The Wooden Carpentry of Roofs in Mediterranean Antiquity

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At the Origins of the Trusses

By

Nicola Ruggieri

Cambridge Scholars Publishing

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To my father
Master Woodworker

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PREFACE

The current historiographical approach, inaugurated in Italy by Gustavo Giovannoni and based on research that arose in the wake of the *annales* of the French sphere, claims analysis of individual historical artefacts equipped with contributions belonging to a varied disciplinary field. The history of architecture contains several disciplines that contemplate interconnections of various kinds, as well as stylistic ones, linked to construction, to the organization of the construction yard and of the structure, without however disregarding the possessed symbolic features.
A heteronomy of the architectural work which receives outside itself the reasons for its existence leads Lucian Febvre to state that,

> … L'histoire se fait avec des documents écrits … [but also] avec des mots. Des signes. Des paysages et des tuiles ... Des expertises de pierres par des géologues et des analyses d'épées en métal par des chimistes. D'un mot, avec tout ce qui, étant à l'homme, dépend de l'homme, sert à l'homme, exprime l'homme, signifie la présence, l'activité, les goûts et les façons d'être de l'homme. … (Febre 1992, 427).

Giovannoni, on the occasion of the inaugural address of the *Scuola Superiore di Architettura* in Rome in 1920 (Zucconi 1997, 74-78), described a historiographical method, in which technique and technology assumed a role of primary importance, as an "integralist method", founded on the integral and multifaceted character of architecture.

Architecture is inextricably connected with aspects of a construction nature, as well as with static research - science and experience - from which it cannot be separated, which leads to believe, in a unitary conception, "… la struttura … la forma stessa dell'opera architettonica …" ("… the structure ... the very form of the architectural work …") (Sanpaolesi 1973, 87). Therefore, the structure is an ontological expression of the form, which coincides in wooden carpentry, unlike other building materials[1], with the

[1] For masonry buildings, the reacting structure varies with changes in the stress regime. The resistant skeleton is never fixed but variable according to external actions and is, therefore, limited to part of the building, leaving inert portions (Di Pasquale, 1996).

construction. In the trusses, the form arises and is defined by the tasks each component performs in the structural configuration.

The present study aims to analyse truss evolution in the Mediterranean Antiquity diachrony. The manuscript's temporal scope is broad and ambitious, spanning the Bronze Age to the sixth century, in which the legacy of Late Antiquity material culture persisted[2]. The research framework includes Egyptian, Minoan and Mycenaean, Phrygian, Etruscan, Greek and Roman civilizations.

The study is therefore limited to the Mediterranean geographical area, where there have been building cultures with deep ties, made for many aspects uniform, with due exceptions and distinctions, by similar climatic conditions essential in the genesis of the conformation and organization of the roof.

In fact, environmental factors, rainfall and, to a lesser extent, wind and snow - in addition to technical skills, tools and available material - were decisive in selecting the type of roofing.

The first shelters probably arose from the imitation and adaptation of prototypes that nature made available. A trunk fallen due to a lightning strike and arranged at an angle, a liana that covered the span between two trees, for example, could be a valid reference for man since Prehistoric times in the construction of shelters. The diffusion of the arrangement with elements placed opposite and inclined in different geographical and chronological contexts, albeit with independent results, is therefore motivated by the availability of the construction principle in nature, in any case, easy to intuit. On the contrary, unlike other structural forms, ancient man had no examples in nature to draw inspiration for trusses.

The genesis of timber trusses is a little explored topic in the literature, with often contrasting opinions and oscillating between a “high” dating that wants a use as early as the sixth century BC in the Greek colonial context (Hodge 1960; Klein 1998) and a more "cautious" position that recognizes an extensive use of trusses at least since the Hellenistic age (Adam 1994; Hellmann 2002). However, both hypotheses raise many perplexities as they are based on deductions derived from indirect and uncertain data and inevitably lead to divergent theses (Barbisan and Laner 2010; Ruggieri 2018, 2022a).

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[2] A condition that lasted until the seventh century (Bonelli Bozzoni and Franchetti Pardo 1997).

In fact, although there were episodic attestations of timbers organized according to truss since the Iron Age[3], a full awareness of the potentialities and systematization took place in the Roman ambit. Furthermore, the notable spread of such an organization of roof woodwork was only in the Late Antiquity Age, especially in basilicas (Tampone 1996; Ruggieri 2018).

However, it should be highlighted that a slow static-constructional conversion process for the carpentry of large roofs has already started from the Greek and Etruscan structures. In fact, the inclined timber that protrudes from the cornice was modified with the creation of grooves in the stone blocks, which, with the aid of metalware, attempted to counteract the translation of the inclined member constituting the pitch. No longer juxtaposed or superimposed, the roof became dependent on the rest of the building. The burden of absorbing the outward thrust was, in fact, assumed by the wall mass with the generation of compression in the inclined member; otherwise, it was simply bent.

Gradually, such an organism was transformed into a different configuration in which equilibrium was guaranteed through new artifices: to the friction arising from the simple support, which is not very effective in preventing the divarication of the oblique members, nails were added, then grooves, for originating beneficial tensile stresses.

Thus, the forces were conveyed in different paths, which made the resistant system closed, devoid of any horizontal component that could exert thrusting on the surrounding walls: this was the birth of the truss. In this way, an "... organismo a semplice azione di peso ..." ("… an organism that transfers only vertical forces …") (Giovannoni 1925, 71)[4] was created, which adopts the more rational configuration of the non-deformable triangle, optimizing the exploitation of the resistance resources of the wooden members (Ruggieri 2019a).

