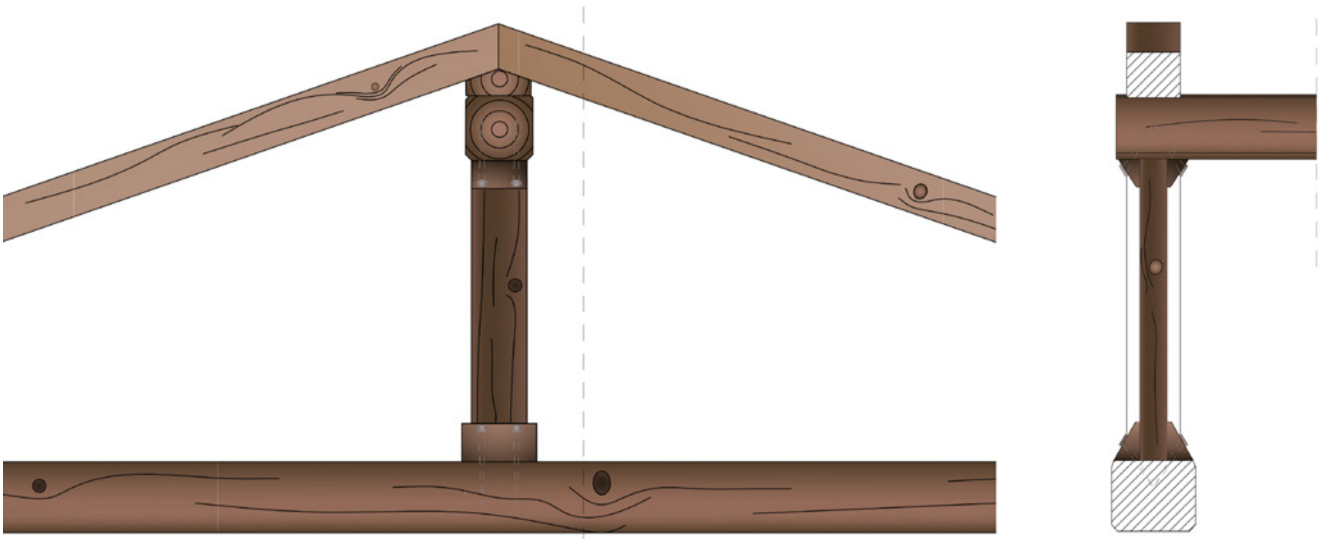

Fig. 4. *Reconstruction hypothesis of the carpentry carved in the Phrygian sanctuaries.*

Fig. 5. *Burial chamber of the tomb of Barone Kestner in the necropolis of Monterozzi, Tarquinia (VT).*

In fact, in these examples, the support of the ridge beam assumes the characteristic hourglass shape in a time horizon that goes from at least the middle of the 6th century BC [20]. The enlargement of the section at the top evokes a corbel, helpful in connecting the *columen* to the vertical prop [9]. In the lower part, this shaping probably refers to a useful geometry to guarantee the equilibrium of an element stressed by compressive-bending stresses. It is strictly rational from a static point of view that the enlargement of the base depicts two triangular cleats or, more generally, inclined elements placed laterally to the prop to counteract the rotation in the plane of the structural unit. In addition, the constraint at the base stiffened by the presence of the cleats reduces the effective length.

The sculpted tympanum does not provide conclusive clues to be able to hypothesize whether, for the sanctuaries of the Anatolian plateau, the configuration of the roof is organized according to a truss system and, therefore, whether the stresses among the members draw closed paths. In fact, essential information on the type of connections and, therefore, the transmitted stresses is lacking.

