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PRIMJENA 3D TEHNOLOGIJE PRI IZRADI DETALJNE DOKUMENTACIJE STAROHRVATSKOG BRODA *CONDURA CROATICA*

Razvojem modernih 3D tehnologija te operativnih sustava i aplikacija iz područja reverzibilnog inženjerstva, 3D modeliranje zauzima sve veće područje primjene. Naime, zbog učinkovitosti i točnosti same tehnologije, osim njezine uobičajene primjene u računalnim igrama, 3D tehnologija danas se primjenjuje i u arhitekturi, medicini, znanosti, inženjeringu, filmskoj industriji itd. Sve je veća primjena 3D tehnologije i u arheologiji i restauraciji, najvećim dijelom pri dokumentiranju, snimanju i mjerenju lokaliteta, objekata ili nalaza koji imaju veliku povijesnu važnost. Starohrvatski brodovi, *Condura Croatica*, dokaz su duge hrvatske pomorske tradicije i jedinstveno su kulturno dobro za koje se nametnula potreba digitalnog dokumentiranja. Dijelovi sačuvanih konstrukcija brodova *Condura Croatica* izloženi su u posebnom paviljonu Muzeja ninskih starina, a radi što preciznijeg dokumentiranja njihova postojećeg stanja primijenjena je jedna od najkvalitetnijih tehnologija 3D skeniranja.

Ključne riječi: 3D dokumentiranje, 3D skeniranje, 3D modeliranje, *Condura Croatica*

THE USE OF 3D TECHNOLOGY IN THE CREATION OF DETAILED DOCUMENTATION OF THE EARLY CROATIAN SHIP *CONDURA CROATICA*

With the development of modern 3D technologies, operating systems, and applications from the field of reversible engineering, the use 3D modelling in various fields is ever-increasing. Namely, due to the efficiency and accuracy of the technology, apart from its common use in computer games, the 3D technology today is also used in architecture, medicine, science, engineering, film industry, etc. The use of 3D technology is also increasing in archaeology and restoration, mostly in the process of documentation, recording and measuring of sites, objects or findings that have great historical importance. The Early Croatian ships, *Condura Croatica*, are a proof of the extensive Croatian maritime tradition, and they are a unique cultural asset which required digital documentation. The parts of the preserved structures of the *Condura Croatica* ships are exhibited in a special pavilion of the Museum of Nin Antiquities, and in order to document their current condition as precisely as possible, one of the highest quality 3D scanning technologies was used in the process.

Key words: 3D documentation, 3D scanning, 3D modelling, *Condura Croatica*

UVOD

Vadeći pijesak s morskog dna, koji se inače koristio kao građevni materijal, privlački je mornar vadio i kamenje i tragove drva. O toj nesvakidašnjoj situaciji izvijestio je kustosa Arheološke zbirke u Ninu, podvodnog arheologa Zdenka Brusića, koji je potom u svom istraživanju 1966. godine na samom ulazu u ninsku luku pronašao mali drveni brod.[1] Dvije godine kasnije širom pretragom terena u blizini prvog broda pronađen je još jedan brod. Brodovi su ležali na dubini od samo 1,5 do 2 m, ispod hrpe kamenja na pješčanom morskom dnu, te su pronađeni bez ostataka tereta i opreme.[2] To navodi na pretpostavku da su brodovi namjerno potopljeni da bi zaštitili ulaz u ninsku luku od mogućih neprijatelja. Zbog nepostojanja ostataka tereta ili opreme nije bilo moguće utvrditi vrijeme njihove plovidbe, stoga je izvršeno radiokarbonsko datiranje uzoraka drva analizom radioaktivnog ugljika ^{14}C. Provedenom analizom brodovi su datirani u sredinu 11. i početak 12. stoljeća, odnosno u kasni srednji vijek, u doba hrvatskih vladara.[3]

Zapisi bizantskog cara Konstantina VII. Porfirogeneta iz 10. stoljeća, u kojima se navodi da su tadašnju hrvatsku mornaricu činili manji brodovi – *kondure* – i veći brodovi – *sagene,*[4] naveli su znanstvenike na pretpostavku da su u Ninu pronađeni brodovi upravo prethodno spomenute kondure. Naime, oni i izgledom odgovaraju kondurama. Kondure su brodovi dugi 7 – 9 m i široki 1,5 – 2 m, uskog trupa i građeni od rebara koja su za oplatu povezana drvenim i željeznim čavlima. Tijekom povijesti bili su poznati kao najmanji, ali i vrlo ubojiti ratni brodovi. Osim u ratne i obrambene svrhe, koristili su se i za ribolov i prijevoz ljudi i materijala. Bili su to brzi brodovi na vesla koji su pri povoljnom vjetru plovili i uz pomoć četvrtastog križnog jedra. Specifičnost konstrukcije trupa je nepostojanje klasične kobilice. Umjesto klasične kobilice brodovi sa svake strane imaju po dvije uzdužne paralelne grede koje se nalaze na vanjskom dijelu trupa. Te su grede korištene za stabilizaciju i držanje linije broda tijekom plovidbe, a također su činile brodove brzima i okretnima što je bilo važno u ratnim vremenima. Zbog plitke krme pretpostavlja se da su grede služile i za izvlačenje broda na obalu.[5] *Condura Croatica* jedinstveni je primjer pomorske tradicije srednjovjekovnih hrvatskih vladara, što te brodove čini iznimnom i vrlo vrijednom kulturnom baštinom Republike Hrvatske.[6]

1 Z. Brusić 1969, 443.
2 Z. Brusić 1969, 444.
3 Z. Brusić 1969, 443; 1978, 1012.
4 M. Kozličić 1991, 18.
5 Z. Brusić 1978, 8–10.
6 O vrijednosti i važnosti brodova govori i činjenica da su po uzoru na arheološke nalaze napravljene dvije replike broda. Inspiracija za izradu replika bili su dolasci pape Ivana Pavla II. u Hrvatsku 1998. i 2003. godine. Prva, manja replika u vlasništvu je gradskog poduzeća Komunalac Nin d.o.o. i usidrena je kraj Donjeg mosta u Ninu. Druga, veća replika koja se koristi za edukativne i promidžbene aktivnosti kao što su regate i festivali tradicijskih plovila u zemlji i inozemstvu u vlasništvu je Arheološkog muzeja Zadar i Sveučilišta u Zadru te je usidrena u Zadru. Replike je izradio betinski brodograditelj Čedomir (Ćiro) Burtina (https://www.unizd.hr/obavijesti/view/manifestacija-plovidba-kroz-vrijemequot).

INTRODUCTION

While extracting sand from the seabed, which was ordinarily used as building material, a sailor from Privlaka also removed stones and traces of wood. He reported this unusual situation to the curator of the Archaeological Collection in Nin, the underwater archaeologist Zdenko Brusić, who subsequently in his 1966 research found a small wooden ship at the very entrance to the port of Nin.[1] Two years later, during a wide search of the area, another ship was found in the vicinity of the first one. The ships were lying at a depth of only 1.5 to 2 m, underneath a pile of stones on the sandy seabed, and there were no remains of cargo and equipment.[2] This leads to the assumption that the ships were sunk on purpose to protect the entrance to the port of Nin from possible enemies. Due to the absence of remains of cargo or equipment, it was not possible to determine the period in which these ships were sailing, therefore, a radiocarbon dating of wood samples was carried out by analysing the ^{14}C radiocarbon. Based on the analysis, the ships were dated to the middle of the 11th and the beginning of the 12th century, that is, to the Late Middle Ages, in the period of Croatian rulers.[3]

The records of the Byzantine Emperor Constantine VII Porphyrogenitus from the 10th century, which state that the Croatian navy of that time consisted of smaller ships – *condurae* – and larger ships – *sagenae*,[4] led the scientists to assume that the ships found in Nin were the aforementioned *condurae*. Namely, they are also visually similar to the *condurae*. The *condurae* are 7 to 9 m long and 1.5 to 2 m wide, with a narrow hull and frames that are nailed with wooden and iron nails to the planking. Throughout the history, they were known as the smallest, but also very lethal warships. In addition to war and defence purposes, they were also used for fishing, and for the transport of people and materials. They were fast oared ships that sailed in favourable winds with the help of a square sail. A specific feature of the hull structure is the absence of a classic keel. Instead of a classic keel, the ships have two longitudinal parallel beams on each side, which are located on the outer part of the hull. These beams were used to stabilize and hold the ship's line while sailing, and they also enabled the ships to be fast and agile, which was important during the times of war. Because of the shallow stern, it is assumed that the beams were also used to pull other ships ashore.[5] The *Condura Croatica* is a unique example of the maritime tradition of medieval Croatian rulers, which makes these

1 Z. Brusić 1969, 443.
2 Z. Brusić 1969, 444.
3 Z. Brusić 1969, 443; 1978, 1012.
4 M. Kozličić 1991, 18.
5 Z. Brusić 1978, 8–10.

Slika 1. Brodovi u Muzeju ninskih starina, AMZd, inv. br. MNS2530 i MNS2531
Figure 1. Ships in the Museum of Nin Antiquities, AMZd, inv. no. MNS2530 and MNS2531

foto / photo: **A. Jelić**

Godine 1974. brodovi su u dijelovima izvučeni iz morskog okoliša. Uslijedio je proces desalinizacije, konzervacije i restauracije te rekonstrukcije jednog od brodova,[7] nakon čega su oba broda izložena u Muzeju ninskih starina, Odjelu Arheološkog muzeja Zadar (Sl. 1).[8] Međutim, zbog osjetljivosti drva na nepovoljne mikroklimatske uvjete u kojima su brodovi izloženi vrlo brzo nakon konzervatorskog postupka, uočene su degradacijske promjene na drvu. To je potaknulo Sveučilište u Zadru na suradnju sa Sveučilištem u Tel Avivu 2008. i Sveučilištem Texas A&M 2010. na analizu uzoraka drva. Analiza je pokazala da su brodovi građeni od više vrsta hrastovine.[9] Daljnje analize pokazale su prisutnost niza kemijskih i fizikalnih procesa koji su, uz neadekvatne uvjete u kojima su brodovi izloženi, uzrokovali uništenje

ships an exceptional and extremely valuable cultural heritage of the Republic of Croatia.[6]

In 1974, the ships were extracted from the marine environment in parts. This was followed by desalination, conservation and restoration, and reconstruction of one of the ships,[7] after which both ships were exhibited in the Museum of Nin Antiquities, Department of the Archaeological Museum Zadar (Fig. 1).[8] However, the degradation changes were observed in

7 Vidi Z. Brusić 1978; R. Jurić, S. Oguić, B. Vilhar 1991; R. Jurić, S. Sutlović, B. Vilhar 1997; M. Kozličić, Z. Brusić 1991.

8 Arheolog Zdenko Brusić, začetnik podvodne arheologije u Hrvatskoj, najzaslužniji je za istraživanje i promidžbu brodova iz Nina, a za uspješnu realizaciju postupka desalinizacije, konzervacije i restauracije te rekonstrukcije najzaslužniji je konzervator Božidar (Darko) Vilhar te njegovi suradnici Stošija Oguić i Radomir (Miro) Jurić (http://www.adriasproject.org/files/file/EDUCATION/Condura-brosura-za-Festival-znanosti.pdf).

9 Vidi I. Radić Rossi, N. Liphschitz 2010.

6 The fact that two replicas of the ship were made based on archeological finds speaks of the value and importance of the ships. The inspiration for the replicas was the visit of Pope John Paul II to Croatia in 1998 and 2003. The first, smaller replica is owned by the city company Komunalac Nin d.o.o. and is anchored near the Donji most in Nin. The second, larger replica, which is used for educational and promotional activities such as regattas and traditional vessel festivals in the country and abroad, is owned by the Archaeological Museum Zadar and the University of Zadar and it is anchored in Zadar. The replicas were made by the Betina shipbuilder Čedomir (Ćiro) Burtina (https://www.unizd.hr/obavijesti/view/manifestacija-plovidba-kroz-vrijemequot).

7 See Z. Brusić 1978; R. Jurić, S. Oguić, B. Vilhar 1991; R. Jurić, S. Sutlović, B. Vilhar 1997; M. Kozličić, Z. Brusić 1991.

8 The archaeologist Zdenko Brusić, the founder of underwater archeology in Croatia, was instrumental for the research and promotion of the ships from Nin, and the conservator Božidar (Darko) Vilhar and his colleagues Stošija Oguić and Radomir (Miro) Jurić were responsible for the successful implementation of the desalination, conservation and restoration and reconstruction process (http://www.adriasproject.org/files/file/EDUCATION/Condura-brosura-za-Festival-znanosti.pdf).