However, it should be emphasized that presumably, rather than the search for an economy of material through the optimization of the configuration, the need to absorb the outward thrust deriving from a sloping roof, functional to respond to the correct outflow of rainwater and which

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[3] For example, as engraved in the stele of San Vitale dating back to the eighth century BC (Ruggieri 2019b), please see *infra.*

[4] Giovannoni, in this passage, slavishly reports the definition provided by Milizia (1781, 190) "… la regola generale è che niuni dei legni spinga immediatamente contro i muri, ma tutti insieme compongano una macchina, che graviti perpendicolarmente su di essi muri…" ("… the general rule is that none of the timbers pushes immediately against the walls, but all together compose a machine, which gravitates perpendicularly on the walls …").

could cause rotations in the masonry or even, in the most extreme cases, overturning, must have led to the truss *inventio*.

The Roman *ars struendi* drew liberally on the Greek and, above all, Etruscan building culture and, from the 3rd century, a system of members, in which new interrelations were determined through the joints, was adopted in a widespread way to cover large spans. Such an organization rationalized the structural behaviour of the component elements to be able to reduce the resistant section.

The truss is a highly efficient structural typology that has gone through the centuries in its almost primitive configuration without substantial modifications. In fact, the organization of the members according to truss, certainly known in Roman times, reached the modern and contemporary age almost unchanged, in a dynamic that is difficult to find comparisons in the history of construction.

The theme dealt with is highly controversial and is challenging to pronounce since the historical sources and findings are not very explicit. The limits are evident, and in some cases insurmountable, since the source of knowledge, which has its essential basis in existence and therefore on the possibility of conducting direct analyses on woodworking and the assembly system, has been deactivated.

The configuration hypotheses described in the various chapters are based on what has recently been produced by the scientific literature. However, it is not particularly extensive, and contemporarily, it is partial as it is essentially concentrated on analysing the roofs of colonial Greece. Furthermore, the manuscript is based on the scanty but precious ancient literary documentation, above all, Vitruvius and foundations for drafting *De Architectura*, and on some epigraphic texts.

The archaeological finds, e.g., the post holes helpful in determining the distribution of resistant elements in the elevation of the huts or the beam pockets still present in some ancient structures, and the iconography of the figurative products that reproduce roofs, contain, if appropriately interpreted, numerous clues for tracing the origins and evolution of the truss system. The laws of statics and construction rationality put in place in the execution of the roofs of ancient buildings are powerful interpretative “tools”. In some cases, neglected by the sector literature, they were decisive in the results presented in the manuscript.

CHAPTER I

AB INITIO: THE ROOFING CARPENTRY IN THE FIRST CIVILIZATIONS OF THE MEDITERRANEAN AREA

Ancient Egypt

Introduction

The discoveries of wooden structures in the Egyptian civilization are not numerous, despite the thermo-hygrometric characteristics of the Nile valley creating conditions that are not very favourable to the action of biotic agents[5]. The scarcity of documentary elements and indirect sources, identifiable in bas-reliefs and paintings of which funerary and religious architecture are rich, allows few observations on the timber framework of the roofs. Furthermore, the aridity of the climate, characterized by modest rainfall, generally led to the creation of flat floors organized in an ordinary way, where the construction artifices to ensure the equilibrium and resistance of the structure were not very complex.

Therefore, it is possible to assume the trilithic system[6] as a founding feature of Egyptian construction, whose construction site only sporadically

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[5] It is worth noting that the presence of termites in the area has constituted a problem for conserving wooden artefacts in various periods. An attestation of termite infestations in Antiquity can be found in the pyramid of Abu Sir, where the original wooden columns, just after completion, underwent punctual repairs with mud bricks, precisely following a probable termite attack (Bleiberg 2004).

[6] This configuration is also attested in hieroglyphic writing, in the ideogram dating back to a period after the V Dynasty, with the meaning of a reed hut and reported in (Lloyd and Muller 1986). The entrance is framed by fork-shaped posts on which a horizontal member rests. Influences can also be found in Egyptian art in general, where a horizontality of the elements prevailed on vertical and inclined lines (Chipiez and Perrot, 1883).

faced problems concerning the absorption of the thrust at the foot of an inclined roof element.

The overall picture that emerges leads us to reserve for ancient Egypt, with due caution, only a marginal place in the history of timber trusses. Nevertheless, among the primates attributable to the Egyptian civilization[7], it is also possible to include that inherent in woodworking and its use in a varied case series. In fact, from the analysis of the boats and the furnishings, both for those depicted and for the archaeological evidence, it can be deduced that, at least from the third millennium (Wright 2005), the construction culture must have possessed advanced mastery of the methods of tree selection, of cutting, of seasoning, and making connections between wooden elements.

Timber Carpentry in the Construction

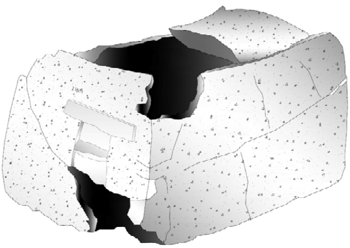

Fig. 1-1 Model of a house from El Amarna.

