Eleni Maragoudaki

Shipbuilding Tools from the Bronze Age Boatbuilder to the Traditional Shipwright: Tracing the Evidence in the Mediterranean Basin

The development of nautical technology concerning wooden shipbuilding depended upon the raw materials available for both hull construction and tool manufacture, as well as upon the knowledge of woodworking techniques. As a result of social, political and economic circumstances the need to produce stronger, sturdy and effective hulls well-suited to environments and intended purposes continuously increased. Consequently, it was required from the shipwrights the ability to solve more complex structural problems. They had to invest considerable time and mental effort in applying different types of joinery and new types of tools for the work, taking advantage of and developing at the same time skill, experience and ingenuity. Therefore, the shipwright had to be always alert, in order to provide solutions to every challenge of his era by having not only an in-depth knowledge of raw materials and woodworking techniques, but also a good array of tools, which constituted the extensions of his mind and hand.

The present study aims to trace the presence of shipbuilding tools through time and to discern, if possible, the changes to which they were subjected, when and why. The target set was developed through the recording, examination and classification of the available archaeological and ethno-archaeological evidence, such as artistic representations, written evidence, toolkits, tool traces etc. Moreover, experimental methods, like tool reconstruction and partial hull rebuilding, proved useful in collating sufficient criteria for the comprehension of tool use (utility, functional differences).

Tools used in shipbuilding: iconographic evidence

The ancient history of woodworking tools used in shipbuilding essentially begins with Egyptian evidence. Egypt has proven to be the largest repository of early ancient watercraft. The study of representations depicting ship construction, the tools themselves, as well as preserved tool marks on the wooden surface of hulls offer a variety of information as far as the woodworking tools used in shipbuilding is concerned. It seems probable that the shipwright's toolkit was standardized only when metal tools, copper and bronze ones, were manufactured to construct more stable and sophisticated structures such as wooden vessels, which reflect and serve more complex social needs.

Beginning our research on the iconographic evidence[1], one could realize the relative abundance of representations concerning ship construction. The shipwright's toolkit seems to have consisted of cutting, percussion and perforation tools, as well as measuring and marking devices. The majority of them, except the bow-drill, were used for two forms of planked ship construction, the lashed and the unpegged mortise-and-tenon one, which dominated Egyptian shipbuilding of the 3rd and the first half of the 2nd millennium BC. By relying on paired deep mortise-and-tenon joints left unpegged, the Egyptian shipwrights continued a tradition that allowed watercraft to be more easily disassembled and reassembled, transported and recycled[2].

The most detailed extant depiction of the unpegged mortise-and-tenon shipbuilding technique is the painted relief in the 5th Dynasty mastaba of Tí at Saqqara[3], where five ships are shown being built in three registers and three more additional phases of ship construction in another one (**fig. 1, 1-2**). All the depicted tools were used in the construction of planked ships with unpegged mortise-and-tenon joints. As for the cutting tools, a whole range of woodworking tools was used in shipbuilding. Specifically, Egyptian woodworkers were depicted in shipbuilding scenes using the axe for felling and trimming trees and roughly shaping planks in different phases of hull construction[4]. Furthermore, an incised depiction of a boat on a heavily used 18th Dynasty axe constitutes a reinforcing element for its use in shipbuilding[5]. Another vital tool in the Egyptian shipbuilder's toolkit was the saw. It was used in various phases of hull construction, not only for the formation of the basic structure (log cutting, plank formation), but also for the upper structure[6]. Cutting on the pull stroke, the Egyptians wood sawyers were equipped with

1 Petrie, Medum. – Steindorff, Grab des Tí. – Bruyère, Deir el Médineh. – Duell, Mereruka. – Wild, Tombeau de Tí. – Mussa/Altenmüller, Nianchchnum. – Dürring, Schiffbau. – Wachsmann, Seamanship.
2 Ward, Egyptian Seafaring 14f.
3 Steindorff, Grab des Tí pls 119-121. – Wild, Tombeau de Tí pls CXXI. CXXVIII.
4 Haldane, Hull Construction 49. – Ward, Egyptian Seafaring 26. – Dürring, Schiffbau 94f. figs 46a-c; 48a. – Wachsmann, Seamanship 230f. fig. 10, 14.
5 Haldane, Hull Construction 49f. – Ward, Egyptian Ships 27.
6 Wachsmann, Seamanship 230f. fig. 10, 15; 233 fig.10, 20; 237 figs 10, 26B; 10, 27.

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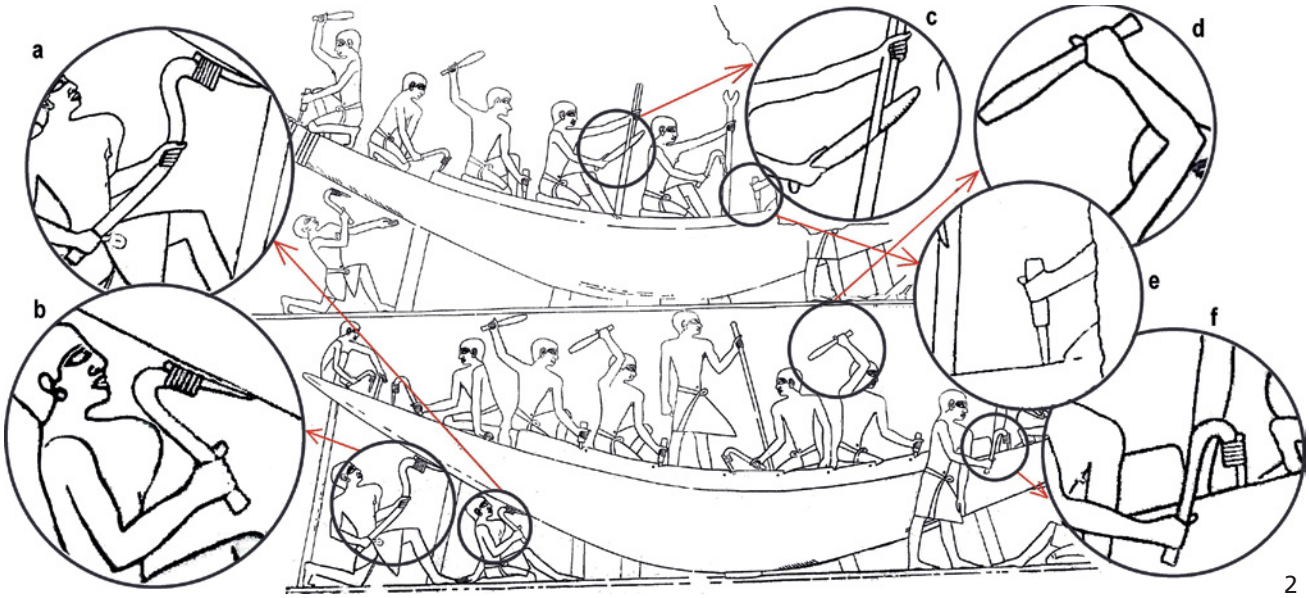

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Fig. 1 Tomb of Tí at Saqqara: **1** ship construction scene. – **2** synthesis of shipwrights' tools used in hull construction: a-b chipping adze; c saw; d mallet; e mortise chisel; f chopping adze. – (1 after Steindorff, Grab des Tí pl. 119; 2 after Maragoudaki/Kavvouras, Tool Kit 200 fig. 1).

saws having teeth pressed over the same side, providing an unusual set unlike that found on a modern saw, where each tooth is set alternately to the left and right of the blade[7]. Owing to this peculiar setting, one side of the blade was in contact with the wet and possible resinous kerf. Therefore, to avoid binding, a vice or a kind of counterlever was often used[8]. Representations often illustrate a weighted stick used to keep the lashing taut, and sawyers are shown adjusting the position of the lashing as they cut lower in the board[9].

