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PROJEKT ZAŠTITE RIMSKOG ŠIVANOG BRODA PULA 2:

OD MULJA DO PONOVOG SJAJA

PROTECTION PROJECT OF THE ROMAN SEWN BOAT PULA 2:

FROM SLUDGE TO ITS FORMER SPLENDOUR

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Od otkrića te istraživanja u 2013. godini, pa sve do okončanja postupka konzervacije u proljeće 2017. godine, brod Pula 2 prošao je kroz različite faze u postupku zaštite. Iako je na zaštitu brodske konstrukcije uloženo puno rada, a jednako tako i financijskih sredstava, među završnim koracima prethodi možda najzahtjevnija zadaća, a to je otkrivanje brodske konstrukcije javnosti.

U nastojanju da će prezentacija broda ubrzo doći na red, namjera ovog rada je prikazati dosad realizirane poslove u okviru tekućeg projekta konzervacije rimskih šivanih brodova iz Pule.

Poslovi odrađeni kroz protekle četiri godine odnose se na cjelokupan proces od arheološkog istraživanja nalaza broda „Pula 2“, postupka desalinizacije odnosno odstranjivanja topivih soli, izradu odgovarajuće transportne ambalaže te pakiranja i prijevoza brodskih ostataka u laboratorij ARC-Nucleart u Grenobleu te konačno na konzervatorski postupak.

KLJUČNE RIJEČI: brodska konstrukcija Pula 2, arheološko istraživanje, desalinizacija arheološkog drva, konzervacija, liofilizacija

From the discovery and investigation in 2013, up to finalization of the conservation process in the spring of 2017, the Pula 2 boat underwent various phases of the conservation process. Although a lot of work and financial resources have already been invested into the protection of the boat, among the finishing steps there is still one, perhaps the most demanding, to be fulfilled - presentation of the boat to the public.

The purpose of the paper is to present all the activities undertaken so far within the ongoing project of the conservation of the Roman sewn ships from Pula, while an upcoming presentation of the boat for the public is under preparation.

The works carried out over the past four years included archaeological investigation of the remains of the boat Pula 2, the desalination process, i.e., removal of soluble salts, construction of the appropriate transport packaging, packing and transportation of the remains to the laboratory at ARC-Nucléart in Grenoble, and finally the conservation process.

KEY WORDS: Pula 2 boat structure, archaeological investigation, desalination of archaeological wood, conservation, lyophilization

UVOD

U okviru zaštitnih arheoloških radova u sklopu projekta izgradnje sustava odvodnje grada Pule, na području Flaciusove ulice, u 2013. godini su istražene i s nalazišta izvađene dvije brodske konstrukcije iz rimskog vremena¹. Radilo se o tehnički zahtjevnim istraživanjima kojima se pristupilo nekoliko mjeseci nakon otkrića dijela brodske konstrukcije (Uhač 2014, 351-353). Istraživanjem je ustanovljeno postojanje još jedne brodske konstrukcije, a sačuvani brodovi su nazvani "Pula 1" i "Pula 2" (Uhač 2014, 351).

Radi se o nalazima rimskih šivanih brodova (sl. 1)¹, datiranim u razdoblje od 1. do 3. stoljeća² (Uhač 2014, 353; Boetto, Koncani Uhač, Uhač 2017, 192-196) čije



Sl. 1 Nalazište rimskih šivanih u Flaciusovoj ulici u Puli (foto: T. Brajković).
Fig. 1 Site of the Roman sewn ships in the Flaciusova Street in Pula (photo by: T. Brajković).

¹ U okviru izvođenja višegodišnjeg projekta izgradnje kolektora oborinskih i fekalnih voda grada Pule od strane tvrtke Pula Herculanea d.o.o. iz Pule, zaštitni arheološki radovi su provedeni na području pulske rive (Flaciusove ulice) između zgrade Hrvatske pošte i brodogradilišta Uljanik.

² Radiokarbonska mjerenja su provedena u laboratoriju Centre de Datation par le Radiocarbone u Lyonu (FR).

INTRODUCTION

During the archaeological investigations carried out in 2013 in the Flaciusova Street within the project of construction of the drainage system for the city of Pula, two ships from the Roman period have been discovered and extracted from the site.¹ The technically demanding investigations initially started several months after the discovery of a section of a hull structure (Uhač 2014, 351-353). The investigations led to the discovery of another ship and the two ships have been named Pula 1 and Pula 2 (Uhač 2014, 351).

These are Roman sewn ships (Fig. 1), dating back to the period from the 1st to 3rd century² (Uhač 2014, 353; Boetto, Koncani Uhač, Uhač 2017, 192-196) whose technical characteristics can be linked to the Northern Adriatic area (Boetto, Rousse, 2011, 178-191). On the eastern Adriatic coast, besides the Pula ships and the find of a sewn boat from Zambratija dated to the period of the Late Bronze Age (Koncani Uhač, 2009; Koncani Uhač, Boetto, Uhač, 2017; Boetto, Koncani Uhač, Uhač, 2017, 189-192), currently there are another six known Roman ships dating back to the period between the 1st and 2nd centuries, known as Caska I, III, IV and Zaton I, II, III (Brusić, Domljan, 1985, 67-85; Brusić, 1995, 39-59; Gluščević, 2004, 41-52; Radić Rossi, Boetto, 2011, 505-512; Boetto, Radić Rossi, 2017, 279-287).

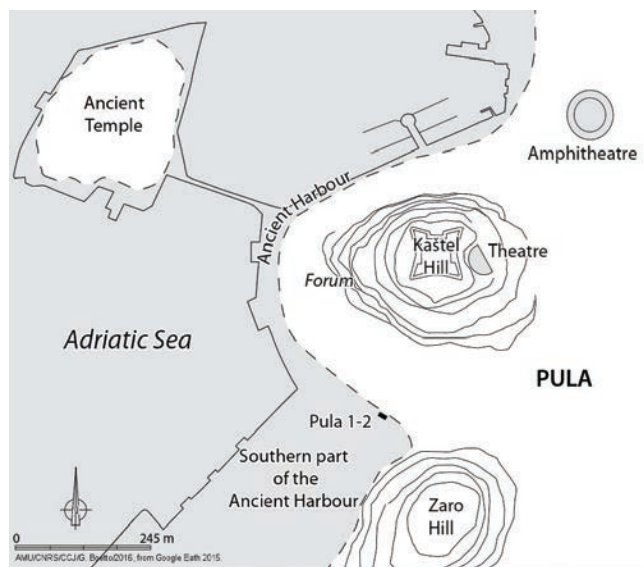
The Roman ships from Pula were excavated in the area which in the antique times most likely belonged to



Sl. 2 Područje jugoistočnog dijela luke.
Fig. 2 Area of the south-eastern part of the port.

¹ During works on the multi-annual project of constructing a stormwater and wastewater collector for the city of Pula by the company Pula Herculanea d.o.o. from Pula, rescue archaeological works were carried out in the area of the seafont (Flaciusova Street) between the building belonging to Croatian Post and the Uljanik Shipyard.

² Radiocarbon measurements were performed at the laboratory Centre de Datation par le RadioCarbone in Lyon (FR).



Sl. 3 Lokacija rimskih brodova i pretpostavljeni izgled antičke linije obale.
Fig. 3 Location of Roman shipwrecks and presumed appearance of the antique coastline.

se tehničke karakteristike vezuju za područje sjevernog Jadrana (Boetto, Rouse, 2011, 178–191). Na istočnoj jadranskoj obali, uz pulske brodove te nalaz šivanog broda iz Zambratije koji datira u razdoblje kasnog brončanog doba (Koncani Uhač, 2009; Koncani Uhač, Boetto, Uhač, 2017; Boetto, Koncani Uhač, Uhač, 2017, 189–192) zasad je poznato još šest rimskih brodova koji datiraju u razdoblje između 1. i 2. st., poznati kao Caska I, III, IV i Zaton I, II, III (Brusić, Domjan, 1985, 67–85; Brusić, 1995, 39–59; Gluščević, 2004, 41–52; Radić Rossi, Boetto, 2011, 505–512; Boetto, Radić Rossi, 2017, 279–287).

Rimski brodovi iz Pule su istraženi na području koje je u antici najvjerojatnije pripadalo jugoistočnom dijelu lučkog bazena kolonijalne luke. Zbog glacioeustatskih i hidroloških utjecaja te ljudskih aktivnosti kroz povijest, danas se ovo područje nalazi udaljeno oko 160 metara od obalne linije (sl. 2, sl. 3).

Grad *Colonia Iulia Pola* utemeljen je u 1. st. pr. Kr. (Degrassi 1954, 62–65; Frascchetti 1983, 90) iznad prirodno zaštićenog zaljeva koji je zbog svog strateškog položaja omogućavao kvalitetnu pomorsku trgovinu između luka na Sredozemlju sa sjevernim Jadranom. O toj intenzivnoj trgovini govore nalazi raznovrsnog pokretnog arheološkog materijala pronađeni u slojevima luke na području brodova. Tu su prikupljeni različiti pokretni arheološki predmeti od kojih je dio stručno obrađen i objavljen (Essert, Koncani Uhač, Uhač, Šoštarić 2018, 957–971; Koncani Uhač 2017, 72–73; Vežnaver 2017). U arheološkim slojevima luke su također pronađeni brojni cjeloviti predmeti od

the south-eastern part of the port basin of the colonial port. Due to glacioeustatic and hydrologic impacts as well as human activity throughout history, this area is today located some 160 meters from the coastline (Fig. 2, Fig. 3).