Along the Nile valley, between the fifth and fourth millennium, nomadism, which corresponded to temporary shelters, contrasted with the immigration of semi-nomadic populations of gatherers and hunters who developed primitive agriculture from which less precarious wooden shelters derived (Davey 1971). The model of a house (Davey 1971), kept in the British Museum and coming from El Amarna (fig. 1-1), gives us an idea of how the dwellings must have looked before the 3rd millennium BC, whose roof of the flat type, was probably made with leaves of palms, acacia branches, alternatively long reeds (Wright 2005) and alluvial mud of the Nile (Davey 1971).

[7] Herodotus, who visited Egypt in the fifth century BC, was fascinated by the technology put in place by the Egyptians to the point of affirming, concerning the labyrinth of Meride: "…This I saw myself, and I found it greater than words can say. For if one should put together and reckon up all the buildings and all the great works produced by the Hellenes, they would prove to be inferior in labour and expense to this labyrinth …" (Hist. II, 148).

However, light roofing with a semi-circular profile, from which outward thrusts are generated near the eaves, is also attested. An ivory engraving dating back to the Neolithic period (Davey 1971, 35) depicts a hut of intertwined branches with a hemispherical roof (fig. 1-2). A configuration whose equilibrium is ensured by constraints made with the aid of vegetable fibres and by an element, probably a timber, arranged horizontally at the eave, which constitutes a barrier to the translation of the meridians. Such a type of roof is evoked in the hieroglyphic representation of the Sanctuary of Buto, the ancient capital of the prehistoric Delta Kingdom (Lloyd and Muller 1986).

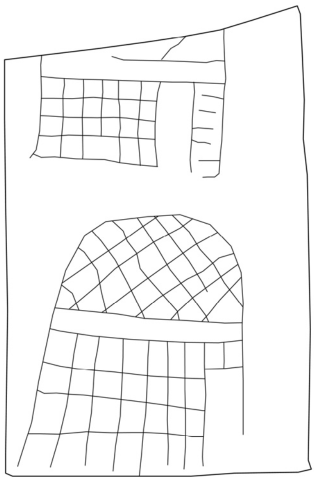

Fig. 1-2 Neolithic ivory engraving that depicts a hut (after Davey, Norman. 1971. A History of Building Materials. New York: Drake Publishers Ltd).

The timber structure must have had a leading role in the Protodynastic period, even in religious architecture. In Hierakonpolis (ancient Nekhen), in the funerary complex dating back to the fourth millennium, the holes in the ground lead us to deduce the presence of tall wooden posts for which a curved profile roof in reeds and clay has been hypothesized (Wilkinson 2005). A similar roof organization[8] can be supposed for the first brick tombs of Cemetery T in Naqada (Petrie and Quibell 1896). Just debarked palm trunks were used in the Saqqara tombs dating from the First and Second Dynasties (Quibell 1908).

The Tomb 3036, belonging to the same cemetery site and built during the reign of Udimu, is distinguished by the roof structure of roundwood with a diameter of about 30 cm arranged horizontally with an interaxis dimension

[8] From the Second Dynasty, the use of bricks arranged in projecting courses became recurrent in tombs (Spencer 2023); interesting examples are represented by the earliest corbelled roofs of any size of the chamber of Snefern at Meydum and in the Grand Gallery of the Great Pyramid (Clarke and Engelbach 2014). It is conceivable that such a construction technique was mainly used to overcome modest spans. If the room to be covered was larger, however, we can assume a wooden structure roof that provided more guarantees in terms of safety.

suitable for being covered by bricks. This floor, concluded at the top by a further layer of bricks arranged orthogonally to the lower ones, may have been characterized by a plank ceiling at the lower edge (Spencer 2023). The adoption of a summer beam, evidence of which can be found in some tombs of Saqqara dating back to the First Dynasty, is a valuable device for covering relevant spans. Similarly, to relieve the static load of a very long beam, intermediate supports made of timber columns were made in Abydos (Spencer 2023).

A significant transition in the history of Egyptian construction is recorded for temple architecture when limestone and sandstone from the Nile Valley became the only structural material.

The "lithification" of religious architecture, which took place during the Old Kingdom, left the image of the wooden temple substantially unchanged without creating a sudden break from tradition[9]. The elements making up the temple, in fact, let themselves be inspired by the autochthonous vegetable world, preserving the full memory of the wooden past[10]. A mutation in which the need for an "eternal" duration of religious architecture, the difficulties of sourcing wood that can be used in construction, and its easy flammability (Porta 1988) played a decisive role.

The construction of entirely stone temples, including the flat-type roof[11] adopting stone slabs, became particularly widespread during the Middle Kingdom (Wilkinson 2005). Using stone for the roof structure imposed a modest length of the slabs to minimize unbearable tensions. In fact, the

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[9] It is widely believed that Egyptian civilization was characterized by a particular static nature and a conservative character despite going through five millennia of history. A judgment already shared by the intellectuals of the eighteenth century, i.e. Milizia (1781) and Winkelmann (1764, 191-192), the latter stated: "... The art of drawing among the Egyptians is to be compared to a tree which, though well cultivated, has been checked and arrested in its growth by a worm, or other casualties, for it remained unchanged, precisely the same ...". Permanence in culture can also be seen during the Greek domination of Alexander the Great and then during the Roman one. A clear break occurred only with the advent of Christianity when the mummification process ceased, the corpses were buried, the temples were closed, and the use of hieroglyphs ended.

[10] The decorative motifs that refer to tied papyrus stems were, as well as in the columns, recurring in general in the temples and palaces. A consolidated practice common to various periods of Egyptian history was to decorate the top part of some buildings, such as towers, with a "cavetto" frame. This conformation, apart from the symbolic possibilities to which it refers, evokes the primitive Egyptian architecture of wood, branches and clay.

