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Comparative Analysis of Lifting from On-Site and Conservation of the Yenikapı Shipwrecks

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Abstract: The important commercial center of Constantinople's Theodosian Harbor was brought to light during the Yenikapı excavations carried out by the Istanbul Archaeological Museums for nine years, starting in 2004. Hundreds of thousands of archaeological finds and the remains of thirty-seven ships sunk in different centuries were discovered at the harbor site. Upon the invitation of the Istanbul Archaeological Museums, Istanbul University undertook the removal, documentation, and construction technology studies of twenty-seven shipwrecks and the conservation work of 31 shipwrecks. Shipwrecks were documented in situ and removed from the site using various methods appropriate to their preserved conditions. Post-excavation documentation, technology research, and conservation procedures of the Yenikapı shipwrecks continue today. This article aims to present a collective evaluation of the lifting and conservation methodology of shipwrecks carried out by the Division of Conservation of Marine Archaeological Objects of Istanbul University. In this context, the relationship between removing ship remains from the excavation site and conservation practices has been analyzed comparatively by referring to display styles.

Keywords: boat and ship archaeology; conservation; lifting shipwrecks; Theodosian Harbor; Yenikapı shipwrecks; waterlogged wood

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1. Introduction

Istanbul Archaeological Museums conducted an archaeological salvage excavation project between 2004 and 2013 at Üsküdar, Sirkeci, and Yenikapı districts, where the main stations of Marmaray and the Metro railway hub were constructed (Figure 1). In the Yenikapı Site, Theodosian Harbor (*Portus Theodosiacus*), one of the most important harbors of Constantinople during the early Byzantine period, was revealed. Named after Byzantine emperor Theodosius I, the harbor was established at the mouth of the Lykos stream and is included in Region XII of the city. Although there are doubts regarding the harbors' precise location due to an earlier harbor in the same area, it is commonly accepted that the earlier Eleutherios Harbour, which dates back to the Constantine I period, was the predecessor to the Theodosian Harbor. The harbor was also referred to as Kaisarios Harbor in the sources from the 6th to the 9th centuries [1] (p. 14). Yenikapı excavations support this idea on the basis of earlier remains and artifacts uncovered at the west end of the site [2]. Furthermore, according to the textual evidence, the presence of two granaries on the east of the harbor, *Horrea Alexandrina* and *Horrea Theodosiana*, indicates that it was a commercial harbor, particularly receiving ships loaded with mass cargoes of grain from Alexandria. It is known that the grain trade was active until the Arabic conquest of Egypt in 641 AD. In addition to the grain trade, construction materials such as marble from Proconnesos, tiles, bricks, timbers, and other food supplies were brought to Theodosian Harbor to answer the growing demands of Constantinople [3] (p. 18). After this active period, the harbor lost a significant part of its function due to the shrinking of the borders of the Empire and the decrease in sea power. However, at the beginning of the 9th century

AD, the harbor had revived due to the investments made in the port and maritime trade and the shift of trade routes from the Eastern Mediterranean to the Aegean Islands and the Black Sea, and it was used until the 11th century AD [2,4,5]. The activities shifted eastward when the western part of the harbor became inutile due to the silting up by sediments constantly carried by the Lycus Stream. The ongoing silting filled the port from the north southward [6]. In this way, throughout this long period, different portions of the Theodosian Harbor, which was active for centuries, were used. This change in the use of the harbor can be traced by thousands of artifacts that shed new light on the daily life, religion, trade, and technology of the period, as well as the different dating and construction techniques of the shipwrecks that have been scattered around the excavation site. Among the findings, 37 shipwrecks constituted the most extensive medieval shipwreck collection ever found at a single site (Figure 2). The shipwrecks, which were sunk at different times between the 5th and 11th centuries, at the harbor deposit layers, are of great importance in studies on Byzantine ship typology, boat and ship archaeology, shipbuilding technology, and maritime history. Scientific studies on the shipwrecks were undertaken by the Istanbul University (27 wrecks), the Institute of Nautical Archaeology (8 wrecks), and the Istanbul Archaeology Museums (2 wrecks). Studies on Theodosian Harbour and some Yenikapı shipwrecks were published before [7–21]. Istanbul University's Department of Conservation of Marine Archaeological Objects studies are conducted by Prof. Dr. Ufuk Kocabaş. The in situ documentation and removal of 27 shipwrecks from the field was completed in 2013. Dismantled ship timbers have been kept in freshwater tanks in the IU Yenikapı Shipwrecks Project Application and Research Laboratory. Following the removal of ships, the work continues with the detailed examination via 1:1 scale digitizer drawings, digital reconstructions, and conservation procedures of waterlogged ship timbers [22,23]. This article focuses on the different methods used to remove the Yenikapı ships and the conservation process of the shipwrecks' timbers as studied by the Istanbul University team.

Figure 1. Yenikapı excavation site. © Bekir Köşker.

Figure 2. Location of the shipwrecks at the site. © Yenikapı Shipwrecks Project (YSP) Archive.