The town *Colonia Iulia Pola* was established in the 1st century B.C. (Degrassi 1954, 62–65; Frascchetti 1983, 90) above the naturally protected cove, which due to its strategic position provided good quality maritime trading between the port in the Middle East and the northern Adriatic region. This intensive trading is evident from the various movable archaeological material found in the layers of the port where the ships have been located. These diverse movable archaeological items have been collected and part of them have been professionally processed and published (Essert, Koncani Uhač, Uhač, Šoštarić 2018, 957–971; Koncani Uhač 2017, 72–73; Vežnaver 2017). The archaeological layers of the port also contained numerous fully preserved items made of organic material (leather and wooden items as well as ship rope). After securing the financial funds for the boat protection program, the items were dispatched and underwent conservation at the workshop of the International Center for Underwater Archaeology in Zadar (see Vrgoč, Jelić 2015, 64–67 for the process of conserving the minor items).

After the investigations, the shipwrecks have been retrieved from the site, using the appropriate methodological approach to extraction for each ship individually. The ships were transferred into a custom-built pool containing water, situated on the premises of the Uljanik Shipyard, and the primary process in preserving the wet wood (desalination) commenced.

Given that the Pula ships were the first and only examples of shipwrecks in Croatia to be investigated in a dry land surroundings and due to the importance of the site, a program was tendered in 2014 for their protection, where the primary goal was the conservation and restoration process. In 2015, the proposed program was included in the Program for the Protection of Cultural Heritage, and thanks to funds from the Croatian Ministry of Culture, the County of Istria and Archaeological Museum of Istria, works commenced on conservation of the wet wood belonging to the ship remains.³

³ The organizer of works for the protection of the Roman shipwrecks was the Archaeological Museum of Istria, while the Conservation Department in Pula was in charge of the protection measures. The protection program leader was Ida Koncani Uhač, a senior curator, and the participants in the activities involving the conservation and restoration process were Monika Petrović, senior restorer and Andrea Sardož, restorer. The conservator in charge of the works for the protection of the Roman ships from Pula was Marko Uhač, conservator and senior expert advisor.

organskog materijala (kožni i drveni predmeti te brodski konopi). Nakon osiguravanja financijskih sredstava, u okviru programa zaštite, predmeti su otpremljeni i konzervirani u radionici Međunarodnog centra za podvodnu arheologiju u Zadru (o postupku konzervacije sitnih predmeta u Vrgoč, Jelić 2015, 64-67).

Nakon istraživanja, brodovi su izvađeni s nalazišta s tim da je pojedinačno za svaku brodsku konstrukciju primijenjen odgovarajući metodološki pristup vađenja. Brodske konstrukcije su prenesene u namjenski izrađen bazen s vodom u prostoru brodogradilišta Uljanik te je na njima započeo primarni proces u konzervaciji mokrog drveta (desalinizacija).

Budući da su pulski brodovi prvi i jedini primjerci brodoloma u Hrvatskoj istraženi u kopnenom okruženju, zbog važnosti nalaza je 2014. godine kandidiran program njihove zaštite čiji je primarni cilj konzervatorsko - restauratorski postupak. Godine 2015., predloženi je projekt uvršten u Program zaštite kulturnih dobara te su zahvaljujući sredstvima Ministarstva kulture RH, Istarske županije i Arheološkog muzeja Istre, započeli radovi na konzervaciji mokrog drveta brodskih ostataka³.

U razdoblju od 2015. - 2017. godine, u laboratoriju ARC-Nucléart / Atelier de Recherche et de Conservation (Grenoble) u Francuskoj, obavljen je konzervatorsko - restauratorski postupak na brodu Pula 2 u kojem su sudjelovali djelatnici Arheološkog muzeja Istre.

Pregled istraživačkih radova i vađenje brodskih ostataka te problematika mokrog drveta i konzervatorsko - restauratorski radovi na brodu Pula 2 iznose se u ovom radu.

1. METODOLOGIJA ISTRAŽIVANJA I VAĐENJA BRODSKE KONSTRUKCIJE PULA 2

Budući da je nalazište u Flaciusovoj ulici (Sektor III, stacionaža 0+085 - 0+095)⁴ bilo ugroženo stalnim poplavlivanjem koje je onemogućavalo terenski rad, u suradnji s investitorom (komunalna tvrtka Herculanea d.o.o. iz Pule) osigurana je konstantna odvodnja fekalnih i oborinskih voda s nalazišta (sl. 4) te je na taj način područje

In the period from 2015 to 2017, the conservation and restoration process on the Pula 2 boat was performed by the ARC - Nucléart / Research and Conservation Workshop (Grenoble) in France, with the participation of the employees of the Archaeological Museum of Istria.

An overview of the investigative works and retrieval of the boat remains, as well as issues relating to the wet wood and the conservation and restoration works on the Pula 2 boat are presented in this paper.

1. METHOD OF INVESTIGATING AND RETRIEVAL OF THE PULA 2 BOAT STRUCTURE

Given that the site in the Flaciusova Street (Sector III, section 0+085 - 0+095)⁴ was jeopardized due to continual flooding that prevented field work, a sustained siphoning of wastewater and stormwater from the site (Fig. 4) has been ensured with cooperation from the investor (municipal company Herculanea d.o.o. from Pula), thus keeping the excavated area dry.⁵ The preparatory works also involved making the assembly structure for the roofing to provide protection against the sun and rainfall.

Having secured the excavation area, rescue archaeological investigations commenced at the site, exploring the smaller area of the port basin of antique Pula with two preserved ship structures.⁶ Once the excavation reached the layer containing the wrecks, a wooden structure, i.e. scaffolding, was assembled above so as to avoid walking on the boat structures during

⁴ Chainage marked the meters along the route of the sewage construction and was the term used for documenting purposes on the site.

⁵ The leader of archaeological investigation was Marko Uhač, conservator and senior expert advisor, and his direct assistant for the investigation was Martina Barada, conservator and senior expert advisor, both from the Conservation Department in Pula. The leaders of individual work shifts on the site were curators from the Archaeological Museum of Istria: Katarina Jerbić and Maja Čuka. The other employees from the Archaeological Museum of Istria who participated in the investigations were Kladija Bartolić Sirotić, curator, Ida Koncani Uhač, senior curator, Elvin Zejnilhodžić, curator, Zoran Grbin, preparator and Luana Milotić Bulić, preparator. Participating in the investigations were Goranka Perković, an archaeology student at the University of Zagreb and Marija Sekulić, a restoration student at the University of Dubrovnik. Investigation of the shipwrecks required contracting international cooperation with Dr Giulia Boetto from the Centre Camille Julian, Aix-Marseille University - CNRS, France). Technical assistance for the investigation was provided by the company Kapitel d.o.o. from Žminj. Works on the site lasted a month (July-August 2013), and took place in two shifts from 6 am to 10 pm.

⁶ Technical assistance for the investigation, documenting and retrieval of the ships was provided by the company Kapitel d.o.o. from Žminj.

³ Nositelj radova na zaštiti pulskih rimskih brodova je Arheološki muzej Istre, dok je za mjere zaštite nadležan Konzervatorski odjel u Puli. Voditeljica programa zaštite je Ida Koncani Uhač, viša kustosica, a sudionici u aktivnostima konzervatorsko-restauratorskog postupka su Monika Petrović, viša restauratorica i Andrea Sardoz, restauratorica. Nadležni konzervator za radove na zaštiti rimskih brodova iz Pule je Marko Uhač, konzervator - viši stručni savjetnik.

⁴ Stacionaža je označavala metre na trasi izgradnje gradske kanalizacije te je termin preuzet i za potrebe dokumentiranja na terenu.

iskopa održavano suhim⁵. Pripremni radovi su također obuhvatili izradu montažne konstrukcije krovišta kako bi se omogućila zaštita od sunca ili iznenadnih oborina.

Nakon osiguravanja iskopa, na nalazištu su započela zaštitna arheološka istraživanja koja su obuhvatila istraživanje manjeg dijela lučkog bazena antičke Pule sa očuvane dvije brodske konstrukcije. Nakon što se iskopom došlo do sloja sa brodovima, iznad njih je u svrhu minucioznog čišćenja, montirana drvena konstrukcija tj. skela koja se poslužila da se izbjegne hodanje po brodskim konstrukcijama⁶. Na brodskoj konstrukciji Pula 1, istraživanje je obavljano po segmentima između rebara dok je na brodskoj konstrukciji Pula 2 istraživanje obavljano po segmentima dijelova brodske oplatae.

Prilikom uklanjanja sedimenta iznad brodova, sve je dodatno močeno vodom i čišćeno kistovima kako bi se lakše uklonio muljeviti sediment koji se nalazio iznad brodske konstrukcije. Voda koja je preostala od ispiranja, iz unutrašnjosti se broskog korita izvlačila spužvama i industrijskim usisavačem. Tijekom trajanja istraživanja, brodske konstrukcije su konstantno močene vodom, ručno ili automatskim štrcaljkama (Uhač 2014, 352).

