SKYLLIS

Zeitschrift für maritime und limnische Archäologie und Kulturgeschichte 19. Jahrgang 2019 Heft 1/2

Deutsche Gesellschaft zur Förderung
der Unterwasserarchäologie e.V.

DEGUWA

Inhalt

Titelmotiv

Front view (head) of Ram 8.

Aus: Sieghard Wagener, A Fatal Crash at the First Punic War. Investigation of an Ancient Sea Battle by Engineering Methods

Vorwort

Um den über die letzten Jahre entstandenen Rückstand der Skyllis aufzuholen, erscheint der vorliegende Band 19-1/2, 2019 nicht wie üblich in zwei Teilheften, sondern als Doppelband.

In diesem Band sind Beiträge unterschiedlicher Herkunft versammelt. Die Beiträge von Michael Jones, Yannis Nakas sowie von Miran Erič, Enej Guček Puhar, Žiga Stopinšek, Aleš Jaklič und Franc Solina gehen auf Vorträge bei der IPR XXIV in Bodrum 2019 zurück. Sieghard Wageners Beitrag entstand aus einem ebenfalls in Bodrum präsentierten Poster, das er in erweiterter Form auf der IPR XXV in Frankfurt vortrug.

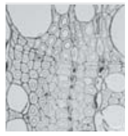
Alle übrigen Beiträge entstanden unabhängig von den Tagungen der DEGUWA. Abgerundet wird der Band durch einen Tagungsbericht zur Unterwasserarchäologie in Bayern sowie eine Rezension.

Generell soll Skyllis künftig nur noch einmal jährlich erscheinen. Da diese Bände entsprechend umfangreicher sein werden, bekommen Sie damit aber genauso viel zu lesen wie bisher. Band 20, 2020 wird Ende dieses Jahres folgen.

Winfried Held

Reconceptualization of the Contemporary Maritime Museum. Do we Really Need the Original Waterlogged Wooden Artefacts and Objects?

Miran Erič – David Stopar – Franc Solina – Katja Kavkler



Abstract *– In the last decade, we have witnessed a revolutionary development of digitally supported information and computer technologies that enable us to acquire highly accurate models of different aspects of the environment. Through advanced technology of three dimensional (3D) printing, it is now possible to reproduce small and large artefacts with high precision and hence reproduce objects at a user selected scale.*

The generally accepted concept of the museum over the centuries has been the preservation of artefacts for educational purposes. It is assumed that by seeing or touching the artefacts, one can get the sense of the past. In case of artefacts made of organic materials which are easily biodegradable this requires extensive conservation and preservation efforts, which is costly, environmentally questionable, and typically irreversibly transforms the chemistry and the spirit of the original object. There are additional means for their presentation in addition to the presentation of the original objects.

To educate the general public about the technology and objects used in the past, a certified copy of the object based on available 3D technology can provide a convenient and less expensive way to reach the same goal. At the same time, it is not necessary that the owners of valuable objects give up the possession of those objects which reduces the risk of their damage. Most importantly, it allows the primary object to stay in the original place which gave in the past the necessary environment for its preservation and enables further scientific study on unperturbed objects. We must rethink therefore the philosophy and ethics of conservation and implement new concepts of preservation and presentation of wooden artefacts for educational purposes, which remains the mission of any museum.

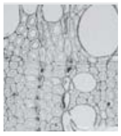
Inhalt *– Im letzten Jahrzehnt wurden wir Zeuge einer revolutionären Entwicklung digital unterstützter Informations- und Computertechnologie, die uns dazu in die Lage versetzt, sehr genaue Modelle von verschiedenen Aspekten der Umwelt zu erstellen. Durch die fortgeschrittene Technik des dreidimensionalen (3D) Drucks ist es heute möglich, kleine und große Objekte mit hoher Präzision zu reproduzieren, sogar in einem wählbaren Maßstab.*

Das seit Jahrhunderten allgemein akzeptierte Konzept eines Museums ist die Bewahrung von Objekten zum Zwecke der Bildung. Man geht davon aus, dass das Betrachten oder Berühren der Objekte einen Zugang zur Vergangenheit vermittelt. Im Falle von Objekten aus organischem Material, die leicht biodegradabel sind, erfordert dies eine aufwendige Konservierung, die teuer und ökologisch fragwürdig ist und zudem die Chemie und das Wesen des originalen Objekts irreversibel verändert. Es gibt andere Möglichkeiten für ihre Präsentation als die der originalen Objekte.

Um der Öffentlichkeit die Technologie und Objekte, die in der Vergangenheit genutzt wurden, nahezubringen, kann eine zertifizierte, auf 3D-Technologie basierende Kopie des Objekts einen einfacheren und weniger kostspieligen Weg bieten, um dasselbe Ziel zu erreichen. Zugleich ist es nicht erforderlich, dass die Besitzer kostbarer Objekte ihr Eigentum daran aufgeben, was das Risiko ihrer Beschädigung vermindert. Vor allem aber erlaubt dies, dass das originale Objekt an seiner Fundstelle verbleibt, die ihm in der Vergangenheit die notwendigen Umweltbedingungen für seine Erhaltung geboten hat, und ermöglicht künftige wissenschaftliche Untersuchungen der ungestörten Objekte. Wir müssen daher die Philosophie und Ethik der Konservierung neu überdenken und neue Konzepte für die Konservierung und Präsentierung hölzerner Objekte zu Bildungszwecken entwickeln, was die Aufgabe eines jeden Museums bleibt.

A few years ago, a very precious archaeological artefact was discovered during the archaeological research in the Ljubljanica riverbed near Vrhnika. It was a small, human-made, hand-sized arrowhead, a pointed wooden object similar to a palaeolithic stone point. The wooden point was made out of yew wood and is about 40,000 years old[1]. Due to the unusual and lucky series of events the artefact was fixed in intact sediments without significant physical, biological and chemical activities which could destroy the point.

This exceptionally old and beautifully crafted artefact which used to be part of a hunting weapon provoked us to reexamine the fundamental concepts of conservation of waterlogged wood. First, we will review the history of the conservation of waterlogged wood; next, we will describe the contemporary methodologies of protection of waterlogged wood, that are mainly designed to preserve the shape of wooden objects. Finally, we will describe the latest digital technologies that enable highly accurate and cost-effective three dimensional (3D) documentation and 3D printing of digital models, which gives us the possibility to replicate, with a very high degree of accuracy, copies of almost any physical object. With the technological advance in preservation the format of presentation of artefacts in dedicated museums has also changed. We will argue that in light of these latest technological advancements in the field of 3D modelling and reproduction the traditional art conservation methods which change the mechanical, biological and/or chemical structure of artefacts should be reexamined and possibly abandoned. We are in a position where the primary object may remain in its original location, which initially gave it the best possible environment for its preservation and it will do so also in the foreseeable future to enable further scientific study on the unperturbed object. At the same time, a certified copy of the object based on available 3D technology may replace the primary object to educate the general public about the technology and objects used in the past.



Let us reflect on the ethical side of the conservation philosophy. For instance, the 40,000-year-old wooden point was preserved by treating it by melamine. Despite a carefully designed and controlled museum environment, we cannot predict what will happen with the object if it is exposed to the detrimental environmental conditions (i.e. humidity, heat, rich nutrient). It is likely that the artefact will be degraded in just a few centuries, perhaps in no more than 200 to 500 years! Do we have the moral right to attempt such an exploit with an uncertain outcome? We will propose in this article that after a detailed 3D documentation that allows precise 3D reproduction, re-burial of such an artefact is the best preservation method. For example, the artefact may be encased into a sufficiently large probe, made out of a degradable material, and returned into the environment where it was found (i.e. clay sediment at a depth corresponding to 40,000-year-old layers) or similar environment, enabling preservation of the object under airless condition. Although the artefact was exposed to harmful biological and chemical influences, during the time of the examination, these should terminate after the artefact is returned into the original environment which was responsible for the long-term survival of the artefact. That would probably assure that the wooden point would remain intact for another several thousand if not ten thousand years. However, since the wooden point was preserved with a current state of the art method, a melamine treatment, it will probably disappear in the next few centuries. The expert decision to preserve the wooden point by infusing it with melamine was based on entirely acceptable arguments and strategies at the time of conservation which was only two decades ago. It would likely be different today. In the last few decades, we witnessed drastic advances in highly accurate digital documentation of heritage objects, including their complete digital reproduction and their physical reproduction[2]. Therefore, considering our professional scientific responsibility and ethics, we must reconsider whether we should in the future continue with the current preservation methods of waterlogged wood, potentially destroying the artefacts in the long run?