Slika 2. Fragmentirana oplata rekonstruiranog broda, AMZd, inv. br. MNS2530, pogled od krme prema pramcu
Figure 2. Fragmented planking of the reconstructed ship, AMZd, inv. no. MNS2530, a view from the stern towards the bow
foto /photo: **A. Jelić**

drvene strukture.[10] Na temelju tih spoznaja 2016. godine dokumentirano je tadašnje stanje brodova, a godinu dana kasnije pokrenut je i opsežan konzervatorsko-restauratorski postupak.[11]

Tijekom konzervatorsko-restauratorskog postupka, preciznije tijekom faze čišćenja brodova, otkrivene su brodske konstrukcije, odnosno niz drvenih elemenata različitog oblika i dimenzija od kojih su same brodske konstrukcije građene (Sl. 2). Naime, zbog upotrebe velike količine sredstva za površinsku zaštitu drva tijekom prijašnje konzervacije i restauracije brodova prethodno navedeni elementi nisu bili vidljivi. Iako su svi otkriveni elementi nacrtno dokumentirani i skicirani tijekom novog konzervatorsko-restauratorskog postupka, iz sigurnosnih razloga

10 Vidi P. Fix, I. Radić Rossi, M. Radović 2011; M. Šimičić, Z. Vrgoč 2016.
11 Projekte dokumentiranja i konzervatorsko-restauratorskog postupka financiralo je Ministarstvo kulture i medija, a proveli su ih stručnjaci Međunarodnog centra za podvodnu arheologiju u Zadru.

the wood, due to the sensitivity of wood to the unfavourable microclimatic conditions in which the ships were exhibited very soon after the conservation procedure. This prompted the University of Zadar to collaborate with the Tel Aviv University in 2008, and also with the Texas A&M University in 2010 for the analysis of wood samples. The analysis showed that the ships were built from several types of oak.[9] Further analyses showed the presence of a series of chemical and physical processes which, in addition to the inadequate conditions to which the ships were exposed, caused the destruction of the wooden structure.[10] Based on these findings, the state of the ships at that time was documented in 2016, and a year later, an extensive conservation-restoration procedure was initiated.[11]

During the conservation-restoration process, more precisely during the cleaning phase, the ships' structures were discovered, i.e. a series of wooden elements of different shapes and dimensions that comprised the ships' structure (Fig. 2). Namely, due to the use of a large amount of wood surface protection agent during the previous conservation and restoration of the ships, the aforementioned elements were not visible. Although all discovered elements were drafted, documented and sketched during the new conservation-restoration procedure, for safety reasons it was decided that ships should be digitally documented, and their current state should be permanently archived.

During the conservation-restoration process, between the planking and the most of the frames, a gap filling mixture was observed, which varies in thickness to a maximum of five centimetres (Fig. 3). It is assumed that these gaps were caused by the metal bases, i.e. the metal cradles in which the ships were displayed, which did not match the dimensions and the shape of the ships. It is suspected that the cradles were constructed according to the measurements taken in 1974, during the extraction of parts of the ships from the seabed. At the time, the possibility of wooden elements expanding was most likely overlooked, which could have happened at the moment of sinking, and during the long-lasting influence of sea water on the wooden structure. Furthermore, the possibility of changes in dimension of wooden elements that can occur during the conservation-restoration process, i.e. the process of impregnation and the drying of wooden material, was also probably overlooked. These are all possible reasons that might have caused the present gap. Although the observed gap indicates the presence of irregularities in the apparently well-positioned frames, the fragmentation of the planking was the primary reason for the digital documentation of the condition of the ships.

9 See I. Radić Rossi, N. Liphschitz 2010.
10 See P. Fix, I. Radić Rossi, M. Radović 2011; M. Šimičić, Z. Vrgoč 2016.
11 The documentation and conservation-restoration projects were financed by the Ministry of Culture and Media, and they were carried out by experts from the International Centre for Underwater Archeology in Zadar.

odlučeno je brodove digitalno dokumentirati i trajno arhivirati njihovo postojeće stanje.

Tijekom konzervatorsko-restauratorskog postupka između oplate i većine rebara uočena je i smjesa za popunjavanje praznina koja varira u debljini od maksimalno pet centimetara (Sl. 3). Pretpostavlja se da su razlog tih praznina metalna postolja, odnosno metalne kolijevke u kojima su brodovi izloženi, a koje im ne odgovaraju dimenzijama i oblikom. Sumnja se da su kolijevke konstruirane prema dimenzijama uzetim 1974. godine, pri vađenju dijelova brodova s morskog dna. Tada se najvjerojatnije previdjela mogućnost širenja drvenih elemenata, do čega je moglo doći tijekom potonuća brodova i dugogodišnjeg utjecaja morske vode na strukturu drva. Također, vjerojatno se previdjela i mogućnost promjene dimenzija drvenih elemenata koje mogu nastati tijekom konzervatorsko-restauratorskog procesa, odnosno procesa impregnacije i sušenja drvenog materijala. Sve su to mogući razlozi prisutne praznine. Iako uočena praznina ukazuje na prisutnost nepravilnosti u naizgled dobro pozicioniranim rebrima, ipak je fragmentiranost oplata bila primaran povod digitalnom dokumentiranju postojećeg stanja brodova.

OPIS I SVRHA PROJEKTA

Znatna fragmentiranost oplata ninskih kondura bio je glavni razlog provođenja projekta digitalnog dokumentiranja brodova. Zbog fragmentiranosti oplata, posebno oplate rekonstruiranog broda koju čine drveni elementi različitog oblika i duljine od 2 do 200 cm, postojala je velika mogućnost dislociranja ili urušavanja i gubitka manjih dijelova kroz velike otvore metalnih postolja u kojima su brodovi izloženi. Iako su tijekom konzervatorsko-restauratorskog postupka nacrtno dokumentirani svi dijelovi, iz sigurnosnih su razloga brodske konstrukcije dodatno i digitalno dokumentirane.

Naime, posljednjih godina sve se više rabe različiti senzori i tehnologije poput laserskog skeniranja, fotogrametrije, modeliranja i računalne grafike u domeni 3D dokumentiranja kulturne baštine. Stoga i ne iznenađuje sve veća upotreba suvremene digitalne tehnologije pri dokumentiranju povijesnih, odnosno arheoloških brodova bilo da se oni nalaze na morskom dnu bilo na kopnu ili u muzeju. Digitalna dokumentacija brodova u kulturnoj baštini otvara nove mogućnosti istraživanja jer pruža veću preciznost i nove procjene koje nisu moguće tradicionalnim metodama. Predimenzioniranost nalaza opravdava upotrebu suvremenih tehnologija za dokumentiranje koje danas predstavljaju standardan postupak te neophodan alat i osnovu pri proučavanju, rekonstrukciji i provedbi različitih analiza brodova te krajnjoj vizualizaciji nautičke kulturne baštine.[12]

Slika 3. Praznina između oplate i rebra 9 rekonstruiranog broda, AMZd, inv. br. MNS2530
Figure 3. The gap between the planking and frame no. 9 of the reconstructed ship, AMZd, inv. no. MNS2530
foto /photo: **A. Jelić**

THE DESCRIPTION AND THE PURPOSE OF THE PROJECT

The considerable fragmentation of the planking of the Nin *condurae* was the main reason for the implementation of the project of digital documentation of the ships. Due to the fragmentation of the planking, especially the planking of the reconstructed ship consisting of wooden elements of different shapes and varying in length from 2 to 200 cm, there was a great probability of dislocation or crumbling and loss of smaller parts that could fall through the large openings in the metal bases in which the ships were exposed. Although during the conservation-restoration process all parts were drafted and documented, for safety reasons the ship structures were also additionally digitally documented.

Namely, in recent years, the use of various sensors and technologies such as laser scanning, photogrammetry, modelling and computer graphics is increasing in the 3D documentation of cultural heritage. Therefore, the increasing use of modern digital technology in documenting historical and archaeological ships, regardless if they are located on the seabed, on land or in a museum, is not surprising. Digital documentation of ships in cultural heritage opens up new possibilities for research because it provides greater precision and new assessments that are not possible with traditional methods. The oversized nature of the findings justifies the use of modern technologies for the purpose of documentation, which today represent a standard procedure, and a necessary tool and basis for the study, reconstruction, and implementation of various analyses of ships, and the ultimate visualization of nautical cultural heritage.[12]

12 Vidi T. Jones 2015; E. Costa, C. Beltrame 2021.

12 See T. Jones 2015; E. Costa, C. Beltrame 2021.

Projekt digitalnog dokumentiranja ninskih kondura prvenstveno je uključivao dokumentiranje postojećeg stanja brodskih konstrukcija. Radi što preciznijeg dokumentiranja postojećeg stanja primijenjena je tehnologija 3D skeniranja. Pri mjerenju i dokumentiranju fragmenti se nisu dodirivali i pomicali, a ta je praktičnost ujedno i prednost samog projekta.

Provedbom projekta trajno se arhiviralo trenutačno stanje brodova u digitalnom obliku te se ujedno otvorila mogućnost buduće preciznije daljnje obrade brodske konstrukcije. Naime, digitalni pregled brodske konstrukcije i mogućnost primjene tehnika digitalnog modeliranja omogućuju proučavanje i analizu brodova te rekonstrukciju kompletnog oblika trupa s visokim postotkom pouzdanosti.[13] Navedeno ukazuje na niz naknadnih mogućnosti poput 3D rekonstrukcije ninskih kondura te jednostavnije izrade replika prema njihovu izvornom izdanju. Moguće je i precizno ugraditi nedostajuće elemente te obnoviti ili zamijeniti oštećene ili uništene dijelove (zamjenski dijelovi gotovo su identični originalima). Nadalje, informacije prikupljene 3D skeniranjem moguće je upotrijebiti u svrhu adekvatnije prezentacije brodova. Naime, one mogu znatno olakšati kreiranje i izradu izložbenih postolja ako se naknadno odluči poboljšati izgled brodova. Osim navedenog, upotrebom aplikacija proširene i virtualne stvarnosti[14] moguća je i izrada atraktivnih virtualnih maketa i animacija unutar muzeja čime bi se javnosti dodatno približila i bolje prikazala specifičnost brodske konstrukcije.

Iako je primarna svrha projekta bila digitalno dokumentiranje i trajno arhiviranje trenutačnog stanja brodskih konstrukcija, projekt je dodatno proširen na izradu 3D modela broda i tehničko-nacrtne dokumentacije, odnosno 2D dokumentacije dobivenog modela. Naime, budući da prethodno spomenuti razmak između oplata i rebara varira, odlučeno je da će se informacije dobivene digitalnim dokumentiranjem upotrijebiti u provjeri koliko naizgled dobro posložena rebra jednog od brodova prate formu koju diktira metalno postolje. Stoga je na osnovi ulaznih podataka dobivenih 3D skeniranjem postojeće brodske konstrukcije odlučeno da će se utvrditi pozicioniranost rebara izradom 3D modela odabranog broda.

Nadalje, nakon modeliranja 3D modela odlučeno je da će se kompletirati projekt dokumentiranja izradom 2D dokumentacije dobivenog modela. Iako izrađena 2D dokumentacija neće predstavljati rekonstrukciju originalnih brodskih linija, dobiveni nacrti mogli bi pomoći u pokušaju određivanja originalnog oblika broda stručnjacima koji proučavaju spomenutu problematiku.

13 Vidi P. Tanner 2013; E. Costa, C. Beltrame 2021.
14 Engl. *augmented virtual reality*.

The project of digital documentation of the Nin *condurae* primarily involved documenting the current state of ship structures. In order to document the current condition as accurately as possible, 3D scanning technology was used. During the measurement and documentation, the fragments were not touched or moved, and this practical feature is the advantage of the project.

By implementing the project, the current state of the ships was permanently archived in digital form, which at the same time, enables the possibility of a future, more precise processing of the ship's structure. Namely, the digital inspection of the ship structure, and the possibility of applying digital modelling techniques enable the study and the analysis of ships, and also the reconstruction of the full shape of the hull with a high percentage of reliability.[13] The above points to a series of further possibilities, such as 3D reconstruction of the Nin *condurae*, and a simpler creation of replicas based on the original vessels. It is also possible to install with precision the missing elements, and restore or replace damaged or destroyed parts (the replacement parts are almost identical to the original ones). Furthermore, the information collected by 3D scanning can be used for a more adequate presentation of the ships. Namely, the information can significantly facilitate the creation and production of exhibition bases if the appearance of the ships is later decided to be improved upon. In addition to the above, the use of augmented and virtual reality applications[14] enables the creation of attractive virtual models and animations inside of the museum, which would allow the public to become further and better acquainted with features of the ship's structure.

Although the primary purpose of the project was the digital documentation and permanent archiving of the current state of ship structures, the project was additionally expanded to the creation of a 3D model of the ship, and technical-drawing documentation, i.e. a 2D documentation of the obtained model. Namely, since the previously mentioned width between the planking and the frames varies, it was decided that the information obtained by digital documentation will be used to verify how do the apparently well-arranged frames of one of the ships follow the shape dictated by the metal base. Therefore, based on the input data obtained by 3D scanning of the ship structure, it was decided that the positioning of the frames will be determined by creating a 3D model of the selected ship.

Furthermore, after the modelling of the 3D model, it was decided that the documentation project will be completed by creating a 2D documentation of the obtained model. Although the created 2D documentation will not

13 See P. Tanner 2013; E. Costa, C. Beltrame 2021.
14 English: *Augmented virtual reality.*

Prema izrađenoj 2D dokumentaciji prikazana je i idejna vizualizacija broda kao primjer moguće dodatne prezentacija brodova čime je projekt ujedno zaokružen u cjelinu.

Prvi korak u provedbi projekta digitalne dokumentacije bio je 3D skeniranje brodova radi njihova trajnog arhiviranja i prikupljanja neprocjenjivih informacija neophodnih za realizaciju i dovršetak samog projekta.

3D SKENIRANJE DRVENIH KONSTRUKCIJA BRODOVA

Ostatci brodskih olupina pronađenih šezdesetih godina prošlog stoljeća bili su jedina realna i postojeća tehnička dokumentacija tijekom 3D skeniranja. Spomenuti ostatci dijelovi su dvaju brodova, pronađenih na istom lokalitetu. Dijelovi su izvučeni s morskog dna, desalinizirani i konzervirani te su brodovi potom obnovljeni u izložbenoj prostoriji Muzeja ninskih starina u Ninu. Jedan od brodova obnovljen je i izložen onako kako je pronađen na morskom dnu, a njegovu brodsku konstrukciju čini isključivo izvorno drvo. Drugi je brod izložen nakon obnove izvornih drvenih elemenata i djelomične stolarske rekonstrukcije od novog drva.[15]

represent a reconstruction of the original ship lines, the obtained drafts could help the experts who study the mentioned issue, to determine the original shape of the ship. According to the created 2D documentation, the conceptual visualization of the ship was shown as an example of the possible additional presentation of ships, which also completed the project as a whole.

The first step in the implementation of the digital documentation project was the 3D scanning of the ships for their permanent archiving and the collection of invaluable information necessary for the realization and completion of the project.