2. Yenikapı Shipwrecks

Six of the 37 shipwrecks discovered at the Yenikapı site have been classified as galleys, and 31 as merchantmen [11,12]. Istanbul University has studied the construction techniques of twenty-three merchantmen and four galleys. The galleys have a unique value as the archaeological samples dating to the Byzantine period were found in Yenikapı for the first time (Figure 3). Yenikapı galleys, mentioned as galea in the Byzantine texts, were scout ships with a single file of oars on each side, up to 30 m in length and 4 m in width. The merchantmen of Yenikapı were of various sizes and features, from 7 m small boats to seagoing vessels with original lengths of up to 30 m (Figure 4). The merchantmen were classified into three groups based on their hull planking joints: vessels with pegged or unpegged mortise-and-tenon joinery, vessels with planking edge dowels, and vessels without any edge fasteners. The hull types consist of flat-floored, wine-glass-shaped, or in-between cross-sections. The boats and ships were classified by size as small, medium, and large vessels [11] (pp. 10–11). Preliminary analyses showed that small vessels vary from 7 to 12 m in length and are flat-floored amidships. Their planking strakes were fastened with edge-dowels except for one. These vessels were likely used for coastal seafaring or fishing over very short distances. The vessels, which vary from 12 to 19 m in length, are flat-floored with hollow garboards or slightly wine-glass-shaped. They are characterized by high load capacity, strong framing, and internal reinforcements such as sternson and stringers. The large vessels, with a length up to 40 m, have wine-glass-shaped cross sections; their hull planking was fastened with unpegged mortise-and-tenon joints. These two latter groups were probably seagoing vessels. Yenikapı vessels have three types of edge joinery: mortise-and-tenon, edge-dowels, and non-edge fasteners [15] (pp. 380–381).

Figure 3. The galley YK16. © YSP Archive.

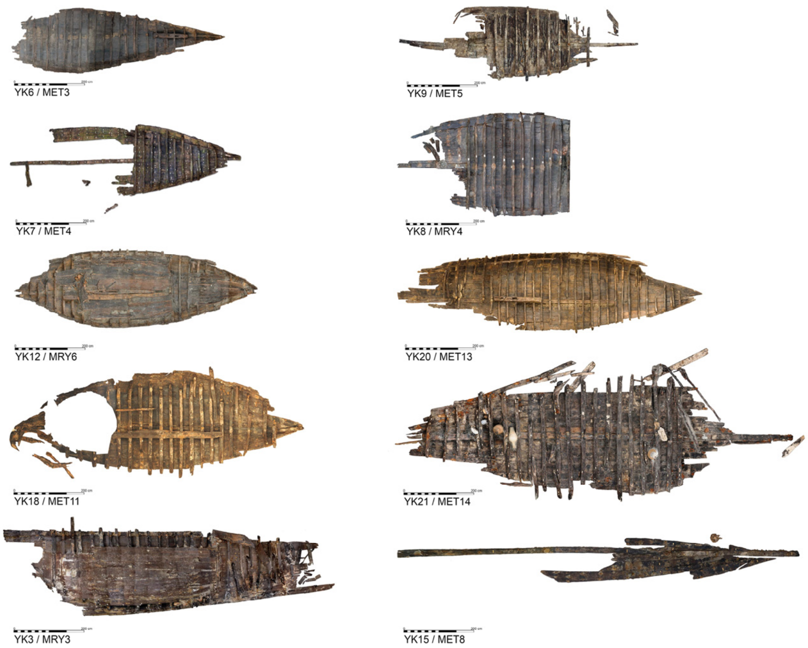

Figure 4. Yenikapı merchantmen. © YSP Archive.

The ship hulls endued with different construction features and various wood species can be considered one of the critical findings that show the commercial networks of the Theodisian Harbor with varying regions in particular centuries. However, the information on the origins of the shipwrecks is limited. By aiming to learn the geographical regions where the ships were built, around 2500 wood samples taken from the shipwrecks have been analyzed at Istanbul University's Forestry Faculty. According to the results, the vessels dating between the 8th and 11th centuries AD were made of walnut, oak, pine, chestnut, ash, beech, and hornbeam trees, which are common in the western and northern Anatolian regions. Furthermore, the timbers of the ships dating 5th–8th centuries were made of pine, cypress, cedar, fir, and elm trees, which are common in the Aegean-Mediterranean areas [24] (pp. 197–198).

3. Lifting the Shipwrecks

The shipwrecks were documented and removed from the site by the protocols and agreements between Istanbul Archaeological Museums and Istanbul University. The documentation was realized by labeling, drawing in situ (manual triangulation and Total Station®® measurements, AutoCAD®®, and handmade sketches), full-scale acetate drawings, photo-mosaic images, photographs, video shoots, and field notes. [25]. The hull remains of Yenikapı shipwrecks were intact, and the wooden elements were found connected to each other in their original places. Therefore, the primary purpose of in situ documentation was to record the volumetric completeness of the hull, the relationship among the members, the structural features, and the dimensions of the wooden members. Documentation work continued during the removal of the hull members.