Character of waterlogged wood compared to other archeological materials

Waterlogged wood is an organic, carbon-based composite material that has been subjected to biodegradation. It is fundamentally an aggregate of hydrogen, carbon, nitrogen, and oxygen composed of cellulose, hemicellulose and lignin. The three main components have different degradation potential. Cellulose and hemicellulose are relatively easy biodegradable polymers. Lignin, on the other hand, can resist biodegradation in waterlogged conditions. Compared to stone, ceramics, metal and bone matter, waterlogged wood is more prone to natural decomposition when excavated and put to ambient oxygen, temperature and relative humidity conditions. Restoration and preservation of organic materials present in general one of the biggest challenges for specialists and employs some of the most expensive methodologies in the field of conservation of heritage artefacts protection (fig. 1)[2a].

In comparison to wood, *stone* is a physical inorganic material, a compressed aggregate of one or more minerals or mineraloids. Three dominant groups of rocks are characterised as volcanic, sedimentary, and metamorphic. At a granular

[1] Erič – Gaspari 2009; Gaspari – Erič – Odar 2011.

[2] Molloy – Milić 2018; Agrafiotis – Drakonakis – Skarlatos 2018; Scopigno et al. 2017; Yamafune – Torres – Castro 2016; Balletti et al. 2015; Jaklič et al. 2015; Neumüller et al 2014; De Reu et al. 2014; Erič et al. 2013; Mahiddine et al. 2013; Seinturier et al. 2013; Remondino et al. 2012; Antlej et al. 2011; Lobb et al. 2010.

[2a] Recently the field of waterlogged wood conservation uses the value of Maximum Moisture Contents Umax (Siau 1984; McConnachie – Rod – Jones 2008) shown as % proportion between cell structure elements (cellulose, lignin, etc.) against bound and free water in the wood. However, in the last decades the Anti-shrink

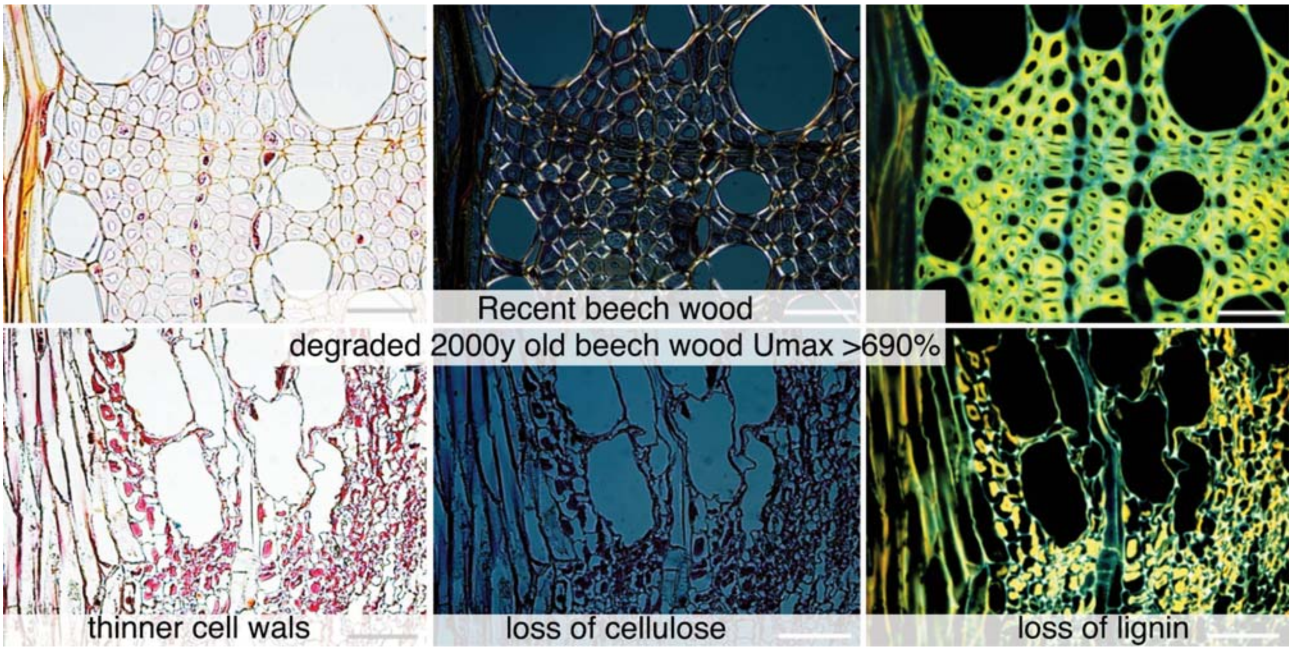
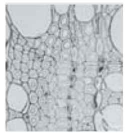


Fig. 1: The cell structure of recent beech wood with less than 200% Umax(top) and fragile cell structure of the flat-bottomed Roman barge from Sinja Gorica (Čufar – Merela – Erič 2014, fig. 7) extremely deteriorated up to 690% Umax (bottom). Photo taken with a microscope Nikon Eclipse E800 (digital camera Nikon DS-Fi1 and software NIS Elements B.r. 3.0) by Dr. Maks Merela, Chair of Wood Science, Department of Wood Science, Biotechnical Faculty, University of Ljubljana



level, a stone is formed out of fragments of minerals, which, in turn, are homogeneous masses formed by a chemical compound that is arranged in an orderly way. Stone artefacts are actually manageable to protect when taken out of the water.

Ceramics are an inorganic, non-metallic, frequently crystalline oxide, nitride or carbide material. Ceramic materials are hard but brittle and have limited resilience in shearing and tension. Ceramics can generally withstand very high temperatures. Traditional ceramic materials include clay minerals such as kaolinite. Ceramics, not as fragile artefacts but as a material, can be efficiently protected from decay, and it is manageable to keep it in unpredictable air conditions.

Glass is a non-crystalline amorphous solid that is often transparent and has broad practical, technological, and decorative usage. The most familiar, and historically the oldest, types of glass are 'silicate glasses' based on the chemical aggregate silica, the principal ingredient of sand. Artefacts made of glass are brittle, except laminated or specially treated glass, but as a material, glass is extremely durable under most conditions. It erodes very slowly and can withstand the action of water. Compared to wood it is comfortable to protect and can be kept it in unpredictable air conditions.

Metal is an inorganic material that is typically hard, opaque, shiny, and has excellent electrical and thermal conductivity. Metals are commonly tractable as well as fusible and ductile. That means that this material can be hammered and pressed permanently out of shape without breaking or cracking. However, nearly 91 of the 118 elements in the periodic table are metals. The high density of most metals is due to the tightly packed crystal lattice of the metallic structure. Metal is highly indestructible and comfortable to keep in unpredictable air conditions considering the protection of metal artefacts.

Bone, ivory, and *antler* are organic materials where cells are embedded in a mineralised organic matrix consisting of organic and inorganic components, primarily hydroxyapatite and other salts of calcium and phosphate. The collagen fibres give bone its tensile strength, and the interspersed crystals of hydroxyapatite give the bone its compressive strength. Artefacts made out of materials with such characteristic are comfortable to protect from decay, and it is also manageable to keep them in unpredictable air conditions.

History of wood conservation

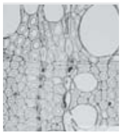
Wood has had a special place and importance throughout the history of humanity[3]. The first known record of timber and care of it can be found in the four-thousand-year-old epics of Gilgamesh[4], based

efficiency -ASE was used. Until the new millennium, acceptable ASE was 75%. Even today acceptable ASE is up to 90% (Grattan – McCawle – Cook 1980; Hoffmann 1996).

