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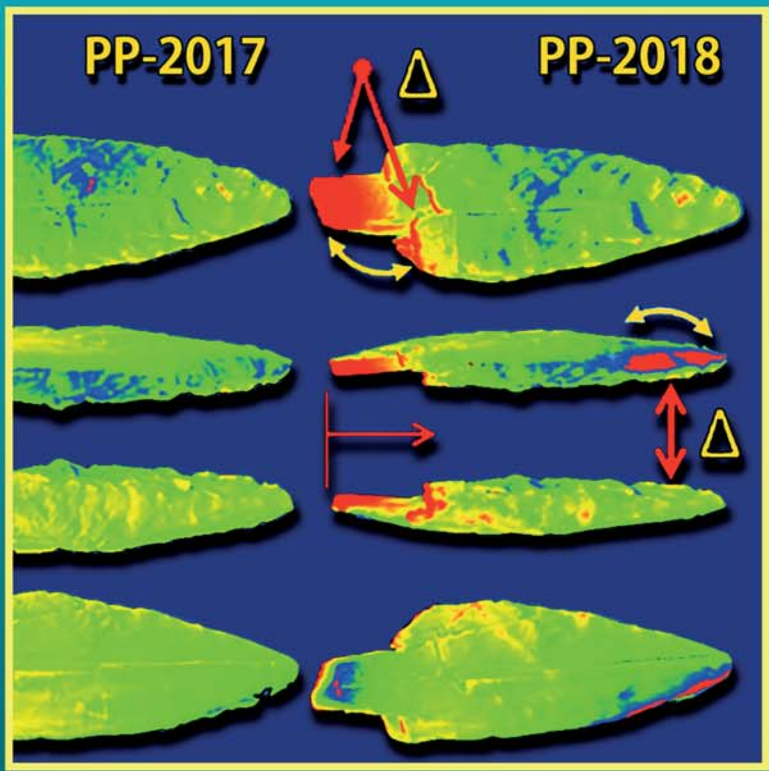

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Titelmotiv

Deformation monitoring (ex situ) of the deformation process of the palaeolithic point after conservation process 2013 and exposed to the climatic environment.

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The Necessity of Changing the Methodology of Preserving Waterlogged Wooden Objects

The Case of a Palaeolithic Wooden Point from the Ljubljanica River

Miran Erič – Enej Guček Puhar – Aleš Jaklič – Franc Solina

Abstract – In the last decade, we have witnessed revolutionary developments 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 printing, it is now possible to reproduce artefacts with high precision and hence reproduce objects at a user selected scale. The article describes the case of comparison and analysis of five 3D models of a Palaeolithic wooden point, a hunting tool from the Ljubljanica river. The comparison of the 3D models serves two purposes. The primary goal is to evaluate the changes of the artefact that occurred during this period and, accurately, to compare its shape before (in situ) and after the treatment (ex situ). The second goal is to assess which software tools are currently available for such comparison and how to effectively present or visualise the sometimes small but critical changes of shape. It is also necessary to continue researching new technologies for the protection of different types of wood, which will protect wooden artefacts against conditions that encourage degradation, deformation or even destruction. We must, therefore, rethink 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 vergangenen Jahrzehnt wurden wir Zeuge einer revolutionären Entwicklung digital unterstützter Informations- und Computertechnologie, die es uns ermöglicht, höchst exakte Modelle verschiedener Aspekte der Umwelt zu erstellen. Durch die Technologie dreidimensionalen Druckens ist es jetzt möglich, Objekte mit hoher Präzision und in einem frei wählbaren Maßstab zu reproduzieren. Der Beitrag beschreibt den Fall des Vergleichs und der Analyse von fünf 3D-Modellen einer paläolithischen hölzernen Lanzenspitze, einem Jagdwerkzeug aus dem Fluss Ljubljanica. Der Vergleich der Modelle hat zwei Ziele. Primär geht es darum, Veränderungen der Form Objekts zu untersuchen und genau zu vergleichen, die vor (in situ) und nach (ex situ) seiner Behandlung aufgetreten sind. Das zweite Ziel ist zu bestimmen, welche Software für einen solchen Vergleich aktuell verfügbar ist und wie man effektiv manchmal geringe, aber kritische Veränderungen der Form visualisieren kann. Es ist auch notwendig, weiterhin neue Technologien für die Konservierung verschiedener Arten von Holz zu erforschen, die Artefakte vor Bedingungen schützen, die Zersetzung, Deformierung oder gar Zerstörung hervorrufen. Wir müssen daher die Philosophie und Ethik der Konservierung überdenken und neue Konzepte für die Erhaltung und Präsentation hölzerner Artefakte entwickeln, was die Aufgabe jedes Museums bleibt.

1. Introduction

Several years ago, during the intensive preventive underwater archaeological research in the Ljubljanica riverbed near Vrhnika in Slovenia, a Palaeolithic yew wooden point was uncovered and recognised as a part of a hunting weapon[1]. Due to an unusual and lucky series of events the artefact was fixed in intact sediments without exposure to significant physical, biological and chemical activities which could destroy the point.

In this article we describe new results of volumetric and deformation analysis of five successive 3D models of the wooden point recorded between 2009 and 2018[2] to illustrate the importance of rethinking the philosophy and ethics of conservation methods and to further the implementation of new concepts for preservation and presentation of wooden artefacts for educational purposes, which remains the mission of any museum[3].

In addition, we also highlight the need to integrate new technologies and experts from other fields into the process, research and preservation of the remains of underwater cultural heritage[4]. The use of new technologies for the protection of the underwater cultural heritage (UCH) is also recommended by international documents such as the ICOMOS Charter for the Protection and Management of the Archaeological Heritage (ICOMOS

Fig. 1: One of the most significant conservation processes is still undergoing (since 2011) in The Guangdong Maritime Silk Road Museum (Nanhai No. 1 Museum), Yangjiang, Guangdong Province, China (photo Miran Erič)

1996), the UNESCO Convention on the Protection of Underwater Cultural Heritage, the London Charter, the Seville Principles, etc.

Particularities of protection of waterlogged wood

Waterlogged wood is an organic, carbon-based composite material that has been subjected to biodegradation[5]. 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 easily biodegradable polymers. Lignin, on the other hand, can resist biodegradation in waterlogged conditions. Compared to stone, ceramics, metal and bone matter, waterlogged wood (and other highly delicate organic materials) is more prone to natural decomposition when excavated and exposed to ambient oxygen, temperature and relative humidity conditions. Waterlogged wood from the cultural heritage sites is often in poor conservation status, as it has been exposed to physical, chemical and biological degradation[5]. Depending on the degree of degradation, artefacts can survive conservation treatments in order to stabilise the wooden structure and avoid shrinkage and decay. It is possible to maintain them by using individual or combined materials for conservation and freezing. In doing so, one must be as close as possible to the situation in situ. Wood can be impregnated with consolidation tools to ensure surface and / or internal reinforcement. In order to prevent the formation of microbes, preservatives (biocides) can be added to the healing solution. Most of the consolidators used in the past are no longer recommended due to their ability to decompose wood, such as cellulose and lignin, and to weaken its structure. In order to establish new methods of conservation, we must take into account the properties of the consolidating agent and its interaction with wood and other existing components and also with the environment. It is important for the consolidator to consider that (*in situ* or *ex situ*): it remains stable over longer periods; it is reversible; it penetrates and spreads evenly across the wood; it prevents dimensional changes and it preserves the original appearance of artefacts; it is compatible with wood, metal or other ingredients that may be present; has a low or no toxicity; and it prevents biodegradation and acidification of wood. The conditions and reasons for choosing an ideal consolidation agent should be thoroughly investigated regardless of whether we decide to protect the artefact in situ or ex situ[6].