Nakon finog čišćenja brodskih konstrukcija, sa nalazišta je uklonjena drvena skela te je izvedeno dokumentiranje u različitim fazama. Obavljeno je fotografiranje nalaza i detalja brodskih konstrukcija te su izrađeni planovi i presjeci brodova *in situ*. Situacijski plan nalazišta je izradila tvrtka Centurion d.o.o. iz Pule. Također je napravljeno 3D skeniranje i fotogrametrijski snimak sačuvanih ostataka broda.

S obzirom na manje dimenzije sačuvane brodske konstrukcije Pula 2 čije je drvo bilo u lošijem stanju očuvanosti (sl. 5), ona je prva izvađena iz iskopa⁷.

⁵ Voditelj arheološkog istraživanja bio je Marko Uhač, konzervator –viši stručni savjetnik, a zamjenica istraživanja je bila Martina Barada, konzervatorica – viša stručna savjetnica, oboje iz Konzervatorskog odjela u Puli. Voditelji pojedinih smjena na terenu bile su kustosice Arheološkog muzeja Istre: Katarina Jerbić i Maja Čuka. Ostali djelatnici Arheološkog muzeja Istre koji su sudjelovali na istraživanju su bili Klaudija Bartolić Sirotić, kustosica, Ida Koncani Uhač, viša kustosica, Elvin Zejnilhodžić, kustos, Zoran Grbin, preparator i Luana Milotić Bulić, preparatorica. Na istraživanju su sudjelovali Goranka Perković, studentica arheologije Sveučilišta u Zagrebu i Marija Sekulić, studentica restauracije sa Sveučilišta u Dubrovniku. Za istraživanje brodskih konstrukcija ugovorena je međunarodna suradnja s dr. Giulio Boetto iz Centre Camille Julian (CCJ, Sveučilište Aix Marseille – CNRS, Francuska). Tehničku podršku istraživanju pružila je tvrtka Kapitel d.o.o. iz Žminja. Radovi na nalazištu su trajali mjesec dana (srpanj–kolovoz 2013), a odvijali su se u dvije radne smjene, od 6 do 22 h.

⁶ Tehničku podršku na istraživanju, dokumentiranju i vađenju brodova, pružila je tvrtka Kapitel d.o.o. iz Žminja.

⁷ Rješenje za adekvatnu metodologiju vađenja brodskih ostataka Pula 2 predložio je konzervator Marko Uhač. Uz djelatnike AMI-ja te djelatnike tvrtke Kapitel d.o.o. koji su sudjelovali u tehničkoj izvedbi, preparatorica Luana Milotić Bulić bila je zadužena za plan vađenja sekcija prema postojećem nacrtu.



Sl. 4 Nalazište prije osiguravanja konstantne odvodnje fekalnih i oborinskih voda (foto: M. Čuka).

Fig. 4 The site before securing constant drainage of faecal waters and stormwater (photo by: M. Čuka).

detailed cleaning. The investigation of the Pula 1 vessel was performed in segments between the frames, whereas investigation of the Pula 2 boat structure was performed in segments of the planking.

During the removal of sediments above the ships, everything was additionally moistened with water and cleaned with brushes to facilitate the removal of sludge sediment found above the ship structure. The excess water left after rinsing was removed from the interior of the ship hull using sponges and an industrial vacuum. During the investigation, ship structures were constantly moistened with water, either manually or with automatic sprayers (Uhač 2014, 352).

After fine cleaning of the ships, the wooden scaffolding was removed from the site and the documenting was performed in various phases. The finds and details of the ship structures were also photographed, and then plans and cross-sections were drawn up *in situ*. The site plan was drafted by the company Centurion d.o.o. from Pula. In addition, 3D scanning and photogrammetric recordings of the preserved hull remains were also performed.

Since the Pula 2 boat structure was smaller in size and its wood was less preserved (Fig. 5), it had to be extracted first.⁷ Parts of the boat were retrieved based on the already existing fragmented segments (sections) of the structure. The separation and lifting of the planking was carried out with the aid of metal “knives” which were placed underneath the planks in a proper sequence

⁷ The solution for an adequate methodology in retrieving the Pula 2 boat remains was proposed by Marko Uhač, the conservator. Along with employees of the AMI and workers of the company Kapitel d.o.o. who participated in the technical plans, Luana Milotić Bulić, preparator, was in charge of the plan to retrieve the sections based on an existing draft.



Sl. 5 Detalj brodske oplata Pula 2 (foto: T. Brajković).

Fig. 5 Detail of the planking of Pula 2 shipwreck (photo by: T. Brajković).

Dijelovi broda su izvađeni prema već postojećim razlomljenim segmentima (sekcijama) konstrukcije. Odvajanje i podizanje brodske oplata je obavljeno uz pomoć metalnih “noževa” koji su se uvlačili ispod broskog korita u pravilnom slijedu na udaljenosti od 15 cm (sl. 6, sl. 7). Nakon što su metalni noževi bili umetnuti ispod oplata broda, dio korita je zatim odvojen odnosno podignut od zemlje te je ispod njega uvučena polikarbonatna podloga (debljine 10 mm) koja

of 15-centimetre intervals (Fig. 6, Fig. 7). After the knives were inserted under the planks, part of the hull was then separated or lifted from the soil and then a polycarbonate base was inserted underneath which served as the sheet (10 mm thick). This technique was applied for the lifting of a total of seven sections of the planking (Fig. 8). Each section was additionally covered with a polycarbonate sheet and bound with PVC ties in a so called sandwich system, which facilitated handling of the retrieved remains. The retrieved hull remains were transferred to a custom-made desalination pool in which they remained until January 2015.

2. THE HULL REMAINS OF THE BOAT PULA 2

The investigated remains of the sewn boat Pula 2 at the site were 6.1 meters long and 2.1 meters wide.

The shipwreck was found in a muddy layer. Given that over the centuries, sludge and other concretions accumulated above the boat, it caused a change in the shape of the wooden structure. Due to subsidence of the boat on the sea bottom of the antique port, the original shape of the boat was lost.



Sl. 6 Podizanje brodske oplata pomoću metalnih “noževa” i polikarbonatnih ploča (foto: T. Brajković).

Fig. 6 Lifting of the planking with the help of metal “knives” and polycarbonate sheets (photo by: T. Brajković).



Sl. 7 Podizanje brodske oplate pomoću metalnih “noževa” i polikarbonatnih ploča (foto: T. Brajković).

Fig. 7 Lifting of the planking with the help of metal “knives” and polycarbonate sheets (photo by: T. Brajković).



Sl. 8 Podizanje brodske sekcije (foto: T. Brajković).

Fig. 8 Lifting of the boat section (photo by: T. Brajković).

je poslužila kao posteljica. Na taj je način podignuto ukupno sedam sekcija brodske oplate (sl. 8). Svaka sekcija je dodatno prekrivena polikarbonatnom pločom povezanom PVC obujmicama u tzv. sistem sendviča koji je omogućio lakše rukovanje s izvađenim ostacima. Izvađeni brodski ostaci su prevezeni u namjenski desalinizacijski bazen u kojem su ostali do siječnja 2015. godine.

2. BRODSKA KONSTRUKCIJA PULA 2

Ostaci šivanog broda Pula 2 na nalazištu su istraženi u dužini od 6,1 m i širini od 2,1 m.

Brodolom se nalazio u muljevitom sloju. Kako se kroz stoljeća iznad broda nataložio mulj te ostale konkracije, došlo je do promjene oblika drvene konstrukcije. Zbog nalijeganja broda na morsko dno antičke luke, došlo je do gubitka izvorne forme broda.

As for the boat structure, the keel, eight strakes on the northern side and five strakes on the southern side of the planking have been preserved *in situ*. In the interior and around the boat structure, twenty dislocated elements were found that belonged to the frames and planking.

The planks were sewn together, which was done through diagonally bored holes on the plank edges. The sewing was done in simple parallel seams (pattern ///). The seam was made using vegetal fibers which passed over a thread that was also made from vegetal fibers and was covering the plank joins (Fig. 9). The holes through which the sewing was executed were subsequently secured with small wooden pegs (Fig. 10).

The frames were not found in the original position, but 11 frame stations at intervals of 40 cm (Fig. 11) have been identified. The frames were fixed to the planking with tapered treenails and in some places with bronze nails.



Sl. 9 Detalj šivanja (foto: T. Brajković).

Fig. 9 Detail of the sewing pattern (photo by: T. Brajković).



Sl. 10 Detalj drvenih čavala kojim su zaptivene rupe (foto: T. Brajković).

Fig. 10 Detail of wooden pegs with which the holes are riveted (photo by: T. Brajković).

Od brodske konstrukcije, *in situ* je bila očuvana kobilica te osam vojeva oplata broda na sjevernoj strani te pet vojeva oplata na južnoj strani broda. U unutrašnjosti i uokolo brodske konstrukcije pronađeno je dvadeset dislociranih elemenata koji su pripadali orebrenju i platicama broda.

Oplata broda je bila spojena šivanjem koje je obavljeno kroz dijagonalno izbušene provrte na sljubnicama platica. Šivanje je bilo izvedeno jednostavnim paralelnim šavovima (uzorak ///). Šav je izveden od niti biljnih vlakana koji je prelazio preko trake, također načinjene od biljnih vlakana, a koja je bila postavljena preko spojeva platica (sl. 9). Rupe kroz koje je obavljeno šivanje naknadno su učvršćene malim drvenim čavlima (sl. 10).