Apart from the aforementioned cutting tools the adze seems to be one of the most essential and versatile tools of the shipbuilder's toolkit. Egyptians woodworkers used the adze for rough shaping and finishing off timbers, as well as for final shaping and smoothing wooden surfaces. A variety of adzes is depicted on wall paintings revealing that a different type of adze with a different hafting angle was used for certain tasks[10]. Specifically, two types of adzes could be discerned based on the haft shape; one Λ-shaped suitable for chopping and another S-shaped, used as a plane, appropriate for chipping[11].

Chisels were used for cutting holes and removing wood along and across the grain. Chiselling is one of the most common elements of ship construction scenes[12]. The type of mortise chisel was the preferable tool to open deep mortises for joining planks. The chisels were used in conjunction with two types of mallets: a) a heavy mallet of hard wood, bulky at one end and with a clearly formed handle at the other[13] and b) the more popular bat-shaped wooden baton[14]. Moreover,

7 Killen, Wood 355.
8 Steindorff, Grab des Tí pl. 119. – Wachsmann, Seamanship 231 fig. 10, 15.
9 Haldane, Hull Construction 50.
10 Dürring, Schiffbau pls 7-10.
11 Maragoudaki, Εργαλεία 78.
12 Dürring, Schiffbau pls 7-11.
13 Dürring, Schiffbau pls 10-11.
14 Dürring, Schiffbau pls 7-10.

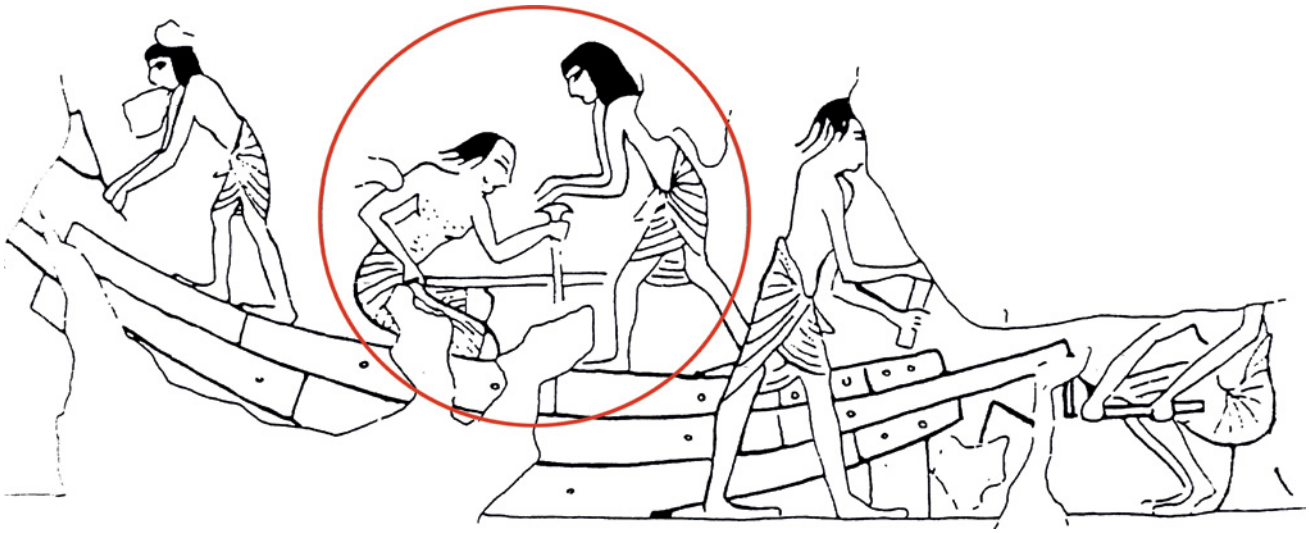

Fig. 2 The tomb of Qaha at Deir el Medinah. – (After Bruyère, Deir el Médineh pl. 26).

another type of percussion tool with a large, two-handled biconical maul probably made of wood is also depicted in shipbuilding scenes dating back to the 5th Dynasty. The shipwrights use these wooden pounders to drive planks onto tenons set in the edges of the lower planks[15].

As far as perforation tools in shipbuilding are concerned, the use of the bow-drill is attested during the late New Kingdom (13th century BC), during which the pegged mortise-and-tenon joinery technique seems to have been introduced in Egypt[16]. The shipbuilding scene from the tomb of Qaha at Deir el Medinah[17] (**fig. 2**) seems to be indicative of this new technique; the use of the bow-drill, as well as that of the two-handed mallet in combination with dots on the hull's exterior strongly suggest that the aforementioned technique was adopted and represented[18]. Consequently, although the Egyptians were familiar with the bow-drill in woodworking, its use in hull construction points to a technological change in shipbuilding. The adoption or evolution of a new technique, that of pegged mortise-and-tenon joinery, necessitated the use of the bow-drill, the first mechanical woodworking tool, to open holes for the insertion of wooden pegs or treenails, in order to secure not only the tenons into the mortises, but also to ensure in general the hull's strength and integrity.

Although the illustrations of measuring and marking devices are sparing, metrological examination of hulls demonstrates certain principles of construction that are based on specific measuring tools, such as cubits of different lengths and their standardized subdivisions[19]. Specifically, the Old Kingdom mastaba of Mereruka includes an unusual illustration of a shipwright using a line, plumb-bob and marking implements, either for establishing a centre line or for checking dimensions of a funerary boat under construction[20]. In the tomb of Khnumhotep and Niankhkhun (5th Dynasty, 2400 BC) a shipwright working in the uncompleted centre of a hull is depicted holding an upright staff in one hand and what appears to be a small stick, possibly for marking, in the other[21]. Supervisors in the tombs of Ti and Khnumhotep and Niankhkhun each hold a coiled line and plumb-bob[22]. Finally, it is worth noting that no set squares have been portrayed in ship construction scenes in comparison to the variety of set squares attested from excavations and representations[23]. Nevertheless, their use is attested later on in wooden shipbuilding[24].