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[7].

This is why it is necessary to reconsider the methods and techniques of conservation of waterlogged wood[8]. In doing so, we must take into account the general criteria, recommendations and standards that, for the effective preservation

* This work was supported by the Slovenian Research Agency, research program Computer Vision (P2-0214), the Ministry of Culture of the Republic of Slovenia.

1 Erič – Gaspari 2009; Gaspari et al. 2011.

2 Guček Puhar et al. 2018; Guček Puhar 2018.

3 Erič 2014.

4 Pearson 2014.

5 Schwabe 2006.

6 Delgado – Staniforth 2002; Jordan 2003.

7 Gregory – Manders 2015.

8 Christensen et al. 2012; Fix 2015; Erič et al. in print.

of underwater artefacts of cultural heritage, are imposed on the signatories of the UNESCO Convention, the London Charter and the Seville Principles. Notwithstanding current or future discussions[9] on the advantages or disadvantages of protecting waterlogged wooden artifacts *in situ*, *ex situ* or in new museum solutions (ie. Museum aquatories – e .g. Nanhai 1[10]; **fig. 1**), underwater archaeological parks[11], special water depots[12], thematic and mobile museums, thematic parks, virtual museums[13], IT/AI aquariums – cells with controlled, biologically steered hydrological climate and the possibility for indoor and outdoor display of chosen artefacts, logboat collections, etc., any future imperative of the conservation profession will remain only one: the wooden artefact must remain stable.

Today, it is imperative that archaeological, national and state institutions for the preservation of cultural heritage and museums adopt a new philosophy of preserving waterlogged wooden object *in situ*[14]. Strategies *in situ* (i.e. preservation of artefacts in their finding-places) and contemporary 3D strategies for visualising artefacts are becoming a modern form of protection and public presentation of UCH remains[15]. According to the recommendations of international conventions (UNESCO Convention on the Protection of Underwater Cultural Heritage; UN Convention of the Law of the Sea; ILA International Convention on the Underwater Cultural Heritage) and agreements (ICOMOS Charter; The London Charter; The Sevilla Principles etc.) they should also be the most appropriate way of preserving and protecting artefacts.

Significant international agreements about the use of modern computer technologies and optimal protection of artefacts of underwater cultural heritage in situ

The ideas of protecting waterlogged wood *in situ* is not the consequence of a planned exploration of the methods of protecting waterlogged wood in the *in situ* conditions (finding-place)[16]. This is primarily the result of two processes that forced the traditional conservation profession[17] to begin to explore new methods and techniques of waterlogged wood protection *in situ*.

The first process was the expansion of underwater archaeology[18] and the discovery of many new cultural heritage underwater sites. The second process is a consequence of the increasing storage problems of museums at the end of the last century, the troubles with the protection of underwater artefacts *ex situ* / *in vitro*, and the ever-increasing demands for public presentations of underwater artefacts.

These two processes have encouraged the emergence of an international initiative to protect underwater cultural heritage (UCH) in situ[19].

In 2001, the UNESCO Convention for the Protection of the Underwater Cultural Heritage[20] was adopted[21], the text of the London Charter[22] was completed in 2009 and the Seville Principles[23] were harmonised in 2011. These international agreements[24] represent the basis for the future philosophy of the protection of underwater cultural heritage. They emphasise the protection of archaeological and underwater artefacts in situ, and require active use of modern technologies in the field of archaeological research and in the protection of cultural heritage[25].

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9 Erič 2014.

10 At the International Symposium on the Discovery and Research of Nanhai I (24.–27. November 2017), the presentation "Discovery and Research of Nanhai I" was given by Sun Jian, Chief Technology Officer of Underwater Archaeology Unit, National Centre of Underwater Cultural Heritage and Cui Yong, Deputy Director of Guangdong Provincial Institute of Archaeology. The presenters explained that even in highly controlled and regulated climate conditions (temp. at 18°C and RH 70-80%) and daily (24/7) automatic water dispensation over the whole digging workspace, the wooden ship construction and the shape of some wooden parts changed due to swelling and bending even up to 25%.

11 Garcia – Barreiros 2018.

12 Gelbrich – Poelmans 2013.

13 Sanders 2004.

14 Delgado – Staniforth 2002; Erič 2014.

15 Richards et al. 2009.

16 Akcar et al. 2008.

17 Pickard 2001.

18 Strate 1995.

19 Gregory – Manders 2015.

20 Rules 1–8 define general principles. Key among these are the complete prohibition of commercial exploitation of underwater cultural heritage and the principle that in situ preservation should always be considered as a first option. The rules also cover aspects such as project design, conservation, documentation, and reporting (2001 UNESCO Convention for the Protection of the UCH).

21 Forrest 2002.

22 The London Charter for the Computer Based Visualisation of Cultural Heritage represents the most significant attempt to establish internationally-recognised principles for the use of digital visualisation by researchers, educators and cultural heritage organisations. A decade on – with the arrival of virtual reality platforms, easy to use photogrammetric software and ever-more sophisticated scanning hardware – the possibilities for representing the past through 3D Visualisation have increased exponentially. However, the progress in 3D Visualisation of cultural heritage has not been commensurate with advances in digital technology. Few 3D Visualisations measure up to the Charter's guidelines, especially in terms of articulating their underpinning metadata in a transparent fashion. Digital past environments generally remain confined to the realm of dissemination and are perceived to lack the credibility of conventional scholarly outputs.

23 Principle 4.3: In so far as many archaeological remains have been and are being restored or reconstructed, computer-based visualisation should really help both professionals and public to differentiate clearly among: remains that have been conserved "in situ"; remains that have been returned to their original position (real anastylosis); areas that have been partially or completely rebuilt on the original remains; and finally, areas that have been virtually restored or reconstructed virtually (The Seville Principles).

24 Staniforth et al. 2009.

25 Curci 2006.

Today, the protection of underwater artefacts and of waterlogged wood is no longer just a domain of archaeological and conservation science. They have become interdisciplinary sciences that require the active participation of archaeologists, conservators, museologists, biologists, chemists, computer scientists, geologists, mathematicians, physicists and other experts in the planning and protection of cultural heritage *in situ* or *ex situ*. We can no longer imagine efficient and effective protection of underwater cultural heritage without new computer and information technologies[26], without artificial intelligence, 3D technology, multimedia, robotics[27], computer analysis of deformations, AR/MR & VR techniques etc.

The imperative of these efforts is to develop such methods and techniques of protection of waterlogged wood (*in situ* or *ex situ*) that will meet the conditions of the finding-place and the type of wood, while the artefact must remain optimally stable.

2. Software tools for 3D evaluation, interpretation and comparison of data sets representing 3D models of cultural heritage artefacts

Many open source software tools for 3D evaluation and 3D interpretation are available today and a user is faced with a serious dilemma which tool to choose[28]. There are no systematic comparisons of usability, usefulness and practical possibilities of individual programs. The user must satisfy himself with formalistic explanations regarding the use of computing platforms (WINDOWS, Mac OS X, LINUX, SOLARIS, UNIX, BSD, etc.) and the format of the data (PLY, STL, OFF, VRML, U3D, OBJ, ASCII, etc.). When it comes to basic 3D model processing, such as archiving or later replication, the choice for the user is relatively simple. However, it is more difficult to select an appropriate graphic program when using it as an analytical tool to further process the 3D point clouds and the corresponding triangulation networks.

