Luka BEKIĆ, Roman SCHOLZ, Mladen PEŠIĆ

FOTOBAZIRANE DOKUMENTACIJSKE METODE U PODVODNOJ ARHEOLOGIJI NA PRIMJERU BRODOLOMA KOD OTOKA VERUDA BLIZU PULE

PHOTOGRAPHY-BASED DOCUMENTATION METHODS IN UNDERWATER ARCHAEOLOGY AS APPLIED AT THE VERUDA WRECK NEAR PULA

Doc. dr. sc. Luka Bekić
Međunarodni centar za podvodnu arheologiju u Zadru
B. Petranovića 1, Zadar, Hrvatska
lbekic@icua.hr

Roman Scholz
Römisch-Germanische Kommission Frankfurt/Main
des Deutsches Archäologisches Institut
Palmengartenstraße 10-12. 60325 Frankfurt a.M.
roman.scholz@dainst.de

Mladen Pešić
Međunarodni centar za podvodnu arheologiju u Zadru
B. Petranovića 1, Zadar, Hrvatska
mpesic@icua.hr

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Otok Veruda, također poznat kao "Fratarski" otok, omiljeno je odredište za odmor stanovnika grada Pule u Hrvatskoj. Arheolozi Međunarodnog centra za podvodnu arheologiju u Zadru (MCPA) istraživali su kod Verude u jesen 2013. i tom prilikom pronađena je gomila balastnog kamena koja je izgledala kao brodolom. Ispod te gomile otkriveni su arheološki artefakti i ostaci strukture drvenog broda. Do 2016. godine MCPA Zadar i Njemački arheološki institut (DAI) pokrenuli su projekt istraživanja Verude. Za potrebe ovog projekta razvijen je potpuno novi sustav digitalne fotogrametrijske dokumentacije koji je i korišten tijekom iskopavanja u proljeće 2016. Na taj je način otkrivena kompletna drvena konstrukcija i izrađen vrlo precizan 3D model i nacrt. Tijekom iskopavanja pronađeni su mnogi artefakti, a čini se da je brod nosio teret otpadnog metala, uglavnom kositra i bakra i nekih poluproizvoda od bakra i bronce. Nekoliko sitnih krhotina ranonovovjekovne keramike i stakla može se datirati u drugu polovicu 16. i početak 17. stoljeća.

KLJUČNE RIJEČI: *Veruda, brodolom, iskop, dokumentacija, fotogrametrija, 3D model*

Doc. Dr. sc. Luka Bekić
International Centre for Underwater Archaeology in Zadar
B. Petranovića 1, Zadar, Croatia
lbekic@icua.hr

Roman Scholz
Römisch-Germanische Kommission Frankfurt/Main
des Deutsches Archäologisches Institut
Palmengartenstraße 10-12. 60325 Frankfurt a.M.
roman.scholz@dainst.de

Mladen Pešić
International Centre for Underwater Archaeology in Zadar
B. Petranovića 1, Zadar, Croatia
mpesic@icua.hr

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The island of Veruda - also referred to colloquially as Monks' Island *- is a favourite holiday destination for the inhabitants of the Croatian city of Pula. Archaeologists with the International Centre for Underwater Archaeology in Zadar (ICUA) surveyed the Veruda area in the autumn of 2013. They identified a mound of ballast stones that appeared to be from a shipwreck. Small archaeological artefacts and the remains of the structure of a wooden vessel were discovered under the ballast stones. By 2016 ICUA Zadar and the German Archaeological Institute (DAI) had jointly initiated the Veruda excavation project. An entirely novel system of digital photogrammetry documentation was developed and used during the excavation in the spring of 2016. In this manner the complete wooden structure was revealed and a very precise 3D model and drawings were produced. Many artefacts were recovered in the course of the excavation, and it appears that the ship carried a cargo of scrap metal, mostly smelted tin and copper and some copper and bronze intermediate products. A few small sherds of post-medieval pottery and glass can be dated to the second half of the sixteenth and early seventeenth century.*