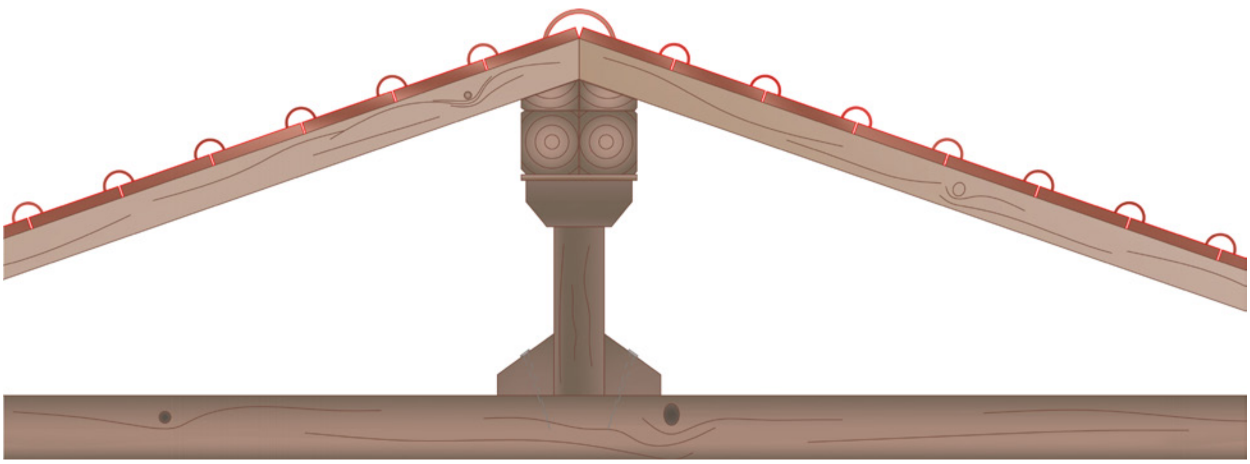

Fig. 6. *Reconstruction hypothesis of the carpentry depicted in the Etruscan Orientalizing period tombs.*

Fig. 7. *Phrygian façade (n. 19) at Demirli Koy. (Redrawn by the author from Berndt-Ersoz, S (2006) Phrygian Rock-Cut Shrines: Structure, Function, and Cult Practice, Brill Academic Pub).*

However, in some facades (e.g., Bahâayiâ - façade/shaft monument *No. 28* at Gökbahçe based on [16]; Mal Taâ - façade/shaft monument *No. 24* - in the Köhnüâ valley; Façade *No. 19* at Demirli Köy; Façade *No. 13* at DöÅer Asar Kaya based on [16]) the presence of a considerable extension of the horizontal member beyond the junction to the rafter, a type of shrine roof called Chinese roof [23], could refer to the shaping of the horizontal member, rational from the static point of view, applicable to contrast the horizontal thrust deriving from the inclined element.

Fig. 8. *Bronzetto dell'Offerente tomb in the necropolis of San Cerbone-Casone, Populonia (LI).*

However, the thesis inspired by the configuration that characterizes the aedicule tomb of the Bronzetto dell'Offerente in the necropolis of San Cerbone in Populonia (6th century BC) remains valid: the continuation of the horizontal member sculpted beyond the joint could reproduce a beam, whose own weight, increased by the load deriving from the roof covering, guarantees equilibrium by counteracting the tendency of the common rafter to translate. The roofing carpentry in this example is composed of inclined lithic slabs but most likely paraphrases a wooden structure, which is contrasted to the foot by a sandstone (i.e., *panchina*) crowning beam.

Fig. 9. *The "West Tomb" in Midas City (Yazılıkaya) in the Phrygian Highlands.*

A different organization of carpentry – the *columen* is depicted above the rafters, referring to the typology known in Italy, in modern times, as "*tetto alla lombarda o alla toscana*", which differs from the "Piemontese" typology where the king-post directly supports the ridge beam – compared to that presumed for the sanctuaries is the one that appears in the "West Tomb" in Midas City (Yazılıkaya) in the Phrygian Highlands, dating back to the 6th century BC. The representation of the interior is remarkably realistic and shows a roof characterized by a considerable inclination. Although not providing any detail on the joints, the craftsman depicts the elements of the secondary roof frame. In fact, the purlins are carved into the rock and the common rafter that rests in correspondence with the posts with the interposition of a perimeter beam. The common and principal rafter perfectly unloads its weight on the post without shear stresses in the horizontal member. The ridge beam, resting on the truss and, in turn, supporting the common rafters, is represented in a pseudo-circular section; the other members appear quadrangular in shape. Horizontal member and king-post have similar dimensions, hierarchically superior, compared to the rafters and common rafters, characterized by a more modest resistant section.