Yenikapı shipwrecks were removed by dismantling, except for the partial mass removal applied to the shipwreck (YK6). The main reason for dismantling was the likelihood of discovering other archaeological artifacts beneath the shipwreck within the harbor deposit and the risk of damaging these artifacts during lifting as a single mass. Another reason was to facilitate the conservation procedures that would be carried out in later stages. Thanks to the dismantling, the fasteners, scarfs, and form of the timbers, which cannot be seen due to the upper elements, were photographed, measured, and drawn. It is of particular importance that the wooden components of the hull are transferred to the laboratory without any damage in their original forms to improve the accuracy of the outcomes achieved in conservation, restoration, and reconstruction procedures. Therefore, during the dismantling of the shipwrecks, broken wooden fragments were connected with steel wires and labeled, reinforcing each one of the members (Figure 5). Dismantling and lifting were carried out using methods developed according to the formal characteristics and degree of preservation of the timbers [23,26]. During the works, the ceiling planks were usually removed first, followed by the mast-step timbers, frames, wales, hull planks, and final keel timbers (Figure 6). The iron and wooden fasteners connecting the timbers were carefully cut at the beginning of the dismantling phase. During the process, scroll saw blades or chisels were used, which were placed between the two elements and moved between the plastic spacer plates that prevent the wood surface from being damaged. Each wooden element removed was placed into a crate. Brass nails and galvanized screws were used to join the woods of chests, which were designed to be placed one on the other. Chests were labeled, indicating the shipwreck's name and the relevant ship timber's name and number. The hull timbers were bound to the carrier molds with buckram bands, and their carriers were supported by wedges and fixed to the crates so that the water in the storage tanks was not affected by the buoyancy force. Following the dismantling and lifting procedures, the ship's timbers in the crates were carried into tanks for wet storage and desalination.

Figure 5. Fixing with steel wires on planks. © YSP Archive.

Figure 6. Dismantling process of shipwreck YK35′s timbers. © YSP Archive.

3.1. Ceiling Planks

The ceiling planks were preserved in only a few Yenikapı shipwrecks. Depending on their conditions, the ceiling planks were lifted by supporting them from their inner and outer surfaces with epoxy sheets or from their exterior surfaces with L-shaped wooden profiles.

3.1.1. Epoxy Sheet Method

Epoxy sheets are used in highly deteriorated, thinned, and non-self-supporting wooden elements (Figure 7). In this method developed by Prof. Ufuk Kocabaş, a thin layer of aluminum foil was placed on the timbers to prevent the epoxy from smearing on the surface of the timbers was coated first [22] (pp. 86–88). Furthermore, a rapid-setting hardener, Araldite®® FC 52, was prepared, applied to the aluminum foil, and supported by fiber textile. Following a polymerization period of 8 to 10 min, a thin framework of wood laths was placed into the epoxy mold, which took the shape of the timber. This mold was then seated on the ceiling plank, and the carrier construction and the ceiling plank were tied with skinny synthetic textile belts. Finally, the ceiling planks were lifted by preserving their forms entirely by using this method. Despite the high cost and the need for specialized personnel to work, this method has been determined to provide excellent protection for the removal of sensitive wood.

Figure 7. Lifting of YK12 ceiling with the epoxy sheet method. © YSP Archive.

3.1.2. External Support Method

The ceiling planks of shipwreck YK3 were lifted with supports placed on the outer surface of the timbers [22] (pp. 82–85) (Figure 8). Initially, 5 × 10 cm timbers cut in appropriate length and width were assembled at a 90-degree angle using galvanized screws to form "L" shaped wooden profiles. A polyethylene foam layer was stapled into the inner surfaces of the carriers to prevent damage to the original timber. Next, the deposits under the ceiling plank were removed with water, and "L" carriers were placed in the spaces between the floor timbers. This way, the ceiling planks were supported from their lower surface. Furthermore, "L" carriers were fixed to a long wooden board. Finally, each ceiling plank was lifted and placed in its crate.

Figure 8. Lifting of YK3 ceiling with the external support method. © YSP Archive.

3.2. Frames

The metal cores of the iron nails used to fasten the frames to the planks were not preserved. However, the nails still preserved specific mechanical strength thanks to the concretion formed on their outer surface. Twisting the floor timbers and the futtocks lightly to the left, then to the right a few times was sufficient to break loose the corroded part from the planks. For nails that could not be detached by this method, the iron nail corrosion was broken with a thin spatula, while the treenails were cut controlled using a fretsaw. Preserved status, shape, and dimensions of the frames were decisive in the selection of the lifting method. In good condition, frame members were slowly and carefully manually lifted and placed on the custom-made wooden stretchers. After the completion of relevant documentation, the frames were placed into wooden chests built to their size. The double plate packing method was applied in frames with a high deterioration rate [22] (pp. 91–92).

Double Plate Packing

For this method, a large-scale profile gauge was manufactured from aluminum to particular dimensions (Figure 9). With this gauge, the curve on the inner surface of each frame was copied. In this way, templates were prepared according to the shape of each frame to be removed. The frame shape in the templates was drawn on 10 mm thick water plywood. Furthermore, the relevant floor timber was compressed with these plywood sheets placed on both sides and lifted with preserved shape (Figure 10).

Figure 9. Usage of profile gauge at the shipwreck YK3. © YSP Archive.

Figure 10. Lifting of a floor timber with the double plate packing. © YSP Archive.