KEY WORDS: *Veruda, shipwreck, excavation, documentation, photogrammetry, 3D model*

Veruda je ime otoka koji se nalazi na sjeverozapadu Hrvatske, na istočnoj obali istarskog poluotoka, blizu grada Pula. Otok Veruda koji je poznat i kao Fratarski otok, omiljeno je izletište stanovnika Pule, posebice u ljetnim mjesecima. Nalazi se južno od istoimene uvale u kojoj se nalaze brojne nautičke marine, te Pješčane uvale (Sl. 1).

Oko samog otoka dosad nisu bili zabilježeni podvodni arheološki nalazi, osim na prolazu između otoka i obližnjeg poluotoka Seline ili Stoka. Na tom mjestu arheolozi Međunarodnog centra za podvodnu arheologiju u Zadru u više su navrata pronalazili brojne rasute arheološke nalaze, od rimskog do novovjekovnog doba, odbačene s brodova. Po svemu sudeći, ovo mjesto bilo je vrlo pogodno sidrište jer ima dovoljnu dubinu (do 10 m) i zaštićeno je od svih vjetrova, a prići mu se može i s južne i sjeverne strane.

Prilikom zadnjeg pregleda ove lokacije, u jesen 2013. g. arheolozi MCPA Zadar su pobliže otoku naišli na gomilu balastnog kamena, koja je na prvi pogled bila indikacija za postojanje brodoloma (Sl. 2). Pomnim pregledom lokacije pronađeni su i pokretni arheološki

Sl. 1 Otok Veruda s ucrtanim položajem nalazišta olupine broda (digitalna ortofotokarta Hrvatske).
Fig. 1 Veruda Island, with the site of the shipwreck indicated (digital orthophoto map of Croatia).

Veruda is an island located in northwest Croatia off the eastern coast of the Istrian peninsula, near the city of Pula. Veruda – also referred to colloquially as Monks' Island – is a favoured excursion area for the inhabitants of Pula, especially during the summer. It is situated to the south of Veruda Cove – home to a number of marinas, and Pješčana Cove (Fig. 1).

Underwater archaeological finds had not previously been identified in the island's immediate vicinity, with the exception of the strait between the island and the nearby peninsula of Seline (also known as Stoka). At this location archaeologists with the International Centre for Underwater Archaeology in Zadar had on several occasions found numerous isolated finds from the Roman to the post-medieval period that had been jettisoned from ships. From all indicators this was a very suitable anchorage, having sufficient depth (up to ten metres), offering protection from all winds, and accessible from both the north and south.

Archaeologists with ICUA Zadar identified a mound of ballast stones near the island during the last survey of the site, staged in the autumn of 2013, indicating the possible presence of a shipwreck (Fig. 2). Closer inspection of the location led to the recovery of small archaeological finds and the discovery of the remains of a wooden vessel beneath the ballast stones (Bekić 2013). This was clearly a wooden sailing vessel, requiring rescue excavation.

The site is at a depth of approximately six metres and less than 100 metres from the shoreline, visibility is good, the site is protected from waves, but the fact that the site lies between the island and the mainland means that maritime currents are frequent and of varying direction. The ballast mound rises to a height of 0.5 metres, extends to a length of about eight metres and is about six metres across, lying directly on a rocky terrace with sporadic sand. The ballast stones are up to 20 by 20 centimetres in size and beneath them was the ship's clearly identifiable wooden structure. The good topographic situation and the particular threat to the site made this wreck suitable for excavation applying an experimental digital documentation technique.

In recent years archaeologists have used a broad range of documentation methods in their fieldwork. Both the 2D photogrammetry and the Structure from Motion (SfM) methods are used to avoid drawing by hand and to save time. Given that the details of these methods are described exhaustively elsewhere, we will avoid repetition and rather direct the reader to other sources, such as the paper penned by Fischer in 2015. We know that nalazi, a uočeno je postojanje ostataka drvene brodske konstrukcije ispod balastnog kamena (Bekić 2013). Očito je bilo da se radi o drevnom jedrenjaku pa je bilo potrebno provesti zaštitno istraživanje.