3D SCANNING OF WOODEN SHIP STRUCTURES

The remains of the shipwrecks found in the 1960s represented the only real and existing technical documentation during the process of 3D scanning. The mentioned remains are parts of two ships, found at the same site. The parts were extracted from the seabed, desalinated and preserved, and the ships were subsequently restored in the exhibition room of the Museum of Nin Antiquities in Nin. One of the ships has been restored and displayed as it

Slika 4. Postupak 3D skeniranja ručnim GO!SCAN SPARK 3D skenerom
Figure 4. 3D scanning procedure with a handheld GO!SCAN SPARK 3D scanner

foto /photo: **A. Jelić**

15 R. Jurić 1995, 81.

Detaljno skeniranje dijelova brodskih konstrukcija provedeno je pomoću ručnog skenera, GO!SCAN SPARK 3D skenera,[16] bez potrebe da se elementi diraju ili premještaju. Beskontaktnim prikupljanjem podataka izbjegnuto je izlaganje drvenih elemenata potencijalno nepovoljnim uvjetima i okolnostima. Međutim, budući da su brodovi u trenutku skeniranja bili u nekoj od faza konzervatorsko-restauratorskog postupka u sklopu kojeg su privremeno i sigurnosno zaštićeni mrežom s vanjske strane oplate, 3D skeniranje izvedeno je samo s unutarnje strane oplate brodova. Naime, prisutna sigurnosna mreža ometala bi rad skenera te podatci zaprimljeni 3D skeniranjem ne bi u potpunosti bili tehnički iskoristivi. Stoga su detaljno skenirani samo unutarnji dijelovi brodskih konstrukcija, odnosno elementi rebara i oplata brodova, a sam proces skeniranja uspješno je izveden za nekoliko sati (Sl. 4).[17]

Budući da je izrada rekonstrukcije brodskih linija bila planirana na temelju brodskih rebara,[18] tijekom skeniranja posebna je pozornost posvećena upravo skeniranju izvornih rebara. Nadalje, s obzirom na to da su izvorna rebra broda izloženog s djelomičnom stolarskom rekonstrukcijom cjelovitija i manje fragmentirana, odnosno bolje sačuvana, odlučeno je da će se 2D dokumentacija izvesti na osnovi 3D modela dobivenog na temelju informacija prikupljenih skeniranjem spomenutog, rekonstruranog broda.

Rekonstruirani brod, AMZd, inv. br. MNS2530,[19] koji je uzet kao osnova za izradu 3D modela, sastoji se od izvornih drvenih elemenata, ali i dodatnih drvenih rekonstrukcija dijelova koji nedostaju. Izvorni dio broda sastoji se od donjeg dijela vanjske oplate s dvije uzdužne paralelne grede i dvije trećine desnog boka broda. Unutar trupa nalaze se 24 nepotpuna izvorna rebra (od rebra 3 do rebra 26) i temeljnica jarbola između rebara 8 i 9. Rekonstruiran je lijevi bok broda, nedostajući dijelovi desnog boka, pramac i krma te devet rebara, dva na pramčanom i sedam na krmenom dijelu broda (Sl. 5).[20]

was found at the bottom of the sea, and its structure consists exclusively of original wood. The second ship is exhibited after the restoration of the original wooden elements and partial reconstruction crafted with new wood.[15]

The detailed scanning of parts of the ships' structures was accomplished by a handheld scanner, the GO!SCAN SPARK 3D scanner,[16] without the need to touch or move the elements. The contactless data collection abolished the need to expose the wooden elements to potentially unfavourable conditions and circumstances. However, since the ships at the time of scanning were in one of the stages of the conservation-restoration process, where they were temporarily and safely protected by a net on the outer planking, the 3D scan was performed only on the inner planking. Namely, the safety net interfered with the operation of the scanner, and the data received by 3D scanning was not entirely usable for engineering. Therefore, only the internal parts of the ship structures, i.e. the elements of the ship's frames and planking, were scanned in detail, and the scanning process was successfully performed in a few hours (Fig. 4).[17]

Since the reconstruction of the ship's lines was planned on the basis of the ship's frames,[18] during the scanning a special attention was paid to the scanning of the original frames. Furthermore, considering that the original frames of the ship exhibited with a partial carpentry reconstruction, are more complete and less fragmented, i.e. better preserved, it was decided that the 2D documentation will be performed on the basis of a 3D model obtained on the basis of information collected by scanning the aforementioned reconstructed ship.

The reconstructed ship, AMZd, inv. no. MNS2530,[19] which was taken as the basis for the creation of the 3D model, consists of original wooden elements, but also additional wooden reconstructions of the missing parts. The original part of the ship consists of the lower part of the outer planking with two longitudinal parallel beams, and two thirds of the starboard side of the ship. Inside the hull there are 24 incomplete original

16 GO!SCAN SPARK 3D skener proizvođača Creaform, Kanada, specificiran je kao kvalitetan, precizan i brz te prenosiv i jednostavan za korištenje. To je svjetlosni 3D skener. U nizu integrirane četiri kamere i jedan projektor omogućuju mu brzo i precizno mjerenje bilo koje složene površine, dok mu visoka razlučivost i razina detalja te sposobnost snimanja boja osiguravaju visoku kvalitetu skeniranja (https://get.creaform3d.com/).

17 Postupkom 3D skeniranja upravljao je djelatnik tvrtke Niteh d.o.o., Duga Resa, ing. Andro Perković, specijaliziran za rukovanje GO!SCAN SPARK 3D skenerom.

18 Rebra su poprečni konstrukcijski elementi broda te s kobilicom, pramčanom i krmenom statvom čine kostur broda. Budući da se na rebra pričvršćuje vanjska oplata broda, rebra ujedno i određuju vanjski oblik brodskog trupa (https://tehnika.lzmk.hr/tehnickaenciklopedija/brod_15_konstrukcija_drvenog_broda.pdf).

19 Tijekom arheološkog istraživanja i prethodne konzervatorsko-restauratorske obrade brodovi su nazvani Nin 1, brod koji je izložen u stanju u kojem je pronađen, i Nin 2, brod koji je izložen djelomično rekonstruiran. Međutim, u pisanoj i fotodokumentaciji provedenih radova Međunarodnog centra za podvodnu arheologiju u Zadru brod koji je izložen djelomično rekonstruiran vodi se pod nazivom Nin 1. Zbog slučajne zamjene naziva, nazivi Nin 1 i Nin 2 ne koriste se u tekstu da ne bi došlo do dodatne zabune ili pomutnje.

20 R. Jurić, S. Oguić, B. Vilhar 1991.

15 R. Jurić 1995, 81.

16 The GO!SCAN SPARK 3D scanner manufactured by Creaform, Canada, is specified as high-quality, precise and fast as well as portable and easy to use. It is a light 3D scanner. Four integrated serial cameras and a projector enable it to quickly and accurately measure any complex surface, while its high resolution and level of detail and colour recording capability ensure high quality scanning (https://get.creaform3d.com/).

17 The 3D scanning procedure was managed by an employee of the company Niteh d.o.o., Duga Resa, the engineer Andro Perković, specialized in handling the GO!SCAN SPARK 3D scanner.

18 The frames are the transverse structural elements of the ship and together with the keel, bow and sternpost they form the skeleton of the ship. Since the outer plating of the ship is attached to the frames, the frames also determine the outer shape of the ship's hull (https://tehnika.lzmk.hr/tehnickaenciklopedija/brod_15_konstrukcija_drvenog_broda.pdf).

19 During the archaeological research and previous conservation-restoration treatment, the ships were named Nin 1, the ship that is exhibited in the condition in which it was found, and Nin 2, the ship that is exhibited partially reconstructed. However, in the written and photo documentation of the work carried out by the International Centre for Underwater Archaeology in Zadar, the ship that is exhibited as partially reconstructed is referred to as Nin 1. Due to an accidental name change, the names Nin 1 and Nin 2 are not used in the text in order to avoid additional confusion or befuddlement.

Slika 5. Rekonstruirani brod, AMZd, inv. br. MNS2530, pogled od pramca prema krmi

Figure 5. Reconstructed ship, AMZd, inv. no. MNS2530, a view from the bow towards the stern

foto /photo: **A. Jelić**

3D skeniranjem uspješno je dokumentirano postojeće stanje brodskih konstrukcija. Prikupljene su neprocjenjive informacije o duljini, dimenzijama i obujmu te o pozicijskim točkama brodova. Nakon prikupljanja svih potrebnih informacija pristupilo se tzv. optimizaciji koja je bila neophodna za daljnji proces izrade 3D modela i tehničko-nacrtne dokumentacije rekonstruiranog broda.

OPTIMIZACIJA 3D MODELA

Optimizacija je postupak kojim se dobiveni 3D skenirani model uređuje i po potrebi popravlja. Optimizacijom se iz navedenog modela uklanjaju svi nepotrebni i za rekonstrukciju neiskoristivi elementi poput slomljenih ostataka dasaka, rebara i raznovrsnih otkinutih i oštećenih dijelova ključne konstrukcije broda.[21] Unutar optimizacije skeniranog rekonstruiranog broda izostavljeni su svi elementi rebara koji nisu odgovarali obliku modela

frames (from frame no. 3 to frame no. 26) and a mast step between the frames no. 8 and no. 9. The port side of the ship has been reconstructed, along with the missing parts of the starboard side, bow and stern, and nine frames, two on the bow, and seven on the stern part of the ship (Fig. 5).[20]

The 3D scanning has successfully documented the current state of ships' structures. Invaluable information was collected on the length, dimensions and volume, and the positional points of the ships. After collecting all the necessary information, the so-called optimization was initiated, which was necessary for the additional process of creating a 3D model and technical drafting documentation of the reconstructed ship.

OPTIMIZATION OF 3D MODEL

Optimization is the process by which the obtained 3D scanned model is edited and, if necessary, repaired. During the optimization all elements that are unnecessary and unusable in reconstruction, such as broken remains of planks, frames and various torn and damaged parts of the ship's key structure, are removed from the mentioned model.[21] All frame elements that did not correspond to the shape of the

20 R. Jurić, S. Oguić, B. Vilhar 1991.

21 https://machina.academy/machina-blog/sto-je-3d-modeliranje.

21 https://machina.academy/machina-blog/sto-je-3d-modeliranje.

koji je određivao 3D program. Naime, tijekom rekonstrukcije forme trupa broda u 3D programu[22] uočena su određena odstupanja naizgled dobro postavljenih rebara. Uočeno je da pojedinačna rebra svojim oblikom ne slijede liniju dobivenog modela te ih nije bilo moguće u potpunosti uklopiti u konačnu projekciju (rebro 6 i rebro 9). Zbog svoje usitnjenosti neka rebra nisu dala dovoljno podataka za potpunu rekonstrukciju (rebro 11 i rebro 16), dok su neka bila deformirana i nisu odgovarala ostatku oblika modela (rebro 5 i rebro 21 te rebro 25 koje je dio stolarske rekonstrukcije). Nadalje, budući da krmeni kraj broda nema sačuvanih izvornih dijelova, iskorištena su samo ona rebra stolarske rekonstrukcije koja najviše odgovaraju dobivenoj liniji trupa. Ostatak rebara pravilno je pozicioniran, zarotiran i postavljen na lokacije unutar trupa koje njima u usporedbi s formom oplate najviše odgovaraju.

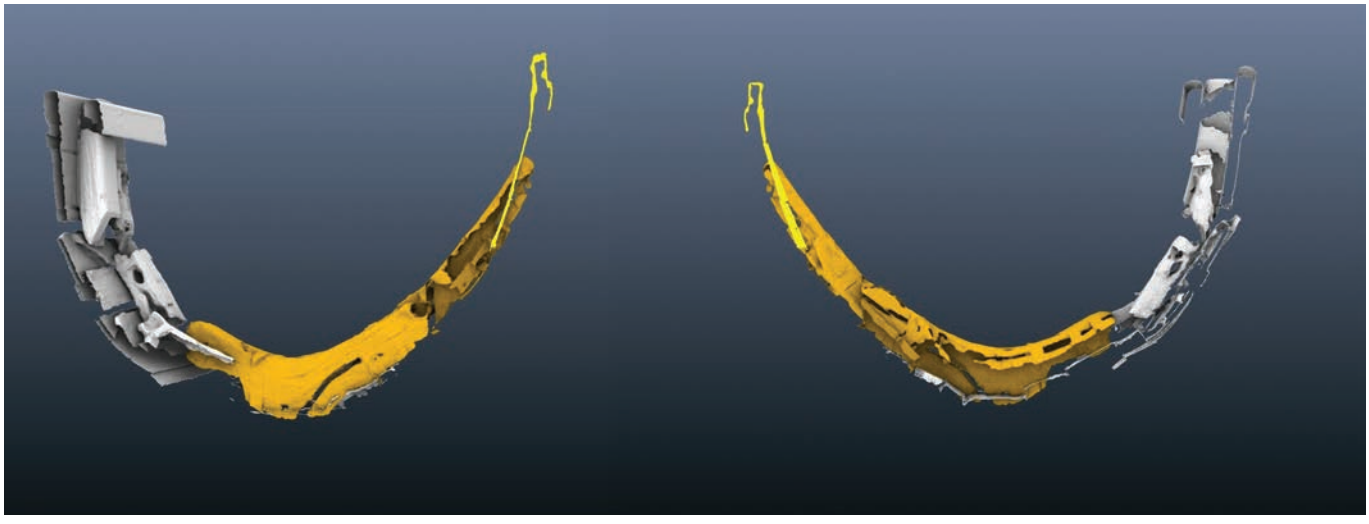
KORACI UNUTAR OPTIMIZACIJE:

- Rekonstrukcijom forme trupa u 3D programu uočeno je da izvorni dio broda „pada" na lijevu stranu, gledajući od krme prema pramcu, za približno 8 – 12 stupnjeva. Stoga se cjelokupni model zarotirao, tj. spustio se desni dio za -6 stupnjeva, a pojedinačna su rebra (izvorni dijelovi) korigirano rotirana za još dodatnih -3 do -10 stupnjeva, ovisno o rebru. Tako je izvorna forma pozicionirana približno u 0.
- Gornji desni dio izvornog rebra 6 ne odgovara poziciji pa nije korišten tijekom 3D vizualizacije. Iskorišten je samo donji, tzv. „V" dio rebra (Sl. 6). Preostali nedostajući dio modeliran je sukladno linijama očuvanih rebara.

model determined by the 3D program were omitted during the optimization of the scanned reconstructed ship. Namely, during the reconstruction of the shape of the ship's hull in the 3D program,[22] certain deviations of the apparently well-placed frames were observed. It was noticed that the shape of the individual frames did not follow the line of the obtained model and it was impossible to completely fit them into the final projection (frame no. 6 and frame no. 9). Due to their fragmentation, some frames did not provide enough data for a complete reconstruction (frame no. 11 and frame no. 16), while some were deformed and did not match the rest of the shape of the model (frame no. 5, frame no. 21 and frame no. 25, which is a piece from the carpentry reconstruction). Furthermore, since there are no preserved original parts of the ship's stern, only the carpentry reconstructed frames that corresponded best to the obtained hull line were used. The rest of the frames were properly positioned, rotated and placed in positions inside of the hull where they fit the best compared to the planking.