For 3D analytical treatment and evaluation, 3D scanners should offer the user a set of tools for analysis and comparison, such as model measurements, comparison and alignment with other models, placement of models in cartesian space, graphic and statistical processing, insertion of new applications, transfer of data between different programs, a wider range of formats, and converting them to others for processing of more suitable formats, etc.

In order to avoid the initial dilemma regarding the choice of a more suitable software tool, it is necessary to prioritise clear goals and modes of processing (graphical, statistical, numerical, volumetric ...), hypothetical assumptions, evaluate mathematical algorithms, investigate the geometric characteristics of the 3D model and select the most suitable record format.

In the case study presented in this article, we selected among a large set of open-source graphic software tools some of the most frequently mentioned ones in archaeological research reports. These are Blender,[29] MeshLab[30] and CloudCompare[31](CC). After ad-hoc program verification of these three open-source graphical software tools we selected the open source graphical computer program CC (v2.9.1) for volumetric and geometric comparison of 3D point clouds and triangulation networks, which is the basis for deformation analysis of the artefact. CC enables the use of a range of advanced algorithms (such as ICP, C2C, M3C2) for registration, pattern replication, colour / normal / scalar processing, basic statistical processing, interactive segmentation, cloud-cloud compilation, cloud-network / plots, comparison between cloud points and flat models etc. Dynamic colour processing system provides effective visualisation of the scalar field for each point.

Systematic use of CC in archaeology in connection with deformation analysis of artefacts has not been established so far.[32] However, it can successfully, accurately and visually respond to our initial hypothetical suspicion of changes that occurred in the palaeolithic wooden point. This comparison has clarified the situation since we have at our disposal five 3D models of the same artefact which were taken at different time points since its discovery. CC may become the *de facto* standard computer application on which a method for shape monitoring of controlled artefacts at predetermined time intervals could be developed.

[26] Remondino 2011; Antlej et al. 2011; Erič 2013; Remondino – Campana 2014.

[27] Scaradozzi et al. 2013.

[28] Remondino 2011; Remondino – Campana 2014.

[29] Blender is a free and open-source 3D computer graphics software toolset used for creating 3D printed models and interactive 3D applications. Blender's features include 3D modeling, UV unwrapping, texturing, raster graphics editing, rigging and skinning, fluid and smoke simulation, particle simulation, soft body simulation, sculpting, animating, match moving, rendering, motion graphics, video editing and compositing. See: <http://www.blender. org>.

[30] MeshLab is a 3D mesh processing open-source software system that is oriented towards the management and processing of unstructured large meshes and provides a set of tools for editing, cleaning, healing, inspecting, rendering, and converting these kinds of meshes. It includes a tool for the registration of multiple range maps based on the iterative closest point algorithm. MeshLab is available for most platforms, including Linux, Mac OS X, Windows and, with reduced functionality, on Android and iOS and even as a pure client-side JavaScript application called MeshLabJS. MeshLab is used in various research contexts, like cultural heritage, surface reconstruction, palaeontology, orthopedic surgery, and desktop manufacturing.

[31] See: <https://www.danielgm.net/cc/>.

[32] Nevertheless, Florent Duguet and Daniel Girardeau-Montaut (Duguet et al. 2004) reported of its usefulness in archaeology.

3. Volumetric comparison of 3D models of the palaeolithic wooden point *in situ* and *ex situ* / *in vitro* (monitoring, analysing and case study)

In September 2008, a wooden point (*European yew*; *Taxus baccata*) was discovered by underwater archaeologists during a preventive archaeological survey of the riverbed of the Ljubljanica river. A radiometric study[33] showed that the wood is older than 40.000 years. This wooden point is so far just one of only eight known wooden palaeolithic artefacts found in Europe[34].

Since its discovery in 2008 and until 2013, the wooden point was stored in conditions as existed at the site of detection (*in situ*). The artefact was stored in distilled water in a refrigerator at a temperature of 4–7 degrees Celsius.

After the artefact's true importance was finally determined, the artefact's protection and conservation were necessary. It is well known that the conservation of waterlogged wooden artefacts is very challenging. The conservation process of waterlogged wood can induce substantial changes to the shape and size of the artefacts. However, it was decided to conserve the palaeolithic wooden point using (*ex situ*) conventional methods by infusing the artefact with melamine and the artefact was sent to the Römisch-Germanisches Zentralmuseum in Mainz where the preservation procedure was performed.

In 2013, the process of conservation of the wooden point with melamine resin began (*ex situ*). The preservation process lasted until 2015. With certain corrections it was completed in 2017.

During the first inspections, archaeologists estimated that the point had changed. It was seemingly smaller and the nasal part of the point was visibly bent. Archaeologists were interested in any changes that occurred to the point before and after conservation. This was the reason why archaeologists and computer scientists tried to prove possible changes in the point using credible technology and computer tools.

Methods and techniques

– 3D modelling of the Palaeolithic wooden point
In the years 2009–2018, five 3D models of the palaeolithic wooden point were produced[35].

The first 3D model (PP-2009) was made after one year of storage in distilled water in a refrigerator and at a temperature of 4–7 degrees Celsius. The second 3D model (PP-2013) was made after intensive irrigation and before adding melamine resin. The third 3D model (PP-2015) was made after adding melamine resin, thermal treatment (60 degrees Celsius), film drying, and after fixing artefact parts with Paraloid B72. The fourth 3D model (PP-2017) was made after the final stage of preservation at The Archaeological Research Institute Mainz, and the fifth model after handing over the artefact to the City Museum in Ljubljana (PP-2018). 3D modelling/scans of the artefact was done with scanners: ZSscanner 800 (PP-2009), Atos III (PP-2013 & PP-2015), Atos Triple Scan (PP-2017) and Micro XCT 400 (PP-2018).

– Computer methods and techniques of comparison of 3D models
For the volumetric processing and comparison of five 3D models, we selected CloudCompare (CC), an open source graphical computer program that uses several advanced algorithms to process and compare two 3D models.

CloudCompare (CC) can process 3D point clouds and triangular meshes. It was originally designed to perform comparisons between two (C2C) dense 3D points clouds or between a point cloud and a triangular mesh. Later, it was extended to a more generic point cloud (C2M and M3C2) processing software, including many advanced algorithms – ICP (i.e. registration, resampling, colour / normal / scalar fields handling, statistics computation, sensor management, interactive or automatic segmentation, display enhancement, etc.). The deformation monitoring of the Palaeolithic point was carried out with the C2M algorithm.

Results

The particular goal is to compare and analyse vertices and polygons of five 3D models of the palaeolithic wooden point to compute the differences in dimensions, volumes and cross-sections of the models. The basic purpose of the volumetric comparison of the 3D models of the palaeolithic wooden point was to investigate and determine the advantages or disadvantages of protecting waterlogged wood from the sites of cultural heritage *in situ* or *ex situ* conservation techniques, in our case with melamine resin $C_3N_3(NH_2)_3$ or $C_3H_6N_6$.