Brodska rebra nisu pronađena na izvornom mjestu, ali su na oplati uočeni tragovi 11 brodskih orebrenja s razmacima od 40 cm (sl. 11). Rebra broda su za oplatu

The quadrangular cross-sectioned keel, narrowing from the sides and with curved external edges was made of oak (*Quercus* sp.). It was joined at the key to the preserved extremity in order to create a space for the knee which was made of evergreen oak (*Quercus ilex*). The scarf was secured by a horizontal key, and vertically locked by a treenail coupled with an iron nail.

The boat structure was coated from the outside and inside with pitch to achieve impermeability of the vessel (Boetto, Koncani Uhač, Uhač 2017, 195-196).

Once the elements of planking, keel and frames were retrieved from the site, their top surface was cleaned with running water. After removal of the sludge and impurities, sections of the Pula 2 boat were returned into the so-called sandwich made from polycarbonate sheeting in order to stabilize the wet wood and to temporarily store it in the pool built at the construction site itself.



Sl. 11 Situacijski plan pulskih brodova (izrada: V. Dumas, Sveučilište u Marseillu, CCJ).

Fig. 11 Site plan of the shipwrecks of Pula (drafted by: V. Dumas, University of Marseille, CCJ).

bila pričvršćena drvenim klinovima te ponegdje brončanim čavlima.

Kobilica četverokutnog presjeka, sa suženim stranicama te zakrivljenim vanjskim rubovima, izrađena je od hrastovine (*Quercus*). Spojena je na ključ sa sačuvanim ekstremitetom kako bi se stvorio prostor za koljeno koje je izrađeno od zimzelenog hrasta (*Quercus ilex*). Spoj je pričvršćen vodoravnim ključem, a okomito je osiguran drvenim čavlima zajedno sa željeznim čavlom.

Brodsk konstrukcija je s vanjske i unutrašnje strane bila premazana smolom kako bi se postigla vodonepropusnost plovila (Boetto, Koncani Uhač, Uhač 2017, 195-196).

Nakon što su elementi brodske oplata, kobilice i rebra bili izvađeni s nalazišta, njihova gornja površina je oprana tekućom vodom. Nakon uklanjanja mulja i nečistoća, sekcije broda Pula 2 su vraćene u tzv. sendviče načinjene od polikarbonatnih ploča kako bi se stabiliziralo mokro drvo te privremeno deponirane u bazen koji je bio izgrađen na samom gradilištu.

3. PRIMARY PROTECTION OF THE HULL REMAINS OF THE BOAT PULA 2 - PACKING AND TRANSPORT

The process involving primary protection of the ship as mentioned above included a desalination process in a custom-built pool situated on the premises of the Uljanik Shipyard.

The desalination process is used on finds that are either found during underwater archaeological investigations or on land sites that contain sludgy soil with the presence of sea water. Desalination was carried out by immersing items into a vessel with (fresh) water, which was changed at regular intervals, and upon each water change, water samples were taken to test the salinity. During the process of desalination of the boat structure surface, deposits of impurities (micro-organisms, sludge, small stones, and the like) fell off, and it was then necessary to carefully clean the ship's timbers and regularly fill and empty the pool with clean water. Desalination continued until the concentration of all salts was reduced to a minimum.

The process of desalination of the boat remains was monitored by the employees of the Conservation-



Sl. 12 Faza desalinizacije - punjenje bazena nakon čišćenja brodske konstrukcije brodova Pula 1 i Pula 2, u ljeto 2015. godine (foto: L. Milotić Bulić).
Fig. 12 Desalination phase - filling the pool after cleaning the Pula 1 and Pula 2 ships, in the summer of 2015 (photo by: L. Milotić Bulić).

3. PRIMARNA ZAŠTITA BRODSKIH OSTATAKA PULE 2 - PAKIRANJE I TRANSPORT

Proces primarne zaštite broda, kako je prethodno spomenuto, obuhvatio je desalinizacijski postupak u namjenski izrađenom bazenu u prostoru brodogradilišta Uljanik.

Postupak desalinizacije provodi se na nalazima koji su pronađeni u podvodnim arheološkim istraživanjima ili na kopnenim nalazištima s muljevitom zemljom u kojoj je prisutna morska voda. Desalinizacija se provodi potapanjem predmeta u posudu s vodom (vodovodnom) u kojoj se voda mijenja u pravilnim intervalima, a pri svakom mijenjanju uzimaju se uzorci vode za testiranje saliniteta. Tijekom procesa desalinizacije s površine brodske konstrukcije otpadaju nakupine nečistoće (mikroorganizmi, mulj, kamenčići i sl.) te je potrebno pažljivo čistiti nalaze te redovito puniti i prazniti bazen čistom vodom. Desalinizacija traje sve dok se koncentracija ukupnih soli ne svede na minimum.

Proces desalinizacije brodskih ostataka bio je praćen od strane djelatnika Konzervatorsko-restauratorskog odjela Arheološkog muzeja Istre u razdoblju od 2013. do 2015. godine⁸.

Po završetku desalinizacije izvršena je katalogizacija sekcija i ulomaka brodske konstrukcije Pule 2 prema čemu je izrađen transportni sanduk na etaže, kojim se zatim mokro drvo prevezlo u laboratorij ARC-Nucléart u Grenobleu (Francuska).

Posebna pažnja posvetila se pakiranju mokrog arheološkog drveta koje je osjetljivo na vremenske uvjete i transport⁹. Sekcije brodske konstrukcije pakirane su zasebno prvo u celofan, pucketavi najlon te su obložene mokrom spužvom koja je učvršćena celofanom na drvenu panel ploču poput "sendviča". Manji ulomci broda spakirani su svaki zasebno, obloženi celofanom ili u plastične vrećice punjene vodom te su pohranjeni u isti tip kutije (sl. 12).

⁸ Za praćenje i kontrolu desalinizacijskog postupka nad brodskim ostacima te izradu kataloga sekcija i ulomaka bila je zadužena Luana Milotić Bulić, preparatorica. Na radovima čišćenja brodske konstrukcije sudjelovali su Zoran Grbin, preparator, Monika Petrović, viša restauratorica, Andrea Sardoz, restauratorica, Marija Sekulić, studentica restauracije i Vanja Ujčić, restaurator. Pri punjenju/praznjenju bazena vodom pomagali su djelatnici brodogradilišta Uljanik.

⁹ Za izradu transportnog sanduka bila je zadužena firma Kapitel d.o.o. iz Žminja prema nacrtima restauratorice Andree Sardoz. Sekcije i ulomke pakirali su Zoran Grbin, preparator, Monika Petrović, viša restauratorica te Andrea Sardoz, restauratorica.

Restoration Department at the Archaeological Museum of Istria in the period from 2013 to 2015.⁸

Upon desalination, cataloguing sections and pieces of the Pula 2 boat structure was completed whereupon a multi-level transport crate was constructed in which the wet wood was transported to the laboratory ARC-Nucléart in Grenoble (France).

Special attention was given to the packing of the wet archaeological wood, which is sensitive to the effects of weather and transport.⁹ Each section of the boat structure was packed individually into cellophane, bubble wrap and then covered with a wet sponge which was fixed onto the wooden panel sheet with cellophane like a sandwich. Smaller pieces of the boat were packed separately, covered with cellophane or placed into plastic bags filled with water and stored in the same type of box (Fig. 12).

4. CONSERVATION AND RESTORATION PROCESS USED ON THE HULL REMAINS

In January 2016, the crates containing the wet wood were unloaded upon arriving to the laboratory at ARC-Nucléart. Prior to the process of consolidating the wet wood, preliminary works were carried out on the materials, including digitally recording and documenting of the items.¹⁰

Prior to immersing the sections and pieces of wood from the Pula 2 boat structure into the solution of polyethylene glycol (hereinafter: PEG 4000),¹¹ cleaning

⁸ The person in charge of the monitoring and control of the desalination process used on the boat remains and the making of the catalogue of sections and pieces was Luana Milotić Bulić, preparator. The works on cleaning the boat structure were performed by Zoran Grbin, preparator, Monika Petrović, senior restorer, Andrea Sardoz, restorer, Marija Sekulić, restoration student and Vanja Ujčić, restorer. Help with filling/emptying the pool with water was provided by the employees of the Uljanik Shipyard.

⁹ Construction of the transport crate was assigned to the company Kapitel d.o.o. from Žminj based on drafts from the restorer Andrea Sardoz. The sections and pieces were packed by preparator Zoran Grbin, senior restorer Monika Petrović and restorer Andrea Sardoz.

¹⁰ Along with professional leadership of the team from ARC-Nucléart: restorer Henri Bernard-Maugiron, restorer Floraine Helias and Stephane Garrvier, leader of the reception workshop, restorer Andrea Sardoz and Monika Petrović were trained and mentored in working on the preparation, processing and treatment of the wet archaeological wood.

¹¹ Polyethylene-glycol (PEG) is a polyester adhesive for many applications. It can be used in industrial and pharmaceutical production. Polyethylene glycol occurs when ethylene oxide and water, ethylene glycol or oligomer ethylene glycol interact. It is also used as a chemical for the conservation of wet archaeological wood.

4. KONZERVATORSKO-RESTAURATORSKI POSTUPAK BRODSKIH OSTATAKA

U siječnju 2016., po dolasku u laboratorij ARC-Nucléart uslijedio je iskrcaj sanduka s mokrim drvom. Prije postupka konsolidacije mokrog drva izvedeni su pripremni radovi na građi, digitalno snimanje i dokumentiranje predmeta¹⁰.