[11] The roof, which can be reached via particular stairs that allowed the image of the deity to be transported, was an integral part of the religious ritual.

distance between the supports of the hypostyle hall of the temples of the Old Kingdom rarely exceeded 3 meters, from which derived a dense system of columns that evoked a forest, a private and mysterious place that hid the *naos* and the divinity from the uninitiated.

The generalized adoption of sandstone from the quarries of Gebel El-Silsila instead of limestone slabs, which took place during the Middle Kingdom, made possible to overcome greater spans. Such an organization of the roof was universally adopted during the New Kingdom, for example, in the Temple of Tuthmosus III at Karnak (fig. 1-3), in the Temple of Seti I at El-Qurna and the Temple of Isis at Philae (Clarke and Engelbach 2014).

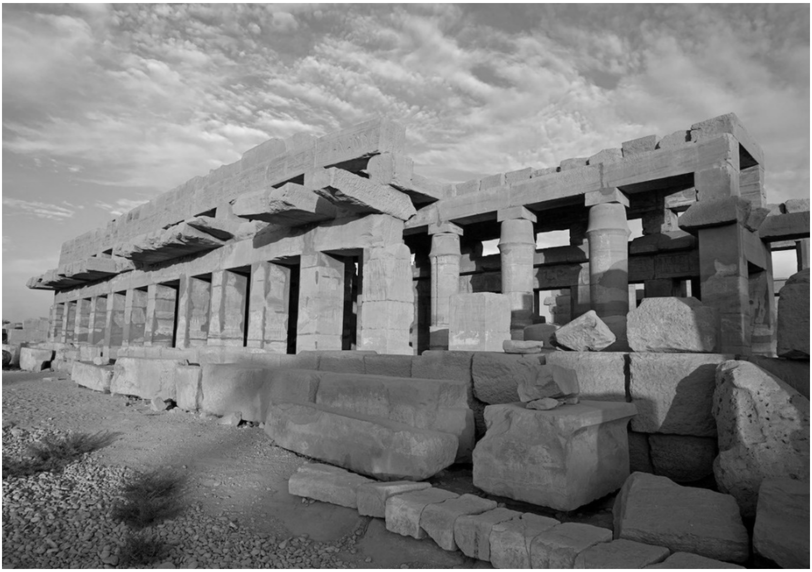

Fig. 1-3 The Festival Hall of Thutmose III (Akh-Menu) in Luxor.

The dimensional relationships dictated by the material's resistance, which resulted from the adoption of stone in roofing, did not adapt to the functionality of domestic spaces that continued to use timbers for the roofs[12].

[12] Further possible reasons that led to such a choice, in addition to the lower cost, were the construction characteristics of the dwelling elevation. In general, the masonry fabric of domestic architecture consisted of raw bricks or, in the most ancient examples, branches and clay, which could hardly have supported the considerable load derived from a stone floor.

The sites of Hieraknpolis and El-Kab have yielded settlements from the Protodynastic period. Other finds of dwellings, probably belonging to priests and datable to the Middle Kingdom, characterize the area adjacent to the pyramid of Amenemhat III in Dashur and Sesostries II in El-Lahun. These archaeological finds attest to the use of flat roofs[13] for large rooms and for smaller ones, whose organization of the carpentry must have had constant construction characteristics, albeit with slight variations.

In fact, it is presumable, in a time frame that goes from the Neolithic to the 20th century and in a geographical area that included the entire Middle East, that the roof woodworks were made up of round beams, on which rested a continuous layer of reeds and branches waterproofed by clay, and, in some variants, probably due to the span to be overcome, preceded by a framework of joists (Wright 2016).

The lack of total homogeneity in Egyptian culture, linked to a kingdom in which differences persisted over the centuries, particularly between Upper and Lower Egypt, also affected the construction.

In addition to the roofing systems examined up to now, it is possible, in fact, to include a further type of roofing of the pitched type used in hypogeal artefacts. It is a structure composed of stone elements of considerable size arranged at an angle and facing each other at the top end[14], whose foot thrust is opposed by the ground[15].

The differences in the materials and construction techniques used, detectable between the religious architecture and the dwellings, were also recorded by Diodorus Siculus in *Bibliotheca historica Diodorus Siculus I, 4* "… Monument of Semiramide ... vaults in masonry ... and large slabs in stone sixteen feet long and four feet wide: then it was covered with many reeds ..." "... dwellings built with reeds; and even today vestiges of them remain among the shepherds".

[13] During the Old Kingdom, the hieroglyph that expressed the sky consisted of a long rectangle with supports at both ends (Adam 2012), which refers to a flat floor.

[14] The structure with two facing stone elements should be considered an involution compared to the roof system with projecting courses. In fact, the first construction technique made possible to cover greater spans and be characterized by a lower cost for procurement, transport and ease of installation.

Variants of the roof organization with two inclined elements are represented by a configuration composed of three stone slabs, constituting a system approximating an arch. Examples can be found in tombs nos. 578, 579, 790, 792 and 994 in Naga ed-Der dating from the IV and V Dynasty.

[15] This system refers to the configuration that characterized the entirely wooden basement of the huts, typical at least since the Bronze Age in various geographical areas, whose thrust generated by the common rafter was counteracted by the ground.