3 Historical overview on wood conservation in Unger – Unger 1990.

4 Epic of Gilgamesh, Table Eleven: »Tear down the house and build a boat! Abandon wealth and seek living beings! Spurn possessions and keep alive living beings! Make all living beings go up into the boat. The boat which you are to build, its dimensions must measure equal to each other: its length must correspond to its width. Roof it over like the Apsu. I understood and spoke to my lord, Ea: 'My lord, this is the command which you have uttered I will heed and will do it. However, what shall I answer the city, the populace, and the Elders!' Ea spoke, commanding me, his servant: 'You, well then, this is what you must

on an extensive collection of Sumerian legends. As indicated, the rich old culture had a broad understanding of nature, architecture and art. Among other things, they were concerned with the resistance of construction materials. A verse in the epic also describes the protection of wood, which was at that time preserved by pouring tar oil on it. In the Sanskrit religious hymns Rigveda (Aranyaka) it is possible to find verses that refer to the season of the year, which is most suitable for cutting down the trees for long-term preservation[5].



The first document on archaeological and conservation activities were discovered on a cuneiform tablet from Larsa (Iraq), which describes that king Nebuchadnezzar II (605–562 BC) and king Naboned (556–539 BC) tried to find evidence of elder cultures and kings. During the excavations of the foundations of a temple, King Naboned found the records of the famous king Hammurabi. The tablet from Larsa also describes the protection of the old architecture[6]. Even more interesting is the fact that the princess Ennigaldi-Nanna, daughter of the king Naboned, preserved and stored the artefacts, including wooden objects, from different periods of their history in one place. This area has been declared as the first real museum[7]. Knowledge about the preserving of wood was growing through the millennia.

From the early 19th century the scientific interest for conservation methods in archaeology has steadily increased[8]. A researcher with the name Kyan registered in 1832 the first patent, which describes the treatment of wood with a solution of (undescribed) sublimate which is considered the beginning of modern wood conservation. Shortly after that, the number of patents for wood conservation significantly increased. F. Moll, for example, has written about conservation with creosol where wood was smoked by resin burning, while Burnett recommends the preservation of wood with zinc chloride[9]. In 1860, under the auspices of the Frederick VII of Denmark, a Society for ‘activities in the field of archaeology and antiquary’ was founded, which was taking care of archaeological excavation and took effort in the development of conservation procedures for the protection of waterlogged wood. The Danish are especially proud of one of their oldest preserved personal records about wooden artefact conservation from archaeological sites. Its author was Christian Jurgensen Thomsen, court administrator for antiques at the Danish court of Frederick VII of Denmark. For example, in 1850 he described the conservation of waterlogged wood: “*Potassium alum for wood, boiling*”[10]. His description of the ‘conservation process’ was very insufficient and does not explain a lot, but suggests that conservation procedures were regularly used. A member of this society was also Christian F. Herbst who published his experience with the protection of waterlogged wood with potassium alum in 1861 in the ‘Antiquarisk Tidsskrift’ journal. His article describes a problem in dealing with wooden objects found in the archaeological excavations in 1850 near Viemos on the island of Funen. Only in the early 20th century, the conservation methods of dry and waterlogged wood were separated[11].

Currently used methods of waterlogged wood conservation

The history of archaeological excavation abounds with stories how waterlogged wood that at the time of exploration was considered to be without significant cultural heritage value has perished in a brief period when exposed to the elements. That is particularly true when the Maximum Moisture Contents (Umax) of the waterlogged wood is higher than 400%. When systematic archaeological excavations began in the middle of the 19th century, the knowledge of how to conserve waterlogged wood was practically non-existent. Research and development of waterlogged wood preservation started only at the beginning of the 20th century (**fig. 2**).

Waterlogged wood is a highly susceptible material. Since it has a partially deteriorated structure, the form is kept by water filling the voids. As soon as the water evaporates, the structure collapses (**fig. 3**). On the other hand, keeping it in tap or distilled water, may promote microbial growth. The wood has

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say to them: “It appears that Enlil is rejecting me so I cannot reside in your city (?), nor set foot on Enlil's earth. I will go down to the Apsu to live with my lord, Ea, and upon you, he will rain down abundance, a profusion of fowl, myriad(!) fishes. He will bring you a harvest of wealth, in the morning he will let loaves of bread shower down, and in the evening a rain of wheat!”' Just as dawn began to glow the land assembled around me, the carpenter carried his hatchet, the reed-worker carried his (flattening) stone, ... the men … The child carried the pitch, and the weak brought whatever else was needed. On the fifth day, I laid out her exterior. It was a field in the area, and its walls were each ten times 12 cubits in height, the sides of its top were of equal length, ten times It cubits each. I laid out its (interior) structure and drew a picture of it (?). I provided it with six decks, thus dividing it into seven (levels). The inside of it I divided into nine (compartments). I drove plugs (to keep out) water in its middle part. I saw to the punting poles and laid in what was necessary. Three times 3,600 (units) of raw bitumen I poured into the bitumen kiln, three times 3,600 (units of) pitch ...into it, there were three times 3,600 porters of casks who carried (vegetable) oil, apart from the 3,600 (units of) oil which they consumed (!) and two times 3,600 (units of) oil which the boatman stored away.« (translation: Kovacs 1989).

5 Gonda 1975.

6 The terracotta cylinder of Nabonidus also describes restoration and conservation works on the temple of Shamash at Larsa between 555–539 BC (Banks 1905, 389–392).

7 Schnapp 1993.

8 Detailed reading about the history and development of ancient wood conservation in this paragraph follows Christensen 1970.

9 Christensen 1970, 12.

10 Christensen 1970.

11 More about the development of wood and organic material conservation from water and wet environmental at Unger – Unger 1990; Suthers 1974; Murray 1981; Schnapp 1993.

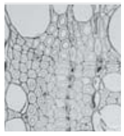

Fig. 2: Alfons Müllner (on the left photo with the white table in his hand) was the curator of the Kranjski deželni muzej – Rudolfinum (Provincial Museum of Carniola – Rudolfinum) and led the excavation of a flat-bottomed Roman ship from Lipe on Ljubljansko barje in November 1890. After measuring and documenting the ship, Müllner ordered the workers to cover the ship again with soil, but unfortunately, they failed to do so. After just several months the exposed wooden remains of the ship have severely deteriorated, and the ship was eventually destroyed. The photograph on the right was made in July 1891 (photo Gustav Pirc © Narodni muzej Slovenije; Gaspari 1998)

remained preserved due mainly to oxygen-free conditions, in which not many microorganisms degrading wood can survive. As soon as excavated, aerobic microorganisms start to degrade it. Their action is much faster. Therefore, as soon as the object has been excavated, it needs to be subject to some conservation procedures to prevent further deterioration.

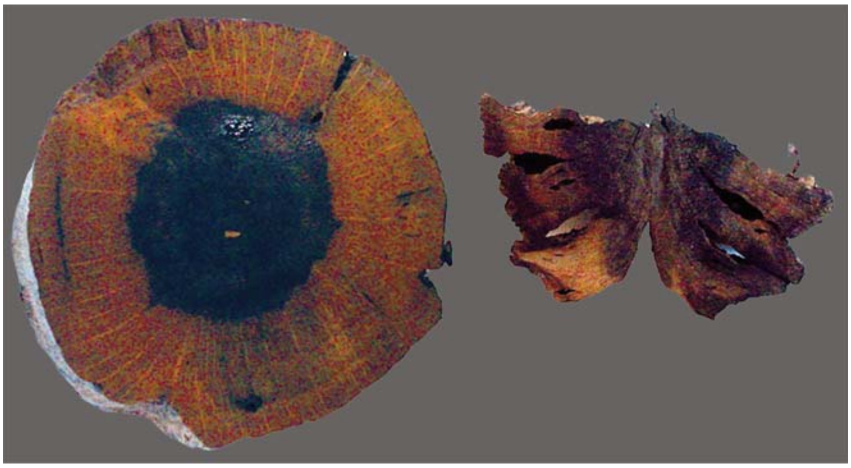

Fig. 3: Waterlogged wood as excavated without conservation treatment (left) and after seven days exposed to room conditions (photo Katja Kavkler)

Several methods of conservation are known, and all of them have the primary goal to preserve only the shape of the wooden part and not the natural organic material[12]. Some of the methods replace the water in the wooden structure with a material which stabilises cell walls and prevents the collapse of the cell structure of the wood. Other methods are based on replacing water with solutions of substances which enhance the cell structure of wood. After consolidation, the liquid, which evaporates during drying, does not have a destructive effect on the cell surface. Then we have a combination of the methods as mentioned above. Finally, there are methods which reduce the influence of surface tension on the fragile wooden panels. For example, methods using polyethylene glycol (PEG) or sugars are combined with freeze-drying and other possibilities.