Nalazište je na dubini od oko 6 metara i udaljeno od kopna manje od 100 metara, vidljivost je dobra, položaj je zaštićen od valova, ali su česte morske struje koje mijenjaju smjer, s obzirom da je riječ o prolazu između otoka i kopna. Gomila balastnog kamena visine je do 0,5 m, dužine oko 8, a širine oko 6 metara i položena je ravno na stjenovitu terasu s malo pijeska. Balastno kamenje je veličine do 20x20 cm, a ispod njega jasno se razaznaje drvena brodska struktura. Zbog dobrog topografskog položaja i posebne ugroženosti nalazišta ova se olupina učinila pogodnom za provođenje istraživanja eksperimentalnom tehnikom digitalnog dokumentiranja.

Posljednjih se godina arheolozi na terenu služe različitim metodama dokumentiranja. Kako bi se izbjeglo ručno crtanje i uštedjelo na vremenu, primjenjuju se ili 2D fotogrametrija ili metoda *Structure from Motion* (SFM). Budući da su pojedinosti ovih metoda iscrpno opisane i u drugoj literaturi, njihovo ponavljanje nije potrebno nego se upućuje na radove poput onog Fischerova iz 2015. Poznato je da se pri iskopavanjima na kopnu obje metode vrlo uspješno primjenjuju. No, unatoč svoj pomnosti uvijek se pojavljuju pogrešni ili neprecizni rezultati. Taj je problem još izraženiji u podvodnoj arheologiji. Cilj ovoga rada jest ukazati na mogući pristup rješavanju problema prilikom terenskih istraživanja i predstaviti prve rezultate istraživačkog projekta "The Analysis of Modern Documentation Methods: A Case Study of a Shipwreck off Veruda Island, Croatia".

U okviru projekta provedenoga zajedničkom suradnjom triju ustanova, odjela Römisch-Germanische Kommission (RGK) Njemačkoga arheološkog instituta (DAI), UNESCO-ova Međunarodnog centra za podvodnu arheologiju u Zadru (MCPA) i učilišta Hochschule für Technik und Wirtschaft Dresden (HTW-DRESDEN), nova je tehnika rada iskušana i poboljšana. Voditelji ovog arheološkog istraživačkog projekta bili su doc. dr.sc. Luka Bekić i Mladen Pešić kao njegov zamjenik. Metodološki dio istraživanja vodili su Roman Scholz (RGK-Frankfurt am Main) i Andreas Grundmann (UWA-Logistik). Oba su tima imala podršku arheologa Maje Kaleb, Roka Surića, Dominica Hosnera te ronilaca Borne Krstulovića, Sandre Kamerla Buljić i Enisa Buljića. Pod vodstvom prof. dr. Marca Block-Berlitza njemački su IT-stručnjaci Benjamin Gehmlich, Dennis Wittchen i Niklaas Görsch s učilišta HTW Dresden pomagali pri radovima na

both methods are very successfully applied at on-land excavation sites. In spite of all the care exercised however, there are occasional occurrences of erroneous or imprecise results. This problem is even more pronounced in the underwater archaeology environment. The objective of this paper is to point to a possible avenue to the resolution of problems that occur in the course of field research and to present the first results of *The Analysis of Modern Documentation Methods: A Case Study of a Shipwreck off Veruda Island, Croatia* research project.

Sl. 2 Stanje nalazišta prilikom njegova otkrića (foto: L. Bekić).
Fig. 2 The condition of the site upon discovery (photo by: L. Bekić).