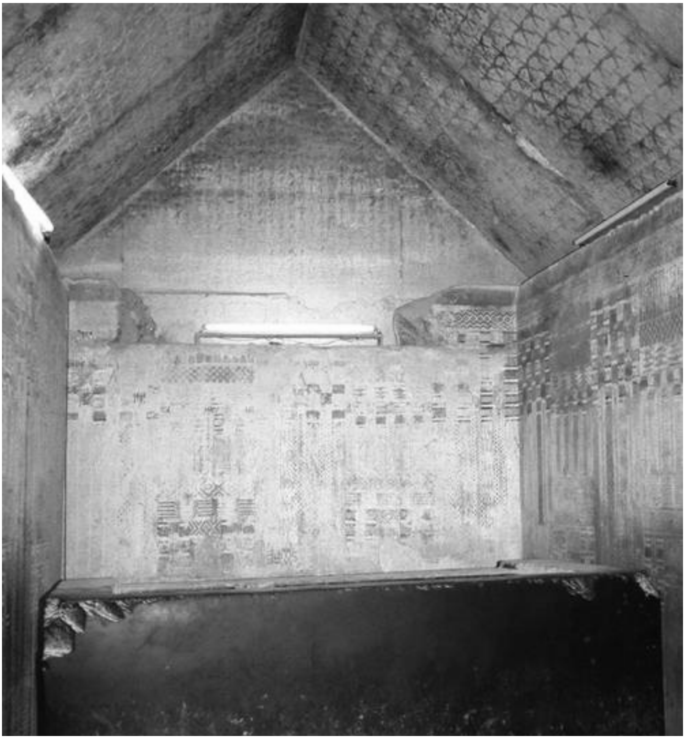

Fig. 1-4 The burial chamber at the Pyramid of Unas, 24th century BC, Saqqara.

This is an articulation of which evidence is preserved, for example, in the entrance of the pyramid of Cheops in Giza, datable to 2550 BC, in the Tomb of Teti and the burial chamber of the pyramid of Unas; the latter two are part of the necropolis of Saqqara and dating back to the 24th century BC (fig. 1-4).

A different way of unloading thrusts to the ground, recording a technological advance of such an organization, could be found during the Middle Kingdom. In the Mastaba of Dahshur (Morgan 1895), the horizontal component coming from the sloping roof is counterbalanced by the wall mass using a recess made in the masonry at the lower end of the sloping slab.

The sedimentation of experiences conducted the ancient Egyptians to a particular awareness of the interactions between masonry and roofing systems.

Furniture and boats

Going beyond the field of roof carpentry and extending the examination to other wooden artefacts, it is evident, already from the Archaic period, a manifest mastery by the Egyptians in the technique and technology of wood. The analysis of the structure of the furnishings and boats reveals a degree of advancement in knowledge capable of dealing with problems of stability, deformability, and resistance[16]. That is a level of expertise around the wood, which, *mutatis mutandis*, laid the empirical foundations to conceive and create trusses.

Half-lap and mortise (hole) and tenon (tongue) connections were commonly employed in furniture-making as early as the First Dynasty. Joints capable of transmitting tensile stresses - such as dovetail joints - were attested during the IV Dynasty in the bed found in the Tomb of Hetepheres in Giza (Killen 2008); these technical goals, whose achievement could not be separated from efficient metal tools.

Until the Protodynastic period, wood was worked with saws and knives still made of flint; from the First Dynasty, the discovery of copper hatchets and saws in Tomb 3471[17] (Emery 1949) testifies to a decisive technological advance.

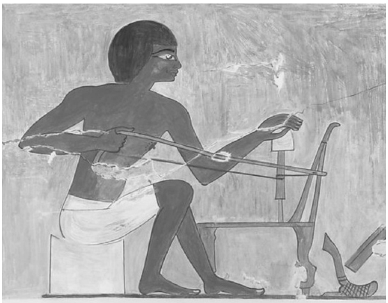

Fig. 1-5 A wall relief from the Tomb of Rekhmire, showing a bow drill.

Since the middle of the third millennium, carpenters already had an extensive kit of tools, which also included bow drills[18] (Singer 1967), with, by now, standardized morphological and functional characteristics, which remained unchanged until more recent times (Wright 2005) (fig. 1-5).

In addition to effective connections to transfer any stress, the carpenters of the New Kingdom made furniture - chairs,

[16] Furthermore, the process of bending wood to make furniture was part of the carpenter's technical background, evidence of which can be found in the bas-relief of the mastaba of Ti in Saqqara dating back to the 5th Dynasty (Montet 1925).

[17] The model of a carpenter's atelier, datable to the 11th Dynasty, is interesting in this regard, highlighting modern woodworking tools.

[18] A realistic description of such a tool is given in the Tomb of Rekhmire from the 18th Dynasty (Davies 1935).

tables, support for transporting objects - whose frames were equipped with inclined bracing elements[19]. Such a configuration, frequently represented in the iconography of the funerary architecture of the 18th Dynasty, is characterized by the application of the triangular mesh, which was known to be non-deformable. An articulation of the members which gives rise to a distribution of stresses comparable to that which characterizes a roof truss.

The scene depicting musicians and dancers in the Tomb of Nebamon, for example, dating back to 1350 BC, part of the collection of the British Museum, has supports for large vases at one end, whose slender line clearly indicates, unequivocally, wooden elements. This structure comprises two piers, arranged to ensure greater stability, bound at the top, and approximately in the middle by horizontal members. Such a frame is equipped with three compressed members: a horizontal element, similar to a crown post, which transfers the static load deriving from the vase as a punctual load on the lower horizontal member, and two diagonal elements - namely principal rafters - arranged symmetrically, whose tendency to translate outwards involves the generation of tension, similarly to a tie-beam, in the horizontal member. The discovery of some furnishings[20] belonging to the same chronological context reinforces the hypothesis of common use in the daily practice of such a configuration (fig. 1-6).