Potassium alum – Glycerine-Flax oil[13]: This method is one of the oldest described methods for waterlogged wood treatment. Methods were developed and tested by S. W. Speerschneider in 1850 on the collection of wooden objects from Flensburg. The wood was first washed with water and then immersed in a boiling solution of potassium alum [$KAl(SO_4)_2$], and cooked for several hours. For large objects, the cooking process must be repeated several times. When the wood is completely dry, it should be rubbed with linseed oil and a thin coat polish. This procedure is very inexpensive. Due to the approving results, the conservation workshop of the Danish National Museum accepted this method, with some improvements, as a standard until 1958. During this

[12] Jenssen – Murdock 1981.

[13] Christensen 1970, 1971.

Fig. 4: Swedish Royal ship Vasa: one of the best world-known artefacts treated as waterlogged wood with PEG method. Left: Vasa during the early stages of conservation at the Vasa Shipyard in January 1963 (Photographer Holger Ellgaard CC BY-SA 3.0). Right: The lower gun deck of the warship Vasa, displayed in the Vasa Museum in Stockholm, Sweden. The picture was taken in December 2009 by photographer Peter Isotalo inside the ship looking forward (CC BY-SA 3.0) <https://en.wikipedia.org/wiki/Vasa_(ship)>

time, about 100,000 wooden artefacts were preserved. After the conservation with alum was finished, shellac was also used instead of linseed oil. Unfortunately, the defects and damage to the preserved wood appeared only several decades later, and this method was subsequently abandoned.

Polyethene glycol – PEG[14] is one of the most popular methods of conservation of waterlogged wood. PEG is a synthetic wax which is wholly soluble in water. The low molecular weight allows a complete penetration of the aqueous solution, and hence PEG into the cellular structure. A dimensionally stable state of the wood can be achieved if a high-percent solution of PEG equilibrium is reached[15]. The essence of the method is that aqueous or alcoholic solutions squeeze out the free and cell-bound water and replace it with PEG. At the beginning of the process, the PEG solution should be of low-concentration due to osmosis which enables more comfortable and more complete penetration of the PEG in the wood structure (**fig. 4**). During the treatment, pure PEG should be gradually added to the solution until a 100% PEG is used. Alternatively, it can be combined with freeze-drying, after soaking the wood with 40% (and other combinations) solution of PEG. The PEG method is still used in many conservation workshops of museums[16].

Melamine: Arigal-C and Kaurin 800[17]: Previously washed and desalinated wooden artefacts (if recovered from the sea) are first impregnated with melamine formaldehyde resin. The wooden artefact is up to 48 hours treated with a 25% solution of the resin in water or pure alcohol. The second part of the treatment requires the immersion of the artefact for up to 40 hours in a 10% solution of the catalyst (carbamide), which provokes the hardening of melamine. Before the resin hardens completely, the surface of the artefact should be washed with hot water. The object shall be stored in a polyethene bag and heated at 65° C for 48 hours. Then, it should be dried slowly at room temperature and in relative humidity above 50%. Variations of the method also provide for the reverse processes in which the subject is first impregnated with a 2–5% solution of a catalyst and then with a 15% solution of melamine-formaldehyde resin in a temperature range from 10° C to 15° C. Some researchers suggest that the object should be drilled in several places so that the solution can permeate the artefacts easier[18].

However, the method was updated in the last decade. After cleaning (great care needs to be taken not to work in too acid conditions) the wood is immersed in 25% aqueous solution of melamine-formaldehyde resin, to which urea and triethylen glycol are added as well as possible triethanolamine as a puffer. The object can be left in solution for several months. Afterwards it is polymerised at a temperature of about 50° C wrapped in cellulose and Polyethylene (PE) foil and finally slowly dried again wrapped in PE foil[19].

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14 Morén – Centerwall 1961; Mühlethaler – Barkman – Noack 1973; Gregson 1975; Pang 1981; De Jong – Eenkhoorn – Wevers 1982; Sawada 1985; Carrlee 2009.

15 Birkner et al. 1961.

16 Morén – Centerwall 1961; Albright 1966; Christensen 1970; Hoffmann 1985, 1986a, 1986b.

17 Müller-Beck – Haas 1957, 1960, 1961; Müller-Beck – Thieme 1966; Brassel 1960; Wittköpper 1998; Cesar et al. 2017.

18 Haas – Müller-Beck – Schweingruber 1963.

19 Cesar et al. 2017.

Alkohol–Ether–Resin[20]: In this experimental method, as soon as the object is removed from the water it must be sunk in and saturated with alcohol. Next, alcohol is replaced by ether, and a mixture of dammar varnish, beeswax, carnauba, paraffin and rosin or gum rosin is added. A high temperature must be maintained so that the solution can easily penetrate into the wood. Just as PEG, this solution penetrates into the wood and once the wood is dry, it tightens the wood cells. The phenomenon of high surface tension is reduced because of the alcohol or ether, which prevents the collapse of wood material. Later, more similar recipes also appeared.

Aceton–Rosin[21]: The most commonly used solution is rosin in acetone. Moreover, many similar recipes are known, since almost every workshop 'invented' its version of a solution. After washing the wood in water, artefacts are treated for several days in a 3% solution of hydrochloric acid and then rinsed out. With the help of acetone, the wood is dried. Next, the wood should be treated for four weeks with a 67% solution of rosin in acetone, heated to 52° C. Later, artefacts should be rinsed with acetone and dried at room temperature. Most experts believe that the method is most useful mainly for softwood, charcoal and small archaeological finds.

Poly-Butyl-Methacrylate[22]: After washing, artefacts should be treated in the following series of three baths: first one with acetone, the second one should be replaced with butyl-methacrylate, and the last one should be enriched with up to 1% solution of benzoyl peroxide as a coagulant. After this treatment, the artefact has to be placed for up to nine hours in an oven heated between 65° C to 95° C to reach polymerisation. A version of the method also provides irrigation in polymethyl-methacrylate, with heating to 45° C[23].

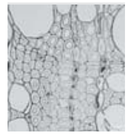
The Electrokinetic method[24] is one of the more infrequent methods that deal with objects *in situ*. The artefact itself and the soil around it should be impregnated with an aqueous solution of sodium silicate and calcium chloride. Around the impregnated object electrodes should be placed. The closed electrical circuit causes solidification of the solution. However, the subsequent laboratory tests did not prove the method to be very useful.

Garrouste/Bouis method[25]: After washing, wood should be sunk into a solution of hydrochloric acid and water. Then follows impregnation with an aqueous solution of chromium acetate, and in some version of the method, up to 20% solution of sodium bichromate could be added. Before washing in fresh water, the wood is also immersed in a solution of sodium chloride. After drying, protection with wax, linseed oil – or any of the synthetic resins – is necessary.

Polymerising with radiation-induction[26]: In the United States, a method of polymerisation of the monomer impregnated wood using gamma radiation was developed. In the beginning, the wood is treated with methanol to substitute all the water. In different laboratories artefacts are impregnated with various monomers. For example, in experiments carried out by a Swiss researcher, styrene, methyl acrylate or methyl methacrylate were used. Meanwhile, in the Netherlands, they use 2-hydroxyethyl methacrylate. When impregnation is completed, instead of draining, the artefact is exposed to the cobalt radiation. Scientists who have studied the method, agree that the method gives excellent results. Dimensional stabilisation is excellent because the shrinkage is less than 1%. Moreover, in many cases, the artefact swells up to 1–3%, but without causing any damage.