The new technique was tested and improved in the frame of a project that saw the collaboration of three institutions: the Romano-Germanic Commission (RGK) of the German Archaeological Institute (DAI), the UNESCO International Centre for Underwater Archaeology in Zadar (ICUA) and the Dresden University of Applied Sciences (HTW Dresden). Leading this archaeological excavation were field director Luka Bekić PhD and deputy field director Mladen Pešić. Roman Scholz (RGK-Frankfurt am Main) and Andreas Grundmann (UWA-Logistik) were responsible for the methodological aspects of the excavation. Both teams were supported by archaeologists Maja Kaleb, Roko Surić and Dominic Hosner and by divers Borna Krstulović, Sandra Kamerla Buljić and olupini broda. Logističku je potporu projekt dobio od ronilačkog centra "Indie" iz autokampa Indije u Banjolama. Istraživački projekt odobrilo je Ministarstvo kulture RH, odnosno Konzervatorski odjel u Puli, a sufinancirali su ga britanska zaklada Honor Frost, DAI Berlin, MCPA Zadar i njemačka udruga "Prijatelji arheologije u Europi".

Terenska je kampanja trajala od 29. ožujka do 19. travnja 2016. g. i tijekom nje istraženo je cijelo područje rasutog kamenog balasta, drvene brodske konstrukcije i nešto šire oko toga (Bekić, Surić 2016; Scholz, Bekić, Pešić 2016, Bekić 2017). Druga kampanja provedena je od 17. do 23. svibnja 2017. a u njoj su ponovo sudjelovali stručnjaci iz prve kampanje. Cilj druge kampanje bio je provjeriti stanje *in situ* zaštite drvene brodske konstrukcije te proširiti istraženo polje oko samog brodoloma za pojas od 2 metara. Ustanovljeno je kako je zaštita dobro postavljena i tijekom godine nije došlo do oštećenja. Pronađeno je i mnoštvo novih pokretnih nalaza u širem pojasu oko brodoloma (Bekić, Scholz 2017).

SFM metoda dosad je u podvodnoj arheologiji korištena i testirana pri dokumentiranju manjih struktura (površine nekoliko kvadratnih metara) s razmjerno malim brojem slika (Jansa 2013). Dokumentiranje većih objekata samim time iziskuje puno veći tehnički i logistički napor. Budući da prvotni pokušaji u podvodnoj arheologiji nisu polučili željene rezultate, moralo se prilikom dokumentiranja SFM metodom razviti način rada koji bi odgovarao zahtjevima rada na većim podvodnim objektima.

Pritom poteškoće uzrokuju posebni okolišni faktori - loša vidljivost uzrokovana česticama u vodi, loše osvjetljenje ili filtriranje pojedinih vidljivih spektara boja u svjetlosti. Stoga je bilo neophodno razviti alternativu slobodnom fotografiranju iz ruke. Uporaba višenamjenskog dokumentacijskog mosta, izuma tvrtke UWA-Logistik iz Njemačke i Zemaljskog udruženja za podvodnu arheologiju Mecklenburga i Prednje Pomeranije, predstavlja presudan napredak, a mogućnosti i granice njegove uporabe po prvi je puta trebalo iskušati i poboljšati u okviru ovoga projekta. Povrh toga ovim se projektom želi ukazati na opće pristupe rješavanja problema vezanih uz SFM metodu pri terenskom istraživanju koristeći se višenamjenskim dokumentacijskim mostom (Sl.3).