STEPS WITHIN THE OPTIMIZATION:

- By reconstructing the shape of the hull in the 3D program, it was observed that the original part of the ship "was falling" to the port side, looking from the stern towards the bow, by approximately 8–12 degrees. Therefore, the overall model was rotated, i.e. the starboard part was lowered by -6 degrees, and certain frames (original parts) were corrected and rotated by an additional -3 to -10 degrees, depending on the frame. Thus, the original shape is positioned approximately at 0.
- The upper right part of the original frame no. 6 does not correspond to the position, so it was not used during the 3D visualization. Only the lower,

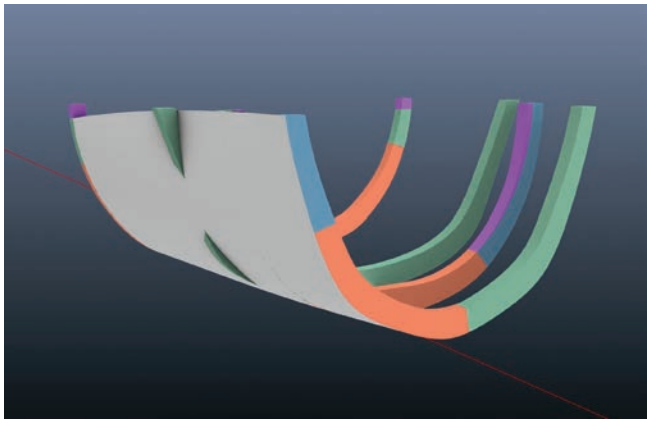


Slika 6. Rebro 6 prelazi izvan oplate broda, pogled s obje strane
Figure 6. Frame no. 6 protrudes outside the ship's hull, view from both sides

foto / photo: **N. Budimir**

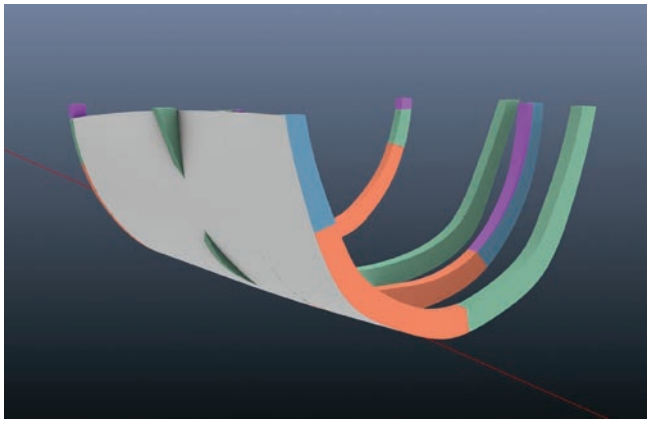
22 Za ovaj projekt korišten je Rhinoceros 3D program.

22 The Rhinoceros 3D program was used in this project.



Slika 7. Rebro 9 ne prati formu 3D rekonstrukcije
Figure 7. Frame no. 9 does not follow the shape of the 3D reconstruction
foto / photo: **N. Budimir**

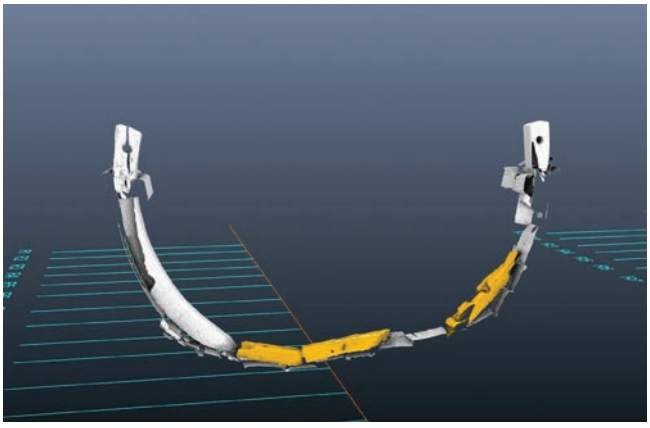
- Izvedena je gotovo potpuna rekonstrukcija rebra 9 prema formi preostalih očuvanih rebara. Iskorišten je samo donji dio rebra jer ostatak izvornog rebra nije pratio formu 3D rekonstrukcije (Sl. 7).
- Izvedena je potpuna rekonstrukcija rebra 11 prema preostalim očuvanim rebrima jer je izvorno rebro previše fragmentirano za kvalitetnu rekonstrukciju (Sl. 8).
- Dio rebra 15 iskorišten je na poziciji rebra 11.
- Rebro 15 oblikom najviše odgovara rebru 22, pa je iskorišteno za nadopunu slabo postojećeg rebra 23.
- Izvedena je potpuna rekonstrukcija rebra 16 prema preostalim očuvanim rebrima jer je izvorno rebro previše fragmentirano za kvalitetnu rekonstrukciju.
- Izvedena je potpuna rekonstrukcija rebra 21 prema preostalim očuvanim rebrima jer je postojeće izvorno rebro previše deformirano i ne poklapa se s ostatkom forme izvornih elemenata i rebara (Sl. 9).



Slika 9. Deformirano rebro 21
Figure 9. Deformed frame no. 21
foto / photo: **N. Budimir**

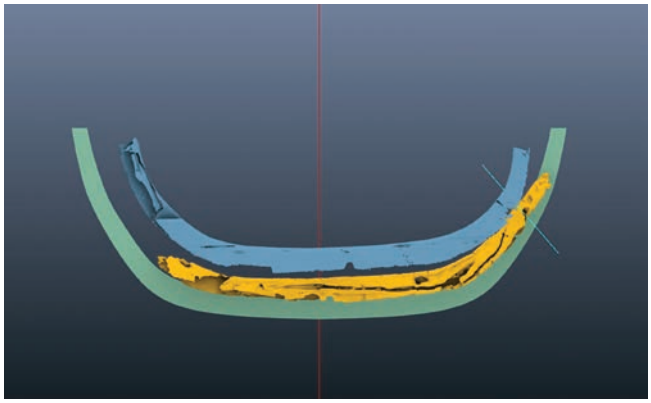
the so-called "V" part of the frame was used (Fig. 6). The remaining missing part was modelled according to the lines of the preserved frames.

- An almost complete reconstruction of frame no. 9 was carried out according to the shape of the remaining preserved frames. Only the lower part of the frame was used because the rest of the original frame did not follow the shape of the 3D reconstruction (Fig. 7).
- A complete reconstruction of frame no. 11 was performed according to the remaining preserved frames, because the original frame is too fragmented for a quality reconstruction (Fig. 8).



Slika 8. Fragmentirano rebro 11
Figure 8. Fragmented frame no. 11
foto / photo: **N. Budimir**

- A part of the frame no. 15 was used in the position of frame no. 11.
- The frame no. 15 is the most similar in shape to frame no. 22, so it was used to supplement the almost non-existing frame no. 23.
- A complete reconstruction of frame no. 16 was carried out according to the remaining preserved frames, because the original frame is too fragmented for a quality reconstruction.
- A complete reconstruction of frame no. 21 was carried out according to the remaining preserved frames, because the original frame is too deformed and does not match the rest of the shape of the original elements and frames (Fig. 9).
- The reconstruction of the shape of the frame no. 22 was carried out according to the remaining preserved element of the frame. However, the original frame (in yellow) was "cut off" in one place (blue line) because it did not follow either the shape of the hull of the original parts (in blue) or the shape of the hull of the mentioned frame no. 25, the carpentry reconstructed frame (in green). Therefore, the mentioned part of the frame, i.e. its right tip,



Slika 10. Rebro 22 (žuto) tijekom izrade 3D rekonstrukcije, pogled od krme prema pramcu
Figure 10. Frame no. 22 (in yellow) during the creation of the 3D reconstruction, a view from the stern towards the bow
foto / photo: **N. Budimir**

- Izvedena je rekonstrukcija forme rebra 22 prema preostalom očuvanom elementu rebra. Međutim, postojeće izvorno rebro (žuto) na jednom je mjestu „odrezano" (plava linija) jer nije pratilo ni formu trupa izvornih dijelova (plavo) ni formu trupa referentnog rebra 25, rebra postojeće stolarske rekonstrukcije (zeleno). Stoga navedeni dio rebra, odnosno njegov desni vrh nije uzet u obzir pri izradi 3D rekonstrukcije (Sl. 10).
- Dio rebra 25 zarotiran je za 180 stupnjeva i iskorišten na poziciji rebro 24.

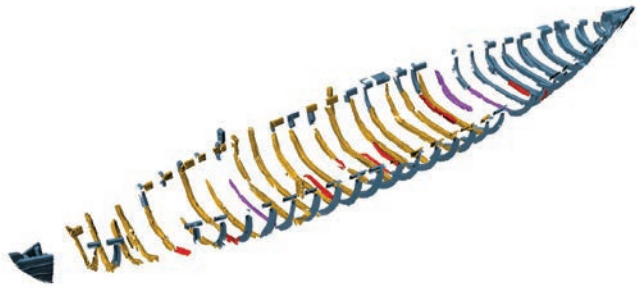
Na slici 11 prikazani su skenirani elementi tijekom 3D obrade gdje žuta boja predstavlja izvorne i sačuvane drvene elemente olupine broda, plava boja postojeću stolarsku rekonstrukciju, crvena boja elemente koji su zbog neodgovarajućeg ili previše deformiranog oblika neiskorišteni u 3D rekonstrukciji, a ljubičasta boja predstavlja elemente koji su sa zatečene pozicije na olupini u 3D modelu premješteni na bolju poziciju.

Na temelju 3D skeniranog modela uočeno je da izvorna rebra, koja su najbolje sačuvana i koja su korištena kao glavna referenca tijekom izrade 3D rekonstrukcije, variraju u dimenzijama tako da su najdeblja na području središnjeg dijela po uzdužnoj osi broda, i to u dimenzijama od 6,5 do 8 cm u visini rebra, dok po boku, pri vrhovima rebara variraju od 4,6 do 5,5 cm. Time se dobila prosječna dimenzija širine rebara korištena za potrebe 3D rekonstrukcije.

Osim toga, vidljivo je da su izvorna rebra većinom izlomljena i fragmentirana u više komada što je najvjerojatnije posljedica dugog ležanja broda na dnu mora, ali i provedbe konzervatorsko-restauratorskog postupka. Međutim, nekoliko rebara desnog boka sačuvano je gotovo u cijelosti, odnosno vidljivo je da su rebra izrađena iz jednog dijela bez obzira na njihov iznimno visok stupanj

was not taken into account in the creation of the 3D reconstruction (Fig. 10).
- A part of the frame no. 25 is rotated by 180 degrees and used in the position of frame no. 24.

Fig. 11 shows the scanned elements during the 3D processing, where yellow represents the original and preserved wooden elements of the shipwreck, blue represents the carpentry reconstruction, red represents the elements that were not used in the 3D reconstruction due to an unsuitable or too deformed shape, and purple represents the elements that were moved from its position on the wreck to a better position in the 3D model.



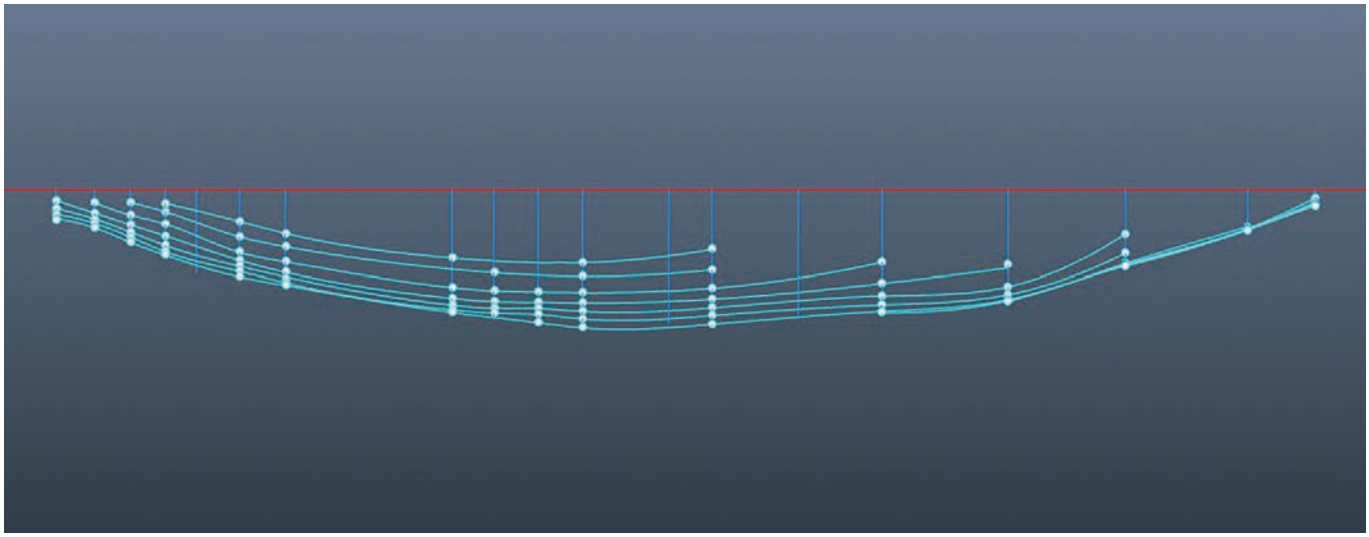
Slika 11. Skenirani elementi tijekom 3D obrade
Figure 11. The scanned elements during 3D processing
foto / photo: **N. Budimir**

Based on the 3D scanned model, it was observed that the original frames, which were best preserved and were used as the main reference during the creation of the 3D reconstruction, vary in dimensions; the thickest are located in the central part along the ship's longitudinal axis, with dimensions of 6.5 to 8 cm in frame height, while on the side, at the tips the frames vary from 4.6 to 5.5 cm. This resulted in obtaining the average thickness of the frames used in 3D reconstruction.