The *Hard wax–mixture*[27] method is relatively old and has been replaced by more recent methods. However, even today in some places and for specific cases (mainly softwood) a mixture consisting of damar varnish, raw carnauba wax, paraffin and beeswax dissolved in toluene or xylol, heated to 80° C, is used. Impregnation begins after the water in the artefact is gradually replaced with toluene.

Sucrose[28] conservation of waterlogged wood artefacts with sucrose is one of the cheapest methods in comparison to the others. Apart from the low cost, the method has some other benefits but unfortunately also some weaknesses. Sucrose does not turn brown, does not evaporate, is not toxic and very soluble in water[29]. Due to the high solubility of sucrose, the method is reversible. Researchers from the Vasa Museum made a comparative study of three different methods: PEG, salt and sucrose[30]. They discovered that the shrinkage of wood (acceptable ASE 75%)[31] with the sucrose method is significantly smaller than with other used methods. However, it was found later that the result of the analysis in controlled laboratory condition (ASE 92%) is not a guarantee to expect the same result with original artefacts treatment, where it could never be above 75% of ASE[32].



The *Autosublimation*[33] method exploits the characteristics of camphor that it is very readily soluble in methanol and can be easily sub-

[20] Christensen 1951.

[21] McKerrell – Roger – Varsany 1972; Bryce – Mckerrell – Varsany 1975.

[22] Nogid – Pozdnjak 1973.

[23] Christensen, 1971.

[24] Cebertowicz – Jasienski 1951; Wielicka 1960.

[25] Garrouste 1965; Bouis 1967.

[26] Munnikendam 1967; Karpov et al. 1960; De Guichen – Gauman – Mühletaler 1966.

[27] Organ 1959; Christensen 1971.

[28] Parrent 1984; Hoffmann 1996; Tahira et al. 2016.

[29] Stamm 1973.

[30] Barkman 1975, 65–105; Barkman et al. 1976.

[31] Tiemann 1951; Grattan – McCawle – Cook 1980.

[32] Hoffmann 1996.

[33] Christensen 1971.

limated. The water is replaced with methanol, and before it is completely replaced, up to 80% solution of camphor should be added. When the artefact is dry, camphor crystalises on the surface. After the process is finished, the wood can also be protected with lacquer while camphor later gradually sublimates.

Controlled drying can be performed only in areas where it is possible to control the level of relative humidity precisely. When artefacts are washed and desalted, they are drying gradually, starting with the highest possible relative humidity. Moisture is then very slowly (in several months or even years) decreased, and shrinkage of wood must be monitored continuously. The method is unpredictable because it is difficult to control the drying process precisely. After the whole procedure is completed, the subject of protection can be stiffened using coatings.

Drying with ethyl ether[34]: The problems with the drying process due to the high surface tension of water are critical. Therefore, in the Danish National Museum in Copenhagen, they replaced water in waterlogged wood with low surface tension liquids. The best results were achieved with ethyl ether. Positive effects were also detected in the case when fresh wood was drying. In the second part of the method, the artefact is impregnated with a solution of polymethyl methacrylate in pure benzene. At the end of the procedure, the wood is treated further with a coating of beeswax and dammar gum dissolved in alcohol.

Lyophilisation, freeze drying[35]: The idea of evaporating water from wood in a cold environment is reasonably old. Water in its liquid form exhibits the well-known phenomenon of high surface tension. However, when water is in the form of ice or steam the surface tension no longer exist. When waterlogged wood is drying, and the water is in ice form, the adhesion to the walls of the cells is lower due to the profoundly decreased surface tension of ice. The essence of the method is, therefore, to deep freeze wood since ice in very low relative humidity (vacuum) sublimates. However, this, at first glance ideal, method is not perfect. The volume of water during freezing increases, which can severely damage the wooden cell of artefacts. Therefore, water can be exchanged for other soluble substances. Most often PEG and sucrose are used, and in this way, better results were obtained during the drying process[36].

Fig. 5: Shipwreck Nanhai I during excavation in Maritime Silk Road Museum of Guangdong in Yiangjiang, China. Details (photo Miran Erič; 25. November 2017)

Lyophilisation with tertiary butanol[37]: Tertiary butanol is the most suitable substance for freezing because freezing starts at 25° C and the boiling point is at 80° C. Therefore, this makes it possible to freeze and dry wood at average room temperatures. An operation with the tertiary butanol begins after the item is already impregnated with up to 66% solution of PEG. The object is immersed for some time in the tertiary butanol which is well miscible with water. As with other methods, the artefact is first impregnated so that the residual water in the wood is replaced with another fluid. Frozen wood, impregnated with tertiary butanol, is wrapped in aluminium foil and dried in a unique vacuum device for freezing.

Multifunctional supramolecular polymer networks[38]: In the last decade the method, based on linear polysaccharide chitosan and/or PolyCatNap (catechol and naphthol), was developed in laboratory condition

34 Christensen 1971.

35 Seborg – Inverarity 1962a, 1962b; Pang 1982.

36 Grattan 1982, 1983a, 1983b, 1984; Grattan – MacKenzie 1985; Grattan – McCawle – Cook 1980.

37 Rosenquist 1959a, 1959b, 1975.

38 Christensen – Kutzke – Hansen 2012; Walsh et al. 2014.

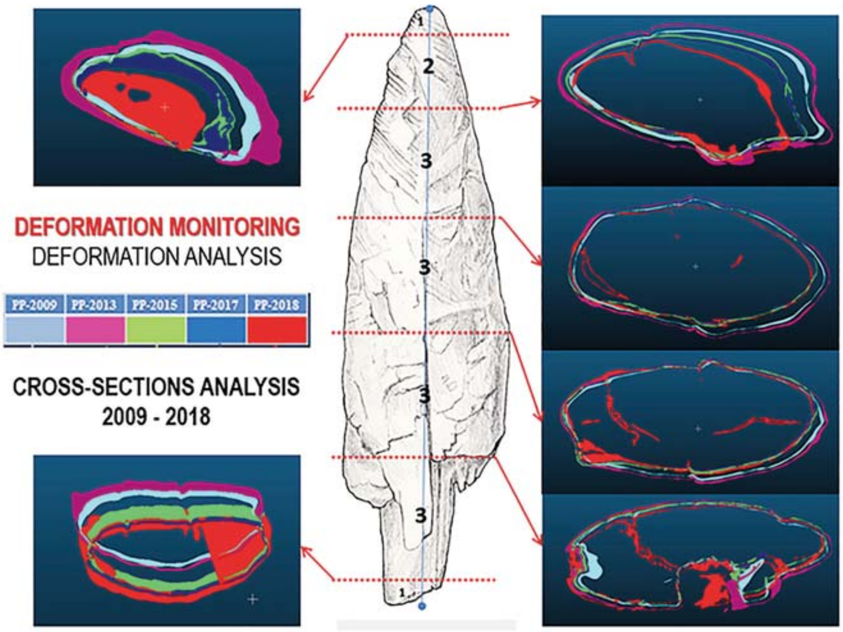


Fig. 6: Volumetric analyses of palaeolithic jew wooden point (Gaspari – Erič – Odar 2011). In the years 2009–2018, INTRI, innovative technologies and solutions, Ltd., Slovenia; The Roman-Germanic Central Museum / The Archaeological Research Institute Mainz, Germany, where the artefact was conserved; and The Slovenian National Building and Civil Engineering Institute Ljubljana, Slovenia produced five 3D models of the paleolithic wooden point (visualisation: Enej Guček Puhar by CompareClaud)

and its advantage should be shortening the process, eliminating the reaction between hemicellulose and iron, non-response to bacteria and persistent prolongation of treated wooden artefacts compared to the other methods.

Today, the most used of the above-listed methods for wood preservation are PEG, sucrose, melamine, lyophilisation or different combinations of these methods.