3.3. Planks, Wales, and Mast-Step Timbers

Two different methods were used to remove the planks. These were created by using the supports from the inner or outer surfaces of the planks. According to the results of lifting studies, it has been understood that the "internal support method" takes more labor and time than the "external support method", and it is more practical to support from the outer surface. Similarly, post-excavation documentation studies on timbers from supporting outer surfaces with L profiles were made easier.

3.3.1. Internal Support Method

This method aimed to remove the planks while preserving their original shape by copying the inner surface forms of the planks and creating their molds (Figure 11). The internal support method was carried out on the shipwreck YK6, which was first removed from the excavation area [26] (pp. 307–308). First, a template drawing was created by measuring the plank's length, width, and slope. According to this template, a carrier timber along the direction of the length of the hull plank and intermediate supports fixed perpendicularly to it, spaced 30 cm apart, were prepared. The length of each intermediate support was determined according to its position and the distance from the hull plank to the carrier board. In this way, carrier support suitable for the slope of each plank, which gives the hull form, has been made. Thin boards of 8 mm thickness and 12 cm width were attached to this supporting construction, and a mold suitable for the slope of each plank was formed. Styrofoam plates were placed between this mold and the original plank during assembly. The mold and original plank were fixed with "U"-shaped clamps made of Styrofoam. The Styrofoam clamps, which were placed between 25 cm and 50 cm depending on the deterioration of the wood, were removed after the plank was rotated and lifted from its place.

Figure 11. Lifting of a plank with the internal support at the shipwreck YK6. © YSP Archive.

3.3.2. External Support Method

In this method, the planks were lifted with supports placed on the outer surface of the hull [22] (pp. 82–85) (Figure 12). L-shaped carriers were prepared as described in the lifting of the ceiling planks. Since the hull planks were in direct contact with the ground and were larger in size, the application was developed accordingly. The sand and sediment underneath the plank to be lifted were moved away with water, and the L-shaped carriers were placed periodically on the outer surface of the plank. The carriers aligned up and down according to the curve of the plank and were fastened to a wooden beam. Finally, each hull plank was lifted, retaining its integrity and original curvature, and placed into custom-made crates. Wales and mast-step timbers were also lifted using the same method.

Figure 12. Lifting stages of a plank with the external support method. © YSP Archive.

3.4. Keel

Wooden Stretchers Method

The keels, which are long and heavy pieces, survived, often unable to bear their own weight. For this reason, the keels were lifted from the area with wooden stretchers. The keel timbers were first freed during the lifting by cleaning the sand layer around and below them. Furthermore, they were supported on one side with a wooden plate prepared according to their lengths and shapes and laid on the stretchers. They were lifted this way and placed in their crates with stretchers.

3.5. Partial Mass Removal

This method was applied for the keel and the three planking strakes on each side of shipwreck YK6 [22] (pp. 88–91). The practices, carried out with the participation of archaeologist Yüksel Dede, started with excavating around the existing hull 1 m wide and 1 m deep. A wooden skeleton with a section of 10 × 10 cm was constituted around the excavated shipwreck. Furthermore, starting from the bow of the vessel, the sand underneath was cleaned in 25 cm sections. The lower and upper forms of the opened part of the hull were copied in a 1:1 ratio with a large-scale profile gauge and drawn on 5 cm of dense styrofoam. Next, styrofoam supports cut with a jigsaw were placed in the gaps under the hull and fixed to the wooden construction. Later, the inner bottom of the hull was supported with styrofoam plates prepared with the same methods (Figure 13). Finally, struts and cross supports were placed on the sides to increase the load-bearing structure of the construction. This way, the hull bottom of the YK6 was lifted as a mass and transported to the tank.

Figure 13. Lifting with the partial mass method of hull bottom of shipwreck YK6. © YSP Archive.

4. Conservation Process

Yenikapı shipwrecks were relatively well preserved in a thick layer of sediment and alluvium that formed due to rapid burial. However, regardless of their fair condition, it is unlikely to store or display any waterlogged ship timber in the museum without conservation and restoration procedures. The biological activity inevitably has caused different levels of degradation on the cell structure of timbers for centuries, even preserved by the heavy mud on them. The conservation procedure was begun immediately as the shipwrecks were brought to daylight [11] (p. 9). The primary works focused on preventive conservation in the excavation site to avoid cracks and shrinkage on waterlogged timbers due to drying out. The excavations started with constructing a temporary tent to shield the shipwreck from external ambient conditions such as sunlight and winds. A water-spray system was installed inside the tent to create an environment of 100% relative humidity and keep the timbers wet for 24 h. During the work on the wrecks, the sprinkler system was operated regularly to prevent the wood from drying out. After the excavation, the timbers were preserved in freshwater tanks constructed of stainless steel and concrete at the Istanbul University Yenikapı Shipwrecks Project Application and Research Laboratory (Figure 14). Desalination and impregnation carried out within the scope of conservation were usually carried out in stainless steel tanks due to their high corrosion resistance [27] (p. 191). One of the biggest problems encountered in the desalination and impregnation of organic artifacts in countries with a temperate climate, such as Turkey, was the activity of fungi and bacteria in shipwreck tanks. To inhibit biological activity during desalination, Acticide SPX (5-chloro-2-methyl-4-iso-thiazolin-3-one and 2-methyl-2H-isothiazol-3-one) liquid biocide was added to the tank at a ratio of 1/1000 [28].