– Volumetric changes of artefacts during its protection in situ
The comparison of 3D models of wooden points in the period of 2009-2013 (PP-2009 and PP-2013) could show us the possible changes (length, width, thickness, volume, ovality, deformation and degrada-

[33] A radiometric study in the Beta Analytic Laboratory in Miami showed that the wood (yew) is older than 43,970 years, and the re-dating in Oxford yielded 38,490 ± 330 years.

[34] Eight wooden palaeolithic artefacts in Europe: Clacton-on-Sea, GB 1911 (424–374 ka date secondary); Lehringen, Germany 1948 (115–125 ka date by stratigraphy); Abric Romani, Spain 1992 (45–49 ka date secondary); Schöningen, Germany 1995 (337–300 ka date secondary); Mannheim, Germany 2004 (18 ka BP date by AMS); Sinja Gorica, Slovenia 2008 (40 ka BP date by AMS); Poggetti Vecchi, Italy 2012 (171 ka date secondary by UDM); Aranbaltza, Spain 2014 (90 ka date secondary by OSL).

[35] Five 3D models have been made: 2009: INTRI d.o.o. (Slovenia); 2013, 2015 and 2017: The Archaeological Research Institute Mainz (Germany), where the artefact was conserved; 2018: The Slovenian National Building and Civil Engineering Institute Ljubljana (Slovenia).

tion) of the artefact under conditions such as at the finding-place / on site (*in situ*). During this period, the point was irrigated in distilled water, which was periodically changed.

Analysing the possible changes in the palaeolithic wooden point (waterlogged wood) in conditions *in situ* can be considered as the benchmark model (index = 100), which was created in 2009 (Y0). It was compared with the model that was made in 2013, when the intensive conservation process of irrigation was started (tab.1–2; fig. 2).

Volumetric data and changes were presented using the composite statistical method – the index. In this way, we can more clearly demonstrate the changes of the artefact. We compared the first (PP-2009) and the second (PP-2013) models. Due to intensive irrigation (preparation for canning), the second model swelled and changed its dimensions (length + 3,44%, width + 1,41% and thickness + 12,63%). Intensive irrigation of the artefact in water influenced the increase in its volume (+ 13,8%).

The volumetric data does not show any other deviations (tab. 2). Ovality and shape remained unchanged. A comparison of the cloud of 3D model points did not confirm the deformation or degradation of the artefact.

– Volumetric changes of the artefact after the use of conventional conservation methods ex situ / in vitro

	In situ			**Ex situ**		
	water			melamine	*air*	
	PP-R* 2008	PP** 2009	PP** 2013	PP** 2015	PP** 2017	PP** 2018
	>1	1	2	3	4	5
	µm	µm	µm	µm	µm	µm
Lenght	160000	155606	160958	152709	151768	150435
Width	51000 48000	50014	52274	50594	50348	48359
Thickness	25000 24000	25579	28810	23856	23585	22689
***Lenght* (1) ± µm ± %**		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) ± µm ± %**		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* (h, d) ± µm ± %**		α	+ 3230 **+ 12,63%**	- 1724 **- 6,74%**	- 1995 **- 7,80%**	- 2890 **- 11,3%**
			α	- 4954 **- 17,20%**	- 5225 **- 18,34%**	- 6121 **- 21,3%**
				α	- 217 **- 1,14%**	- 1167 **- 4,89%**
					α	- 896 **- 3,80%**
Volume	µm³	µm³	µm³	µm³	µm³	µm³
		7065,6	*80404,1*	*66382,8*	*65238,9*	*63871,9*
± µm³ ± %		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 **- 13,78%**
		OSMOSIS			α	- 1367 **- 2,1%**

* PP-R 2008 manually measured and visually estimated distance
** PP 2009 - PP 2018 measured distance with CloudCompare computer program

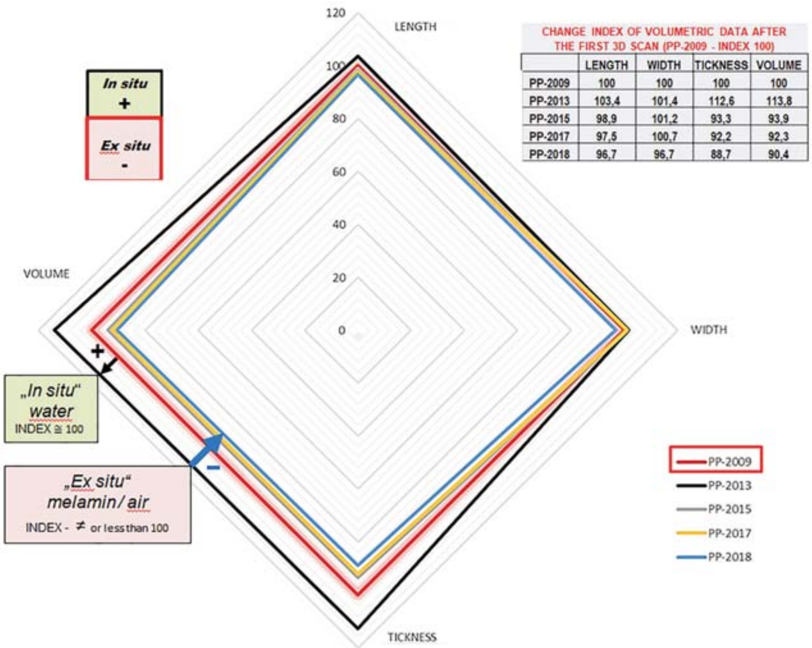
Tab. 1: Volumetric comparison of five 3D models of the palaeolithic wooden point from the Ljubljanica river

Comparison of 3D models of wooden points in the period 2013–2018 (PP-2013, PP-2015, PP-2017 and PP-2018) analysing the possible changes (length, width, thickness, volume, ovality, deformation and degradation) of the artefact design conservation (*ex situ / in vitro*) with melamine resin (C3H6N6).

Protection		**In situ**		**Ex situ**		
3D model		**PP-2009**	**PP-2013**	**PP-2015**	**PP-2017**	**PP-2018**
			Δ	Δ	Δ	Δ
Volumetric parameters ±	Length	-	*Enlargement* +*	*Reduction* –	*Reduction* –	*Reduction* –
	Width	-	*Enlargement* +*	*Reduction* –	*Reduction* –	*Reduction* –
	Thickness	-	*Enlargement* +*	*Reduction* –	*Reduction* –	*Reduction* –
	Volume	-	*Enlargement* +*	*Reduction* –	*Reduction* –	*Reduction* –
	Deformation	-	***No***	***Bending***	***Bending***	***Bending***
	Degradation	-	***No***	***Crack***	***Crack***	***Crack/Fracture-?***
	Ovality	-	***No***	***Change***	***Change***	***Change***

* in our case study there was an increase due to intensive irrigation of the artefact in an aqueous solution (the pre-preparation phase for the conservation process)

Tab. 2: Volumetric changes of artefacts in situ and ex situ (conservation with melamine resin)



CHANGE INDEX OF VOLUMETRIC DATA AFTER THE FIRST 3D SCAN (PP-2009 - INDEX 100)

	LENGTH	WIDTH	TICKNESS	VOLUME
PP-2009	100	100	100	100
PP-2013	103,4	101,4	112,6	113,8
PP-2015	98,9	101,2	93,3	93,9
PP-2017	97,5	100,7	92,2	92,3
PP-2018	96,7	96,7	88,7	90,4

Fig. 2: Change index of volumetric data after the first 3D scan in 2009 (index 100); in situ (water condition); ex situ (melamin treatment & exposed to the meteorological environmental condition) consequently dimensional and structural deformation and degradation