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[19] Pioneering stiffening systems can be deduced from the representations that characterize some vases painted in red of the Protodynastic period (Landström 1970) in which boats are depicted with, above the hull, braced frames. A cabin is probably reproduced in the vase dating back to Negadeh II. The artefact is characterized by a gabled roof at the foot of which there is a horizontal line that evokes, compatible with such an organization of the roof, a member helpful in absorbing the thrust of the two inclined elements.

[20] They are chairs from Thebes and kept in the British Museum in London (no. 2476 and no. 2472), as well as at least two artefacts found in 1922 by Carter and Carnervon in the far end of the antechamber of Tutankhamen's Tomb (Winston 2007). Furthermore, the same organization of the resistant structure is depicted in the sculptural group of Yuny and his wife Renenutet, dating back to the period between 1294 and 1279 BC.

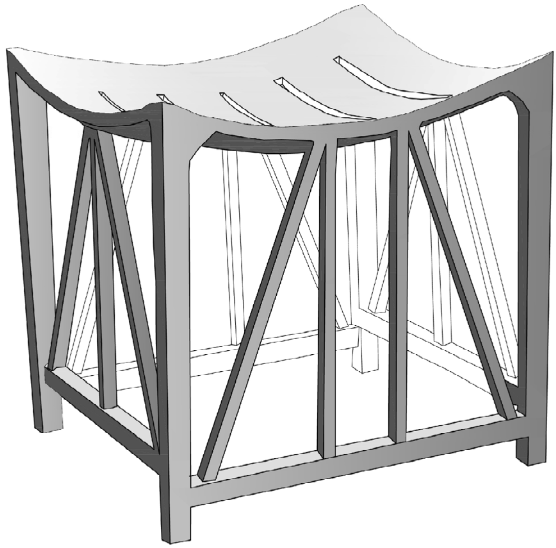

Fig. 1-6 Wooden stool with lattice bracing from Thebes dating back to the New Kingdom.

This articulation of the members varied in the case of artefacts with a similar function but with the length prevailing over the other dimensions[21]. In fact, a further strut was added to the members of the support for vases, showing attention to both resistance and deformability. A module composed of compressed and tensioned elements, repeatable according to need, remembers the arrangement of chords, diagonals and verticals, defined as a "Howe" truss by the modern engineering science of materials (fig. 1-7). The mutual relationships among the components allowed a pioneering optimization and reduction of the resistant section, in which the connections played a strategic role, to whose degree of stiffness the vegetable fibre ropes[22] contributed. Just the analysis of the joints leads to further observations on the technical background of the Egyptians, who possessed the solution to the problem of connecting three converging members at the same point.

[21]For example, in the lower register of the west wall at the North end of the Tomb of Puyemre at Thebes (Davies 1922), in the Tomb of Meryra at Tell El-Amarna, the transport support found in 1922 in the Tomb of Tut-Ankh-Amen discovered by Carnarvon and Howard Carter.

[22] Such devices, on a larger scale, for example, in roofing carpentry, with stresses characterized by much higher values, would not have been able to guarantee the transfer of stresses between the various components.

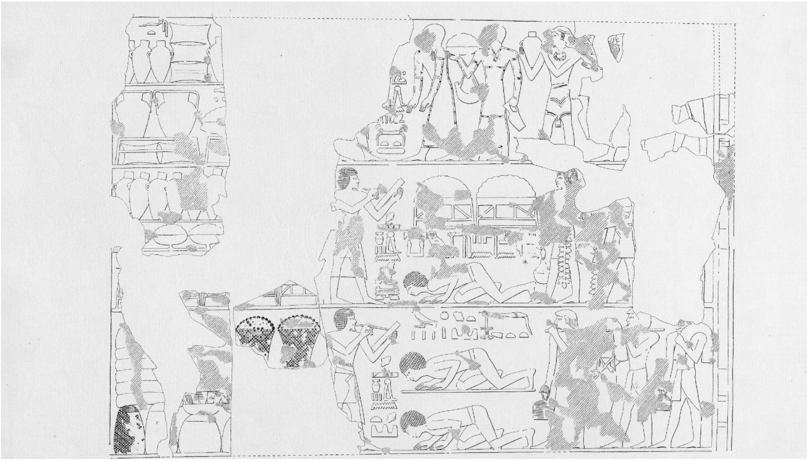

Fig. 1-7 Supports for vases are depicted in the central register. These remember a modern "Howe" truss (Davies N. de G. 1922).

The confirmation of the acquisition of fundamental notions on the "science" of wood is provided by the technological level reached by the Egyptians in boats. Herodotus defines Egypt as the "gift of the Nile" to underline how the great river was strategic in the genesis and development of Egyptian civilization. The Nile, in fact, permeated various aspects of culture, from religion to the economy to society. A centrality, therefore, in the life of the Egyptians from which a particular ability in navigation followed, which also allowed the Mediterranean and the Red Sea to be exploited as an artery for transporting goods and information. The organization of the wooden hull structure, already at least from the Ancient Kingdom, presented peculiar aspects[23], regardless of the oldest boats made from bundles of bound papyri[24] that go beyond the scope of study proposed by the manuscript.