As for the artistic representations, beginning with the Hellenistic period, a small fragment of a relief bowl from Iolkos dating to the late 3rd century BC depicts Odysseus building his vessel using a chisel with a mallet, an adze and probably a bow-saw, in case the semicircular shape to his left portrays a tool and not some other object[25]. Moving on to the following century, the most famous shipbuilding scene in ancient iconography is the construction of Auge's raft on the Telephos frieze from the Altar of Zeus at Pergamon (**fig. 3**) dating to the 2nd century BC[26]. It condenses all the vessel construction phases into one depicting shipbuilders using a saw, bow-drill, chisel with mallet or hammer and adze. The axe is not depicted, probably because it had been used at the earlier stages of construction for log splitting.

15 Wild, Tombeau de Tí pl. 129.
16 Wachsmann, Seamanship 235-237.
17 Bruyère, Deir el Médineh 75 pl. 26.
18 Wachsmann, Seamanship 238.
19 Ward, Egyptian Ships 30.
20 Ward, Egyptian Ships 30. – Duell, Mereruka pl. 152.
21 Ward, Egyptian Ships 29. – Dürring, Schiffbau. – Mussa/Altenmüller, Nianchchnum pls 19-20.
22 Ward, Egyptian Ships 29. – Steindorff, Grab des Tí pl. 119.
23 Śliwa, Egyptian Handicraft 38-40.
24 Udell, Woodworking Tools 210f.
25 Brommer, Odysseus 93 fig. 46. – Höckmann, Seefahrt 152 fig. 131.
26 Pollitt, Hellenistic Age 203 fig. 216.

Fig. 3 Pergamon: construction of Auge's raft on the Telephos frieze from the Altar of Zeus. – (After Politt, Hellenistic Age 203 fig. 216).

Moreover, the significance of the adze is highlighted on the funerary relief of a shipwright at Ravenna dating to the 1st century AD[27] (**fig. 4b**). Specifically, the shipwright »faber navalis« Publius Longidienus Camillus is depicted while working with his adze on an interior rib destined for the hull of a boat under construction. The inscription on a small plaque in front of the craftsman proclaims: »Longidienus pushes ahead with his work«[28]. Another famous relief from Rome (**fig. 4a**), depicting Jason building the Argo using a mortise chisel and a mallet to open probably a mortise is dated to the same period[29]. Furthermore, a gilt glass vessel (**fig. 5**) found in the catacombs of Rome dating to the 4th century offers a visual encyclopaedia of shipwrights using the basic woodworking tools, under the patronage of Daedalus, the inventor of many of them[30].

27 Casson, Ancient Shipbuilding 28-33 pl. 1.
28 Liversidge, Woodwork 164f. fig. 273. – Casson, Seafaring 34 fig. 28. – Ulrich, Roman Woodworking 18. 20 fig. 3, 9.
29 Orlandos, Δομής 56f. fig. 32.
30 Garrucci, Vetri Ornati 63 pl. XXXIII. – Frontisi-Ducroux, Dédale fig. 11. – Liversidge, Woodwork 158f. fig. 264. – Ulrich, Roman Woodworking 35 fig 3, 23.
31 Moll, Schiff.
32 Bass, Seafaring fig. 11.
33 Thompson, Medieval Artisan 392 fig. 357. – Moll, Schiff 9. 67 pl. BXe 121. 124.

By the end of antiquity, shipbuilding scenes are depicted by the artists on different materials (cloth, stone, paper, glass etc.)[31]. The following indicative references shed light on the uniformity of shipbuilding tool types through the ages. On the famous Bayeux tapestry (**fig. 6**) of the mid-11th century shipbuilding scenes were embroidered on a cloth approx. 70 m long depicting among the events leading up to the Norman Conquest of England shipwrights constructing vessels using axes, adzes, mallets and chisels, as well as pump-drills[32]. A century later (12th century), Noah is depicted building the ark on the mosaics at the cathedral of Monreale (**fig. 7**), as well as in Palermo's Royal Palace[33]. The shipwrights on the ark use two fine saws: a frame-saw on the left and a pit-saw on the right. Below, another two men are trimming, the one on the left with an adze, another on the right with an axe. Another relief, at the main entrance of St. Mark's Cathedral represents

Fig. 4 Reliefs: **a** Rome: Jason building the Argo. – **b** Ravenna: funerary relief of the shipwright Publius Longidienus Camillus building a hull. – (a after http://commons.wikimedia.org/wiki/File%3ABuilding_Argo_BM_TerrD603.jpg; b after http://ancientrome.ru/art/artworken/img.htm?id=4899).

a

b

Fig. 5 Gilt glass vessel: shipwrights using woodworking tools (see clockwise from top right: mallet and chisel, bench plane, adze, bow-drill, small hatchet, frame-saw) under the patronage of Daedalus. – (After Frontisi-Ducroux, Dédale fig. 11).

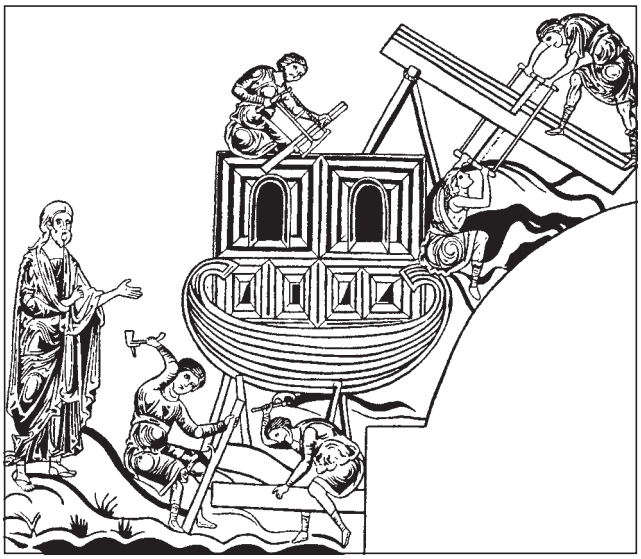

Fig. 7 Monreale cathedral: mosaic depicting the building of Noah's Ark. – (After Thompson, Medieval Artisan 392 fig. 357).

craftsmen of Venice dating to the 13th century. Included are shipbuilders (**fig. 8**) building a small round ship[34], the construction scene of which portrays one man in the bow boring a hole with an auger, another in the stern removing an adze from a tool basket, while two others working from below caulk with a hammer and chisel or a caulking-iron. Shipbuilders are also represented on a French historical manuscript dated to the same period[35]. Despite the distortion, a clawed hammer and a trimming axe are well represented, while the teeth of the saw and the nail are inversely proportional to their actual size.

Passing on to the art of painting, Paolo Veneziano, the famous Venetian painter of the 14th century, illustrates the construction in progress of a frame-first vessel in an Italian shipyard (**fig. 9**), probably in Venice[36]. Two shipwrights bore holes with their augers, one at the sternpost and the other at a frame near the bow. In the middle, a third one sketches plans on the ground, while two others within the ship employ cutting tools (adze and axe) to finish off the timbers.

34 Thompson, Medieval Artisan 395 fig. 361. – Martin, Venetian Ships 127. 129 fig. 115.

35 Thompson, Medieval Artisan 390 fig. 353.

36 Casson, Seafaring 31 fig. 23. – Martin, Venetian Ships 112 f. fig. 98.

Fig. 6 Bayeux tapestry: shipbuilding scene. – (After Bass, Seafaring fig. 11).