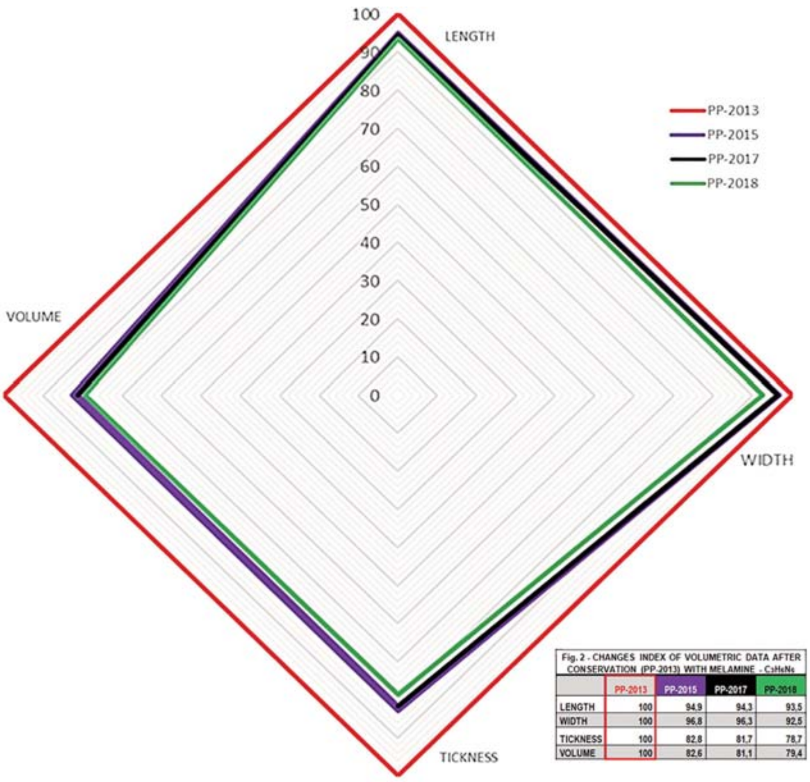


Fig. 2 - CHANGES INDEX OF VOLUMETRIC DATA AFTER CONSERVATION (PP-2013) WITH MELAMINE - $C_3H_6N_6$

	PP-2013	PP-2015	PP-2017	PP-2018
LENGTH	100	94,9	94,3	93,5
WIDTH	100	96,8	96,3	92,5
TICKNESS	100	82,8	81,7	78,7
VOLUME	100	82,6	81,1	79,4

Fig. 3: Changes of volumetric data after conservation (index PP-2013=100) with melamine resin (ex situ) C3H6N6

For the analysis of the possible changes of the Palaeolithic hunting weapon under *ex situ* conditions was the reference model (index = 100), which was created in 2013. It was compared with the models that were created in 2015, 2017 and 2018 when the intensive conservation process was completed. Volumetric data and changes were presented using the composite statistical method (the index).

A significant change in the palaeolithic point occurred during the preservation process (volumetric reduction of all dimensions and volume, bending, shape change). A larger deviation of dimensions is the result of irrigation, swelling, adding consolidation means, etc. All volumetric measurements show that the chosen classical conservation method has a strong (decisive) effect on the deformation process. Today's practice in conservation of this type of waterlogged wooden finds by means of melamine is unfortunately deficient and unsatisfactory.

Although the first signs of deformation of the point were partially indicated in the PP-2015 model, the deformation process of the point can be clearly identified in the PP-2017 model. Even more obvious was the deviation of the root work in the cross-sections of the palaeolithic point. The C2M algorithm found a smaller bending of the upper part of the point, which was not observed until then. The 3D CT scan additionally highlighted the possible assumption that the deviation at the top of the point is the result of two opposite internal processes in the upper and middle part of the artefact. The first internal process is shrinkage, the second process is bending.

A comparison of 3D models confirmed that there were significant changes of the artefact. These were particularly prominent in the preservation phase (2013–2015) when we identified changes and deformations along all three axes of the artefact model as well as in its volume.

Volumetric measurements of the point (length – width – thickness) confirmed the initial assumption that in the last five years (2013–2018) there have been certain changes in size, volume (also indirectly in weight) and ovality. The point shrank in all three directions (tab. 1). The length is shorter by 1,1

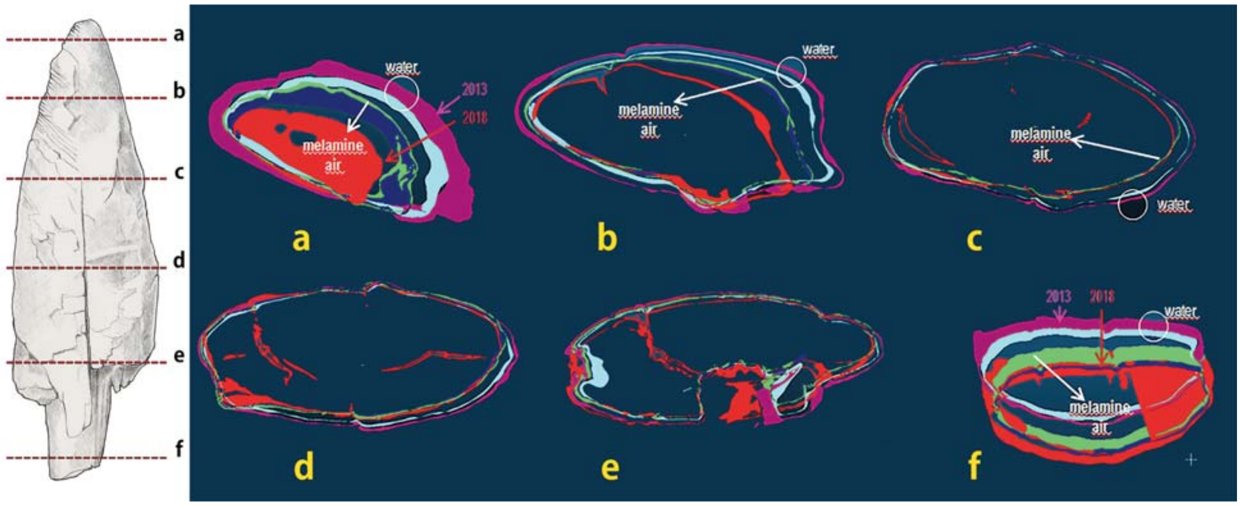


Fig. 4: Deformation monitoring: changes in the six cross-sections of the palaeolithic point (2009–2018)

mm, the width is smaller by 3,9 mm and the thickness by 6,1mm.

This reduction in dimensions is due to the process of the selected conservation process of water-logged wood with melamine resin (irrigation, swelling, adding consolidators, etc.). All volumetric measurements indicate that the selected preservation method has a strong and decisive effect on the deformation process of wood (yew). Changes in dimensions in the PP-2015, PP-2017 and PP-2018 models show a certain moderation, but not stabilisation.

A comparison was made between the PP-2013, PP-2015 and PP-2017 models, which in the deformation analysis are the most prominent. Measurements show (fig. 6) that the artefact was significantly deformed and degraded in the time interval between 2013 (start of conservation) and 2015/2017 (completion of preservation). Four years after the completion of the conservation, the point was thinner in thickness by 18,3% (5,2 mm), shorter by 5,7% (9,2 mm) in length and narrower by 3,7% (1,9 mm). Archaeologists faced similar problems with other wooden palaeolithic artefacts, namely how archaeological wood reacted to the conservation process (cp. Clacton, England; Aranbaltza, Spain).