[23]Herodotus provided numerous construction details and methods for assembling the hull of a boat. He also refers to *internal ribs*, transversal elements to the hull, useful for stiffening and counteracting the action of water (II, 96).

[24] The expansion of commercial traffic by sea, starting in the third millennium, created a decisive impulse in the variation of materials, dimensions and configuration of boats. This condition led to forced changes in the structure of the boats. Greater stiffness, for example, was necessary to face the wave motion and the storms, which were absent in the Nile.

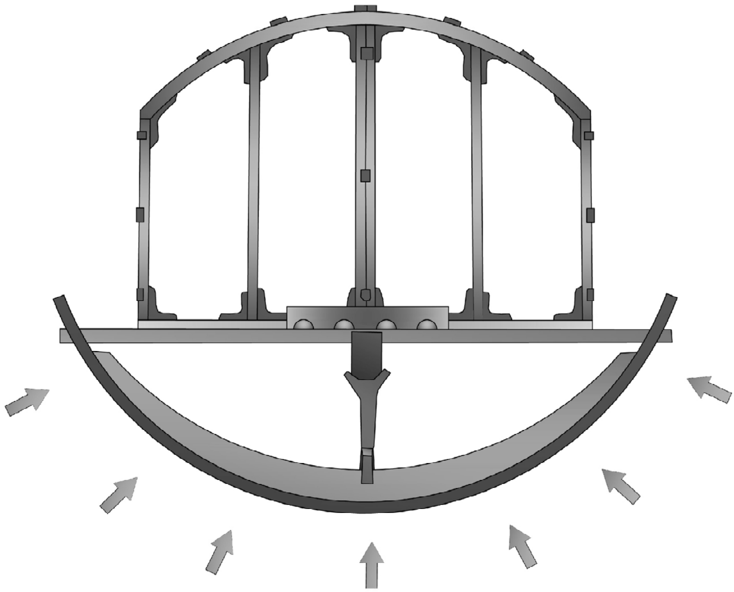

Fig. 1-8 A reconstruction of the solar boat of Cheope.

The *solar boat* of Cheops (fig. 1-8), dating back to around 2500 BC, was made of wooden elements, mostly cedar wood from Lebanon, connected by tenons and mortises, with the aid of pegs[25] and ropes (Landström 1970). The latter, used widely, created states of coaction generating self-stresses, thus the force-fitting of wooden components. Furthermore, a valuable contribution to the pre-induced stresses was the volume variation resulting from the contact of the wood with water. The hull reproduced the same stress regime as an overturned wooden truss. The action of the loads was imposed by the thrust exerted by the water and by its own weight. In fact, the floor received the water thrust through the plating, from which compression-bending stresses arose, analogous to the principal rafters. In contrast, the upper beam, subjected to tension, similar to a tie-beam, stemmed the tendency of the hull to spread out[26] due to the loads imposed by occupancy and the cab. A vertical member in the position of the

[25] The use of long dowels and papyrus, which, in contact with the water swelling, exerted a beneficial strengthening of the joint, represented a constant in the carpentry of boats, as attested by Herodotus (II, 96).
[26] Phenomenon whose contrast also contributes to the push of the water itself.

paramezzal, connecting the beam and the floor and evoking a crown post subject to compression, completed the structural unit.

The mastery of the shipwrights of the First Intermediate Period is exemplified in the model of a boat found in the Tomb of Mesehti in Asyut (Reisner 1913). The roof structure of the cabin is reproduced with extreme realism. The profile is curved, and the organization of the carpentry is made up of two orthogonal frameworks, creating a lattice that rests on the perimeter curbs. A dimensional hierarchy is noted, the curved element is larger than the ones above it, which is compatible with a real reinforcement of a roof. The timber posts are stiffened, near the connection between the beam and the post, by an "L" shaped element.

The woodwork of the Cretan roofs from the Late Minoan to the Archaic period

Introduction

Greek mythology sets the construction of the labyrinth, which enclosed the Minotaur, in Crete at the behest of King Minos. A work whose legend goes beyond geographical and temporal spheres and represents, in the collective imagination, the architectural invention par excellence[27]. As it is known, the creator of the labyrinth was Daedalus - Architect in the meaning given by Vitruvius – the personification of the creative genius of the Minoan building culture. The first representation of Daedalus was provided by Homer (Iliad Il.18.590–594), who described him as an architect at work in the act of drawing a circle, attracted, among the materials that nature offered, by wood (Palyvou 2018).

The iconography of the paintings and seal-stones and some models that depict architectures are the few documents available to outline, with physiological uncertainties, the characteristics of the roof structure that distinguished the buildings of the Minoan Age generally preserved only at the foundation level.

[27] In the Middle Ages, especially from the mid-13th century, laudatory inscriptions can be found on buildings such as on the southern transepts of Amiens and Paris and in the labyrinths reproduced on the floors, i.e. Reims, Amiens, St-Quentin, Lucca, which refer to Daedalus, the mythical ancestor of the architects (Kimpel 2005).