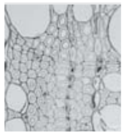
Controversy of usable waterlogged wood conservation methods

However, even with the most useful waterlogged wood conservation methods in use today in conservation institutions and museums, many controversies exist (fig. 5)[39]. There are several unacceptable consequences of the use of current conservation methods that demand the reconceptualisation of our understanding of the role and goal of preserving waterlogged wood for future generations.

We do not understand adequately the *chemical* and *biological reactions* between different kinds of materials (i.e. between wood and metals or wood and consolidants), which is a severe weakness for all waterlogged wood conservation methods used today. Significant artefacts (boats and ships) are constructed with many different kinds of material, which demand different conservation methods, which in turn may change the colour of wood and material itself. This may not happen immediately after treatment but may progress with time even under controlled air microclimatic conditions[40].

The next problem is the *destructive shrinkage process* (fig. 6) after the preservation process and drying[41]. Just several decades ago at the beginning of the 1990s, the acceptable shrinkage standard of ASE was 75%. That is now unacceptable. Currently, acceptable shrinkage of treated wood is between 90–95% of ASE. However, the controversy is, that the ASE value is calculated in a controlled laboratory environment regarding wooden blocks. However, each treated object is unique, and with a different history, character and shape[42].

Another problem is the necessary *control of the environment* of the preserved waterlogged wood and other organic materials in the conditions of a very narrow zone of relative humidity and temperature. The microclimatic air conditions with controlled exhibition rooms or depositories of museums and other institutions which keep restored organic material are costly and difficult to achieve. Even today most museums are not able to support climatic condition under the ±5% variable of relative humidity and temperature. For organic material, such oscillations are unacceptable. The unchangeable microclimatic conditions are one of the most critical parameters to keep the material intact.



Also, the *costs/efficiency* of current conservation methods of waterlogged wood and other organic material should be considered as we can learn from the WreckProtect project Guidelines[43] which compared cost-benefit analysis between *in situ* wreck protecting (Stora Sofia, Zakynthos, Burgzand noord 10, Hårböllebro) with few most significant conservation projects across Europe (Vasa, Mary Rose, Bremer

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[39] At the International Symposium on the Discovery and Research of Nanhai I, 2017, the paper "Discovery and Research of Nanhai I" was presented by Sun Jian, Chief Technology Officer of Underwater Archaeology Unit, National Center of Underwater Cultural Heritage and Cui Yong, Deputy Director of Guangdong Provincial Institute of Archaeology. They told that the wooden ship construction even after rigorous highly controlled and regulated climate condition (temp. at 18° C and RH 70–80%) with every day (7/day) automatic water disperse of the whole digging workspace, and every day automatic 3D modelling of the whole workspace, the wood condition and shape in some parts changed even up to 25%.

[40] e.g., Bjordal – Nilsson – Daniel 1999; Sandström et al. 2002; Fors – Sandström 2006; Mortensen et al. 2007; Almkvist – Persson 2008a, 2008b; Carrlee 2009; Bjurhager et al. 2012.

[41] Tiemann 1951; Grattan – McCawle – Cook 1980.

[42] Guček Puhar et al. 2018.

[43] Manders 2011.

and Kolding cog, New Port, Roskilde 2). The analysis showed significant differences between the costs of different conservation processing. For instance, shipwreck lifting, conservation and exhibition display costs could rise to 65 million in case of Mary Rose (38m)[44]. On the other hand, *in situ* protection of Burgzand noord 10 (35m) in the Netherlands with the geotextile, sandbags, and gravel cost just around 70,000[45].

As a consequence of the controversy over the waterlogged wood conservation methods, a new Network of Monitoring of Preserved Ships was established in june 2017 in Bremerhaven to compare different conservation practices in the long run. The network is currently composed of waterlogged wood researchers from European Ship Museums (Bremer Cog, Vasa, Mary Rose, Vikingship), universities and other waterlogged wood conservation centres (University of Lund, ArcNucleart, Conservation Centre of IPCHS[46]).

Basic ethic guidelines for underwater heritage protection

Ethics of conserving archaeological findings from underwater sites are guided by the Committee for Conservation created in 1967 as part of the International Council of Museums[47]. Furthermore, in the last decade, several new guidelines have been issued, for example, guidelines of the Center for Maritime Archaeology and Conservation Texas A&M University[48], Wreck-Protect project Guidelines for the protection of underwater wooden heritage[49], and SASMAP project Guideline Manual 2[50].

Ethical standards that were developed for art conservation may apply to archaeological preservation as well. Knowledge of ethical considerations helps to understand the reasoning behind a conservator's decision and proper selection of a procedure for treating an artefact. Conservation ethics adopted by the International Institute for Conservation outline eight principles that can help in deciding on the selection of conservation methods and other preservation activities[51].

1. Respect for the Integrity of Object: All professional actions of the conservator are governed by unswerving respect for the aesthetic, historical and physical integrity of the object. Regardless of an artefact's condition or value, its aesthetic, historical, archaeological, and physical integrity should be preserved. After conservation, an object should retain as many diagnostic attributes as possible.

2. Competence and Facilities: It is the conservator's responsibility to undertake the investigation or treatment of a historical work only within the limits of his expertise and facilities.

3. Single Standard: With every historical work he undertakes to conserve, regardless of his opinion of its value or quality, the conservator should adhere to the highest and most exacting standard of treatment. Although circumstances may limit the extent of treatment, the quality of the treatment should never be governed by the quality or value of the object.

4. Suitability of Treatment: The conservator should not perform or recommend any treatment which is not appropriate for the preservation or best interests of the artefacts. The necessity and quality of the treatment should be more critical to the professional than his remuneration. No treatment should be used that is not in the best interest of the object. Any treatment, even if less expensive, extensive, or time-consuming should be avoided if there is a possibility of damaging the artefact. For these reasons, near-term and long-term goals are not pertinent when it comes to deciding the best treatment for an artefact.

5. The Principle of Reversibility: The conservator is guided by and endeavours to apply the 'principle of reversibility' in his treatments. He should avoid the use of materials which may become so intractable that their future removal could endanger the physical safety of the objects. He also should desist the use of techniques, the results of which cannot be undone if that should become desirable. No treatment should be used that will occur damage to the object if it has to undergo further treatment. In general, all treatments should be reversible. This requirement recognises that a conservation treatment may not last indefinitely nor remain superior to all future techniques.

6. Limitations on Aesthetic Reintegration: In compensating for damage or loss, a conservator may supply little or much restoration, according to a previous firm understanding with the owner or custodian and the artist, if living.

7. Continued Self-Education: It is the responsibility of every conservator to remain abreast of current knowledge in his field and to continue to develop his skills so that he may give the best treatment circumstances permit.

8. Auxiliary Personnel: The conservator should protect and preserve the artefacts under his care at all times by supervising and regulating the work of all auxiliary personnel, trainees and volunteers under his professional direction. In underwater archaeology, conservation is not just a set of procedures and treatments.

We can see unquestionably that several of the ethical principles

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44 Manders 2011, 44.

45 Manders 2011, 43.

46 Institute for the Protection of Cultural Heritage of Slovenia.

47 ICOM-CC 2017.

48 Hamilton 2010.

49 Manders 2011.

50 Gregory – Manders 2015.

51 Hamilton 2010.

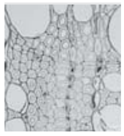
mentioned above are violated with current conservation methods for waterlogged wood from archaeological sites. Therefore there is an urgent need to improve our methods to better comply with the ethical principles of artefact conservation.