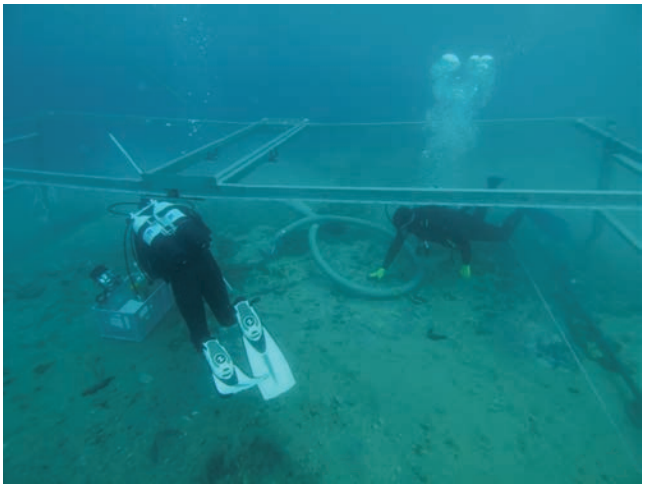
Iskopavanje olupine kod otoka Verude moralo je zadovoljiti više uvjeta. S jedne je strane ugroženo nalazište trebalo po mogućnosti u cijelosti otkopati i istražiti. S konzervatorskog gledišta dijelovi olupine

Enis Buljić. German IT experts Benjamin Gehmlich, Dennis Wittchen and Niklaas Görsch of HTW Dresden worked under the leadership of Dr Marco Block-Berlitz in providing support to the work at the shipwreck site. The Indie Diving Centre from the Indije camping grounds at Banjole provided logistical support for the project. The research project was approved by the Croatian Ministry of Culture (Conservation Department in Pula) and co-financed by the Honor Frost Foundation of Great Britain, DAI Berlin, ICUA Zadar and the Friends of Archaeology in Europe association from Germany.

The field campaign ran from 29 March to 19 April of 2016, in the course of which an area was excavated covering and extending slightly beyond the whole of the field of scattered ballast stone and the wooden ship's structure (Bekić, Surić 2016; Scholz, Bekić, Pešić 2016, Bekić 2017). A second campaign was conducted from 17 to 23 May of 2017, reuniting the experts from the first campaign. The objective of this campaign was to check the condition of the *in situ* protection of the ship's wooden structure and to broaden the excavated field around the wreck by a two-metre wide zone. It was determined that the protective installation had been well set and that no damage had occurred in the intervening year. Numerous new small finds were recovered in the broad zone around the wreck (Bekić, Scholz 2017).

To date the SfM method has been used and tested in underwater archaeology when documenting small structures (areas of a few square metres) with a relatively small number of images (Jansa 2013). Documenting larger objects requires a much greater technical and logistical effort. With initial attempts in the underwater archaeology environment not producing satisfactory results, a new methodology had to be developed for SfM method documentation specifically geared to the challenges posed by work on large-scale underwater structures.

In this process difficulties are caused by the particular environmental factors - poor visibility caused by suspended particulate matter in the water, poor light conditions and the filtering out of some of the visible spectrum of light. It was essential, then, to develop an alternative to hand-held photography. The use of a multifunctional documentation bridge, developed by the German-based UWA-Logistik company and the Landesverband für Unterwasserarchäologie Mecklenburg-Vorpommern (the Mecklenburg-Vorpommern State Association for Underwater Archaeology), is a critical step forward, and the capabilities and limitations of its use had to be tested and improved for the first time in the frame of this project. Moreover, this project aims to highlight general morali su ostati na mjestu i biti konzervirani na što bolji način. Kvaliteta dokumentiranja pritom nije smjela biti lošija od standardne kvalitete dokumentiranja nalazišta na kopnu, već naprotiv, trebala je biti poboljšana korištenjem SFM metode. Budući da se očekivalo mnoštvo nalaza, moralo ih se pojedinačno izmjeriti i prikupiti. No, za sve je radove bilo predviđeno svega 20 dana iskopavanja. Stoga je svaki korak morao biti pomno promišljen i proveden jer, govoreći iz iskustva, dokumentiranje i mjerenje nalaza zahtijeva mnogo vremena. Za sve dokumentacijske zadatke uspostavljen je stabilan lokalni sustav mjerenja koji je služio kao osnova svakoj izmjeri i crtežu. U podvodnoj arheologiji za to se uglavnom koriste i postavljaju fiksni okviri koji, ovisno o strukturi i nalazištu, mogu dosegnuti velike razmjere. Stoga rad roniocima otežavaju mnoge cijevi i konopci ili pak sustav ometaju vanjski utjecaji poput nevremena ili nepažljivog sidrenja zbog kojeg se okviri mogu poremetiti. Pritom ponovno postavljanje sustava nije rijetkost.