Fig. 8 St. Mark's Cathedral, Venice: shipbuilders building a small round ship. – (After Martin, Venetian Ships fig. 115).

Fig. 9 Painting by Paolo Veneziano: construction in progress of a frame first vessel in an Italian shipyard. – (After Martin, Venetian Ships fig. 98).

Textual evidence

The written evidence, although scant, sometimes elucidates the rather puzzling image of shipbuilding and the shipwright's world, while at other times it causes numerous problems in interpretation, particularly in the many technical terms, the exact meaning of which continues to elude us. Dating to the beginning of the 2nd millennium BC, dockyard records from the time of Senwosret I (12th Dynasty, 1971-1926 BC) confirm the use of the majority of the tools in the shipwright's toolkit[37]. Specifically, the use of the axe is attested in many stages of the shipbuilding process, with standardized axe weights of 700 and 500 g. Moreover, at the same time, lighter adze blades weighing 200 g were used as adzes, but New Kingdom carpenters used heavier blades of 364-455 g. A number of chisel blades dating back to the 5th Dynasty and equipped with rounded handles were included in Ka-em-ankh's list of tools for the shipyard, which points to their use in shipbuilding[38]. Its use is also confirmed by the words of an Egyptian shipwright in the 6th Dynasty tomb of Aba, who shouts: »Lo, I am chiselling«, while the dockyard workshop of Senwosret I dealt with chisels of 196 or 280 g[39].

Passing to the Aegean region, the term »shipbuilders« (na-u-do-mo) appears in several Linear B texts in Knossos and, in particularly, in Pylos[40]; it heads PY Vn 865, which contains a list of twelve extant masculine personal names. This group, as well as other groups of craftsmen, seems to belong to the directly dependent personnel controlled by the palace. It is very probable that they were granted plots of land upon which they could subsist, and for the holding of which they were obliged to fulfil a twofold service: they had to deliver natural products and they had to practice their special trade[41]. Unfortunately, it is impossible to determine whether the Mycenaean na-u-do-mo are the equivalent of shipwrights, i. e. the technical specialists in ship construction, who in the role of master planners would each supervise the construction of a single ship, or whether they were skilled woodworkers used in the labour of ship assembly, i. e. merely ship carpenters. In classical inscriptions the shipbuilders were associated individually with the ships whose construction they oversaw[42]. Furthermore, it is worth noting that, apart from pieces of information concerning their social and economic status, no correlations related to specific tools and shipbuilders or carpenters have been detected in Linear B records.

37 Ward, Egyptian Ships 30.
38 Ward, Egyptian Ships 28 f. with note 39.
39 Ward, Egyptian Ships 28 with notes 32. 34.
40 Ventris/Chadwick, Documents 123. 298 f. 562. – Lindgren, People (I) 175; (II) 100. – Palaima, Maritime Matters 287 f.
41 Hiller, Dependent Personnel 60.
42 Palaima, Maritime Matters 288.

However, far beyond doubt, the most famous and controversial passage in literature is the vessel building passage in book 5 of the Odyssey[43]. Although this passage appears clear, there has been considerable disagreement over its interpretation, mainly because of the various translations of the terms pegs (γόμφοι) and fasteners (αρμονίαι). Whichever technique – laced or pegged mortise-and-tenon joinery – is described, the reference to the basic shipwright toolkit comprising the axe, adze, chisel, mallet and drill is undeniable. The absence of the saw is not surprising, since the plank production could have been done by other cutting tools like the axe and adze. Furthermore, the adze was used not only to form, but also as a plane for final shaping and smoothing[44]. The plane with the form of a blade being boxed in a wooden frame was invented by the Romans and its use is attested much later in shipbuilding (De Meern 1). Moreover, Homer refers to the drill and adze, two of the most basic shipbuilding tools, using eloquent similes[45].

Another important reference relating to the shipwright's, as well as to the carpenter's tools is in the Onomasticon dated to the 2nd century AD, where the grammarian and sophist Pollux refers to the woodworking tools used by the shipwright: axe, adze, saw, hammer, chisel, drill, awl(?) and rasp[46].

Traces of tools on shipwreck hulls

A valuable source of information about the tools used in shipbuilding is also provided by the tool marks preserved on shipwrecked hulls. In several cases we have the chance to recognize marks of specific types of tools, as well as details of their constructional geometry, such as the widths of the cutting edge and drill-bit or teeth density. As for some tools, among other things owing to their indirect use in construction (i. e. the mallet) or their use in the early stages of construction (i. e. the axe), it is almost impossible to discern their use. Their practice is confirmed by other sources (iconographic and written evidence).

Specifically, the physical remains of Egyptian hulls, funerary or otherwise, provide evidence concerning the use of the adze, chisel, as well as bow-drill in ship construction. The use of the chisel is dominant in creating mortises. Mortises, known to be partially drilled in later times, have many chisel marks, but never any drill marks[47]. However, there is some evidence of its use in shipbuilding, judging by the pegged mortise-and-tenon joints in the Khufu I's deckhouse or the cylindrical holes in the bottom of Lisht planks which both probably were made with a bow-drill[48]. Nevertheless, nobody can deny the use of bow-drill in shipbuilding up to late Pharaonic times, but not for the construction of essential parts of the hull. It is worth noting that only the Mataria vessel dating to the 5th century BC provides physical evidence for drilled peg holes[49].

In the Mediterranean Basin the Uluburun shipwreck provides some pieces of information, while the Ma'agan Mikhael and Kyrenia shipwrecks offer greater variety. Traces of the basic tools of the shipwright's toolkit (adze, chisel, drill, saw and probably axe) were recognized on the Uluburun shipwreck's hull. Specifically, adze marks were identified on the starboard strake S1, as well as on the body of wooden pegs for the production of which twelve facets had been made by an adze[50]. Also, the use of adze or axe was detected for the sharpened ends of stakes (4-5 strokes) of the bulwark's fencing[51]. Chisel marks were visible on the sides of some mortises, an element which suggests that the width of the chisel blade was equal to that of the mortise (2.1 cm)[52]. It is also worth noting that a mortise retained traces of three possible chisel marks[53]. The use of a drill is verified by the holes opened for the insertion of the wooden pegs for tenon locking. The diameter of the holes (2.1 cm) reveals the drill-bit's width[54]. Moreover, evidence of drilling prior to chiselling was probably detected, but more scrutiny is required[55]. Finally, a saw was used for cutting off the protruding ends of the pegs after have been driven through the mortise-and-tenon joints[56]. Additionally, evidence of saw marks was traced along the surface of some tenons[57]. It is also noteworthy that variable tools, such as sickles, awls, drill-bits, a saw, a pair of tongs, chisels, adzes, axes, a ploughshare and whetstones were discovered in the shipwreck hull[58]. It would be interesting to look into whether some of them were used for minor repairs by the ship's carpenter during the voyage.