Prije uranjanja sekcija i ulomaka drva brodske konstrukcije Pule 2 u otopinu polietilen glikola (u daljnjem tekstu: PEG 4000¹¹ izvedeni su postupci čišćenja i dokumentacije. Mehanički je očišćena površina drva vodom i mekanim kistovima. Nakon pranja svaki je dio broda malim alatima detaljno očišćen (lice i naličje) od ostataka mulja i ostalih nečistoća (zaostalih na drvu još od arheoloških istraživanja) koje bi mogle uzrokovati razvoj bakterija i mikroorganizama, a također naštetiti daljnjem procesu konzervacije i samoj građi (sl. 13).

Dokumentacija je izrađena vrlo detaljno. Za svaki komad drva (sekcije / ulomaka) je sastavljen zapis koji podrazumijeva uvođenje podataka u restauratorske kartone. Osnovne podatke o građi čine opis, dimenzije te karakteristike samoga drva (vrsta drva, od kojeg dijela drva je određeni dio broda izrađen, degradacija drva itd.). Nakon fotografiranja svih ulomaka pristupilo se iscrtavanju sekcija na prozirnoj foliji u mjerilu 1:1 dok su manji ulomci skicirani u restauratorske kartone radi detaljnije dokumentacije¹².

Tijekom rada na ulomcima/sekcijama, prilikom otkrivanja mogućih štetnih dijelova/elemenata, kao što su razne naslage ili željezni čavli, uzimani su uzorci radi kemijske i biološke analize¹³.

Nakon čišćenja i dokumentiranja građe, Pula 2 se pričvrstila na metalnu konstrukciju od nehrđajućeg čelika. Ulomci/sekcije koji su imali organske ostatke konopa na sebi, osigurani su laganom mrežicom koja je učvršćena pomoću spojnika od nehrđajućeg čelika. Također su pomoću nehrđajućih spojnika učvršćeni i ponovno



Sl. 13 Otvaranje transportnog sanduka u radionici ARC-Nucléart u Grenobleu /Francuska, zima 2016. (foto: M. Petrović).

Fig. 13 Opening of the transport crate in the workshop at ARC-Nucléart in Grenoble, France, winter 2016 (photo by: M. Petrović).

and documenting processes were performed. Damaged surfaces of wood were cleaned mechanically with water and a soft brush. After the cleaning, small tools were used for a detailed cleaning of each boat part (front and back), removing remains of sludge and other impurities (left as residue after archaeological investigations) which could lead to the development of bacteria and microorganisms, and also jeopardize the ongoing process of conserving the boat timbers (Fig. 13).

Documentation was performed in great detail. A record was made for each piece of wood (section/fragment), which involved writing the data on restoration sheets. The basic data on the materials included the description, dimensions and characteristics of the wood itself (i.e. species of wood, the specific wood used to build a particular part of the boat, degradation of the wood, etc.). After taking photographs of all pieces, the sections were then drawn on transparent folios at a scale of 1:1, whereas the smaller fragments were sketched on the restoration sheets for a detailed documentation.¹²

The pieces/sections were checked to detect possible damaged parts/elements, such as various deposits or iron nails, of which samples were then taken for chemical and biological analysis.¹³

¹⁰ Uz stručno vodstvo tima iz ARC-Nucléarta: restauratora Henrija Bernarda-Maugirona, restauratorice Floraine Helias, i Stephanea Garrviera, voditelja prijemne radionice, restauratorice Andrea Sardoz i Monika Petrović educirane su i praćene u radu na pripremi, obradi i tretiranju mokrog arheološkog drva.

¹¹ Polietilen-glikol (PEG) je polieterski spoj s mnogim primjenama. Može se koristiti u industrijskoj i farmaceutskoj proizvodnji. Polietilen glikol nastaje interakcijom etilen oksida s vodom, etilen glikolom ili oligomerima etilen glikola. Ujedno se koristi kao sredstvo u konzervaciji mokrog arheološkog drva.

¹² Fotografiranje je obavio službeni fotograf iz ARC-Nucléart-a Christophe Terpent, sekcije i ulomke iscrtale su restauratorice Irene Garcia, Monika Petrović i Andrea Sardoz.

¹³ Uzimanje uzoraka i analizu izvršio je kemičar ARC-Nucléarta Thomas Guiblain.

¹² The photographing was done by the official photographer at the ARC-Nucléart, Christophe Terpent; sections and pieces were drawn by the restorer Irene Garcia, Monika Petrović and Andrea Sardoz.

¹³ Samples were taken, and an analysis performed by the chemist from the ARC-Nucléart, Thomas Guiblain.



Sl. 14 Pripremna faza prije uranjanja u PEG: čišćenje sekcija Pule 2 (foto: M. Petrović).

Fig. 14 Preparatory phase prior to immersing into PEG: cleaning of sections of Pula 2 (photo by: M. Petrović).



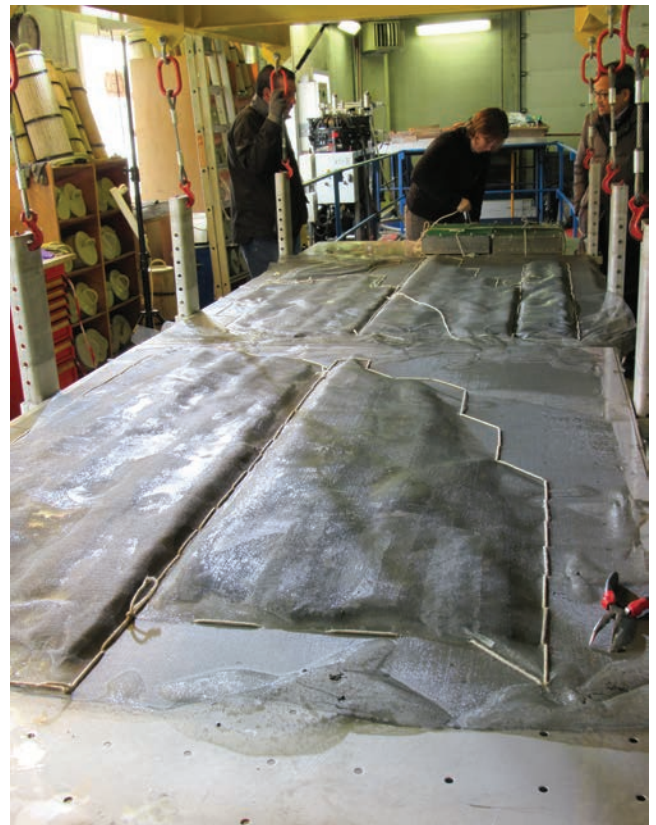
Sl. 15 Pripremna faza prije uranjanja u PEG: dokumentiranje - iscrtavanje sekcija Pule 2 u mjerilu 1:1 (foto: A. Sardoz).

Fig. 15 Preparatory phase prior to immersing into PEG: documenting - drawing the sections of Pula 2 at a scale of 1:1 (photo by: A. Sardoz).



Sl. 16 Pripremna faza prije uranjanja u PEG: učvršćivanje organskih ostataka - konopa mrežicom (foto: C. Terpent).

Fig. 16 Preparatory phase prior to immersing into PEG: fixing the organic remains - ropes with mesh (photo by: C. Terpent).



Sl. 17 Brodska konstrukcija Pula 2, pričvršćena na metalnu konstrukciju od nehrđajućeg čelika (foto: M. Petrović).

Fig. 17 Pula 2 boat structure, fixed to the stainless-steel metal structure (photo by: M. Petrović).

spojeni dijelovi drva koji se odvajaju. Tako osigurane sekcije položene su na velike nehrđajuće ploče metalne konstrukcije te su na njih učvršćeni mrežicom i konopom.

Manji ulomci drva spremljeni su u košare od nehrđajućeg čelika kako se prilikom uranjanja u otopinu PEG-a 4000 i vode ne bi pomakli ili oštetili (sl. 14 - sl. 17).

Once the material has been cleaned and documented, Pula 2 was fixed to a stainless-steel structure. The pieces and sections that had organic remains of rope on them were secured using a light mesh which was fixed using stainless-steel clips. In addition, stainless steel clips were used to fix and fasten together parts of wood that have

Prije uranjanja drvene brodske konstrukcije Pule 2 u bazen od nehrđajućeg čelika zbog konsolidacije, načinjena je kupka s otopinom PEG 4000 i vode. U prvoj fazi koncentracija PEG-a bila je 16 %, a u sljedećim fazama se koncentracija PEG-a povećavala s ciljem da se tijekom konsolidacije dostigne udio od 35 %.

Sljedeća tablica pokazuje razvoj koncentracije otopine PEG 4000 u razdoblju od veljače 2016. do veljače 2017. godine (Bernard Maugiron 2017, 15) (sl. 18).

Datum	PULA II // PEG 4000
12/02/2016	15,5 %
23/03/2016	15,8 %
11/04/2016	16,8 %
19/05/2016	18,8 %
28/06/2016	21 %
19/07/2016	24,8 %
14/08/2016	27 %
15/09/2016	31,4 %
06/10/2016	33,2 %
23/11/2016	35 %
6/02/2017	35 %

Sl. 18 Tablica razvoja koncentracije otopine PEG 4000 u razdoblju od veljače 2016. do veljače 2017. (preuzeto iz Izvještaja o restauraciji / konzervaciji Pula 2, H. Bernard-Maugiron).