The volume of the point confirms the same trend (tab. 1), as one can observe on the length, width and thickness of the artefact (fig. 3).

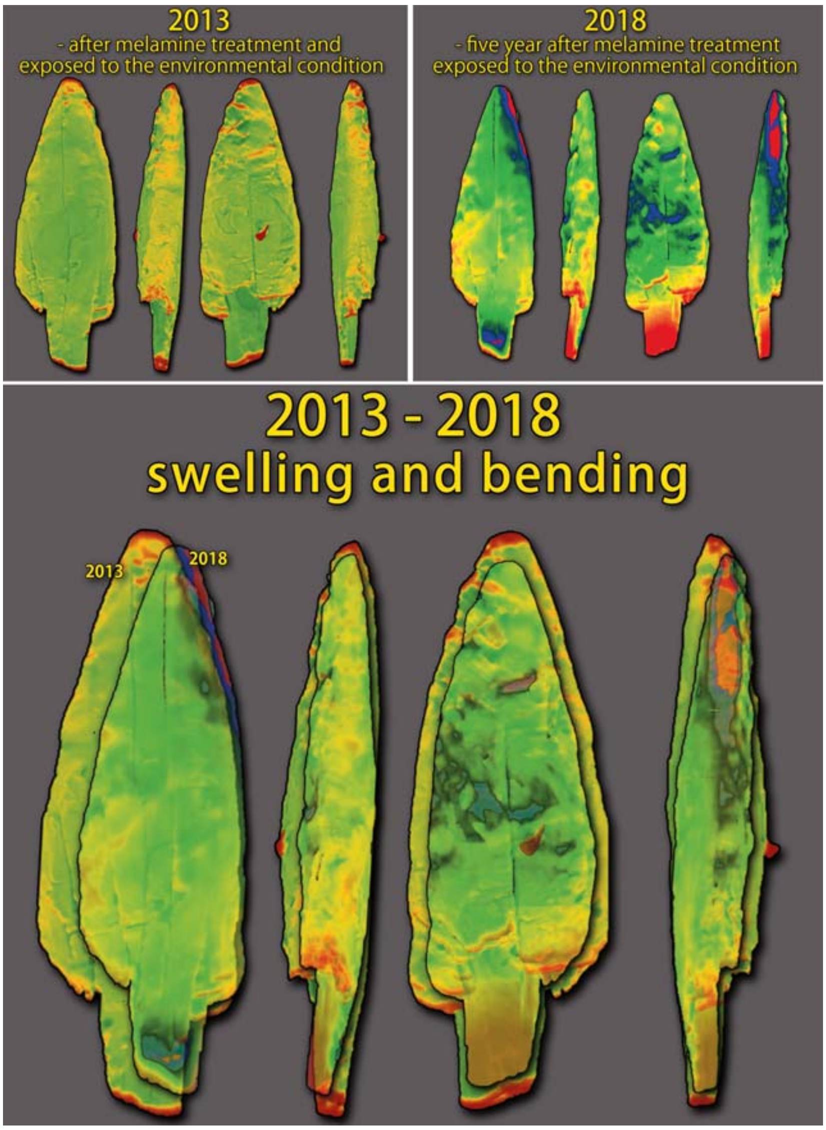


Fig. 5: Deformation monitoring (ex situ) of the deformation process of the palaeolithic point after 2013; Comparison of models PP-2013 and PP-2018

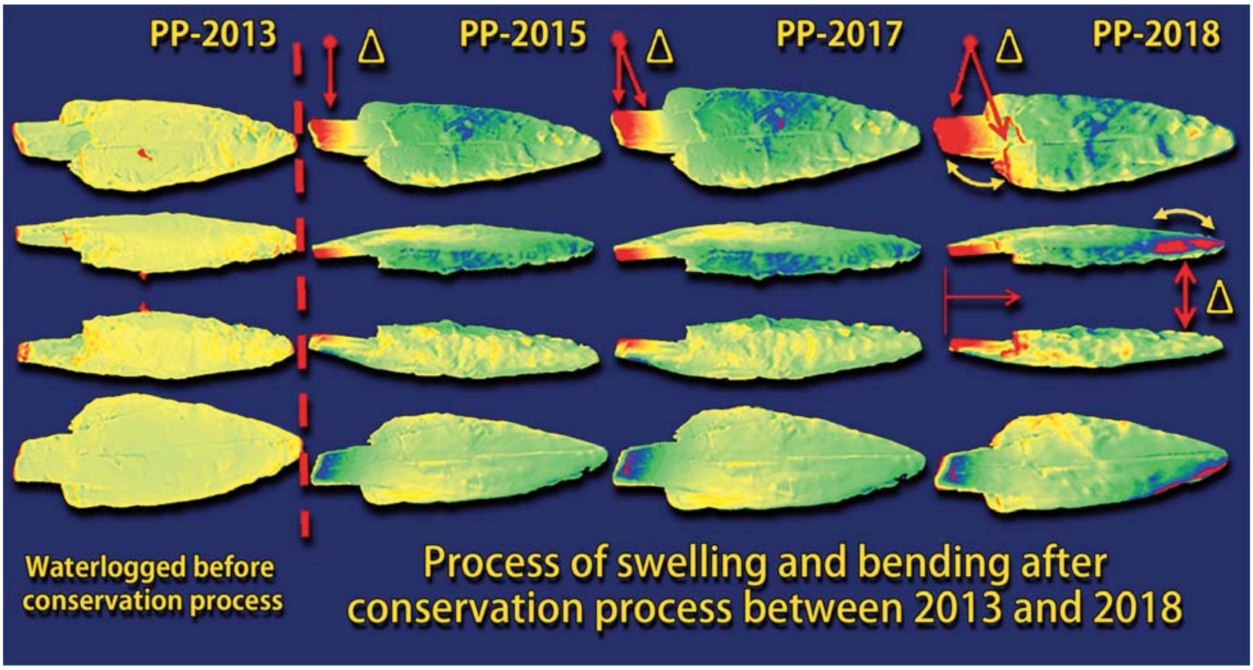


Fig. 6: Deformation monitoring (ex situ) of the deformation process of the palaeolithic point after conservation process 2013 and exposed to the climatic environment

Compared to 2013 (PP-2013), the volume of the model PP-2018 decreased by 1,7 µm3 or up to 20.6% (fig. 5). The decrease in volume and hence the weight of the point is influenced by the same factors that caused the changes in its length, width and thickness.

– Deformation monitoring
We measured the risk of deformation of the wooden point with the C2M (cloud-mesh) algorithm. We compared all 3D models (tab. 1–2; fig. 4–6). Due to intensive irrigation (preparation for canning), the second model swelled strongly and changed its dimensions more severely (length + 3.44%, width + 1.41% and thickness 12.63%). Although the first signs of deformation of the point were partially indicated in the PP-2015 model, the deformation process of the point can be clearly identified in the PP-2017 model. The measurements showed that the deformation processes take place in two directions: in the direction of bending and in the direction of contraction of the point. The bending of the point was more prominent. The deviation at the intersection of the socket and point was 0.8 mm in comparison with the PP-2009 model, while its deflection at the root of the socket was already 4.1 mm.