In addition, it is evident that the original frames are mostly broken and fragmented into several pieces, which is most likely the result of the ship lying at the bottom of the sea for a long time, but also a result of the conservation-restoration process. However, several frames of the starboard side have been preserved almost in their entirety, i.e., it is evident that the frames were made from a single part, regardless of their extremely high degree of line complexity. Based on the 3D scan, it is also evident that the frames were actually made as single frames, so the same principle was used during the creation of the 3D reconstruction.

THE CONSTRUCTION OF THE HULL

After the correct positioning of the ideal shape, the reconstruction of individual frames, and determining dimensions of the frames, the construction of the hull was started. The original and best-preserved frames were used for the purpose of



Slika 12. Izvlačenje linija forme zatečenog stanja broda
Figure 12. Drawing of the lines of the current state of the ship

foto / photo: **N. Budimir**

složenosti linije. Na temelju 3D skena također je evidentno da su rebra zapravo napravljena kao jednostruka pa se isti princip koristio i pri izradi 3D rekonstrukcije.

IZRADA TRUPA

Nakon pravilnog pozicioniranja idealne forme, rekonstrukcije pojedinih rebara te određivanja dimenzija rebara pristupilo se izradi trupa. Za potrebe izrade trupa korištena su izvorna rebra koja su u najvećemu dijelu očuvana pa se na temelju njih mogla izvesti adekvatna linija forme trupa. Također, budući da krmeni kraj broda nema sačuvanih izvornih dijelova, postignut je sporazum – iskorištena su pojedina rebra stolarske rekonstrukcije koja su najviše pratila liniju koju su diktirala izvorno sačuvana rebra. Uslijedilo je izvlačenje postojećih linija forme broda, odnosno linija rebara i oplate zatečenog stanja brodske olupine (Sl. 12).

Tek nakon izvlačenja postojećih linija moglo se pristupiti tzv. „peglanju" linija, odnosno postavljanju linija koje odgovaraju pravilno složenim elementima rebara u konstrukciji broda. Međutim, s obzirom na to da 3D program korišten tijekom rekonstrukcije forme trupa „pegla i zagladuje" površine, jasno se uvidjelo koliko na prvi pogled odlično postavljena i prilagođena rebra zapravo odstupaju i ne odgovaraju novonastalom 3D modelu (Sl. 13).

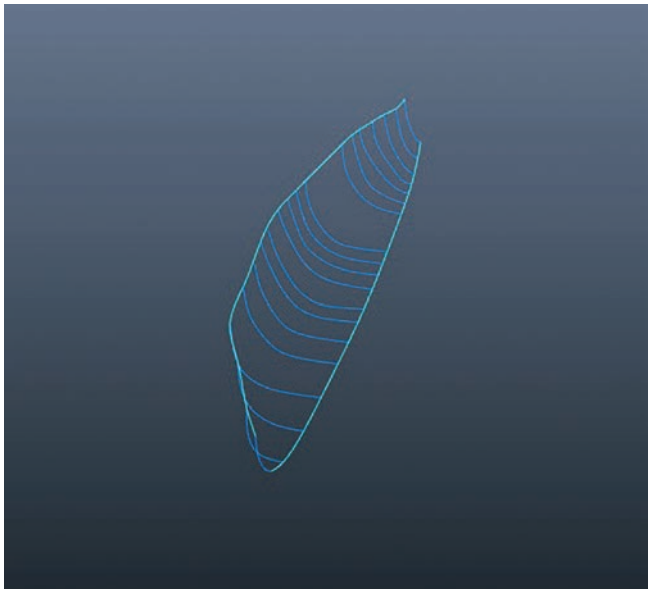
Odstupanje rebara najvjerojatnije je posljedica sušenja drva, kuta savijanja rebara zbog sušenja, pomicanja rebara za nekoliko centimetara naprijed-natrag u odnosu na izvornu poziciju te nedostataka degradiranih dijelova u nekim drvenim elementima. Stoga su izvedene određene korekcije namještanja pozicija rebara te optimizacija forme rebara jer korišteni 3D program sam „ravna", odnosno izravnava rubne linije forme oplate na temelju određenih prosječnih vrijednosti kontrolnih točaka linija rebara. Tako se postigla zadovoljavajuća vizualna i tehnička prezentacija forme trupa u 3D rekonstrukciji (Sl. 14).

creating the hull, so an adequate line of the hull form could be created on their basis. Also, since there are no preserved original parts of the stern, an agreement was reached – individual carpentry reconstructed frames were used, which mostly followed the line dictated by the originally preserved frames. This was followed by the drawing the lines of the shape of the ship, that is, the lines of the frames and hull of the current state of the shipwreck (Fig. 12).

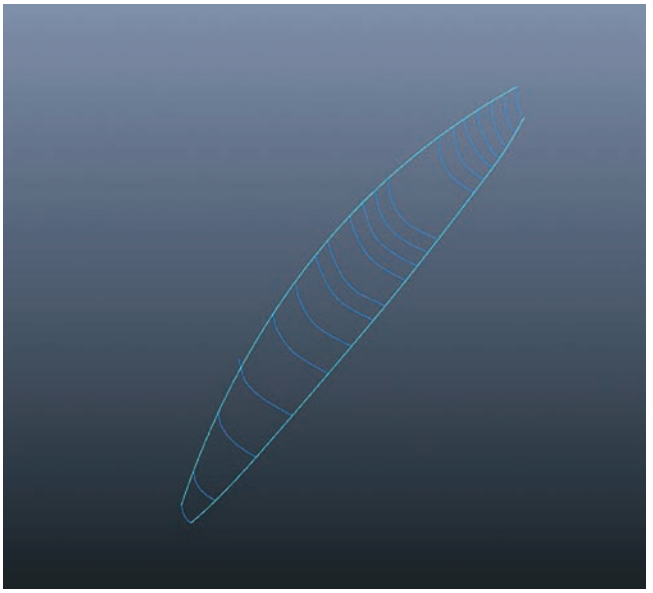
After the drawing of the lines, the so-called the "ironing" of the lines was started, i.e. the placement of lines that correspond to the correctly arranged frame elements in the ship's structure. However, considering that the 3D program used during the reconstruction of the hull shape "irons and smooths" the surfaces, it was obvious that the seemingly perfectly placed and adapted frames actually deviate from and do not correspond to the newly created 3D model (Fig. 13).

The deviation of the frames is most likely a consequence of drying of the wood, the angle at which the frames bend due to drying, the moving of the frames back and forth by several centimetres in relation to the original position, and the defects of the degraded parts in certain wooden elements. Therefore, certain corrections were made to adjust the position of the frames and optimize the shape of the frames, because the used 3D program "straightens" the edge lines of the hull shape based on certain average values of the control points of the frame lines. Thus, a satisfactory visual and technical presentation of the hull shape in 3D reconstruction was achieved (Fig. 14).

During the creation of a satisfactory 3D reconstruction of the hull shape, two frames proved to be the most problematic because they did not follow the shape of the remaining structure: the frame no. 5, which is the original part of the shape of the ship, and frame no. 25, which is a part of the carpentry reconstruction. Frames no. 5 and



Slika 13. Linija forme oplate dobivena na temelju prosječnih vrijednosti kontrolnih točaka linija rebara prije poravnavanja
Figure 13. The line of the hull obtained on the basis of the average values of the control points of the frame lines before alignment
foto / photo: **N. Budimir**



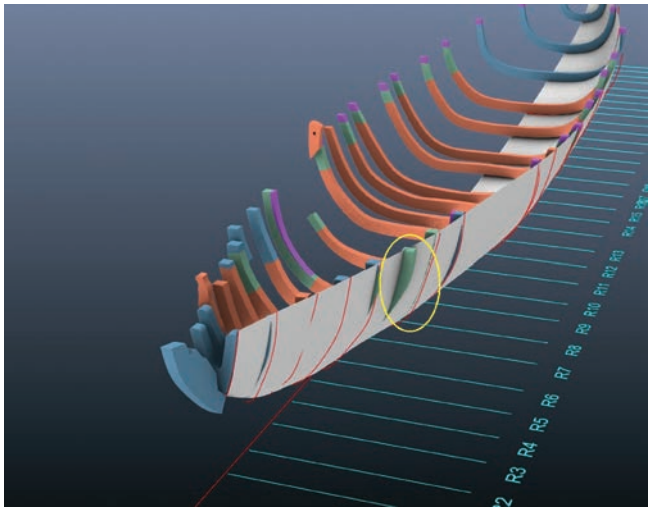
Slika 14. Linija forme oplate dobivena na temelju prosječnih vrijednosti kontrolnih točaka linija rebara nakon poravnavanja
Figure 14. Hull line obtained on the basis of the average values of the control points of the frame lines after alignment
foto / photo: **N. Budimir**

Tijekom izrade zadovoljavajuće 3D rekonstrukcije forme trupa dva su se rebra pokazala najproblematičnijima jer nikako nisu pratila formu preostale konstrukcije: rebro 5, koje je izvorni dio forme broda, i rebro 25, koje je dio stolarske rekonstrukcije. Rebra 5 i 25 nisu se uklopila u formu rekonstrukcije te su rekonstruirana prema formi ostalih izvornih rebara (Sl. 15 i 16).

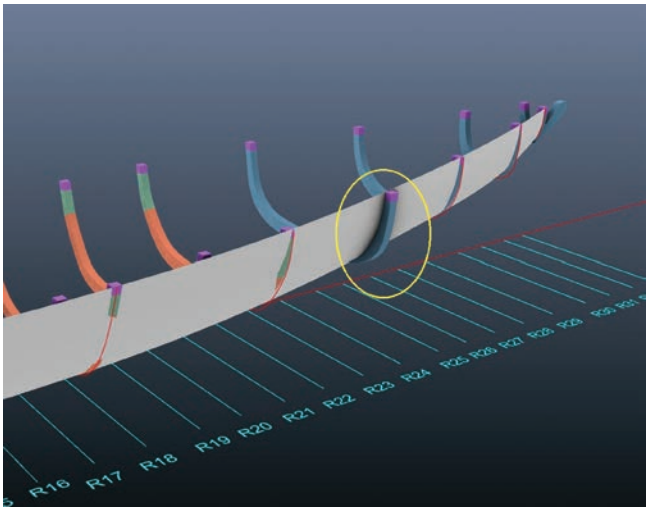
S obzirom na to da zadnji, odnosno krmeni dio broda nema sačuvanih izvornih dijelova, odnosno iskoristivih

no. 25 did not fit into the shape of the reconstruction and were reconstructed according to the shape of the remaining original frames (Fig. 15 and 16).