Figure 14. The storage tanks at the IU Yenikapı Shipwrecks Project Application and Research Laboratory. © YSP Archive.

The most crucial stage of the conservation procedure is the impregnation of chemicals into the cell structure of the wood. By this technique, chemical material penetrates into the cells, replaces water in the cell structure, and provides mechanical strength. After the process, the wood is dried in a controlled manner and taken under protection in a suitable environment. Two conservation methods are used in the IU Yenikapı shipwrecks project. Polyethylene glycol (PEG) impregnation and vacuum freeze-drying are the main methods [29,30]. Reversible, water-soluble, and usable for large-sized timbers, the savings of approximately 50% in PEG when a vacuum freeze-drying device is used, the color of the treated woods being close to natural, rates of less shrinkage and twisting after conservation, and the ability to shape timbers before and after drying are reasons to choose this method. The method uses PEG with different molecular weights of 400, 2000, 3350, and 4000, determined according to the density and maximum water content values of the wood. For example, impregnation begins at a 5% concentration to minimize the occurrence of osmotic collapse in wood using PEG 2000. Although the application in which PEG of a single molecular weight is impregnated is mainly preferred, applications in which PEG of different molecular weights are mixed and impregnated are also carried out on woods with varying density values. Scanning Electron Microscopy (SEM) and Fourier Transform Infrared Spectroscopy (FTIR) analyses are performed by taking samples from the wood (via drilling with an increment borer for FTIR and dicing with a craft knife for SEM) during the impregnation process to detect the distribution of the chemical and its presence in the wood [20] (pp. 38–42). Before PEG impregnation, iron compounds in wood are cleaned to eliminate the corrosive effect of PEG on metals and to prevent post-drying iron sulfide oxidation in wood. For this, iron nails and corrosion in timbers are removed mechanically. In addition, iron compounds are removed by buffering with a 5% disodium EDTA and 5% oxalic acid (w/v) solution, and then the timbers are soaked in distilled water. After PEG impregnation, the wood is subjected to vacuum freeze-drying. The procedure that takes place according to the sublimation principle; consists of freezing, freeze-drying, and returning the wood to ambient conditions [20] (pp. 43–45). The other method is melamine formaldehyde (Kauramin®® 800). The melamine formaldehyde method has disadvantages such as being irreversible, having harmful effects on human health, whitening the color of the treated wood, being unbecoming to the shaping of timber after conservation, and having an unstable curing time. However, due to the impregnation and drying being completed in a short period of 3–6 months, depending on the thickness of the wood, we have been used in timbers with high deterioration, dispersed, and highly fractured timbers that other methods cannot salvage. The timbers of two shipwrecks (YK26 and YK36) and some hull timbers of four shipwrecks (YK3, YK8, YK9, and YK16) are treated with this method. Based on the polymerization principle of the melamine formaldehyde method, the wood is impregnated by dipping and drying by heating in the oven [31,32]. Low molecular weight (400–700 g/mol) melamine formaldehyde prepolymer is dissolved at 25% concentration in deionized water. 0.5% triethanolamine based on melamine formaldehyde is added to increase the pH of the solution and to extend the curing time of the solution (12–14 months). In addition, 10% triethylene glycol is added to the solution to give flexibility to the wood, and 5% urea is added to support absorption by obtaining a more fluid solution. Polycondensation of melamine formaldehyde is carried out at a temperature of 50–55 °C, and a 10 m long furnace is used for this process in Yenikapı [29].