2.3. THE OLDEST SURVIVING WOODEN CARPENTRY

The historical sources of Antiquity, both Latin, Assyrian as well as Greek, are in agreement in pointing out the government in the Anatolian region of an important dynasty – Midas – between 733 and 677 BC, coinciding with the heyday of the Phrygian civilization, during which technical and technological innovations made possible to create wooden roofing structures capable of overcoming notable spans [24]. Evidence of such an advancement in the construction culture can be traced in some *tumuli*. More than 100 specimens located around the ancient capital Gordion can be dated between the 9th and 6th centuries BC. The most impressive in size, recognized by tradition as belonging to King Midas, is the Tomb called "MM" [25], dating back to around 740 BC.

With a diameter of about 300 meters, the *tumulus*, made up of clay, earth, and stones [26], rises to approximately 53 m, enclosing the burial chamber made entirely of timbers. The internal measurements of such a burial chamber are 5.15 m x 6.20 m, with a height of about 3.20 m [26]. The vertical structure, consisting of overlapping rectangular section members, widely varying in height, rests on a pine and cedar floor. Members' variability, from about 18 cm to 48 cm, is presumably due to the necessary adaptations to the geometric characteristics of the available Juniper roundwood logs immersed in a filling of stones surrounding the entire burial chamber.

The sloping roof, different from the flat roofs of the other *tumulus* tombs, for example, those called "P" and "W" in central Anatolia, represents the oldest surviving wooden carpentry. Both partially collapsed structures are roofs of the flat type with beams arranged side by side for mechanical reasons to prevent material from penetrating through the upper covering interstices. They are devoid of particularly advanced devices from a technical and technological point of view.

Relative to *tumulus* "P", the carpentry comprises two orders of black pine beams arranged side by side. The upper framework, consisting of 12 beams with a span of more than 5.2 m, is linked to the vertical wooden structure through half-timber joints, with recesses in both orthogonal members. The 11 outermost members, with a higher section and longer than 7 m, continue consistently beyond the vertical structure [27].

The "W" *tumulus* roof is organized according to a single frame of 13 beams, which cover a 3.3 m span, with a variable height between 21 cm and 48 cm and a thickness of about 22 cm [27].

The main "MM" roof frame is represented by wooden elements composed and shaped like a tympanum. These are two members placed side by side – whose width is about 34 cm, the height of about 42 cm, and cover a span of 11.5 m [26] – arranged with two additional overlapping rectangular elements. Such timbers are surmounted by two additional wooden elements that longitudinally taper at both ends, creating a triangle.