Fig. 18 Table of the development of PEG 4000 concentration in the period from February 2016 to February 2017 (taken from the Report on the Restoration/Conservation of Pula 2, H. Bernard-Maugiron).

Za dobar učinak konsolidacije PEG-om potrebno je konstantno praćenje aktivnosti u bazenu da se ne razvijaju mikroorganizmi štetni za drvo. Kontrolirani uvjeti omogućuju održavanje otopine PEG-a u optimalnim uvjetima pomoću kontinuiranog filtriranja pomoću filtera (2 mikronska i 1 smolni), u kombinaciji s upotrebom UV-C lampi¹⁴.

Po završetku postupka (u veljači 2017) drveni dijelovi brodske konstrukcije Pule 2 izvađeni su iz 35 %-tne otopine PEG-a 4000. Izvađena brodska konstrukcija ispirana je vodom od viška PEG-a na površini natopljenog drva. Potom su komadi drva raspoređeni po pločama čineći homogene skupine prema debljini drva te su bili spremni za fazu sušenja (sl. 19, sl. 20).¹⁵

¹⁴ Za biološko praćenje aktivnosti u bazenu s PEG-om bio je zadužen biolog iz centra ARC-Nucléarta Loic Caillat.

¹⁵ Pripreme radove za postavljanje Pule 2 u liofilizatore obavili su Stephane Garrvier, voditelj prijemne radionice, restauratorice Andrea Sardoz i Monika Petrović, a liofilizacijski postupak nadzirao je kemičar iz centra ARC-Nucléarta Gilles Chauma.

been separated. These secured sections were laid on large stainless-steel sheets to which they were fastened with mesh and rope.

Smaller pieces of wood were stored in stainless steel baskets to avoid damaging them during the immersion into the PEG 4000 solution and water. Prior to immersing the Pula 2 wooden boat structure into the stainless-steel pool for consolidation purposes, a bath containing the PEG 4000 solution and water was prepared. In the first phase, the concentration of PEG was 16%, and in the following phases the concentration of PEG was increased to 35% during consolidation (Fig. 14 - Fig. 17).

The following table shows the increase in concentration of the PEG 4000 solution over the period from February 2016 to February 2017 (Bernard Maugiron 2017, 15) (Fig. 18).

A satisfying outcome of consolidation using PEG required constant monitoring of activities in the pool to prevent the development of micro-organisms harmful to wood. Controlled conditions enabled maintaining the PEG solution at optimal conditions using continuous filtering through filters (2 micron types and 1 resin type), in combination with UV-C lamps.¹⁴

Upon completion of the process (in February 2017), the wooden parts of the Pula 2 boat structure were retrieved from a 35% solution of PEG 4000. The retrieved



Sl. 19 Brodska konstrukcija Pula 2 - izvlačenje iz bazena s otopinom PEG 4000 (foto: M. Petrović).

Fig. 19 Pula 2 boat structure - retrieval from the pool containing the PEG 4000 solution (photo by: M. Petrović).

¹⁴ The biological monitoring of the activities in the pool containing PEG was assigned to the biologist from the ARC-Nucléart center, Loic Caillat.



Sl. 20 Dijelovi brodske konstrukcije Pula 2 raspoređeni u liofilizatore (foto: C. Terpent).
 Fig. 20 Parts of the Pula 2 boat structure placed into lyophilizers (photo by: C. Terpent).

5. FREEZE DRYING ILI LIOFILIZACIJA

Liofilizacija podrazumijeva sušenje tvari osjetljive na toplinu smrzavanjem otopine (u ovom slučaju PEG-a i vode) i sublimacija tog leda u visokom vakuumu (Coles, Dobson, Coles 2010, 29–30). Sušenje zamrzavanjem ili zamrzavanje je postupak kojim se voda uklanja iz mokrog arheološkog drva, u ovom slučaju, koje može biti oštećeno zagrijavanjem ili sušenjem na zraku, a istodobno čuva strukturu, volumen, obim i sastav drva.

Liofilizacija mokrog arheološkog drva se temelji na zamrzavanju mješavine PEG-a i vode, nakon čega slijedi smanjenje tlaka i dodavanje dovoljne količine topline za evaporiranje smrznute vode u drvu izravno od čvrstog do plinovitog agregatnog stanja.

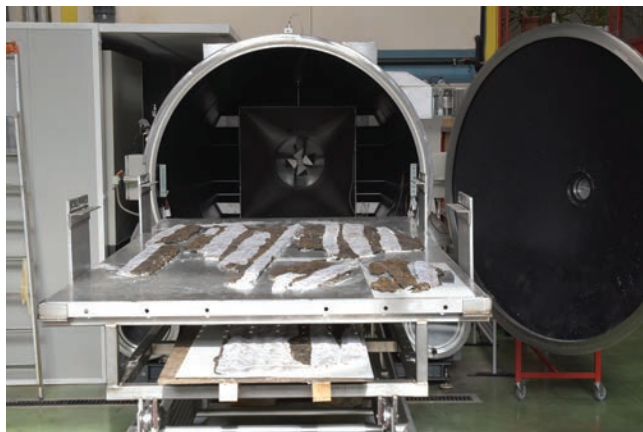
Kod zamrzavanja je važno da se materijal ohladi ispod njegove trostruke točke, na najnižu temperaturu ($-30\text{ }^{\circ}\text{C}$). To osigurava pojavu sublimacije i izbjegava taljenje. Faza zamrzavanja najkritičnija je tijekom čitavog procesa liofilizacije jer se u slučaju nepravilne primjene proizvod može uništiti (Leszek Babinski 2007, 95–97). Nakon toga dolazi do faze primarnog sušenja gdje se tlak smanjuje (na nekoliko milibara) tako da drvo proizvede dovoljnu

boat structure was rinsed with water to remove excess PEG from the surface of the immersed wood. Then, the pieces of wood were sorted and laid on the sheeting in homogeneous groups based on the thickness of wood and were prepared for the drying phase (Fig. 19, Fig. 20).¹⁵

5. FREEZE DRYING OR LYOPHILIZATION

Lyophilization process involves drying of a substance sensitive to heat by freezing the solution (in this case PEG and water) followed by the sublimation of the thus obtained ice under a deep vacuum (Coles, Dobson, Coles 2010, 29–30). Freeze drying or freezing is a process that removes water from wet archaeological wood, which might otherwise, like in this case, be damaged through heating or air drying, while at the same time preserving the structure, volume, dimensions and composition of the wood.

¹⁵ Preliminary works for placing Pula 2 into lyophilizers were carried out by Stephane Garrvier, leader of the preliminary workshop, and restorers Andrea Sardož and Monika Petrović, while the lyophilization process was overseen by the chemist from the ARC-Nuclart center, Gilles Chaum.



Sl. 21 Vađenje drva iz liofilizatora (foto: C. Terpent).
Fig. 21 Retrieval of wood from the lyophilizers (photo by: C. Terpent).



Sl. 22 Vađenje brodskih dijelova iz liofilizatora (foto: C. Terpent).
Fig. 22 Retrieval of boat parts from the lyophilizers (photo by: C. Terpent).

toplinu da se voda sublimira. Ova faza mora biti spora jer u slučaju prevelike topline može doći do promjene strukture drva. Tlak se kontrolira djelomičnim vakuumom koji ubrzava sublimaciju. Prilikom sekundarnog sušenja uklanja se ostatak vodenih molekula. Led je već uklonjen sublimacijom tijekom faze primarnog sušenja. U ovoj fazi temperatura je viša nego u primarnoj fazi sušenja i može biti čak i iznad 0 °C. Tlak se smanjuje kako bi se ubrzala desorpcija (proces suprotan adsorpciji).

Sušenje drva liofilizacijom je proces koji se u početnoj fazi svodi na zamrzavanje smjese vode i smole (PEG-a) u drvu na -30 °C, nakon čega slijedi postupak stvaranja vakuuma kako bi se potaknula zamjena vode, odnosno isparavanje vode iz leda (led se smatra stabilnijom krutinom) koji sprječava urušavanje porozne strukture drveta tijekom sušenja (ovim se postupkom sprječava gubitak obima, volumena i distorzija drva prilikom sušenja). Smola PEG je ispunila unutrašnjost pora, te time omogućila konsolidaciju krhke strukture mokrog arheološkog drva.

Proces liofilizacije trajao je od početka veljače 2017. do početka ožujka 2017 (sl. 21, sl. 22).

Nakon sušenja drva postupkom liofilizacije pod vodstvom Stephanea Garriviera u ožujku 2017. godine restauratorice su započele s radom na čišćenju i restauriranju broda Pula 2.

Prvi je korak bio pražnjenje liofilizatora. Ulomci i sekcije broda Pula 2 pažljivo su preneseni sa nehrđajućih stolova na propilenske ploče (Coroplast ploče). Ploče su zatim prevezene, pomoću radnih stolova na kotačima, u zasebnu radionicu namijenjenu za restauraciju.

6. ČIŠĆENJE

Nakon vađenja osušenog drva iz liofilizatora, bilo je potrebno ukloniti sve viškove smole PEG 4000, koja

Lyophilization of wet archaeological wood involves freezing of a mixture of PEG and water, after which pressure is reduced and ample heat is added to induce evaporation of frozen water in the wood directly from a solid to gaseous state.