Even more obvious was the deviation of the root of the transverse cut. The C2M algorithm found a slight bending of the upper part of the point (approximately 3–6 cm below the point), which was not observed until then. In the PP-2018, the CT scan further highlighted the possible assumption that the deviation found at the top of the point is the result of two opposite internal processes in the upper and middle part of the artefact. The first is shrinkage, the second is bending. These two processes were intensified in model PP-2018 and became a risk factor. Graphic comparisons (fig. 6) additionally point out that the middle part of the spike is unevenly crushed (blue raster) and causes bending of the upper side of the point. In addition, model PP-2018 found that the deviation of the lower root part is already progressing towards the junction of the nasal part and the point (emphasised red raster).

Data and measurements confirm that the wooden point has not stabilised after conservation (2015), but is facing internal counter pressures that needs to be carefully monitored and controlled. A plan to protect the point should be prepared as it is a precious artefact of global cultural significance in order not to be left to natural uncontrolled processes leading to a possible collapse of the artefact.

To illustrate the swelling and contraction process in all five models, a transverse cut in the middle of the 3D models was made. The outer edges of the transverse cuts were stained differently and then merged into one image. The cross-section confirmed the contraction in the dimensions of the point (fig. 6). The maximum cross-sectional area of model PP-2013 (pink line) deviates from other models in all dimensions (l, d, b, V) for already known reasons (swelling, preparation for preservation). On a somewhat smaller scale, than PP-2013 model has the cross-section of model PP-2009 (blue line). The shifts of both models are consistent in shape, although they vary in size from 1 to 1.8 mm. This circumstance is important because it proves that the deformation of artefact has not occurred in the time interval 2009-2013 when the artefact was stored primarily in distilled water and at the appropriate temperature (*in situ*). There was a swelling that did not affect the shape of the point.

For the first time (tab. 2), we can find a more pronounced deformation of the artefact, i.e. shape change, on the lower and longitudinal sides of model PP-2015 (*ex situ*). On the basis of this observation, one can conclude that the deformation of the point occurred after completion of the irrigation of the point, that is, either in the final stage of adding the consolidating agent or in the stage of rapid thermal and natural drying of the artefact. The PP-2015 model of the artefact has taken on a new form.

4. Discussion

The results obtained during this research project can be summarised as follows:

- The intention to compare the five 3D models of the palaeolithic point measured between 2009 and 2018 is not to discuss the quality of the conservation method by Melamine per se;
- the conservation of waterlogged wood, irrespective which of the contemporaneous methods (melamine, polyethylene glycol, sucrose etc.) is used, is still a delicate and somewhat uncertain process with regards to the long-term survivability of such artefacts;
- however, the most harmful process for degradation of the waterlogged wood which is exposed to the climate conditions is heavily controlled;
- differences in volumetric measurements were observed of the artefact *in situ* and the artefact *ex situ*;
- *in situ*, the artefact did not significantly change its dimensions nor shape; more intensive changes (length, width, thickness and volume), as well as certain deformation changes of the artefact (deviation, bending, signs of fractures) have been volumetrically confirmed in the state of *ex situ* (after preservation) (tab. 2);
- computer software tools and equipment used (3D recorders, photogrammetry, computing tomography, 3D modelling, software tools such as CloudCompare, etc.) have been certified as suitable new technological tools for identifying and monitoring changes of artefacts[36].
- Volumetric measurements and deformational analysis that were carried out indicate that the process of preserving waterlogged wood of yew with melamine resin does not ensure a permanent stabilisation of the artefact;
- The case study highlighted the need to take into account the recommendations on the use of modern computer technology and the priority protection of artefacts of underwater cultural heritage *in situ*[37], as recommended by: UNESCO Convention on the Protection of the Underwater Cultural Heritage (adopted in 2001), the European Convention on the Protection of the Archaeological Heritage (1992), the ICOM Code of Ethics for Museums (2004), The London Charter (2001) and the Seville Principles (2011);
- Alternative methods for preservation of important waterlogged wooden artefacts should be developed where the preserved artefacts remain in the watery environment. However, such an environment should be supported by new technology (automatic measurement and control of microbiological changes, cavitation supported cleaning, artificial intelligence).

At the same time, research also confirmed that the development of new computer-assisted technologies in underwater research (3D modelling, 3D measurements, 3D replication, 3D visualisation and Augmented Reality) opens up new possibilities for the development of modern methodologies and technologies for the protection and presentation of archaeological artefacts[38]. The production of precise virtual or physical copies of artefacts made out of degradable organic materials (wood) for disassembly and education allows the original objects to be preserved in original conditions (*in situ*), where they have been preserved for many millennia prior to their discovery (e.g.: replicas of well-known ships such as Sun Ra, Uluburun, Kyrenia, Gyptis, Viracocha etc.).

5. Conclusion

Today, it is imperative that archaeological, national and state institutions for the preservation of archaeological cultural heritage and museums adopt a new philosophy of preserving waterlogged wooden objects *in situ*[39]. It is our obligation to implement the principles of the UNESCO Convention on the Protection of the Underwater Cultural Heritage (adopted in 2001), the European Convention on the Protection of the Archaeological Heritage (the Valletta Convention or Malta Convention 1992), the ICOM Code of Ethics for Museums (2004), The London Charter (2001) and The Seville Principles (2011).

It is also necessary to continue researching new technologies for the protection of different types of wood, which will protect artefacts made out of wood against conditions that encourage degradation, deformation or even destruction.
New computer 3D technologies and software tools allow not only sophisticated replication of artefacts. 3D modelling, mapping and documenting can store a large array of volumetric and other important data (texture, colour, dimensions, etc.) that can be analysed, evaluated and explored without interference with the arte-

36 Bandiera et al. 2013.

37 Aznar Gómez 2018.

38 Bandiera et al. 2015.

39 Gregory – Manders 2015; Emesiochel et al. 2017.

fact itself, since the artefact can be safely preserved under conditions *in situ*. This approach to 'preservation' through replication is becoming an indispensable standard defined in archaeology and in the preservation of cultural heritage by the UNESCO Convention for the Protection of Underwater Cultural Heritage, the London Charter, the Seville Principles and other international documents and projects[40].

New technologies and new approaches in the protection of various sort of waterlogged wood are our strategic and moral obligation to future generations. At the same time, they offer also an opportunity for a more stable protection of artefacts of underwater cultural heritage in the future.

[40] e. g., guidelines of the Center for Maritime Archaeology and Conservation Texas A&M University (Hamilton 2010), WreckProtect project Guidelines for the protection of underwater wooden heritage (Manders 2011), SASMAP project Guideline Manual 2 (Gregory – Manders 2015), documents and guidelines ICOM etc.

Bibliography

Akcar et al. 2008
N. Akcar – S. Ivy-Ochs – C. Schlüchter, Application of In-Situ Produced Terrestrial Cosmogenic Nuclides to Archaeology: a Schematic Review, Eiszeitalter und Gegenwart Quaternary Science Journal 57 (1-2), 2008, 226–238

Antlej et al. 2011
K. Antlej — M. Erič — M. Šavnik — B. Županek — J. Slabe — B. Battestin, Combining 3D Technologies in the Field of Cultural Heritage: Three Case Studies, in: M. Dellepiane — F. Niccolucci — S. Pena Serna — H. Rushmeier — L. Van Gool (eds), The 12th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2011) 1–4.