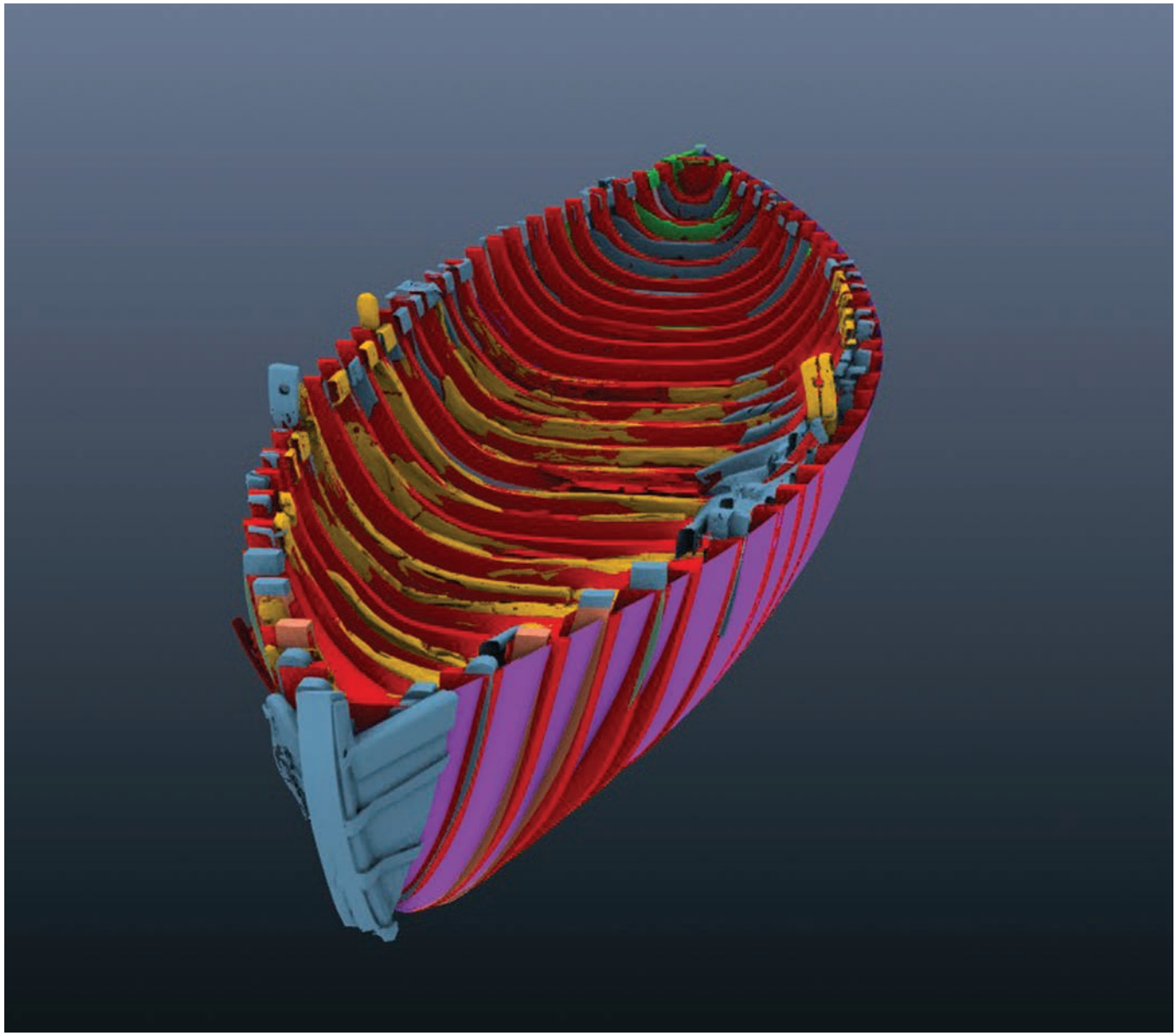
Considering that the back, or stern part of the ship has no preserved original parts, i.e. usable original frames, and in order to obtain an ideal reconstruction, the shape of the carpentry reconstruction and the shape of individual carpentry reconstructed frames that best corresponded to the originally preserved frames were used. However,



Slika 15. Izvorno rebro 5 ne prati formu preostale brodske konstrukcije
Figure 15. The original frame no. 5 does not follow the shape of the remaining ship structure
foto / photo: **N. Budimir**



Slika 16. Rebro stolarske rekonstrukcije, rebro 25, ne prati formu preostale brodske konstrukcije
Figure 16. The frame made by carpentry reconstruction, frame no. 25, does not follow the shape of the remaining ship structure
foto / photo: **N. Budimir**



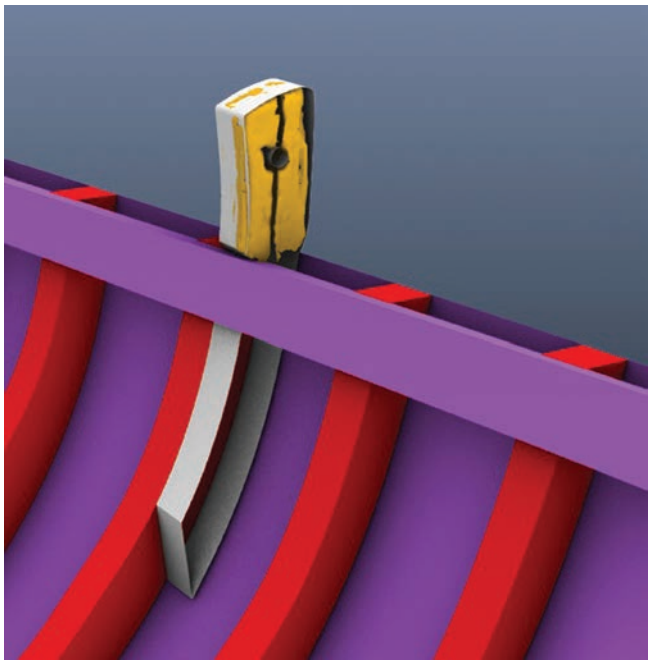
Slika 17. Provjera forme 3D rekonstruiranih i izvornih elemenata rebara
Figure 17. Verification of the shape of 3D reconstructed and original frame elements

foto / photo: **N. Budimir**

izvornih rebara, a da bi se dobila idealna rekonstrukcija, korištena je forma postojeće stolarske rekonstrukcije te pojedinačna rebra stolarije koja su najbolje odgovarala izvorno sačuvanim rebrima. Međutim, stolarska rekonstrukcija u određenim dijelovima ima značajno predimenzionirana rebra u odnosu na ona izvorna, stoga su dobivena 3D rebra krmenog dijela stanjena za otprilike 1 cm u svojoj širini da bi čim više dimenzijama i izgledom nalikovala izvornim rebrima, odnosno da bi se ujednačio okvirni i prosječni izgled svih rebara. Nadalje, obnovljeni su propali ili nedostajući elementi broda, rekonstruirane pukotine, napuknuća ili rupe nastale zbog djelovanja morskih organizama, tereta mulja, morske okoline, ali i zbog konzervatorsko-restauratorskih procesa. Uređeni i rekonstruirani 3D elementi rebara broda poslužili su kao glavni parametri za izradu odgovarajuće forme 3D rekonstruiranog trupa i oplate broda. Slika

the carpentry reconstruction in certain parts has significantly oversized frames in comparison to the original ones; therefore, the obtained 3D frames of the stern part were thinned by approximately 1 cm in their width in order to resemble the original frames as much as possible in terms of dimensions and appearance, that is, the general and average appearance of all frames was evened out. Furthermore, the deteriorated or missing elements of the ship were restored, and cracks, fissures or holes caused by maritime organisms, silt loads, marine environment, but also due to conservation-restoration processes were also reconstructed. The arranged and reconstructed 3D elements of the ship's frames served as the main parameters for creating the appropriate shape of the 3D reconstructed ship hull and planking. Figure 17 shows the confirmation of the shape of the 3D reconstructed and original elements

17 prikazuje provjeru forme 3D rekonstruiranih i izvornih elemenata rebara gdje žuta boja predstavlja izvorno očuvane drvene dijelove, plava postojeću stolarsku rekonstrukciju, a crvena dijelove koji tvore idealnu liniju 3D modela.



Slika 18. Izvorni dio probušene bitve (žuto) tijekom izrade 3D rekonstrukcije
Figure 18. The original part of the pierced bitt (in yellow) during the creation of the 3D reconstruction
foto / photo: **N. Budimir**

BITVE I PRIVEZNI ELEMENTI

Brod je rekonstruiran s više priveznih elemenata poput bitve te pramčanih i krmenih držača vesala. Međutim, samo su dva elementa izvorno sačuvana. To su prednji desni, vidljivo vješto izrađeni zakrivljeni privezni element te lijeva, također pramčana, probušena bitva (Sl. 18). U izradi 3D rekonstrukcije korišteni su prethodno navedeni izvorni elementi koji su rekonstruirani prema dostupnim informacijama i izvornom obliku. Kao i na izložbenom brodu, unutar 3D rekonstrukcije navedeni su elementi pozicionirani uz jači element – prislonjeni su na rebro ispred njih samih, tj. na rebro 2 i na rebro 11. Također, unutar 3D rekonstrukcije navedeni elementi su i poduplani, tako da na svakoj strani postoji po jedan isti element.

STATVA, KOBILICA, TEMELJ JARBOLA

Pri izradi 3D rekonstrukcije pramčane i krmene statve za referencu je korištena forma stolarske rekonstrukcije uz sitne korekcije koje se odnose na njihovo izravnavanje. Stoga je u 3D modelu postignut kompromis između postojećeg stanja na olupini te finog „upasavanja" na poziciju koju je diktirao novonastali 3D model. Tako je

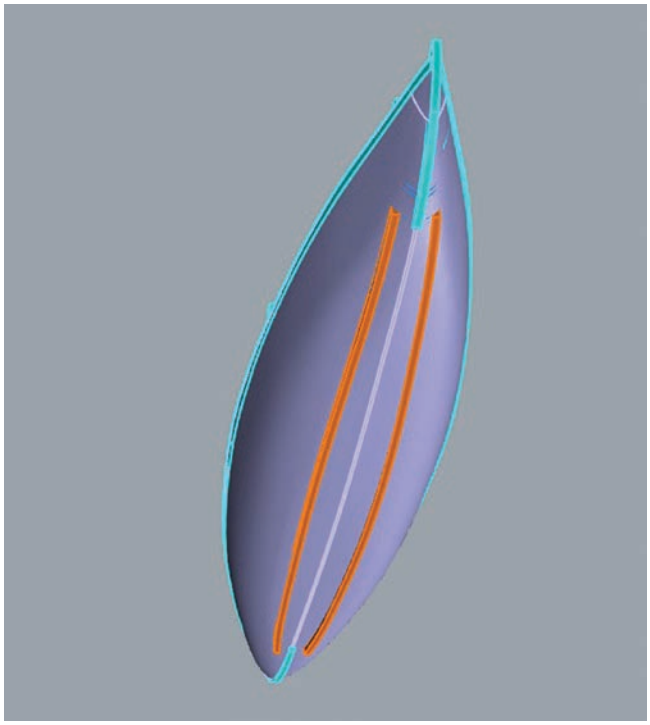
of the frames, where yellow represents the originally preserved wooden parts, blue represents the carpentry reconstruction, and red represents the parts that create the ideal line of the 3D model.

BITTS AND DOCKING ELEMENTS

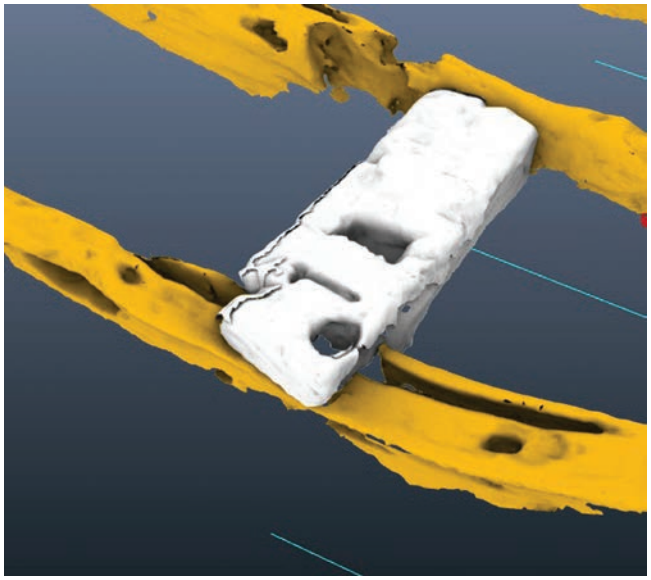
The ship was reconstructed with several mooring elements such as cleats and bow and stern tholepins. However, only two elements were originally preserved. These are the front right, visibly skilfully made, curved mooring element, and the left pierced bitt also from the bow (Fig. 18). In the creation of the 3D reconstruction, the aforementioned original elements were used, which were reconstructed according to the available information and the original shape. As on the exhibition ship, the listed elements within the 3D reconstruction were positioned next to the stronger element – they were rested on the frame in front of them, i.e. on frame no. 2 and on frame no. 11. Also, within the 3D reconstruction the listed elements were doubled so that each side has the same element.

STEM, STERNPOST, KEEL, MAST STEP

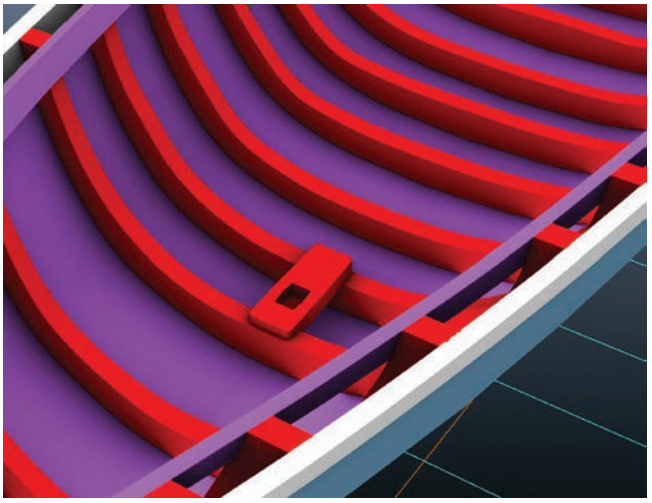
During the creation of the 3D reconstruction of the stem and sternpost, the shapes from the carpentry reconstruction were used as a reference with minor corrections related to their alignment. Therefore, a compromise was reached in the 3D model between the current state of the wreck and the fine "tuning" to the position dictated by the



Slika 19. Dvije uzdužne paralelne grede, odnosno kobilice tijekom izrade 3D rekonstrukcije
Figure 19. Two longitudinal parallel beams, i.e. the keels during the creation of a 3D reconstruction
foto / photo: **N. Budimir**



Slika 20. Temelj jarbola nakon skeniranja
Figure 20. Mast step after scanning
foto / photo: **N. Budimir**



Slika 21. Temelj jarbola nakon reverzibilnog 3D modeliranja u Rhinoceros 3D programu
Figure 21. Mast step after reversible 3D modelling in Rhinoceros 3D program
foto / photo: **N. Budimir**

zadovoljeno praćenje forme 3D rekonstruiranog dijela prema izvornim elementima, ali i prema stolarskoj rekonstrukciji.

Za izradu bočnih uzdužnih paralelnih greda, odnosno kobilica, služile su mjere uzete direktno s elemenata olupine broda te neke informacije dobivene na temelju 3D skeniranog modela (Sl. 19).

Temelj jarbola modeliran je na temelju ulaznog 3D skeniranog elementa (Sl. 20), međutim za određeni je stupanj zarotiran te revidiran tako da su popunjena sva oštećenja i pravilno oblikovani rubovi novog 3D modela, ali unutar dimenzija izvornog elementa (Sl. 21).