During the freezing, it is important that the material is cooled below its triple point, to the lowest temperature (-30 °C). This ensures the onset of sublimation and prevents melting. The freezing phase is most critical during the entire lyophilization process, because in case of incorrect use, the material may be destroyed (Leszek Babinski 2007, 95-97). This is followed by the primary drying phase where the pressure is decreased (to a few millibars) so that the wood produces enough heat for sublimation of the water. This phase must be executed slowly, otherwise excessive heat may lead to changes in the structure of the wood. The pressure is controlled via a partial vacuum that accelerates sublimation. The secondary drying removes the remaining water molecules. Ice has already been removed through sublimation during the primary drying phase. In this phase, the temperature is higher than in the primary drying phase and may even be above 0 °C. The pressure is decreased to quicken desorption (the opposite of absorption).

Drying wood by lyophilization is a process which freezes the water and resin (PEG) mixture in the wood to -30 °C in the initial phase and is then followed by creating a vacuum to initiate water replacement, i.e., evaporation of water from ice (ice is considered a more stable solid) and which prevents the degradation of the porous structure in wood during drying (this process prevents the loss of size and volume, and the distortion of wood during drying). The PEG resin fills the inside of the pores, enabling consolidation of the fragile structure of the wet archaeological wood.



Sl. 23 Sekcija broda na kojoj su vidljivi ostaci PEG-a (foto: A. Sardoz).
Fig. 23 Boat section on which the remains of PEG are visible (photo by: A. Sardoz).



Sl. 25 Detalj brodske oplata nakon postupka liofilizacije (foto: A. Sardoz).
Fig. 25 Detail of boat planking after the lyophilization process (photo by: A. Sardoz).

se tijekom liofilizacije kristalizirala na površini drvenih sekcija i ostalih dijelova broda.

Čišćenje sekcija i ulomaka broda rađeno je mehanički. Površinu se čistilo pomoću mekih kistova, vatiranih štapića i PVC četkica uronjenih u destiliranu vodu. Neki su kristali PEG-a bili malo tvrdi, pa se njih uklanjalo vatiranim štapićima uronjenim u 50 % otopinu destilirane vode i etilnog alkohola. Svakom se milimetru drva pristupalo s velikim oprezom jer bi prevelika količina vode mogla otopiti suviše PEG-a, a tim činom bi se ugrozila stabilnost već konzerviranog drva. Zato se nakon svakog prelaska vodom preko višaka kristala na drvenim sekcijama i ulomcima suvišna količina vode odmah upijala pomoću papirnatih ubrusa. Tako se samo površinski uklonio višak PEG-a (sl. 26 - sl. 29).

Pojedini manji ulomci su se odvojili prilikom pranja, uranjanja i sušenja te ih je bilo potrebno ponovo spojiti



Sl. 24 Detalj sekcije s ostacima PEG-a (foto: A. Sardoz).
Fig. 24 Detail of a section with PEG remains (photo by: A. Sardoz).

The lyophilization process lasted from the beginning of February 2017 to the beginning of March 2017 (Fig. 21, Fig. 22).

After drying the wood through lyophilization under the guidance of Stephane Garrivier in March 2017, the restorers commenced working on cleaning and restoration of the Pula 2 boat.

The first step was the emptying of the lyophilizers. Fragments and sections of the Pula 2 boat were carefully transferred from stainless steel tables to propylene sheeting (Coroplast sheeting). The sheeting was then transferred on worktables equipped with wheels to a separate workshop for the restoration.

6. CLEANING

After removing the dried wood from the lyophilizers, all the excess PEG 4000 resin that was crystallized on the surface of wooden sections and other boat parts during lyophilization, had to be removed (Fig. 23 - Fig. 25).

Cleaning of the boat sections and fragments was executed mechanically. The surface was cleaned with small soft brushes, cotton buds and larger PVC brushes dipped into distilled water. Some of the PEG crystals were more resistant, so they had to be removed using cotton



Sl. 26 Postupak čišćenja viška PEG-a (foto: A. Sardoz).
Fig. 26 Procedure for the removal of the excess PEG (photo by: A. Sardoz).



Sl. 27 Postupak čišćenja (foto: A. Sardoz).
Fig. 27 Removal procedure (photo by: A. Sardoz).



Sl. 28 Dio sekcije prije čišćenja PEG-a (foto: A. Sardoz).
Fig. 28 Part of the section prior to the removal of the PEG (photo by: A. Sardoz).

na njihovo originalno mjesto. Takvi ulomci zalijepljeni su 15% otopinom termoplastične akrilne smole u acetonu (Paraloid B72).

7. SKLADIŠTENJE

Nakon čišćenja svake sekcije i ulomka svaki je pripremljen za transport. Prije pakiranja sekcija i ulomaka u Grenobleu, nakon što su se uzele točne mjere svake sekcije i ulomka, u Puli se pristupilo izradi sanduka za

buds immersed into a 50% solution of distilled water and ethyl alcohol. Each millimetre of the wood was treated with great caution, because a large amount of water could dissolve too much PEG, thereby jeopardising the stability of the already conserved wood. That is why after each application of water over excess crystals on the wooden sections and fragments, the excess amount of water was immediately absorbed using paper towels. This enabled removal of excess PEG from the surfaces (Fig. 26 - Fig. 29).

transport. Sanduci su napravljeni od strane djelatnika na održavanju Arheološkog muzeja Istre¹⁶. Svaki je sanduk napravljen od vodootporne šperploče s nogama i bravama od nehrđajućeg metala, da bi se spriječilo bilo kakav doticaj broda Pula 2 sa željeznom ili bilo kojom drugom korozijom koja bi mogla ugroziti stabilnost drva (sl. 30, sl. 31).



Sl. 30 Pakiranje sekcija broda (foto: C. Terpent).
Fig. 30 Packing of the boat sections (photo by: C. Terpent).



Sl. 31 Pakiranje rebra i kobilice broda (foto: C. Terpent).
Fig. 31 Packing of the frames and keel (photo by: C. Terpent).

Sekcije broda, prije stavljanja u drvene sanduke, položene su na ploče od polietilenske pjene. Na svakoj je ploči točno određeno mjesto gdje su sekcije “polegnute”. Duž rubova poli-etilenske pjene umetnut je bezkiselinski papir kako bi se izbjegla bilo kakva abrazija drva (sl. 32).

Ispod svakog elementa umetnuta je i šperploča kako bi se izbjeglo bilo kakvo savijanje originalnog drva i kako bi se nakon transporta moglo lakše rukovati pločama u budućnosti.

Nakon detaljne pripreme na pločama, moglo se iste ukrcati u drvene, transportne sanduke. Sanduci s konzerviranim ostacima brodske konstrukcije su krajem ožujka 2017. dovezeni u Pulu.

¹⁶ Sanduci za prijevoz su napravljeni pod vodstvom radnika na održavanju Admira Dizdarevića.



Sl. 29 Postupak čišćenja (foto: C. Terpent).
Fig. 29 Removal procedure (photo by: C. Terpent).

Certain smaller fragments had become separated during washing, immersing and drying, and had to be put back to their original position. These fragments were glued using a 15% solution of thermoplastic acrylic resin in acetone (Paraloid B72).

7. STORAGE

After cleaning all the sections and fragments, each one was prepared for transport. Prior to the packing of the sections and fragments in Grenoble, each timber section and fragment was measured and the transport crates were then constructed in Pula. The crates were made by maintenance employees of the Archaeological Museum of Istria.¹⁶ Each crate was made from water resistant marine-grade plywood and equipped with stainless-steel legs and locks, so as to prevent making any contact between the Pula 2 boat and iron or any other corrosive material that could jeopardise the stability of the wood (Fig. 30, Fig. 31).

Prior to being placed into the wooden crates, boat sections were laid out on a sheeting made from polyethylene foam. Each sheet had an exact marking where the sections were to be “laid”. Inserted along the edges was polyethylene foam without acidic paper so as to prevent abrasion of the wood (Fig. 32).

In addition, plywood was placed under each element to avoid any bending of the original wood and to make handling of the sheets after transport easier in the future.

After such detailed preparation, the sheetings with boat sections could then be loaded into the wooden transport crates. The crates containing the conserved remains of the boat structure were delivered to Pula at the end of March 2017.

¹⁶ The crates used for the transport were made under the guidance of the maintenance worker Admir Dizdarević.



Sl. 32 Pakiranje (foto: A. Sardoz).

Fig. 32 Packing (photo by: A. Sardoz).

Po dolasku u Pulu, sanduci su smješteni u skladišne prostore Arheološkog muzeja Istre. Restauratorice su na mjestu gdje su sanduci pohranjeni postavili monitore za mjerenje vlage i temperature jer tretirano arheološko drvo podliježe određenim parametrima radi njegovog očuvanja. Preporučeni parametri u ovom slučaju su relativna vlaga u okolišu u kojem se drvo nalazi bi trebala biti oko 50%, te temperatura ne bi smjela prelaziti 21–22 °C. S obzirom da se na sekcijama broda očuvala špaga kojom je brod bio konstruiran, bilo ju je potrebno konsolidirati, odnosno dodati joj elastičnost. Restauratorice su taj postupak napravile u Puli i to premazivanjem špaga 50% otopinom kopolimer etilen-vinil acetata (Evacon) u destiliranoj vodi.