Sl. 3 Iskopavanje ispod aluminijskog mosta (foto: M. Pešić).
Fig. 3 Excavation under the multifunctional documentation bridge (photo by: M. Pešić).

Tijekom projekta ispostavilo se da se razvojem višenamjenskog dokumentacijskog mosta mnogi od navedenih problema daju riješiti. Za jedan i pol radni dan na nalazištu su najprije postranično postavljene dvije paralelne osi. U tu su svrhu spojene po dvije cijevi duljine 6 metara fiksirane horizontalno iznad dna. Razmak između cijevi pritom je bio otprilike 6,5 metara, što je uvjetovao sam objekt, a same cijevi služile su kao 'tračnice' za višenamjenski dokumentacijski most. Taj most je u visinu i dužinu varijabilna aluminijska konstrukcija koja uz pravilno usmjerenu silu može prevaliti veće razmake bez savijanja po sredini.

Budući da je višenamjenski dokumentacijski most bio pozicioniran otprilike 1,6 m iznad strukture,

approaches to the resolution of problems associated with the SfM method in field excavations using the multifunctional documentation bridge (Fig. 3).

There were a number of requirements that had to be met in the excavation of the Veruda wreck. On the one hand, the endangered site had to be excavated and studied to the greatest possible extent. With regard to the aspect of conservation, the remnants of the ship had to remain in place and be conserved as best as possible. In the process the standard of documentation had to be as good as the quality expected of on-land documentation: it should, in fact, be improved by the application of the SfM method. Numerous finds were expected and they had to be individually measured and recovered. Only a short window of twenty days, however, was planned for all the excavation work. Our experience tells us that documentation and find measurement consume considerable time - every step, then, required careful planning and execution. A stable local survey system was set up for all documentation tasks and served as the point of reference for all measurements and drawings. For the most part fixed frames are used to this end in underwater archaeology that, depending on the structure and site, are often quite extensive. The work of divers is thus often hampered by the many poles and lines, and the setup can be interfered with by external factors such as storms or careless anchoring that may disturb the frames. Reinstallations of the system are, then, not a rarity.

This campaign demonstrated that the development of the multifunctional documentation bridge allows us to overcome many of the cited difficulties. The first step was to install two parallel axes to the sides of the site - this occupied one and a half working days. This involved connecting two six-metre pipes and anchoring them horizontal to the seafloor. The distance between the pairs of pipes was about 6.5 metres, dictated by the space occupied by the wreck, with the pipes serving as rails on which the multifunctional documentation bridge could ride. The bridge consists of an aluminium frame of variable height and length able to bridge large distances without sagging in the middle by means of precise buoyancy adjustments.

With the multifunctional documentation bridge positioned approximately 1.6 metres above the structure, divers were able to work directly beneath it. As finds were cleared a second diver would immediately measure and collect them. The excavation area was divided for documentation purposes into five two- to three-metre-wide strips. The zero point on the rails at the northeast corner also served as the excavation starting point. The ronioci su mogli raditi direktno ispod samog mosta. Čim su nalazi bili iskopani, drugi ih je ronilac odmah izmjerio i prikupio. Za dokumentiranje je sonda bila podijeljena u 5 površina širine 2 do 3 metra. Nulta točka "tračnica" ležala je u sjeveroistočnom kutu i bila ishodišna točka iskopavanja. Pjeskoviti slojevi debljine od 5 do 30 centimetara odstranjeni su pomoću podvodnog "usisavača", tzv. mamuta, pokretanog pomoću vodene pumpe. Nalazi, koji bi promakli roniocima, odvajali su se sa sedimentom prema površinama i kvadrantima u košare koje su potom pretraživane na plovilu. Otprilike 30 do 60 posebnih nalaza dnevno bi se odmah fotografiralo, izmjerilo pomoću višenamjenskog dokumentacijskog mosta i prikupilo. Tako je u samo 8 dana odstranjeno balastno kamenje i iskopana je cijela olupina broda površine 13 sa 6,5 metara. No tek su se kod SFM metode dokumentiranja s fotografskom osnovom pokazale prave prednosti višenamjenskog dokumentacijskog mosta.