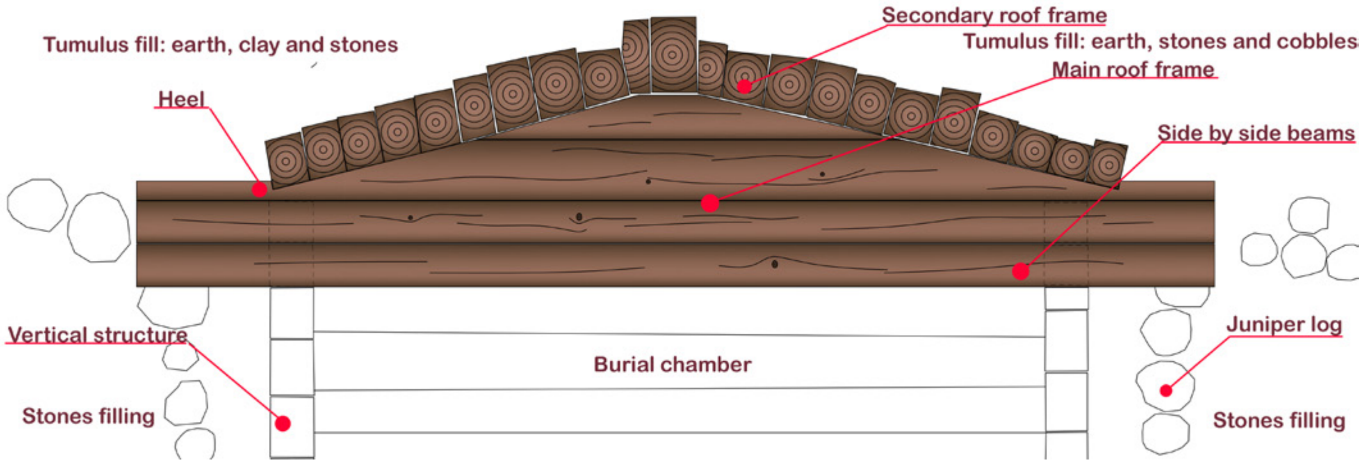

Fig. 10. *Detail of the carpentry roof of the tumulus tomb "MM".*

The side-by-side elements have "double T" – shaped tenons on both beams' transversal section ends, able to receive a mortise and counteract the distancing between the two members in the transverse plane. At the current state, they are significantly deformed with maximum deflection approximately in the middle and with a crack which – triggered at the lower edge due to excessive tensile stresses – continued horizontally on the lateral face breaking the fragile bonds between the wood grain. Over the side-by-side elements, there are 28 wooden pegs [26] aimed at improving the cooperation between the components of the triangular portion, whose boundary lines are perfectly matched horizontally. It should be emphasized that the size and number of such constraints are insufficient to make an effective connection, although they are useful for keeping the members in place during the several phases of the installation process.

The secondary roof frame is organized peculiarly and finds few comparisons in the wooden structures of Antiquity.

Pseudo-rectangular section beams are arranged perpendicularly to the described gable and placed side by side. The motivation is to avoid the fall of material into the sepulchral chamber, as well as of mechanical nature. When the load is applied, these beams, similar to voussoirs of an arch, generate sliding along the gable's inclined upper edge, which is contrasted by recesses made to the impost. Such a configuration causes compression transversal to the central axis of the beam and, therefore, friction, which helps absorb the bending stresses deriving from the load of the ground above. The central members, continuing beyond the support of the perimeter wall, consist of a more marked trapezoidal shape section, helpful in putting the system into compression. The recess mentioned above at the beam end – properly called heel – receives the horizontal component of the purlins thrust and generates tensions in the members making up the gable. Therefore, the heel is subject to shear stresses parallel to the wood grain, supported thanks to the contribution, near the junction, of the compression deriving from the above-ground weight. A rationalization of the resistant section is to be recognized, which extends the height, although composed of autonomous elements devoid of effective bond, near the centreline where the flexural burden is most significant. As described, it can be said that the stresses transferred among the members create a "closed" flow path for the internal forces, similar to a truss.

3. CONCLUSIONS

In the herein paper, it was preferred not to go into what has been a controversial "archaeological" debate linked to Etruscan origins. From this study emerges the undeniable and notable contribution that the construction culture of the two people had on the evolution of wooden carpentry in a time horizon between the 9th and 6th centuries BC. Furthermore, the paper highlights the "coincidences" between the Etruscan and Phrygian civilizations.

The various clues in the presented investigation, mainly interpreted according to the laws of statics and construction rationality, made it possible to reconstruct, albeit with the prudence imposed by decidedly exiguous and incomplete data, the wooden carpentry in the Etruscan and Anatolian areas.

The huts reproduced in the engraving discovered in the Megaron 2 and the stele of San Vitale, although they show many similarities in the articulation of the roofing elements, could be the result of autonomous construction development. In any case, in a pioneering way, the framing of a truss in its essential elements is defined in both reliefs. Nevertheless, it is worth noting that the configuration, rather than tending to create a truss system with awareness, derives from the need to tie and conclude the framing at the top.

However, such an organization of the roof members remains identical in the iconographic schemes of the Phrygian reliefs between the 8th and 6th centuries and in the Etruscan figurative products of the 6th century. This almost immutability led to believe in the achievement of an optimization of the structural type, at least from the point of view of equilibrium.

Throughout the contribution, no hypothesis is provided regarding the classification of the examples described as trusses, as data in possession, particularly on the type of connections, are not adequately explanatory. In fact, any attempt to depict the morphology of the nodes, given the absence of clues, can only be conjectural. Therefore, it is impossible to infer whether the members are or whether there are notches to transfer tensional and shear stresses. However, it should be noted that for the carpentry used in the "MM" Tomb of Gordion, even if the articulation of the resistant elements shows various peculiarities, the internal forces triggered in some of the timbers, thanks to the particular joints, are comparable with those of a truss.

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