Digital technologies and waterlogged wood

With the new millennium, we unmistakably entered a digital era where computer technology plays a crucial role in most human endeavours. Measurement and processing of electromagnetic waves is possible in virtually the entire spectrum, reaching deeper and deeper into space, across the Earth's surface and sub-surface, into underwater environments, into our habitats, heritage sites of all scales, from entire landscapes, to individual cultural objects, down to nano-sized details of surfaces and internal cell structures. The research activities related to cultural heritage are using remote sensing technology such as, for example, Airborn Laser Scanner method (ALS), Geo-electric Resistivity, Ground Penetrating Radar, EM Conductivity Magnetometry, Multibeam Sonar, Sub-bottom Profiler, and other. For field research and during archaeological excavation methods such as Terrestrial Laser Scanner (TLS) measurements and photogrammetry provide incredibly accurate documentation of 3D shape[52]. All these techniques can produce vast amounts of 3D data, primarily in the form of 3D point clouds that cover the surfaces of the measured objects. Such data offers exciting opportunities for visualising the data. If the corresponding photographic texture is also available, one can generate views of the objects from any direction to produce virtual video fly-throughs, which helps in archaeological analysis but also brings cultural heritage to the attention of the general public. 3D data is usually calibrated so that models can be precisely measured and analysed (fig. 7) using various automated computer methods for segmentation and modelling of the data with a different surface or volumetric models[53].

	PP-R2008	PP-2009	PP-2013	PP-2015	PP-2017	PP-2018
	0	1	2	3	4	5
	μm	μm	μm	μm	μm	μm
Length	160000	155606	160958	152709	151768	150435
Width	51000 48000	50014	52274	50594	50348	48359
Thickness	25000 24000	25579	28810	23856	23585	22689
	+-μm / %	+-μm / %	+-μm / %	+-μm / %	+-μm / %	+-μm / %
Length+-% (l)		α	+5352 +3,44%	-897 -1,86%	-3838 -2,47%	-5171 -3,3%
			α	-8249 -5,12%	-9190 -5,74%	-10523 -6,54%
				α	-941 -0,62%	-2274 -1,49%
					α	-1333 -0,88%
Width+-% (b)		α	+2260 +1,41%	+580 +1,2%	+334 +0,68%	-1655 -3,31%
			α	-1680 -3,21%	-1926 -3,68%	-3915 -7,49%
				α	-246 -0,49%	-2235 -4,42%
					α	-1989 -3,95%
Thickness+-%		α	+3230 +12,63%	-1724 -6,74%	-1995 -7,8%	-2890 -11,3%
			α	-4954 -17,2%	-5225 -18,34%	-6121 -21,3%
				α	-217 -1,14%	-1167 -4,89%
					α	-896 -3,80%
	μm^3	μm^3	μm^3	μm^3	μm^3	μm^3
Volume		70653,6	80404,1	66382,8	65238,9	63871,9
	+-μm^3 / %	+-μm^3 / %	+-μm^3 / %	+-μm^3 / %	+-μm^3 / %	+-μm^3 / %
Volume +-%		α	+9751 +13,80%	-4271 -6,05%	-5414 -7,66%	-6781 -9,60%
			α	-14022 -17,44%	-15166 -18,86%	-16532 -20,56%
				α	-1145 -1,72%	-2511 -3,78%
					α	-1367 -2,1%

Fig. 7: Volumetric measurements on the five 3D models confirm the hypothesis that in ten years there was a change in the length, width and thickness of the palaeolithic point, as well as a reduction in its volume up to 20% (Enej Guček Puhar by CompareClaud)



Recent advances in 3D shape measurement are also used in an underwater environment. Unfortunately, most of the so-called active 3D measurement methods, employing lasers or structured light, are not suitable for an underwater application. Established powerful underwater measurement techniques, such as sonar, can detect only larger artefacts. There is a need, however, for greater precision also in underwater 3D measurement, especially in underwater archaeology. For detailed and precise documentation underwater, photogrammetry is at the moment the only viable and practical method[54].

Although photogrammetry has been used already at the very beginning of underwater archaeology, in the 1960s[55], this turned out to be excessively complicated and expensive due to complicated acquisition of precisely aligned underwater photographs and tedious manual image registration[56].

Recently, developments in computer vision enable automatic computation of geometric information

52 De Reu et al. 2014.

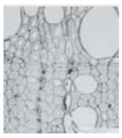
53 Jaklič et al. 2015; Guček Puhar et al. 2018.

54 Drap 2012; Erič et al. 2013; McCarthy – Benjamin 2014; Menna – Agrafiotis – Georgopoulos 2018.

55 Bass 1966; Throckmorton 1987.

56 Canciani et al. 2003; Erič et al. 2016.

from a large set of overlapping images. This approach to photogrammetry, which is called multi-image photogrammetry[57], is based on the principle of 'structure from motion'. Corresponding points in partially overlapping images are identified with the help of the SIFT algorithm[58] which works even if images have different magnification and orientation. If at least three corresponding points can be found in three consecutive images in a large set of partially overlapping photographs, the relative 3D position of that point can be computed. Not only a dense cloud of such 3D points but also the optical properties of the camera can be determined at the same time. That means that complicated and time intensive prior camera calibration is not needed. Since 2010 many commercial and open-source software programs exist for this purpose[59]. The output of these programs is a dense 3D point cloud which can be covered with detailed texture from the original photographs.



The photographs for the photogrammetric program need not be precisely aligned. Only following images should overlap for about 70%. The camera can, therefore, be held in the hands of a diver. In under-water archaeology, this is much faster than traditional documentation and lowers the cost due to a smaller number of diving hours and consequently increases also the safety of divers.

Although imaging underwater has many problems due to the nature of the medium and the environment, such as lack of sufficient light, refraction and scattering of light, these problems could be solved with some additional effort and time investment. On dry land, one can take photographs suitable for photogrammetric reconstruction from a greater distance. Underwater, however, we are limited by reduced visibility. Even in very clear water, one can not see much further than 15 m, in turbid waters the visibility can often be less than a meter. This circumstance means that we must take photographs for photogrammetric reconstruction from smaller distances which means that a larger number of photographs of sufficient quality, needed for corresponding point identification, must be taken. The lens with shorter focal length is routinely used in underwater photography to cover a more significant portion of a scene from a small distance. Even low-cost, compact cameras with a small sensor can, therefore, be as suitable for underwater photography as expensive SLR cameras with large 35 mm sensors[60].

Most published studies on the use of photogrammetry underwater are on documenting ancient shipwrecks[61]. The most recent systematic study of this topic from a technical viewpoint was published by McCarthy and Benjamin 2014.

Multi-image photogrammetry offers therefore extremely accurate digital models of objects measured underwater *in situ*. As we already argued, organic materials such as waterlogged wood, at each manipulation and due to environmental changes are exposed to the risk of substantial deformable changes in a brief period[62]. Digital models will on the other hand even after decades, centuries and millennia (if they survive) provide information accurate up to a thousandth of a millimetre as it was captured during the measuring process. Therefore the need to raise waterlogged artefacts from the water to document it is debatable.

If necessary, for post-production processed out of the water, laser and structured light scanners are also available for capturing the 3D shape, as well as a variety of microscopic measurements. Finally, for analysing the internal structure of artefacts, Computer Tomography and micro-CT is available.

When physical copies of artefacts out of many different materials (composite materials, metal, stone, wood, resins, plastics, and other) at different scales are needed, digital 3D models can guide additive technologies such as 3D printing[63] or subtractive technologies such as robot carving[64], a practise already well established in cultural heritage. However, the most crucial aspect of digital models is that they are stable. Best practices for long-term storage and structured access to digital information must be adhered though[65].

We argue that with advanced digital technologies the ethical standards exposed above can be relatively efficiently adhered to. Besides, new technologies allow unprecedented possibilities of presentation of archaeological wood, either just as virtual 3D models for observation and analysis or as physical copies of original artefacts.

How shipwrecks can be protected *in situ*

As mentioned, the dilemma still exists what to do with the discovery of waterlogged wood once it has been digitally documented. An accepted solution is physical protection *in situ* in several different ways, depending on the natural environmental conditions and the type of risk[66].

One of the most well-known and effective methods is to cover the entire heritage site with bags filled with sand, combined with an additional layer of sand. For an extra protective layer, covers and nets

57 McCarthy 2014.

58 Lowe 2004.

59 Remondino et al. 2012.

60 McCarthy 2014.

61 Drap 2012; Diamanti – Georgopoulos – Vlachaki 2013; Mahiddine et al. 2013; Seinturier et al. 2013; Balletti et al. 2015; Erič et al. 2014; Yamafune – Torres – Castro 2016.