ZAVRŠNO POZICIONIRANJE 3D MODELA

Nakon završetka svih relevantnih elemenata unutar 3D rekonstrukcije, na temelju zaprimljenog 3D skeniranog modela i njegovih ulaznih parametara, rekonstruiran je 3D model. Budući da je brod u stvarnosti zakošen, dobiveni 3D model zakošen je u gotovo istom kutu kao i skenirani model (Sl. 22). Međutim, prava brodska konstrukcija u izložbenom je prostoru pozicionirana u metalnom postolju, odnosno u metalnoj kolijevci te je gotovo u potpunosti izravnata, odnosno vanjski rubovi trupa maksimalno su prilagođeni ravnom podu. Stoga se pri izradi 3D rekonstrukcije novostvoreni 3D model nastojao poravnati da čim više podsjeća na izložbeni brod (Sl. 23).

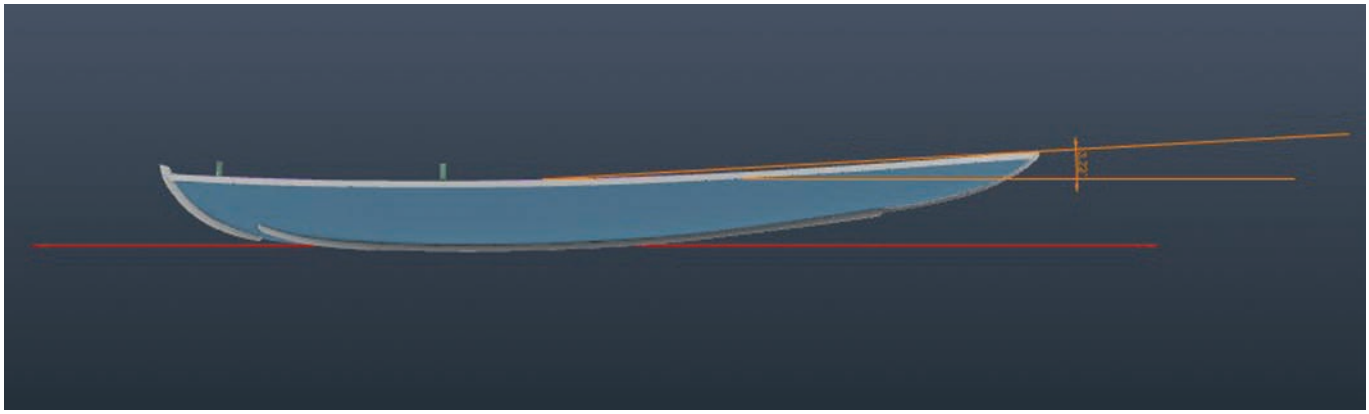
newly created 3D model. Thus, the tracing of the shape of the 3D reconstructed part according to the original elements, but also according to the carpentry reconstruction was accommodated.

The measurements taken directly from the elements of the shipwreck and certain information obtained on the basis of a 3D scanned model (Fig. 19) were used to create the side longitudinal parallel beams, that is, the keels.

The mast step was modelled on the basis of the input of a 3D scanned element (Fig. 20), however, it was rotated to a certain degree and revised so that all damages were filled and the edges of the new 3D model were properly shaped, all within the dimensions of the original element (Fig. 21).

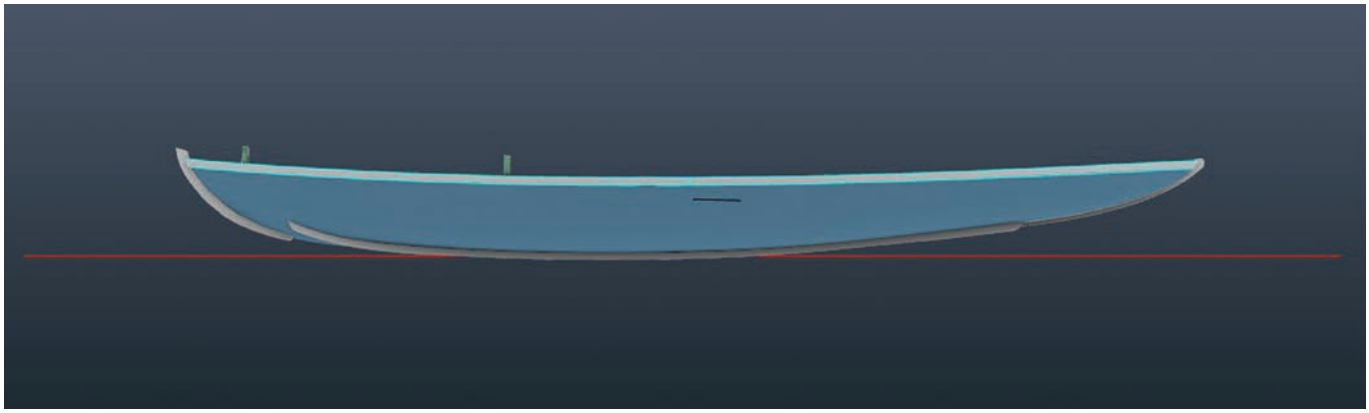
FINAL POSITIONING OF THE 3D MODEL

After the completion of all relevant elements within the 3D reconstruction, based on the received 3D scanned model and its input parameters, the 3D model was reconstructed. Since the ship is inclined in reality, the resulting 3D model is inclined at almost the same angle as the scanned model (Fig. 22). However, the real ship structure in the exhibition room is placed in a metal base i.e. in a metal cradle and it is almost completely levelled, i.e. the outer edges of the hull are maximally adjusted to the flat floor. Therefore, when creating the 3D reconstruction, the newly created 3D model was aligned to resemble the exhibited ship as much as possible (Fig. 23).



Slika 22. Zakošen 3D model
Figure 22. Inclined 3D model

foto / photo: **N. Budimir**



Slika 23. 3D model izravnat s ravninom poda
Figure 23. 3D model aligned with the floor

foto / photo: **N. Budimir**

Tek po završetku izrade 3D rekonstrukcije, odnosno 3D modela,[23] bilo je moguće započeti s pripremom 2D nacrtne dokumentacije, odnosno s izvlačenjem linija forme modela broda.

IZRADA 2D DOKUMENTACIJE

Nakon izrade 3D modela rekonstruiranog broda izvedena je tehničko-nacrtna, odnosno 2D dokumentacija novonastalog modela. Međutim, dobivenu cjelokupnu 2D tehničko-nacrtnu dokumentaciju 3D modela bilo je potrebno „pročistiti" i optimizirati za potrebe izrade preglednih i jasnih nacrta linija modela. Naime, sve 2D linije dobivene su na temelju projiciranja na 3D skenirane površine te su bili vidljivi svi obrisi utora, pukotina i deformacija. Jedino uklanjanjem tih nepravilnosti dobivene su linije mogle predstavljati relevantnu formu modela broda u 2D nacrtima.[24] Budući da je tijekom 2D dokumentiranja broda ostvaren

Only after the completion of the 3D reconstruction, i.e. of the 3D model,[23] it was possible to start the preparations for the 2D drawing documentation, i.e. the drawing the lines of the shape of the ship.

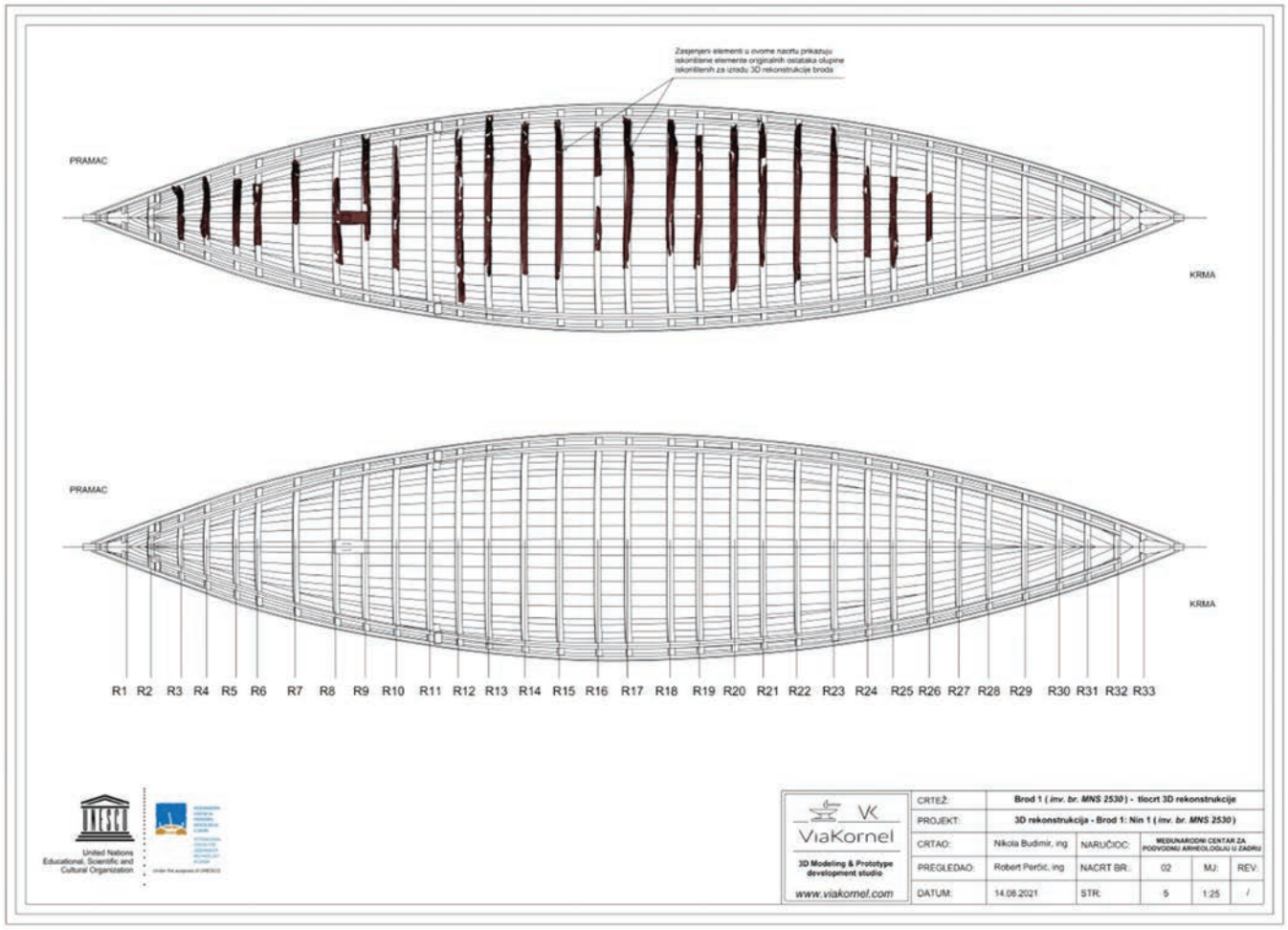
CREATION OF THE 2D DOCUMENTATION

After the creation of the 3D model of the reconstructed ship, the technical-draft, i.e. the 2D documentation of the newly built model was created. However, the complete obtained 2D technical-draft documentation of the 3D model had to be "refined" and optimized for the needs of creating precise and clear drafts of model lines. Namely, all 2D lines were obtained based on the projections of the 3D scanned surfaces, and all contours of the grooves, cracks and deformations were visible. Only by removing these irregularities could the resulting lines represent the relevant shape of the ship model in 2D

23 Cjelokupnu izradu 3D modela proveo je Nikola Budimir, mag. ing., član tima i vlasnik riječkog ViaKornela, studija za 3D modeliranje i izradu prototipova, s višegodišnjim iskustvom u domeni 3D rekonstrukcije brodskih olupina.

24 Preciznu tehničko-nacrtnu 2D dokumentaciju izradio je Nikola Budimir, mag. ing., a nacrte je pregledao Robert Perčić, mag. ing., obojica članovi tima ViaKornel.

23 The entire creation of the 3D model was carried out by Nikola Budimir, M.Sc. in engineering, a team member and owner of the ViaKornel from Rijeka, a studio for 3D modeling and prototyping, with extensive experience in the field of 3D shipwreck reconstruction.



Slika 24. 2D nacrt s naznačenim izvornim elementima korištenim u izradi 3D modela
Figure 24. 2D drawing with indicated original elements used in the creation of the 3D model

foto / photo: **N. Budimir**

kompromis između izvornih dijelova konstrukcije broda i postojeće stolarske rekonstrukcije, na 2D nacrtima jasno je naznačeno koji su izvorni elementi upotrijebljeni za izradu 3D modela (Sl. 24).

Budući da su linije forme i nacrti linija broda izvučeni na temelju 3D dokumentiranja postojećeg stanja, dobivena 2D dokumentacija predstavlja samo osnovni ili uvodni dokumentacijski materijal za eventualne daljnje i detaljnije povijesno-tehničke rekonstrukcije i analize brodske konstrukcije te omogućava usporedbu i reviziju već postojećih nacrta linija broda.[25] Dobivena 2D dokumentacija i nacrti, međutim, ne predstavljaju rekonstrukciju originalnih brodskih linija ni radioničke nacrte za izradu replika brodova ili nacrte za provedbu mogućih analiza stabiliteta ili drugih maritimnih sposobnosti brodova.

drawings.[24] Since a compromise was reached during the 2D documentation of the ship between the original parts of the ship's structure and the carpentry reconstruction, the 2D drawings clearly indicated which original elements were used in the creation of the 3D model (Fig. 24).

Since the shape lines and drafts of the ship's lines were drawn on the basis of the 3D documentation of the current state, the resulting 2D documentation represents only the basic or introductory documentation material for the possible future and more detailed historical-technical reconstructions and analyses of the ship's structure, which enables the comparison and revision of the existing drafts of the ship lines.[25]

24 The precise technical drawing 2D documentation was created by Nikola Budimir, M.Sc. in engineering, and the designs were reviewed by Robert Perčić, M.Sc. in engineering, both members of the ViaKornel team.