Almost the same range of basic woodworking tools, apart from the axe, was used in the construction of the Ma'agan Mikhael hull[59]. As far as the discovered tools marks on the hull's surface are concerned, they provide evidence for the adze, saw, bow-drill, chisel, as well as carving knife and marker. Specifically, the use of more than one adze was identified with blade edge widths of 2-4 cm. These tool marks are slightly curved inwards, verifying that the blades were arched. Evidence of saw marks on the ship appeared on the sides of the keel, some of the planks, the tenons at the bottom of the mast step and ends of the beams. The marks on the strakes sawn from the wood core revealed the use of a pit-saw, while

43 Hom. Od. 5, 234-257. – Casson, Seamanship 217-219. – Casson, Odysseus' Boat. – Mark, Reappraisal. – Mark, Clarification. – Mark, Homeric Seafaring 25 f. 81-87. – Kamarinou, Determination.
44 Maragoudaki, Εργαλεία 325-344.
45 Hom. Od. 9, 382-388. 391; 5, 162-163.
46 Poll. Onomasticon 7, 113-114.
47 Ward, Egyptian Ships 29. – Wachsmann, Seamanship 236.
48 Ward, Egyptian Ships 29.
49 Ward, Egyptian Ships 29. 131-133.
50 Pulak, Uluburun Hull 629 f.
51 Pulak, Hull Construction 212.
52 Pulak, Uluburun Hull 629.
53 Pulak, Uluburun Hull 626.
54 Pulak, Joints 31 pl. 7, 1.
55 Pulak, Uluburun Hull 628.
56 Pulak, Hull Construction 218. – Pulak, Uluburun Hull 629.
57 Pulak, Uluburun Hull 628.
58 Pulak, Uluburun Shipwreck 208.
59 Udell, Woodworking Tools 212.

the marks on the tenons indicate the use of a small hand saw[60]. The drill was used to drill holes: a) into the knees – after triangular pilot holes had been cut by the chisels to direct the bit –, b) through planks and tenons for locking pegs and c) to bore holes in the planks and frames for the plug treenails and clenched iron nails. The bit used to drill the knee holes were of 0.6 cm and 0.9 cm for the holes for the tenon locking pegs. Drilled holes which traversed the planks and frames measured approx. 1.1 cm[61]. Moreover, the shipwrights of the Ma'agan Mikhael used the chisels to cut mortises into the vessel's planks, keel, wale, mast step and deck partners, into anchor parts and to make triangular mortises in the stern and stem knees. The triangular mortises with sides of 1.0-2.5 cm were made by using the chisel at a sharp angle and facilitated the drilling of the holes at oblique angles. It is also noteworthy that the mortises in the planks measuring 8.0 cm deep, 4.0 cm long and 0.6 cm wide required the shipwright to employ an extremely narrow blade of less than 0.6 cm[62]. Consequently, the shipwright used the chisel which had a cutting edge length equal to that of the narrow side of the mortise, probably saving time and energy. Imagine the time and the labour needed to cut over 4000 mortises; an estimate of 4080 made for the construction of this particular hull (24 strakes with c. 170 mortises per strake every 12-13 cm)[63]. Finally, the wooden pegs formation was done with a carving knife, while a kind of marker, probably an awl, was used to mark with the sign X the frame position[64].

Furthermore, the Kyrenia hull of the 4th century BC preserved traces of different tools used in its construction. Specifically, marks of the adze, chisel, saw and mallet were detected. Adze marks were identified across the seam created by the keel and the port garboard, as well as on the centre of the concave planking surfaces[65]. The adze was also used during repairs for smoothing the bottom of the keel, in order to receive the new false keel[66]. A fine toothed saw was used to cut the chamfered end to the keel at an angle of 140°[67]. Saw marks were detected in repaired points of the hull, such as the upper edge of post strake 2, as well as in the bottom part of the keel after the removal of the false keel[68]. Additionally, the stem post was scarfed to the keel by means of a short hooked scarf. Judging from the tool marks left on the scarf, cross-cuts were made with a fine saw, while tables and lips were finished off with chisels[69]. The chisel is the dominant tool for cutting mortises, especially those which served the plank jointing. In the Kyrenia hull the mortises were cut in two ways using a chisel alone or a chisel in combination with a drill. Specifically, the mortises of the outer planking appear to have been cut with mortising chisels alone, consequently

Fig. 10 De Meern 1 shipwreck, Utrecht: synthesis of woodworking tools found in the river barge De Meern 1: **a** adze-hammer fig. 852. – **b** single axe fig. 844. – **c** drill-bit fig. 849. – **d** axe-adze fig. 854. – **e** frame saw fig. 858. – **f** frame saw fig. 859. – **g** plane fig. 845. – **h** plane fig. 847. – (After Jansma/Morel, De Meern 1).

their bottoms were shaped irregularly. On the other hand, in the starboard ceiling planking, where the wood from another hull apparently was re-used for this use, holes were drilled to make the outer edges of the mortises[70]. As for the drill, it was used for making holes of 0.6 cm drilled about 2 cm from the keel's and planks' edges, as well as on the floor timbers, which were perforated for the garboard and stern knee[71]. Finally, the use of a mallet is indirectly detected on the heads of wooden pegs, which were subjected to impact with wooden mallets[72].

Tools and toolkits recovered from shipwrecks

Apart from the marks left on the hull's surface, it is fascinating to trace the existence of toolkits found in excavated shipwrecks and to correlate them with the ships' carpenters. The only well-known toolkit found in a shipwreck of a seagoing vessel comes from the Ma'agan Mikhael ship. The condition, location and typology of the tools suggest

60 Hadas More, pers. comm.
61 Udell, Woodworking Tools 206.
62 Udell, Woodworking Tools 204.
63 Udell, Woodworking Tools 204 with note 10.
64 Hadas More, pers. comm.
65 Steffy, Kyrenia Ship 87. 101.
66 Steffy, Kyrenia Ship 97.
67 Steffy, Kyrenia Ship 76.
68 Steffy, Kyrenia Ship 96 f.
69 Steffy, Kyrenia Ship 88.
70 Steffy, Kyrenia Ship 90 fig. 14.
71 Steffy, Kyrenia Ship 91. 93.
72 Steffy, Kyrenia Ship 88.

that they belong to the ship's carpenter or shipwright, and it could have been used for the maintenance and perhaps the construction of the vessel[73].

The tools recovered comprised five chisels (three socketed and two tanged handles), two possibly tanged awls, four bow-drill shafts (two of them with their naves), two mallets, a set square, a measuring stick (ruler), a whetstone (of emery originating from the island of Naxos) and a plumb-bob. They were all stored in a plaited grass basket[74]. While the collection is extensive, it appears to be incomplete, considering the tool marks found throughout the hull. Consequently, it is reasonable to assume that at least three additional, but basic tools should have been recovered from the vessel: the adze, saw and hammer[75]. It is noteworthy that, had the woodworking tools of the ships been found outside the context of an archaeologically excavated seagoing vessel, it is doubtful whether they could have been precisely dated or attributed as belonging to a shipwright[76].