5. Discussion and Conclusions

The Yenikapı Shipwrecks studied by Istanbul University were removed from the field with appropriate methods and stored in the stainless steel and concrete tanks at the IU Yenikapı Shipwrecks Project Application and Research Laboratory. The preservation status of the Yenikapı shipwrecks, the number of existing hull elements, their structural features, the chemical and biological deterioration of their wood, and how they were removed from the site vary. These parameters play a decisive role in the decisions and methods followed in the post-excavation work. In the general workflow, the conservation process begins after the documentation and technology studies on the wrecks are completed. However, as in the YK12 example, only the drawing time of small-sized wrecks may take more than one year [15,21]. The high number of wrecks prolongs the waiting time for the timbers in the tanks. Therefore, it increases the risk of deterioration in the right proportion with time elapsed in the waterlogged wood waiting in line. For this reason, it was decided to conserve the shipwreck timbers, which have a high risk of deterioration, by drawing the outlines and then carrying out detailed documentation. PEG (polyethylene glycol) impregnation followed by vacuum freeze-drying is applied in most Yenikapı shipwrecks. However, the melamine formaldehyde (Kauramin®®) method is used in conserving ship woods with high water content and low density, requiring immediate intervention (Figure 15). Depending on the deterioration of wood, as a single method is used on all woods of a shipwreck, two different ways can be applied. For example, melamine formaldehyde was used in the highly deteriorated floor timbers from the plane tree of the YK3 and YK16 shipwrecks [31,32]. In contrast, the other elements of these shipwrecks in better condition were conserved using the PEG method [29,33]. Both methods successfully provided dimensional stabilization (Figure 16). However, using two different chemicals in the elements of the same shipwreck causes different colors, mechanical strength, fragility, flexibility, and weight in the wood. Similarly, their resistance to biological activation, environmental impact values, and reactions to the support materials used vary by impregnation chemicals. Cracks, excessive lightening of the natural color, and whitening are observed in the woods that have been treated with the melamine formaldehyde method. In addition, wooden elements become lighter than necessary [31,34]. These disadvantages are not seen in the use of PEG. However, using iron in the supports that will carry the body or in the storage construction has not become a problem for timbers impregnated with melamine formaldehyde, but it has created a corrosive effect on PEG [35,36]. When iron is combined with sulfate in the wood structure and high relative humidity in the environment, reactions that cause acidity, salt precipitation, and the risk of deterioration develop in waterlogged woods [37–40]. Furthermore, timbers treated with PEG, a hygroscopic chemical, can become heavier by absorbing atmospheric moisture [41] (p. 4). In addition, ultraviolet radiation and high light intensity cause degradation in PEG [42] (pp. 268–269). High ambient temperatures can cause softening of treated woods, separation of bonded surfaces, and deterioration of PEG. This issue should be considered in the re-installation of the shipwreck's hull for exhibition purposes, in the exhibition environment, and in the creation of storage conditions. Melamine formaldehyde has more flexible conditions for relative humidity, temperature, and light values than PEG. However, direct sunlight is a negative factor for both materials. For all these reasons, environmental conditions such as temperature, relative humidity, and light intensity should be regulated according to the optimum values of both the wood and the used conservation chemicals to prevent further deterioration in treated ship timbers during display and storage. Temperature, relative humidity, and pH controls regularly occur in the IU Yenikapı Shipwrecks Project storage area [35,43].

Figure 15. Waterlogged timbers from shipwreck YK26, after melamine formaldehyde conservation. © YSP Archive.

Figure 16. The condition of a frame timber before (above) and after (below) PEG impregnation vacuum freeze-drying. © YSP Archive.

The methods used in the removal of shipwrecks, the conservation process, and the exhibition approach are closely related to each other. The lifting techniques from the excavation area vary according to the excavation conditions and possibilities and the preservation status of the ship's timbers. The removal of large shipwrecks is carried out according to the decisions taken for the excavation, laboratory, and storage facilities. As with the Vasa and Mary Rose ships, very large and highly preserved shipwrecks can be removed as a single mass [39,44]. In contrast, smaller shipwreck hulls can be lifted by cutting them into pieces, as with the Dover and Arles-Rhône 3 boats [45,46]. Dismantling is a preferred method for detailed in situ documentation as well as excavation conditions and possibilities. Many shipwrecks, including Kyrenia, Serçe Limanı, Yenikapı, and Skuldelev shipwrecks, in scattered or intact conditions from underwater and wetlands, have been removed by dismantling [26,47–49].