25 Ship lines drawn on the basis of 3D documentation were compared to earlier ship line drawings. The results of the comparison, i.e. the revision of the ship structure of the *Condura Croatica* were presented at the symposium ISBSA 16 (16th International Symposium on Boat and Ship Archaeology), held in Zadar from September 26 to October 1, 2021. The publication of the article on the results of the ship structure revision by A. Jelić and M. Pešić titled *Condura Croatica – A Revision of the Structural Drawings* is expected in ISBSA 16 Proceedings which is currently in print.

25 Nacrti linija broda izvučeni na temelju 3D dokumentiranja uspoređeni su s već postojećim nacrtima linija broda. Rezultati usporedbe, odnosno revizije brodske konstrukcije broda *Condura Croatica* predstavljeni su na simpoziju ISBSA 16 (16th International Symposium on Boat and Ship Archaeology), održanom u Zadru od 26. rujna do 1. listopada 2021. godine. Objava članka o rezultatima revizije brodske konstrukcije autora A. Jelić i M. Pešić naziva *Condura Croatica – A Revision of the Structural Drawings* očekuje se u ISBSA 16 Proceedings koji je trenutačno u tisku.

Slika 25. Fotorealistična vizualizacija idejne rekonstrukcije broda *Condura Croatica*
Figure 25. Photorealistic visualization of the conceptual reconstruction of the ship *Condura Croatica*

foto / photo: **N. Budimir**

Završni dio dokumentiranja bilo je vizualno sagledavanje modela broda, odnosno prijenos 3D modela u sliku te izrada kvalitetnih fotorealističnih vizualizacija idejne rekonstrukcije broda *Condura Croatica*. Naime, tijekom sagledavanja model je djelomično oblikovan prema pisanim izvorima, poput jarbola i snasti,[26] te „obojen" i vizualiziran isključivo prema povijesnim materijalima korištenim za gradnju broda – u najvećem dijelu radi se o nekoliko vrsta hrasta (Sl. 25).[27]

ZAKLJUČAK

Kada je jedan privlački sabunjar šezdesetih godina prošlog stoljeća slučajno pronašao drvenu građu u pijesku, na svjetlo dana napokon su izišli drveni dijelovi brodske konstrukcije. Dijelovi su stoljećima ležali zakopani na pješčanom morskom dnu, pod hrpom kamenja na ulazu u samu ninsku luku. Ispostavilo se da su to konstrukcijski dijelovi dvaju brodova jedinstvenih predstavnika hrvatske srednjovjekovne pomorske tradicije, danas poznatih kao

The obtained 2D documentation and the drafts, however, do not represent the reconstruction of the original ship lines, or the workshop drafts used in building of the ship replicas, or the drafts for the implementation of possible analyses of the stability or other maritime capabilities of the ships.

The final part of the documentation was the visual observation of the ship model, that is, the transfer of the 3D model to an image, and the creation of high-quality photorealistic visualizations of the conceptual reconstruction of the ship *Condura Croatica*. Namely, during the observation, the model was partially shaped according to written sources, such as the mast and the rigging,[26] and it was "coloured" and visualized exclusively according to the historical materials used in the construction of the ship – generally several types of oak (Fig. 25).[27]

CONCLUSION

In the 1960s, when a sand-worker from Privlaka accidentally found a wooden structure in the sand, the wooden parts of the ship's structure finally came to light. For centuries, the

26 Vidi Z. Brusić 1978; M. Kozličić, Z. Brusić 1991.
27 Vidi I. Radić Rossi, N. Liphschitz 2010.

26 See Z. Brusić 1978; M. Kozličić, Z. Brusić 1991.
27 See I. Radić Rossi, N. Liphschitz 2010.

Condura Croatica. Nakon provedenih arheoloških i konzervatorsko-restauratorskih radova tijekom 1970-ih i 1980-ih godina brodovi su predstavljeni javnosti u Muzeju ninskih starina gdje se i dandanas nalaze i gdje se o njima brine. Nažalost, tadašnji skromni muzejski uvjeti u kombinaciji sa sredstvom korištenim za stabilizaciju drvene strukture učinili su svoje, pa su ti brodovi iz godine u godinu sustavno i ubrzano propadali. Ta činjenica potaknula je niz suradnji da bi se pojasnio uzrok propadanja, ali i da bi se pronašlo adekvatno rješenje ne bi li se njihovo propadanje maksimalno usporilo. Stoga je 2017. godine i pokrenut sveobuhvatan konzervatorsko-restauratorski projekt pod pokroviteljstvom Ministarstva kulture i medija, a provode ga stručnjaci iz Međunarodnog centra za podvodnu arheologiju u Zadru. Iako je primarna svrha projekta provođenje konkretnih zahvata i faza da bi se u konačnici brodovi maksimalno zaštitili i njihovo propadanje usporilo, tijekom radova došlo se do novih spoznaja o izgledu elemenata brodske konstrukcije te su uočene nepravilnosti vezane za provedenu rekonstrukciju brodova. Naime, uočen je niz drvenih elemenata različitog oblika i dimenzija od kojih su brodske konstrukcije građene, a koje su nas potaknule na odluku da se u sklopu konzervatorsko-restauratorskog projekta digitalno dokumentira i arhivira postojeće stanje brodskih konstrukcija tehnikom 3D skeniranja. Osim navedenog, uočene su i praznine između oplata i rebara u debljini od oko pet centimetara što je dovelo u pitanje dosadašnje znanje o rekonstrukciji brodova. Stoga je odlučeno da se informacije dobivene digitalnim dokumentiranjem upotrijebe u provjeri pozicioniranosti rebara izradom 3D modela jednog od brodova.

Tijekom izrade modela jasno se uvidjelo koliko na prvi pogled odlično postavljena i prilagođena rebra zapravo odstupaju i ne odgovaraju novonastalom 3D modelu. Pretpostavlja se da spomenuti elementi ne odgovaraju novonastalom 3D modelu zbog sušenja drva i pomicanja rebara nekoliko centimetara naprijed-natrag u izvorni položaj, zbog kuta savijanja rebara uzrokovanog sušenjem i zbog nedostatka degradiranih dijelova u nekim drvenim elementima. S obzirom na to da na krmenom kraju broda nema sačuvanih izvornih dijelova, u svrhu adekvatne rekonstrukcije korištena su i pojedinačna rebra stolarske rekonstrukcije koja su najbolje odgovarala liniji izvorno sačuvanih rebra.

Pri izradi modela ostalih elemenata broda, kao što su unutarnja oplata, bitve i elementi za privez, pramčani i krmeni držači vesala i bočne grede (kobilice), korišteni su izvorni elementi u dijelu u kojem su bili dostupni, a model je dopunjen na temelju stolarske rekonstrukcije i pisanih izvora u dijelovima gdje je nedostajao izvornik.

Pri izradi adekvatne rekonstrukcije broda, na temelju 3D skeniranog modela, bilo je moguće redizajnirati i optimizirati unutarnje elemente brodske konstrukcije na njihove pozicije odgovarajućim softverskim alatima a da se oni

parts lay buried on the sandy seabed, under a pile of stones at the entrance to the port of Nin. These turned out to be the structural parts of two ships, the unique representatives of Croatian medieval maritime tradition, known today as *Condura Croatica*. After the archaeological and conservation-restoration works carried out in the 1970s and 1980s, the ships were presented to the public in the Museum of Nin Antiquities, where they still remain and where they are preserved. Unfortunately, the modest museum conditions of that period combined with the agent used to stabilize the wooden structure took their toll, so these ships systematically and rapidly deteriorated year after year. This fact prompted a series of collaborations in order to clarify the cause of the deterioration, but also to find an adequate solution in order to slow down their deterioration as much as possible. Therefore, in 2017, a comprehensive conservation-restoration project was launched under the auspices of the Ministry of Culture and Media, and it is carried out by experts from the International Centre for Underwater Archeology in Zadar. Although the primary purpose of the project is the implementation of specific procedures and phases in order to ultimately protect the ships as much as possible, and slow down their deterioration, during the works, a new insight was gained about the appearance of the elements of the ship's structure, and certain irregularities related to the reconstruction of the ships were observed. Namely, a number of wooden elements of different shapes and dimensions used in the construction of the ship's structures were observed, which prompted us to digitally document and archive the current state of the ship's structures using 3D scanning as a part of the conservation-restoration project. In addition to the above, the gaps between the hull and the frames about five centimetres thick were also observed, which called into question the previous knowledge about the reconstruction of the ships. Therefore, it was decided to use the information obtained through digital documentation to check the positioning of the frames by making a 3D model of one of the ships.

During the creation of the model, it was obvious how seemingly perfectly placed and adapted frames actually deviate and do not correspond to the newly created 3D model. It is assumed that the mentioned elements do not correspond to the newly created 3D model due to the drying of the wood and the movement of the frames several centimetres back and forth to the original position, due to the angle at which the frames bend due to drying, and also due to the defects of the degraded parts in certain wooden elements. Given that there are no preserved original parts at the stern end of the ship, for the purpose of adequate reconstruction, certain individual carpentry reconstructed frames were used, which best corresponded to the line of the originally preserved frames.

During the creation of the model of other ship elements, such as the inner planking, bitts and docking elements, bow and stern tholepins, and side beams (the

ne diraju ili premještaju na izvornom brodu. Time je ujedno izbjegnuto i izlaganje drvenih elemenata potencijalno nepovoljnim uvjetima i okolnostima. Upravo je mogućnost beskontaktnog prikupljanja podataka i njihova digitalna obrada bila osnovna prednost i specifičnost ovog projekta.

Nakon izrade 3D modela izvučene su brodske linije i izvedena 2D dokumentacija modela. Budući da je tijekom izrade 3D modela ostvaren kompromis između izvornih dijelova konstrukcije broda i postojeće stolarske rekonstrukcije, na 2D nacrtima jasno je naznačeno koji su izvorni elementi korišteni za izradu modela. Dobivena 2D dokumentacija predstavlja podlogu za eventualne buduće analize brodske konstrukcije te omogućava reviziju već postojećih nacrta linija broda. Međutim, dobiveni nacrti ne predstavljaju rekonstrukciju originalnih brodskih linija ni radioničke nacrte za izradu replika brodova ili nacrte za provedbu mogućih analiza stabiliteta ili drugih maritimnih sposobnosti brodova. Završni dio detaljnog dokumentiranja bila je transformacija 3D modela u sliku te izrada kvalitetnih fotorealističnih vizualizacija idejne rekonstrukcije ninskih brodova *Condura Croatica* čime je cjelokupni projekt dokumentiranja ujedno i zaokružen u cjelinu.

3D skeniranje samo je jedna od novih tehnologija korištena da pripomogne u dokumentiranju, bilježenju i prikazu predmeta i objekata koji imaju veliku povijesnu važnost, a upravo su takvi jedinstveni brodovi *Condura Croatica*. Jednom tako dokumentirani predmeti ili objekti uvijek se mogu naknadno 3D rekonstruirati, obnoviti ili izraditi kao replike, prema svom davno postojećem izvornom izdanju. Upotrebom tehnologije 3D ispisa, laserskog izrezivanja te CNC obrade glodalicama i specijaliziranim alatima, na temelju izvedenih i tako rekonstruiranih 3D modela moguće je zamijeniti dotrajale ili propale elemente, tj. izraditi elemente identične originalima gotovo u desetinku milimetara.

Ubrzanim razvojem aplikacija proširene i virtualne stvarnosti moguće je novostvorenu i rekonstruiranu tehničku 3D/2D građu starohrvatskih brodova približiti posjetiteljima muzeja, brodograditeljima, ali i svim zainteresiranima za povijesnu i tradicijsku brodogradnju u vidu atraktivnih virtualnih maketa i animacija te tako spojiti tehničku dokumentaciju s modernim digitalnim tehnologijama.

keels), the original elements were used in the part where they were available, and the model was supplemented on the basis of carpentry reconstructions and written sources in parts where the original parts were missing.

During the creation of an adequate reconstruction of the ship, based on a 3D scanned model, it was possible to redesign and optimize the internal elements of the ship structure to their positions with appropriate software tools without touching or moving the elements on the original ship. This also avoided the exposure of wooden elements to potentially unfavourable conditions and circumstances. Precisely this possibility of non-contact data collection and their digital processing was the main advantage and particularity of this project.

After the creation of the 3D model, the ship lines were drawn and the 2D documentation of the model was created. Since during the creation of the 3D model a compromise was achieved between the original parts of the ship structure and the carpentry reconstruction, the 2D drawings clearly indicate which original elements were used to create the model. The obtained 2D documentation serves as the basis for possible future analyses of the ship structure and enables the revision of existing drafts of the ship lines. However, the obtained drafts do not represent the reconstruction of the original ship lines, or the workshop designs for the production of ship replicas, or the designs for the implementation of possible stability analyses or other maritime capabilities of the ships. The final part of the detailed documentation was the transformation of the 3D model into an image, and the creation of high-quality photorealistic visualizations of the conceptual reconstruction of the Nin ships *Condura Croatica*, which completes the documentation project.

3D scanning is only one of the new technologies used to help with the documentation, recording and displaying of the items and objects of great historical importance, such as the unique ships *Condura Croatica*. Such documented items or objects can always be subsequently 3D reconstructed, restored or made as replicas, based on their long-existing original. The use of the 3D printing technology, laser cutting and CNC processing with milling machines and specialized tools, based on the 3D created and thus reconstructed models, enables the replacing of worn out or degraded elements, i.e. the creation of elements identical to the originals almost to a tenth of a millimetre.

The accelerated development of augmented and virtual reality applications, it is possible to present the newly created and reconstructed technical 3D/2D structures of old Croatian ships to museum visitors, shipbuilders, but also to all those interested in the historical and traditional shipbuilding in the form of attractive virtual models and animations, thus combining technical documentation with modern digital technologies.

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