Moreover, it is worth noticing a group of woodworking tools found in the river barge of De Meern 1 (**fig. 10a-h**) near Utrecht dating to AD 148[77]. Whether these tools belonged to the captain or constituted a shipwright's toolkit or that of an itinerant carpenter will probably never be known. A fully equipped toolkit of remarkably preserved wooden and metal parts was recovered. It contained four planes, four chisels, an axe, a bow-drill, two frame saws and two adze-hammers.

Another toolkit, more complete this time, was retrieved from the Yassı Ada 7th century shipwreck. The ship's carpenter stored his tools in a locker in the galley's forward partition wall[78]. These tools – twelve in number – comprised one adze, chisel and gouge, two drill-bits, a compass or dividers, two files, three nails and a bronze belt buckle that may have been used on a tool belt. Moreover, in another part of the vessel (sector 8A/B) agricultural together with the following woodworking tools were also retrieved: two axes, four adzes, five knives, two punches, a caulking-iron, five chisels, four hammers, a drill-bit, three files and two gouges. With these tools the carpenter was equipped with almost everything needed ranging from minor repairs to the construction of a new hull.

Additionally, except for the toolkits, some isolated examples of tools have been found in shipwrecks, the existence of which denotes that they were used by the carpenter of the ship or the shipwrights covering emergency needs during the journey. A wooden cylindrical mallet discovered in the Kyrenia shipwreck was probably used to adjust the lead sheathing for protecting the lower part of the ship, the false-keel, while pulling the ship out of the water[79]. Finally, a pair of carpenter's caliper gauges with one fixed and one movable jaw mounted on a straight wooden bar was recovered from the Giglio shipwreck off the coast of Tuscany dating back to the late 7th century BC. It is the only one to have survived from antiquity and was used to transfer measurements offering accurate scribing on a wooden surface[80]. It is worth noting that it looks much like its modern counterparts.

Traditional shipbuilding tools

From 16th century onwards whether private or state supported, the shipbuilder owned a fully or basically equipped toolkit which comprised the fundamental woodworking tool types. Dockyard records from the 16th to 18th century in England give valuable pieces of information concerning the shipwrights' social status, as well as details of their craft and its specializations[81]. Specifically, the English shipwright's toolkit of that period included all the known tool types used in shipbuilding, such as axe, adze, saw, chisel, hammer, maul, auger, gouges, caulking-iron and mallet[82]. However, this study for obvious reasons focuses on the traditional shipbuilding hand tools as recorded and used mostly during the 19th century onwards in the Aegean region.

The tools of the traditional shipbuilder can be divided into the following categories: a) measuring, b) cutting, c) perforating, d) percussion, e) grinding and f) caulking tools[83]. The basic measuring tools used were the ruler, tape measure (cord), plumb line, calipers or compass and the angle. The cutting tools comprise the saw, axe, adze and chisel. The single axe with a curved cutting edge was used to cut, split and shape the wood. For splitting a log across and along the grain, the cross-cut saw and the large frame saw were used respectively. For sawing wood of a smaller scale hand saws, ripping or cross-cut ones, or frame saws were used. The adze, the most basic and essential tool for a shipwright, was used for removing heavy waste, levelling, shaping or trimming the surfaces of timber (**fig. 11a-b**). On the iron/steel adze the cutting edge may be flat for smoothing work to very round for hollowing work. The long, U-shaped blade formed an angle of 65° to the haft assuring a smooth cut. A variety of shapes and handles made it one of the most versatile tools in the shipwright's hands for joining planks along or across the grain (chipping or chopping action).

Two basic types of chisels were used by the traditional shipwrights: a) the mortise and b) the paring chisel. The mortise chisel has a thick, rigid blade with a straight cutting edge and deep, slightly tapered sides for creating mortises and similar joints. It has the thickness to withstand levering out, the stout blade angle to resist damage, as well as the length to put leverage behind the levering out. The paring chisel has

73 Udell, Woodworking Tools 203 with note 4.
74 Udell, Woodworking Tools 203f. 213.
75 Udell, Woodworking Tools 204.
76 Udell, Woodworking Tools 213.
77 Mols, Review Ulrich 538f. fig. 1. – Jansma/Morel, Rijnaak.
78 Bass/Van Doorninck Jr., Yassı Ada 265. 314.
79 Swiny/Katzev, Kyrenia Shipwreck 351 fig. 11.
80 Bound, Calipers 99f. figs 11-22. – Ulrich, Roman Woodworking 52f. fig. 3, 44.
81 Dodds/Moore, Fighting Ship 39f.
82 Dodds/Moore, Fighting Ship 42f.
83 Damianides, Ναυπηγική, 115f. – Dervenis, Ξυλοναυπηγού 289f.

Fig. 11 Traditional shipbuilders: **a** the Greek traditional shipbuilder N. Daroukakis building a traditional wooden vessel. – **b** different types of adze from N. Daroukakis's shipyard. – **c** Arabian gulf traditional shipbuilder using a bow-drill. – **d** detail of the bow-drill. – (a-b after Maragoudaki, Ergaleia 86 fig. 29b; c-d after http://catnaps.org/islamic/boats.html).

a long blade ideal for cleaning grooves and accessing tight spaces. It is a light, long, thin, almost flexible chisel, which is never malleted. It is used primarily for carefully shaving off thin amounts of wood when fitting joints. The long length gives maximum control. One hand on the handle pushes the chisel forward while the other hand at the front of the blade guides the cutting action. A classic use is to dress the sides of a mortise after roughly chopping it square with a mortise chisel.

As far as the perforation tools are concerned, a great variety of drill-bit augers was used for drilling holes vertically or at an angle. The auger is a T-shaped bore with a twisted bit that can be turned continuously in one direction. Its dimensions could reach 2 m in length and more than 8 cm in diameter. A variety of bit geometry is discerned comprising twisted or fully spiral bits, as well as spoon-shaped bits with twisted ends. Sometimes a crank handle is used for types of shorter lengths. Although the bow-drill is not attested in the Aegean, its use is attested in traditional boat construction into the 20th century at the eastern part of the Mediterranean Basin (i. e. Jordan) (**fig. 11c-d**)[84]. This tool type was needed to produce the holes through which the nails are hammered to fix the planking to the ribs. A variety of drill-bits is recorded depend on the diameter of the hole needed. Moreover, the drill shank is not of great length as happens with the augers.

As for smoothing diverse planes were used to flatten, reduce the thickness of and impart a smooth surface to a rough piece of timber. They are used exclusively for cutting along the grain. The most popular types in shipbuilding are the grooving plane, used to cut grooves along the edge of a board for joining, and the rabbet plane, which cuts rabbets (rebates), i. e. shoulders or steps. The rabbet planes are used to produce horizontal, vertical or inclined flat surfaces, as well as curved surfaces such as plank bevelling, forming tenons or the final forming of hull planking for frame adjustment. Larger planes of this type are recorded up to 70 cm in length.

Rasps constitute another category of scraping tools for rapidly removing wood from curved surfaces, as well as for shaping wood. There are half round, round and flat rasps. Rasps scrape away wood and are well suited to shaping wood quickly. The size and distribution of teeth determine a rasp's degree of coarseness and the amount of wood it can remove. Generally, they cut rapidly, though leaving a rough surface. Traditional shipbuilders used metal hammers and mallets.