The wood species available

Cretan builders had large wood reserves[28] at their disposal (Singer 1967). However, after the mid-16th century, it is widely believed that they had to suffer from a growing wood shortage, attributed to the island's possible deforestation[29] (Meiggs 1982). Tamarix and Olive wood were used in the construction of the prehistoric house (Palyvou 2005a). The historiography of antiquity, with particular reference to Theophrastus (Historia Plantarum II.2.2; III.1.6; IV.5.2) and Pliny (Nat. Hist. 16.141), described the Cypress as a native plant of Crete from which to assume a widespread use in construction[30]. Furthermore, the use of fir wood (*Abies cephalonica*), pine (*Picea orientalis*), elm (*Quercus ilex*), and cedar of Lebanon (*Cedrus libani)*[31] is attested (Sarpaki 1987).

The Minoan civilization

Finds from the Early Neolithic age attest to a permanent settlement at Knossos (Castleden 1993). The village continued to thrive during the Middle and Late Neolithic with dwellings built of adobe on a stone base (Mcnroe 2010). In the final Neolithic, the development of other settlements was recorded in the rest of the island, with dwellings distinguished not only by the rooms of modest dimensions but also by storeys above the first. A common feature of the buildings of the Neolithic age was the rectilinear walls onto which the roof structure weight was discharged. In the case of the "House D" of Knossos, it benefited from further support, a post placed inside the house (Mcnroe 2010) that was useful for reducing the span of the flat roof.

However, the presence of huts with a pseudo-circular development[32] - to which Evans attributed the genesis of the morphology of the tholoi -

[28] Still, in the first century, Strabo described the island as rich in woods (Geography 10.4).

[29] One of the causes of the fall of the Cretan Thalassocracy is attributed to this event (Meiggs 1982).

[30] Confirmation of this assumption is provided by Evans (1930), who found charred samples and fragments of cypress wood during his excavations of Knossos. However, more recent analyses seem to have disproved the hypothesis, as they are fragments of fir (*Abies cephalonica*) (Meiggs 1982).

[31] Vitruvius (2.IX.13) describes cedar as a native wood species of Crete.

[32] Singer (1967) also shares the hypothesis of circular huts on the island between the second and third millennia, perhaps of a provisional type. In the more modest cases, from the point of view of size, they could be covered by branches and clay (Evans 1921).

cannot be excluded, which is confirmed by the pre-palatial evidence of Festus.

A similar dating can be attributed to the circular tombs attested in Messara and, with quadrangular annexes, in Apesokari and Kamilari. For these artefacts, the presence of a wooden roofing carpentry for the rooms characterized by considerable span, which entailed a static load poorly supported by a stone roof (Cucuzza 2002), is possible to assume. In light of this, Tomb A in the Messara plain, which reaches 18 meters in external diameter, is characterized by cross sections of relatively modest walls and leads to the exclusion of the possibility of a vaulted roof structure.

The collection of seals from Knossos dating back to MM II-III (Evans 1921) (fig. 1-9), according to the authoritative opinion of Arthur Evans, depicts the facade of sanctuaries[33] in at least three variants: punctuated by two, three or four columns, on which the roof is set with a significant slope. The roof morphology, common in the three types of buildings, comprises a horizontal element, probably a curb predominant in size, onto which the common rafters rest. The horizontal member to common rafter constraint is located towards the inside of the construction to have as much resistant material as possible to withstand the outward thrust deriving from the inclined element.

Fig. 1-9 Seal-Stones with Facades of Gabled Buildings dating back to MM II-III (Evans 1921).

[33] Hagg (1990) also shared this hypothesis. Other authors, instead, hypothesize a depiction of fishermen's or shepherds' barracks (Mersereau 1993).

The timber carpentry is also equipped with a lattice of slats arranged on different planes, perhaps parallel rings and meridian ribs of a domed roof. In fact, they are depicted as inclined with respect to the orthogonal and vertical axis of the building, a probable attempt by the craftsman to represent the pseudo-circular development of the roof. The latter distinctive character is evidenced by some models produced in Crete between Late Minoan IIIA2 and the Orientalizing period, found in Kato Zakros, Amnisos, Khania, Kastri-Palaikastri, Festo, Karphi and Knossos[34] (Mersereau 1993; Vassilis 2006). The references to the roof are rather vague, and the presence of a central panel in the cylindrical artefact remembers a door from which the models are assumed to represent buildings. In the model found at Kato Zakros (fig. 1-10) and dating back to LM IIIA2 (Hagg 1990), bands of darker colour, both at the eave and along the vertical development of the roof, could refer to hoops. These help counteract the tendency to translate towards the outside of the primary roof framework.

Fig. 1-10 Cylindrical model from Kato Zakros.

The Cretan civilization of the Bronze Age took full advantage of the mechanical properties of timber by using wooden reinforcements in the masonry to contribute to the seismic response of the building[35]. Notable examples of such a fabric organization can be found in the palaces of Knossos, Phaistos and Mallia, where the wall base was surmounted by clay bricks or rubble masonry equipped with wooden elements arranged in three directions (Wright 2005; Palyvou 2017a; Tsakanika 2017) (fig. 1-11).

[34] The discovery of the various models took place in different contexts, only some of a funerary type and others of a ritual type, which leads to difficulties in decoding their function irrefutably. For Petrakis (Vassilis 2006), they would represent circular tombs, whose covering could be in stone ashlars arranged in projecting courses. Such roofing is attested in funerary buildings in the Aegean civilization around 2300 BC (Palyvou 2009).

[35] A construction technique that found correspondences in Cyprus, in a later chronology, the 13th century BC, compared to the Cretan examples, i.e. Enkomi and Kition (Wright 2005). A similar archaeological record can be found in the northern Syrian city of Ras Shamra, Ugarit, characterized by commercial relations with Cyprus during the last part of the Late Bronze Age.