Aznar Gómez 2018
M. J. Aznar Gómez, In Situ Preservation of Underwater Cultural Heritage as an International Legal Principle, Journal of Maritime Archaeology 13 (1), 2018, 67–81

Bandiera et al. 2013
A. Bandiera – C. Alfonso – R. Auriemma – M. Di Bartolo, Monitoring and Conservation of Archaeological Wooden Elements from Ship Wrecks using 3D Digital Imaging, in: A. C. Addison et al. (eds.), Digital Heritage International Congress, Marseille 2013 (Piscataway 2013) 113–118

Bandiera et al. 2015
A. Bandiera – C. Alfonso – R. Auriemma, 2015: Active and Passive 3d Imaging Technologies Applied to Waterlogged Wooden Artifacts from Shipwrecks, The international Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-5/W5, 15–23

Christensen et al. 2012
M. Christensen – H. Kutzke – F. K. Hansen, New Materials Used for the Consolidation of Archaeological Wood – Past Attempts, Present Struggles, and Future Requirements, Journal of Cultural Heritage 13-3, 2012, 183–190

Curci 2006
J. Curci, 2006, The Reburial of Waterlogged Archaeological Wood in Wet Environments, Technical Briefs in Historical Archaeology 1, 21–25

Delgado – Staniforth 2002
J. P. Delgado – M. Staniforth, Underwater Archaeology, Social Sciences and Humanities, in: Encyclopedia of Life Support Systems (EOLSS), Developed under the Auspices of the UNESCO (Paris 2002) <http://www.eolss.net>

Duguet et al. 2004
F. Duguet – G. Drettakis – D. Girardeau-Montaut – J. L. Martinez – F. Schmitt, 2004: A Point-Based Approach for Capture, Display and Illustration of Very Complex Archaeological Artefacts., in: The 5th International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage, Oudenaarde 2004 (Aire-la-Ville 2004) 105–114

Emesiochel et al. 2017
C. Emesiochel et al., Safeguarding Underwater Cultural Heritage in the Pacific: report on good practice in the protection and management of World War II related underwater cultural heritage (2017) <http://unesdoc. unesco. org/images/0026/002604/260457E. pdf>

Erič 2013
M. Erič, 2013: The Impact of Latest 3D Technologies on Documentation of Underwater Heritage Sites, in: A. C. Addison et al. (eds.), Digital Heritage International Congress, Marseille 2013 (Piscataway 2013) Vol. 2, 281–288

Erič 2014
M. Erič, New Reflections on the Protection of World Heritage in the Future: Global symbolic meaning of autochthonous and indigenous origins of water navigation, International Journal of Heritage in the Digital Era 3-4, 2014, 597–612

Erič – Gaspari 2009
M. Erič – A. Gaspari, Sinja Gorica: poročilo o arheološkem podvodnem pregledu struge reke Ljubljanice na območju zavarovanja desne brežine ob Sinjegoriških ribnikih. Poročila skupine za podvodno arheologijo 28 (Ljubljana 2009)

Erič et al. in print
M. Erič — D. Stopar — F. Solina — K. Kavkler, 2018: Reconceptualization of the Contemporary Maritime Museum. Do we really need the original waterlogged wooden artifacts and objects?, Skyllis 19-1, 2019 (in print)

Fix 2015
P. D. Fix, Archaeological Watercraft: A Review and Critical Analysis of the Practice (unpubl. PhD dissertation, Texas A&M University 2015)

Forrest 2002
C. Forrest, A New International Regime for the Protection of Underwater Cultural Heritage, International & Comparative Law Quarterly 51-3, 2002, 511–554

Garcia – Barreiros 2018
A. C. Garcia – J. P. Barreiros, Are Underwater Archaeological Parks Good for

Fishes? Symbiotic Relation between Cultural Heritage Preservation and Marine Conservation in the Azores, Regional Studies in Marine Science 21, 2018, 57–66

Gaspari et al. 2011
A. Gaspari – M. Erič – B. Odar, A Palaeolithic Wooden Point from Ljubljansko Barje, Slovenia, in: J. Benjamin et al. (eds.), Submerged Prehistory (Oxford 2011) 186–192

Gelbrich – Poelmans 2013
J. Gelbrich – L. Poelmans, Post-excavation storage of large waterlogged wooden objects–pilot project in monitoring of degradation activity, in: T. Grant – C. Cook (ed.), Proceedings of the 12th Conference ICOM-CC Wet Organic Archaeological Material, Istanbul 2013 (ICOM-CC 2019) <https://www.researchgate.net/publication/292906329>

Gregory – Manders 2015
D. Gregory – M. Manders, Best Practices for Locating, Surveying, Assessing, Monitoring and Preserving Underwater Archaeological Sites, SASMAP Guideline Manual 1–2 (2015)

Guček Puhar 2018
E. Guček Puhar, Primerjava 3D modelov paleolitske lesene konice (B.Sc.thesis, University of Ljubljana, Faculty of Computer and Information Science 2018) <https://repozitorij.uni-lj.si/Dokument.php?id=112750&lang=slv>

Guček Puhar et al. 2018
E. Guček Puhar et al., Comparison and Deformation Analysis of Five 3D Models of the Palaeolithic Wooden Point from the Ljubljanica River, in: Proceedings of 2018 IEEE International Workshop on Metrology for Archaeology and Cultural Heritage, Cassino (MetroArchaeo 2018) 444–450

Jordan 2003
B. A. Jordan, Analysis of Environmental Conditions and Types of Biodeterioration Affecting the Preservation of Archaeological Wood at the Kolding Shipwreck Site (Doctoral diss. University of Minnesota 2003)

Pearson 2014
C. Pearson, Conservation of Marine Archaeological Objects, Butterworth Series in Conservation and Museology (London 2014)

Pickard 2001
R. Pickard, Policy and Law in Heritage Conservation (London 2001)

Remondino 2011
F. Remondino, Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning, Remote Sensing 3-6, 2011, 1104–1138

Remondino – Campana 2014
F. Remondino – S. Campana (eds.), 3D Recording and Modelling in Archaeology and Cultural Heritage. Theory and Best Practices, BAR Int. Ser. 2598 (Oxford 2014) 111–127

Richards et al. 2009
V. Richards et al., 2.2 In-situ Monitoring and Stabilisation of the James Matthews Shipwreck Site (2009) <http://forestpathology.cfans.umn.edu/pdf/WOAM%20James%20Matthews%20shipwreck.pdf>.

Sanders 2004
D. H. Sanders, Virtual Archaeology. Yesterday, Today, and Tomorrow, in: F. Nicolucci – S. Hermon (eds.), Beyond the Artifact. Digital Interpretation of the Past, Proceedings of CAA 2004, Prato 2004 (Budapest 2004) 319–324

Scaradozzi et al. 2013
D. Scaradozzi – L. Sorbi – F. Zoppini – P. Gambogi, 2013: Tools and Techniques for Underwater Archaeological Sites Documentation. OCEANS IEEE, San Diego 2013 (Piscataway 2013) 1–6

Schwabe 2006
A. Schwabe, Zur Volltränkung von Holz mit Methylmethacrylat (B.Sc.Thesis TU München 2006)

Staniforth et al. 2009
M. Staniforth – J. Hunter – E. Jateff, International Approaches to Underwater Cultural Heritage, in: J. W. Harris, (ed.), Maritime Law Issues, Challenges and Implications (New York 2009) 1–25

Strate 1995
A. Strate, The Protection of the Underwater Cultural Heritage: an Emerging Objective of the Contemporary Law of the Sea, Publication on Ocean Development 23 (Den Haag 1995)

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