84 Gulf Traditional Boats.

Fig. 12 Mycenaean shipwright reconstructed tool kit. – (Maragoudaki/Kavvouras, Tool Kit 206 fig. 4).

The metal hammers are used for driving metal pegs into the wood. The usually oaken mallets give a softened strike with a positive drive and are used to knock wooden pieces together without deforming or to work in chisels, wooden pegs and dowels. A whetstone is always useful for sharpening tool blades. Made of emery it was usually encased in a wooden frame. Lubricants such as oil facilitate the sharpening, creating at the same time greater thinness to the cutting edge.

Finally, there are the caulking tools consisting of caulking mallets of different dimensions, as well as caulking-irons of different cutting edge width and bevel, with the help of which fibres are driven into the wedge-shaped seams between the planks assuring the hull becomes watertight.

Mycenaean shipwright toolkit: an experimental approach

The aforementioned evidence constitutes a well-structured basis for an enlightening approach concerning shipbuilding tools through the ages. Nevertheless, it seems to be incomplete, since the tool evaluation is based on typological and morphological criteria. Consequently, the identification of discovered metal implements as woodworking tools and their use-based classification constitute an extremely difficult task to perform. Part of this research gap was filled by the recently developed study concerning the reconstruction and evaluation of the Mycenaean shipwright toolkit[85].

Questions of utility and efficiency of the woodworking toolkit used in shipbuilding can be answered on the basis of archaeological evidence through experimental methods, which include a reconstruction of the finds, i. e. casting, elaboration of metallic parts and reconstruction of the hafts, as well as their use and evaluation (qualitative, quantitative and ergonomic) through the reconstruction of a section of the Uluburun shipwreck hull. Following the aforementioned methodological approach the knowledge of Late Bronze Age tool production has been furthered. The toolkit of the Mycenaean shipwright is proved to consist of cutting tools (axe, adze, chisel and saw), percussion tools (mallet and hammer) and perforation tools (bow-drill and awl) (**fig. 12**).

The reconstructed tools appear suitable for use in pegged mortise-and-tenon joinery in shipbuilding by skilled woodworkers. Functional differences between the tools were shown

85 Maragoudaki, Εργαλεία.

and questions on utility were answered. The Late Bronze Age shipwright, as a master of his craft and tool use, could make new tools or adjust them to the demands of a particular job, as well as to his own body build. The range of tools used for shipbuilding in the Late Bronze period, although subjected to the restrictions of the construction of the raw materials (made of bronze, heavy enough, frequent resharpening etc.), is equally effective and comparable to the hand tools used today in traditional shipbuilding[86].

Relating tool types to shipbuilding techniques

Having in mind the aforementioned evidence, it is nonetheless difficult to relate tool types to specific shipbuilding techniques. Only some interesting remarks can be made emanating from archaeological evidence, as well as ethno-archaeological parallels. Specifically, as far as the Egyptian evidence is concerned, it is noteworthy that some building tradition seen in riverine craft is adapted for open-sea conditions: i. e. cedar hull planks are much sturdier as far as the thickness is concerned and much more solid by doubling the mortise-and-tenon joints than those on riverine vessels[87]. Furthermore, ship timbers discovered along Egypt's Red Sea coast testify not only to the viability of Egyptian riverine construction, with some modification, for seagoing vessels, but also to different constructional methods that suggest possible diffusion of technology between Egypt and the Aegean or Levant[88]. The tool types used for both types of vessels were undoubtedly the same and they were used in the construction of different kind of vessels, as the iconographic and archaeological evidence reveal.

Generally, the change in shipbuilding techniques is rather slow and the adoption of new techniques does not exclusively mean the abandonment of older ones. The discovery of mixed techniques on the same vessel or on contemporary ships of the same or different geographic regions denotes experimentation, as well as the shipbuilders' conservatism. Holding in their hands the same tools or making the proper adjustments related to their form and dimensions, these practitioners became proficient at constructing elegant, sturdy and capable boats and ships well-suited to their environments and intended purposes.

Specifically, construction evidence from Greek shipwrecks spanning the late 6th, 5th and 4th century BC (Jules Verne 7, César 1, Grand Ribeau F, Gela 2 and Ma'agan Mikhael) indicates that a major technological shift occurred in Greek shipbuilding that transformed the Archaic laced construction into the so-called Graeco-Roman building tradition[89]. The choice of the joinery was the product of how the shipwright conceived and approached the hull construction, as well as of cultural factors and not of the specific tool types the craftsmen had at their disposition. Both constructional techniques could not have been realized by different shipbuilding tools.

Moreover, the use of the basic woodworking tools (adze, chisel-mallet, saw and drill) in hull construction is attested on the surfaces of the Uluburun, Kyrenia and Ma'agan Mikhael hulls, even though they were constructed a thousand years apart. It is obvious that some tools were used for tasks different to those for which they were initially intended at the earlier stages of ship construction. For instance, the bow-drill was used for opening holes for the insertion of wooden pegs on the Uluburun hull[90], as well as on the Kyrenia hull, but also for creating mortises[91], while in the Giglio, Bon Porté and Jules Verne 9 shipwrecks it was used for plank fastening with round dowels. Furthermore, for the lacing system of the Archaic period the shipwrights first used a chisel to cut small tetrahedral notches and using them as guides drilled small angled holes from their base through the thickness of the plank to the outside corner of the seam edge. Consequently, chisels and bow-drills of different dimensions were used for both types of construction.

Specifically, it is not known in laced technique what kind of perforating tool was used for rendering angled holes from the base of each notch through the thickness of the plank to the outside corner of the seam edge. Although the use of the auger is not attested before the Roman period, it is worth noting that the use of the bow-drill for producing holes at an angle is, if not impossible, rather laborious. The use of the bow-drill is attested in shipbuilding until the Roman period, as the De Meern 1 shipwreck toolkit reveals, but its use seems to decrease in favour of the auger during the Byzantine and Medieval period, as witnessed by the iconography of the period[92]. Nevertheless, the bow-drill seems to be included in the traditional shipbuilder toolkit till the late 1960s in the Mediterranean region[93].

Furthermore, the adze constitutes one of the most versatile tools in the shipwrights' hands all through the Bronze Age, as well as during the 1st millennium BC. Bound differently to the handle, the adze blade was used as a plane until the Roman period, when the traditional wooden frame was invented[94]. Undoubtedly, a skilled shipwright would use the adze as a plane for smoothing surfaces prior to the Roman period during which there is evidence of its use in ship construction[95]. However, the Latin term »runcina« derived from the Greek »rhykane« indicates an earlier existence of this elegant cutting tool in woodworking and furniture making[96].