ZAKLJUČAK

Unatoč očitom značenju u prošlim kulturama, nalazi drva su slabo zastupljeni u muzejskim zbirkama. Brodovi Pula 1 i Pula 2 predstavljaju prvi susret arheologa i restauratora Arheološkog muzeja Istre s mokrim arheološkim drvom u kopnenom okruženju. Stoga je jasna potreba da se konzervira i restaurira mokro arheološko drvo te tako zadrži u regionalnim i nacionalnim muzejima, kako za studij, tako i za prikaz unutar stalnog postava muzeja.

Arheološko drvo natopljeno vodom jednim se dijelom u postdepozicijskim procesima nepovratno deformira, a samim sušenjem na zraku bez intervencije došlo bi do većih deformacija/distorzija takvog drva koje bi se očitovale u nestanku drvenih vlakana, staničnom propadanju sastavnica od kojih je jedna celuloza. U navedenom slučaju mehanički otpor staničnih stijenki (koje čine poroznu strukturu drva) slabi i one više ne mogu podnijeti kapilarnu snagu prolaska vode kroz drvo.



Sl. 33 Pakiranje (foto: A. Sardoz).

Fig. 33 Packing (photo by: A. Sardoz).

Upon arrival in Pula, the crates were placed in the storage section of the Archaeological Museum of Istria. The restorers placed monitors for measuring humidity and temperature at the location where the crates were stored, because the treated archaeological wood depends on certain parameters for its conservation. The recommended parameters in this case are such that the relative humidity in the environment containing the wood should be about 50%, and that the temperature should not exceed 21–22 °C. Given that the rope used for construction has been preserved on the boat sections, it had to be consolidated, i.e., given more elasticity. The restorers performed this process in Pula by coating the ropes with a 50% solution of ethylene-vinyl acetate copolymer (Evacon) in distilled water.

CONCLUSION

Despite their obvious significance in past cultures, wood finds are poorly represented in museum collections. The discovery of ships Pula 1 and Pula 2 represented the first encounter of the archaeologists and restorers of the Archaeological Museum of Istria with wet archaeological wood in land surroundings. The discovery reflected the need to conserve and restore wet archaeological wood material so that it can remain part of the regional and national museums for study purposes and conceivably as part of the permanent display of the museum.

Archaeological wood soaked in water can be irreversibly deformed during post-depositional processes and without proper intervention even further damaged or distorted by air drying, which would result in the destruction of the wood fibers and cellular degradation of components of which one is cellulose. In the stated case, mechanical resistance of cellular walls (which make up the porous structure of wood) is weakened and can

Zbog toga je proces konzervacije nužan za ovakav tip arheoloških nalaza.

Po pronalasku broda specifičnost situacije s kojom se radna ekipa dotad nije susrela, zahtijevala je nove smjerove u razmišljanju i djelovanju pri istraživanju, vađenju i preliminarnoj obradi nalaza. Prvi je problem svakako bio održavanje odgovarajućih uvjeta za istraživanje, ali i očuvanje drvenih nalaza. Usljedio je sistem osiguranja adekvatne podloge/nosača broda kako bi se spriječile bilo kakve deformacije mokroga drva pri prijevozu u desalinizacijski bazen. Svako se problematici pristupalo zasebno i detaljno. O problemima je raspravljano te je za svaki problem utvrđen modalitet zahvata.

Fazu primarne konzervacije odradio je tim arheologa, restauratora i preparatora u Puli.

Primarna konzervacija sastojala se od demontaže brodova s arheološkog lokaliteta, preko pranja ulomaka i sekcija *in situ* te transporta i stavljanja na desalinizaciju kako brodova tako i ulomaka koji su bili uokolo. S obzirom da se konzervatorsko-restauratorska radionica muzeja po prvi put susrela s ovakvom vrstom nalaza, jasno je bilo da zbog nedostatka potrebne opreme i materijala, nije bilo moguće ostvariti proces konzervacije i restauracije u Puli. Odabir metodologije konzervacije i restauracije drva je također bila problematika o kojoj se raspravljalo prije konačne odluke. Radi toga je donesena odluka da se brod Pula 2 otpremi na konzervaciju u europski poznati laboratorij ARC-Nucléart (Grenoble-Francuska) koji se niz godina bavi konzervacijom i restauracijom mokrog arheološkog drva te ostalih organskih materijala.

Restauratorice Arheološkog muzeja Istre su radom na konzervaciji Pule 2 i boravkom u laboratoriju stekle neprocjenjivo iskustvo u radu i rukovanju s mokrim drvetom.

Radovi konzervacije drvenih ostataka broda Pule 2 tek su jedan korak prema valorizaciji tj. prezentaciji ovih jedinstvenih nalaza u Hrvatskoj. Nakon konzervacije trebao bi uslijediti postupak restauracije brodske konstrukcije i njezino izlaganje javnosti. Brod bi se trebao izložiti u namjenskom prezentacijskom prostoru s odgovarajućim mikroklimatskim i drugim uvjetima. Međutim, s obzirom da zasad na obližnjem području ne raspoložemo prostorom/galerijom koja bi bila dostatna za prezentaciju dva rimska šivana broda, predstoji zahtjevan zadatak u potrazi potencijalnog izložbenog prostora. Brodovi već i sad (usklađeni u sanducima ili u bazenu s vodom) plijene pažnju struke i šire javnosti.

Napomenut ćemo da su jedini primjeri zaštite drvenih brodova u Hrvatskoj dva starohrvatska broda *Condura Croatica* iz 11. stoljeća, pronađena i istražena šezdesetih

no longer support capillary strength of passing water through the wood. Consequently, a conservation process is necessary for these types of archaeological finds.

Upon the discovery of the boat, the specificity of the situation, which was unlike anything the working team has met before, demanded new directions in reflection and approaches during investigations, retrieval and preliminary treatment of the finds. The first concern was certainly maintaining the appropriate conditions for the investigation, and also the preservation of the timber finds. The efforts were made to ensure an adequate base/support for the boats to prevent any deformation of the wet wood during transport to the desalination pool. Each problem was approached separately and in detail. The issues were discussed, and specific action was determined for each problem.

The primary conservation phase was performed by a team of archaeologists, restorers and preparators in Pula. Primary conservation implied disassembly of the boats at the archaeological site, washing of fragments and sections *in situ* as well as transport and preparation for desalination of both the ships and their dispersed fragments. Given that this was the first such find encountered by the Museum's Conservation-Restoration Department, it became clear that performing the conservation and restoration process in Pula was not possible due to insufficient equipment and materials. Selecting the method for conservation and restoration of the wood was also an issue that was discussed prior to the final decision. Consequently, a decision was made to dispatch the Pula 2 boat for conservation to a known European laboratory at ARC-Nucléart (Grenoble, France) which has for years been doing conservation and restoration of wet archaeological wood and other organic materials.

While working on the conservation of Pula 2 in the laboratory at ARC-Nucléart, the restorers of the Archaeological Museum of Istria gained valuable experience in working with and handling wet wood.

The work on conservation of the wet remains belonging to the Pula 2 boat was only the first step towards the valorization, i.e., presentation of these unique finds in Croatia. After conservation, the next step would be the restoration of the boat structure and its presentation for the public. The boat will be exhibited in a purposeful presentation area along with the appropriate micro-climate and other conditions. However, given that we do not have at our disposal some nearby premises or gallery appropriate for presenting the two Roman sewn ships, there remains the demanding task of finding the possible exhibition premises. The ships (stored in crates or in the pool of

godina 20. stoljeća kod Nina, od strane prof. Zdenka Brusića iz Arheološkog muzeja u Zadru. Brodovi su izvađeni njegovom i inicijativom konzervatora Božidara Vilhara iz Arheološkog muzeja u Zadru koji je na njima proveo metodu konzervacije polietilen glikolom (Šimičić 2017, 51-59).

Suvremena konzervacija koja se primjenjuje u europskim laboratorijima je znatno unapredovala u metodologiji i materijalima koji se koriste u konzervaciji. Jednako tako, svjedoci smo da se u posljednjem desetljeću na području Hrvatske (uglavnom u podmorju, rijekama, ali i na kopnu kao što je slučaj u Puli) pronašlo nekoliko brodova i drugih nalaza od organskog materijala. Samim time otvara se potreba za visoko opremljenim laboratorijem na području Hrvatske koji bi mogao prihvatiti i ovako velike nalaze te ih sukladno načelima suvremene restauratorske struke konzervirati tj. restaurirati.

water) even now draw the attention of the profession and wider public.

We would like to mention that the only examples of protected wooden ships in Croatia are two old Croatian *Condura Croatica* from the 11th Century, found and investigated in the 1960s in the area of Nin, by Prof. Zdenko Brusić from the Archaeological Museum in Zadar. The ships were retrieved at both his and the initiative of the conservator Božidar Vilhar from the Archaeological Museum in Zadar who had performed the polyethylene glycol conservation method on them (Šimičić 2017, 51-59).

Contemporary conservation which is used in European laboratories has significantly advanced in terms of methodology and materials used in conservation. Moreover, we have witnessed over the past decade that a number of shipwrecks and other finds made of organic material have been discovered in the region of Croatia (mostly in the sea, rivers but also on land as is the case in Pula). Consequently, there is an obvious need for a well-equipped laboratory in Croatia that could receive these large finds and conserve and restore them in accordance with the principles of the modern restoration profession.

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