When the museum exhibitions of archaeological ship remains are examined, two different principles emerge: in situ display and exhibition according to reconstruction. The term in situ display covers the reassembling or consolidation of the existing hull without correcting the deformations in the shapes of shipwrecks as they are found on the site. Shipwrecks whose hull parts were removed in mass are generally exhibited in situ. Different methods are applied in conserving the shipwrecks that have been removed in mass. Mainz wrecks were removed in a single mass, conserved with the melamine formaldehyde (Kauramin®®) method, and exhibited as they were [50]. The 31 m in length, well-preserved Arles-Rhône 3 shipwreck was cut into ten pieces, which were removed in mass. The conservation of each mass part was done by freeze-drying after impregnation with 35% PEG [46,51]. Another method is partial mass lifting. After some timbers of the shipwreck YK6 were dismantled during the Yenikapı excavations, its lower hull was lifted as a mass. However, the hull timbers were dismantled beforehand and included in the PEG impregnation-vacuum freeze-drying conservation procedure. The Vasa ship is a characteristic example of large-scale, complex, and costly applications. The 69 m in length, 11.70 m in width, and 19.4 m high 95% preserved hull of the shipwreck was lifted as a single mass, and it was conserved with PEG spraying and controlled drying [39]. The display by reconstruction is based on reforming the shipwreck timbers to their form at the original hull. In addition, the hull structure of the original ship can be emphasized by complementing the missing parts of the existing hull with various materials and adding representative lines. The shaping procedure considering the reconstruction can be done during the conservation process or during re-assembling. Since the re-assembly and the envisaged display method will change the workflow in conservation practices, it is crucial to make plans for this and to determine the shipwrecks to be exhibited and stored in advance. The melamine formaldehyde method is not suitable for pre-forming. This method can be used on the timbers of shipwrecks that will be displayed in their current form or preserved in storage. Today, the PEG method is preferred for display, according to reconstruction. Kyrenia, Ma'agan Mikhael, and Serçe Limanı ships exemplify the solution in three different conditions for shaping PEG fully-impregnated timbers during assembly. The Kyrenia shipwreck, of which 75% of its original length of a 14 m hull was preserved, was conserved with PEG full-impregnation and controlled drying after its timber was dismantled and removed from underwater. The timbers of the shipwreck were shaped according to the reconstruction by heating them during the reassembling [49]. The 11.15 m in length preserved hull of the Ma'agan Mikhael shipwreck was raised in pieces by dismantling all its timber elements and cutting some of its planks. For the reason that all timbers were very soft and fragile, only a few wooden members were documented in detail in the laboratory before conservation treatment. Detailed documentation was performed after conservation and during reassembly [52] (p. 108). The meticulous reconstruction of the ship was performed after the conservation with PEG full-impregnation by heating and controlled drying method. During the reassembly, timbers were reheated in PEG, softened, and reshaped in molds [53]. Less than 20% of the Serçe Limanı shipwreck was preserved, and its timbers were found in small pieces and scattered on the seabed. Its timbers were conserved by PEG full-impregnation and controlled drying. The fragmented nature of the preserved hull elements and the scarcity of hull planks necessitated a method by which reconstruction and reassembling proceeded together. Since the hull timbers are small in size, no compelling shaping was required; they were placed in their original shape by being completed with metal lines created according to the reconstruction during reassembling [54]. Contrary to these practices, reconstruction work must be completed beforehand for shaping to be carried out during the conservation process. PEG impregnation and freeze-drying are considered the most effective conservation methods for this application. In the Barcode 6 and Roskilde 6 shipwrecks, the hull timbers were shaped according to the reconstruction drawings during conservation. After the wrecks were removed from the excavation site, they were documented in detail, and their reconstructions were studied. The conservation of Barcode 6 was done by applying intermittent heating with 40% PEG 2000 pre-impregnation and vacuum freeze-drying. Shipwreck timbers were shaped to their original shape before freeze-drying [55]. The conservation of the Roskilde 6 shipwreck was carried out with 40% PEG 2000 pre-impregnation and vacuum freeze-drying. A detailed reconstruction of the shipwreck was studied before drying; the timbers impregnated with PEG were shaped according to their original shape, fixed in their correct positions, and taken to the drying procedure [38]. Various lifting solutions have been applied to the Yenikapı shipwrecks, which have different preservation rates. However, the general principle is to remove the wooden elements by dismantling them in molds that maintain their existing form. These molds act as carriers for the hull timbers in the tanks until the studies on the wrecks begin. The crates and supports are reinforced regularly to reduce the risk of loosening the supporting construction due to prolonged waiting times in the tanks. The lifting by the dismantling of the shipwrecks facilitated detailed documentation and reconstruction works, as well as conservation and drying works. In the vacuum freezing process, the timbers are fixed to the product table of the device by using stainless steel profiles to prevent deformation (Figure 17). Small-sized floor timbers and futtocks, removed from the field with molds, were fixed more easily and without radical shaping when placed on the device table as they preserved their forms. In the shaping works before drying, the planks, preserved in forms close to the original thanks to the molds, can be shaped by removing the overhanging edges without being exposed to various regressions. In freeze-drying applications, the fact that large-size timbers do not fit inside the device is a different problem. For this reason, sometimes archaeological timbers are lifted by cutting them into pieces [46] (p. 72). Istanbul University Yenikapı Shipwrecks Project Application and Research Laboratory has two devices for the vacuum freeze-drying procedure. Thanks to these devices, which are 2.50 m in length, 90 cm in diameter, and 8.50 m in length, 2.10 m in diameter product chamber, the conservation of wooden elements of various sizes can be done as a whole (Figure 18).

Figure 17. The fixing of timbers on the product table of the device. © YSP Archive.

Studies on the shipbuilding technology and conservation of Yenikapı shipwrecks continue. The laboratory studies of the IU team started with the YK6 wreck in 2006. In the sixteen years that have passed since this date, the difficulties brought about by the process and the results of the first practices have emerged. Studies are performed continuously for the drawing, photographing, analysis, desalination, cleaning, impregnation, and drying processes of innumerable wooden elements from 31 shipwrecks in various sizes ranging from 2 m to 23 m in existing length. The studies are blended with struggles for the area's safety, financing the works, and the sustainability of the current opportunities, beyond the intensive labor and workforce. The most significant handicap has been the time factor, which works against the preservation of the timbers. After the conservation process, there is a need for climate-controlled storage areas for ship timber, a museum for the reassembled ships, and a display of shipwrecks. In the Yenikapı Shipwrecks Project, storage and museum construction responsibilities are with Istanbul Archaeological Museums, the General Directorate of Monuments and Museums, and Istanbul Metropolitan Municipality.

We have periodically conveyed our requests to these authorities. However, no results have been obtained from this until today. As a result of a competition for the construction of the museum in 2010, the projects of Peter Eisenman and Aytaç Architecture were accepted. Although the necessary official procedures were completed, this museum has not been established until today. During this period, the conserved timbers were stored in three containers of 3 × 7 m belonging to the Yenikapı Shipwreck Project. In 2022, with the efforts of our project, a temporary storage unit of 300 square meters was created, and the shelf system and air conditioning work are still ongoing. For the reason that the storage problem for ship timber was not resolved, disruptions started in our workflow. For example, the freeze-drying processes of the works whose PEG impregnation was finished were not started, and the timbers were kept in their tanks. This has caused freeze-drying devices to remain idle and, more importantly, the wooden carriers of the artifacts waiting in the storage tanks for a long time to lose their properties. After the first five years, the wooden supports and crates carrying the ship's elements started to become heavy by absorbing water, loosening at the joints, and rusting the fasteners. For this reason, regular checks and necessary repairs are made on the wooden crates. In addition, pool water is regularly analyzed for acidity and biological activation, and biocide is added when necessary. Structural conditions are checked by taking samples from ship timbers. This situation creates the need for extra labor and chemical use.