86 Maragoudaki/Kavvouras, Tool Kit 199-208.
87 Polzer, Early Shipbuilding 359.
88 Polzer, Early Shipbuilding 360.
89 Polzer, Early Shipbuilding 366.
90 Pulak, Hull Construction 629.
91 Steffy, Kyrenia Ship 90 fig. 14.
92 Martin, Venetian Ships 112 f. fig. 98.
93 Gulf Traditional Boats. – Damianides, Ναυπηγική 123 f. figs 144-146. – Dervenis, Ξυλοναυπηγού 291.
94 Maragoudaki, Εργαλεία 334 f. – Ulrich, Roman Woodworking 41-45.
95 Mols, Review Ulrich 538 f. fig. 1. – Jansma/Morel, Rijnaak.
96 Ulrich, Roman Woodworking 41.

Another factor that influences the use of certain tool types, as well as of certain techniques, is the shipbuilder's propensity to adapt. Shipwrights generally operate rather conservatively. It is true that they should invest considerable time in mastering new techniques, such as different types of joinery, as well as the latest tools. We must understand that ancient shipwrights spent their lives mastering their crafts. A drastic change would require shipwrights to have a very strong incentive, because they needed not only to learn new techniques, but also to adopt a new philosophy of construction[97]. At the same time, not only did they have to transform their tools to the required standards of the new constructional techniques, but also to adjust their tools to the demands of particular tasks and their own body build. Of course, the politico-economic demands, as well as the working conditions in which the shipwright works (i. e. private or state supported shipyards, production rhythm etc.) also play a substantial role in a shipbuilder's adaptation to new perspectives and techniques. Undoubtedly, to change from one technique to another would have necessitated improved skills and increased abilities concerning woodworking, as well as suitable and improved technical equipment.

Conclusions – further research

In conclusion, the basic types of woodworking tools used in wooden shipbuilding have continued almost the same without fundamental changes. Tool evolution is due to the material and techniques used, as well as to socio-cultural influences. It is true that the use of iron as a raw material for tool construction gave the metallurgist the chance to produce more sophisticated tools that could cover the needs of even the most demanding craftsmen. The tools became finer and lighter, stronger and more durable, while their cutting accuracy, as well as quantitative, qualitative and ergonomic efficiency was improved. Concerning their forms, they are subjected to the constructional demands derived from the techniques used and the personal needs of the shipwrights, as well as by cultural influence, such as local traditions.

Taking into consideration the evaluation of the reconstructed woodworking tools of the Mycenaean na-u-do-mo, as well as the aforementioned evidence, some interesting remarks could be made. By examining each tool type separately, it is remarkable that the single axe evolved, as far as hafting and blade shape are concerned, as a result of the change of the metal used, energy consumption reasons, specialization related to the demanding tasks, as well as influence of local metallurgical traditions. The adze remained the most essential tool in the shipwright's hand, whatever technique was used. It was transformed to a more versatile one acquiring a different hafting (from a flat blade to one with a hole for fixing a handle) and a blade inclination related to the demands of different tasks (i. e. chopping and chipping action). As for smoothing, the adze was replaced during the Roman period by the plane. Basically, it is the same flat adze blade which was enclosed in a wooden frame. A variety of planes is attested from the Roman period onwards in shipbuilding, as well as in woodworking employing blades of different cutting angles and cutting edges for diverse tasks. As for the saw, the simpler types such as hand saws remained similar as far as the shape is concerned, but changed with regards to the material used and the blade constructional geometry. The band saw was boxed in frames of different sizes and a teeth-set variety was invented and applied according to different constructional demands (cross-cutting, ripping, flush-cutting saws etc.).

The chisel preserved almost the same form, a metallic shank inserted into the haft, but the cutting edge acquired the desired form depending on the intended use. Iron ensured better cutting accuracy, stouter shanks, less resharpenings and generally more durability. As for the caulking chisels, they constitute a sophisticated type related to caulking work, possibly resulting from the change of shipbuilding technique from shell first to skeleton first. The mallet was subjected to formal changes. It is an object made by the shipwrights themselves using wood found in their vicinity. The shape was determined by the respective constructional demands. As for the bow-drill, its presence seems to be continuous through the ages till the 1960s, but the adoption of the auger in combination with iron nails related to changes of technique and resulted at times in the downgrading of its use in larger-scale constructions.

Ultimately, regarding the evolution of nautical technology, as well as the availability of raw materials, it seems plausible that the range of tools used in wooden shipbuilding is generally comparable in all periods without radical changes and adaptable to different needs, materials, techniques and cultural environments. This freedom in use in combination with craftsmanship makes the humble shipbuilder the absolute master of his craft and tool use.

For filling gaps in our knowledge, further research is necessary on tool specialization related to constructional techniques used, social structures and local traditions, in order better to understand the internal social processes that influence tool evolution. Further reconstruction and experimentation concerning raw materials, tool types, as well as woodworking techniques applied in shipbuilding would provide more efficient criteria for a use-based classification and, consequently, accurate identification of the tools. Moreover, the study and correlation of tool alloys and use could extrapolate data concerning the cost and time needed for ship construction, as well as tool specialization and technological know-how interaction.

97 Mark, Homeric Seafaring 61 f.

Finally, a fundamental study of shipbuilding tool evolution and specialization through time in the Mediterranean Basin could trace the convergences or divergences of cultural entities with common geographic characteristics, as far as shipbuilding technology is concerned.

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Zusammenfassung / Summary

Werkzeuge des Schiffbaus von den Schiffbauern der Bronzezeit bis zu traditionellen Schiffbauern: eine Suche nach Zeugnissen im Mittelmeerraum

Die vorliegende Studie verfolgt die Präsenz von Werkzeugen des Schiffbaus durch die Epochen und erkennt Veränderungen, denen sie ausgesetzt sind, wann und warum. Das Ziel wurde entwickelt durch Erfassung, Überprüfung und Klassifikation der zur Verfügung stehenden archäologischen und ethno-archäologischen Quellen. Darüber hinaus helfen experimentelle Methoden wie die Rekonstruktion der Werkzeuge und ein partieller Nachbau von Rümpfen bei der Ermittlung hinlänglicher Kriterien für das Verständnis des Werkzeuggebrauchs (Brauchbarkeit, funktionale Unterschiede). Durch den zuvor beschriebenen Prozess konnte belegt werden, dass sich die Werkzeuge zur Holzverarbeitung, wie sie im Schiffbau verwendet werden, überwiegend ohne fundamentale Veränderungen erhalten haben, während die Entwicklung der Werkzeuge durch Material, genutzte Techniken sowie soziokulturelle Einflüsse bedingt wurde.

Übersetzung: Th. Schmidts

Shipbuilding Tools from the Bronze Age Shipbuilder to the Traditional Shipwright: Tracing the Evidence in the Mediterranean Basin

The present study traces the presence of shipbuilding tools through time and discerns the changes to which they were subjected, when and why. The aim set was developed through the recording, re-examination and classification of the available archaeological and ethno-archaeological evidence. Moreover, experimental methods like tool reconstruction and partial hull rebuilding proved useful in the allocation of sufficient criteria for understanding the use of a tool (utility, functional differences). Through the aforementioned process it could be proven that the types of woodworking tools used in shipbuilding have persisted largely without fundamental changes, while the tool evolution is due to the material and techniques used, as well as to socio-cultural influences.