62 Lobb et al. 2010; Antlej et al. 2011.

63 Neumüller et al. 2014; Molloy – Milič 2018.

64 Scopigno et al. 2017.

65 Rowley – Hartley 2008.

66 Manders 2011.

made of polyethene or geo-textile can be used, which must be anchored to concrete blocks or wedges. A combination of sandbags and protective covers can be finally planted with artificial seagrass. Such covers provide efficient and financially advantageous protection against damage caused by natural erosion, light anchors, trawling and at least in part also to looting. Moreover, it is useful in making the environment unfavourable for the growth of microorganisms, higher organisms, and corrosion, which slows down by an increment of marine sediments covering the endangered site.

However, irrespective of the *in situ* conservation method the underwater cultural heritage, in particular the most fragile wooden artefacts, are endangered to the highest degree in the vicinity of commercial ports all over the world by ever larger cargo ships and an increase of marine traffic[67]. Direct damage to sunken heritage is affected in particular by multi-ton anchors and chains, but also by induced turbulence by marine propellers and thrusters when ships manoeuvre into ports. In such cases merely covering the heritage site does not provide adequate protection. Possible protection of the most valuable wrecks could be achieved only with vast and costly artificial reefs in combination with traditionally covered sites.

Where marine traffic does not endanger the underwater sites, protective plates of fibreglass or metal mounted on prefabricated frames at the site, and further protected by a metal cage and sandy gravel can be used. This solution is particularly suitable for sites undergoing research. In case a shipwreck site is attractive and endangered by treasure hunters, but not archaeologically surveyed yet, this allows to transparently protect the site and at the same time enable visits to the site. According to the experience gained by the cultural heritage authorities in the Republic of Croatia, metal screens (i.e. cages) which are anchored to the bottom with concrete weights or wedges provide the best protection of exposed sites. They are equipped with two locked doors, which enable visits and ensure safe diving inside the cage. When a heritage site is not endangered by treasure hunters but due to aggressive bottom fishing, large multi-ton concrete pyramids, equipped with systems for signalling the obstacle to the fishing vessels can be put in place.

After a given shipwreck has been wholly documented and researched it might be sensible to present the found artefacts, the remains of the ship construction or even the entire shipwreck site to the general public for its educational, promotional and economic value. In combination with the recent policy of preservation of underwater heritage sites *in situ*, a new type of cultural tourism can be developed in the form of underwater parks and museums using various walkways above and under water. For those unable to visit underwater sites, a 3D documentation attainable with current research methods in the form of 3D models can be used as VR in a more traditional museum setting, or as AR applications on actual heritage locations. Such applications could raise the awareness of archaeological sites hidden below the water surface. An added value of such virtual museums could include all relevant scientific data about a given site, not only about archaeology but additional layers of information from geology, biology, ichthyology, ecology etc. could be added.

In nearby ports, towns, communities and touristic areas information centres could be set up, possibly containing scaled 3D models of relevant shipwrecks, anthropogenic underwater landscapes and natural underwater environment as a new aesthetic urban architecture site. Such models could be explored by children, blind and visually impaired visitors or other vulnerable groups.

Good practice from around the world employs submerged walking tubes to present wooden remains *in situ* or in unique aquariums. Underwater archaeological parks must use debris management to enable constant maintenance and conservation, and in some cases, stabilisation and restoration of endangered wooden remains.

What should we do?

The research community in the field of preservation and protection of organic materials, in particular of waterlogged wood, must reconsider the usage of currently available conservation methods for the consolidation of original artefacts and objects made of organic materials and waterlogged wood. Despite highly professional efforts to provide suitable microclimate conditions (i.e. temperature, relative humidity, lightning) exposure of waterlogged wood to an altered environment is costly, not working in the long term, and with the current digital advancement not acceptable anymore.

The discovered waterlogged wood belongs to the site where it was found since the conditions there were most favourable for its preservation that allowed our discovery in the first place. We propose that upon accurate 3D modelling that documents the shape and texture information and after analysis of the internal structure of artefacts reburial of such artefacts should be done. There have been several efforts in recent decades to develop re-burial and *in situ* methodologies for underwater heritage site protection[68].

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67 Erič – Poglajen 2014.

68 Good Practices: Manders 2011; Project SASMAP: Gregory – Manders 2015; Baiheliang; Alexandria Ancient Port; Croatian cage project: Bekič – Miholjek 2009; Bekič 2014; English Waterlogged Wood guideline: Brunning – Watson 2010; and others.

Fig. 8: In situ *shipwreck protection by metal cages implemented in the Adriatic sea in Croatia was recognised by UNESCO as one of the best self-sustainable systems of underwater heritage protection. Diver at protection cage in Cavtat, Croatia (photo Irena Radić©UNESCO, <http://www.unesco.org/new/en/culture/themes/underwater-cultural-heritage/protection/protection/preservation/>)*

The already developed methodologies should be studied further to find the most advantageous methods for the protection of organic materials. More attention should be devoted to the study of different habitats such as wetland, freshwater and marine environments; to differentiate between deep water and shallow water environments; to local geographical factors; to the stability of different types of organic materials and various tree species.

In the context of re-burial or *in situ* methods (Fig. 8) very delicate or precious small artefacts could not be protected adequately due to looting. In such cases, one can build so-called 'Controlled Natural Environmental Depositories', which can be located even in urban environments, in buildings, where continuous monitoring is much easier to achieve. A protocol of systematic, sustained and continuous monitoring of physical, biological and chemical changes in a controlled natural environment, supported by the latest digital technology and instrumentation should be established. In parallel, automatic monitoring and recording of vital changes in the physical appearance of artefacts, as well as of microbiological and chemical processes should be performed.

For some time already, the methodology of constructing replicas of attractive and well-known ships (Sun Ra, Uluburun, Kyrenia, Gyptis, Viracocha, Abora) has been used. However, for educational and sustainable heritage promotional purposes, we should also develop methodologies of 3D replicas at different scales, not only at full-scale. Virtual and augmented reality applications can supplement underwater heritage parks and museums. For such applications and purposes of new protocols, standards and guidelines are necessary that will enable sharing of data and applications for comfortable promotion and education of cultural heritage. New guidelines for sustainable and perpetual conservation of waterlogged wood, for reconstruction of replicas, for museums and heritage parks and for using all this in educational context must be established. Despite all the efforts, however, the automatic systems for observation and monitoring of original heritage sites and artefacts left *in situ* available to experts will continue to be significant.

Conclusion

Generations of researchers have tried to stabilise waterlogged wood for air exposed exhibition rooms or preserved it in depositories. Although the research was conducted in good faith, many of the attempts failed miserably. It is not possible to claim that we are now more qualified to protect restored wooden material or that we can guarantee the existence of wooden artefacts for more than a few hundred years. We should understand that different species of polymers substance (i.e. melamine, acrylates) which we introduce into the intercell space are not long-term tested and may not be able to assure long-term preservation of the artefacts.

On the other hand development of computer-based *in situ* underwater measurements, 3D printing technology and increased usage of IT technology in general public over the last decades, in general, give us new possibilities to develop new methodologies preserving waterlogged wood. Making exact virtual or physical copies of artefacts made out of wood and other degradable organic materials for display and education suggests that the original artefacts can be preserved *in situ* under the original conditions under which the artefacts have initially been preserved in the first place. This approach of preservation through replication is gaining a foothold also in other cultural heritage domains[69].

It is our moral obligation as researchers to do all that is possible to preserve waterlogged wood artefacts for the future generation which may have better analytical techniques and insight as available today. At the same time, we should strive to standardise new trustworthy methodologies which extend the stability of significant underwater heritage artefacts and prolong its life expectancy. Inevitably, despite all the conservation efforts, natural cycling of elements will end the existence of unspecified artefacts made of organic materials, but we may widen the window

[69] Reeser Lawrence 2015.

of opportunity to study and appreciate it by preserving the gist of its existence. The new technology enables this, so why not using it.

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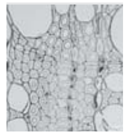

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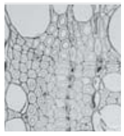

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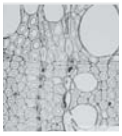

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