Figure 18. Vacuum freeze-drying device at Yenikapı laboratory (ø 2.10 m/L. 8.50 m). © YSP Archive.

This picture, encountered during the post-excavation studies of Yenikapı shipwrecks, reveals the importance of pre-designing and constructing structures such as equipped storages facilities and museums that will preserve the archaeological artifacts after and during the conservation process. Financial resources and state support are undeniably essential to continue archaeology and conservation studies. The conservations of 70% of the Yenikapı shipwrecks are finished or continuing, and 30% have not yet started (Table 1). The conservation of the shipwrecks is expected to continue for about 15 years. Measures to be taken and solutions to be developed in this direction will positively affect the success of the studies.

Table 1. Conservation status of the Yenikapı shipwrecks [20] (p. 49).

Wreck	Desalination	Cleaning of Iron Products	Conservation Method	Status
YK 1	Completed	5% mixture of disodium EDTA and oxalic acid solution	PEG impregnation-vacuum freeze-drying	Completed in 2016
YK 2	Completed	5% mixture of disodium EDTA and oxalic acid solution	PEG impregnation-vacuum freeze-drying	Concentration of PEG 30% (continuing)
YK 3	Completed	5% mixture of disodium EDTA and oxalic acid solution (for PEG impregnation)	PEG impregnation-vacuum freeze-drying and Melamine formaldehyde	Concentration of PEG 45% (continuing) Melamine formaldehyde treatment (MFT) completed
YK 6	Completed	5% disodium EDTA solution	PEG impregnation-vacuum freeze-drying	Concentration of PEG 40% (continuing)
YK 7	Completed	5% disodium EDTA solution	PEG impregnation-vacuum freeze-drying	Concentration of PEG 30% (continuing)
YK 8	Completed	5% disodium EDTA solution (for PEG impregnation)	PEG impregnation-vacuum freeze-drying and Melamine formaldehyde	Concentration of PEG 40% (continuing) MFT completed
YK 9	Completed	5% disodium EDTA solution (for PEG impregnation)	PEG impregnation-vacuum freeze-drying and Melamine formaldehyde	Ready for PEG impregnation MFT completed
YK 10	Completed	Not started	Not started	Not started
YK 12	Completed	5% mixture of disodium EDTA and oxalic acid solution	PEG impregnation-vacuum freeze-drying	Concentration of PEG 45% (continuing)
YK 13	Completed	Not started	Not started	Not started
YK 15	Completed	5% mixture of disodium EDTA and oxalic acid solution	PEG impregnation-vacuum freeze-drying	Ready for PEG impregnation
YK 16	Completed	5% disodium EDTA solution (for PEG impregnation)	PEG impregnation-vacuum freeze-drying and Melamine formaldehyde	Ready for PEG impregnation MFT completed
YK 17	Completed	5% disodium EDTA solution	PEG impregnation-vacuum freeze-drying	Ready for PEG impregnation
YK 18	Completed	5% disodium EDTA solution	PEG impregnation-vacuum freeze-drying	Ready for PEG impregnation
YK 19	Completed	5% disodium EDTA solution	PEG impregnation-vacuum freeze-drying	Ready for PEG impregnation
YK 20	Completed	5% disodium EDTA solution	PEG impregnation-vacuum freeze-drying	Ready for PEG impregnation
YK 21	Completed	5% disodium EDTA solution	PEG impregnation-vacuum freeze-drying	Concentration of PEG 15% (continuing)
YK 22	Completed	Not started	Not started	Not started
YK 25	Completed	Not started	Not started	Not started
YK 26	Completed	-	Melamine formaldehyde	Ready for MFT
YK 27	Completed	5% mixture of disodium EDTA and oxalic acid solution	PEG impregnation-vacuum freeze-drying	Concentration of PEG 40% (continuing)
YK 28	Completed	5% mixture of disodium EDTA and oxalic acid solution	PEG impregnation-vacuum freeze-drying	Ready for PEG impregnation
YK 29	Completed	Not started	Not started	Not started
YK 30	Completed	5% mixture of disodium EDTA and oxalic acid solution	PEG impregnation-vacuum freeze-drying	Concentration of PEG 30% (continuing)

Table 1. *Cont.*

Wreck	Desalination	Cleaning of Iron Products	Conservation Method	Status
YK 31	Completed	5% disodium EDTA solution	PEG impregnation-vacuum freeze-drying	Ready for PEG impregnation
YK 32	Completed	Not started	Not started	Not started
YK 34	Completed	Not started	Not started	Not started
YK 35	Completed	Not started	Not started	Not started
YK 36	Completed	-	Melamine formaldehyde	Completed in 2015
YK 37	Completed	Not started	Not started	Not started

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