Sve veća potreba za crtačkim dokumentiranjem prilikom arheoloških istraživanja dovodi do sve češće uporabe fotogrametrijske SFM metode. Pritom su ušteđeno vrijeme i veća sadržajnost snimaka odlučujući. Te su prednosti bitne u podvodnoj arheologiji jer se ostali postupci uvriježeni pri arheološkim istraživanjima na kopnu, poput tahimetrije i laserskog skeniranja, u podvodnoj arheologiji zbog vodene barijere ne mogu koristiti. Dokumentiranje na fotografskoj osnovi u toj je istraživačkoj grani poznato već dulje vrijeme – tako George F. Bass jezuitu Péreu Poidebardu pripisuje prve fotografije u podvodnoj arheologiji, snimljene tijekom njegova istraživanja luke u Tyru od 1935. do 1937. godine (Bass 1967, 117 i dalje).

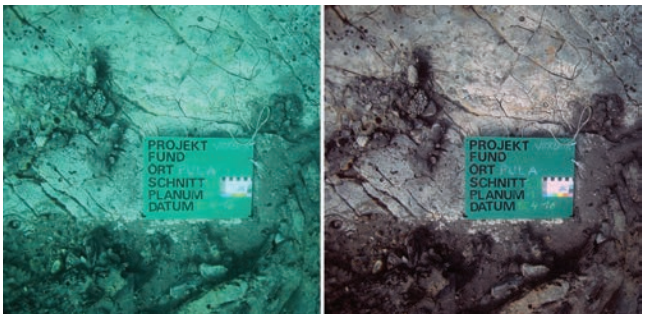
Kvaliteta fotografije ovisi o više faktora. Tako radi apsorpcije svjetlosti u vodi, ovisno o dubini i udaljenosti kamere od objekta, nedostaju pojedini spektri svjetlosti na snimljenoj fotografiji. Kako se ne bi stvorio krivi dojam zbog krivih vrijednosti boja, prije daljnje obrade slika neophodan je ispravak tih vrijednosti. Tako tabela s bojama u području fotografiranja omogućuje kasniju kontrolu rezultata (Sl. 4).

Kod SFM metode dolazi do daljnjih problema. Inače se veći objekti fotografiraju iz višestrukih kosih pozicija (Fischer 2015, 9). Na taj način nastaju fotografije s varijabilnim razmacima između kamere i objekta. Nadalje, dolazi do nepovoljne prostorne dubine. Budući da se kod ispravka boja radi o prilagodbi pojedinih boja, područja koja se nalaze bliže kameri lažno su crvenija (Sl. 5). Pozadina ostaje plava jer ne sadrži crveno svjetlo. Zbog lošijih svjetlosnih uvjeta mora se fotografirati s manjim otvorom blende, čime neoštri dijelovi objekta

sand deposits, from five to 30 centimetres deep, were removed using a counter current underwater "vacuum", i.e. a dredge powered by a water pump. Any finds that escaped the watchful eyes of the divers would be drawn up to the surface with the sediment and located by strip and quadrant in collection baskets further examined on board the research boat. The 30 to 60 special finds recovered daily were immediately photographed, measured using the multifunctional documentation bridge and collected. Over a space of just eight days the ballast stones were removed and the entire wreck area of 13 by 6.5 metres was excavated. The real advantages of the multifunctional bridge were, however, best revealed in the photo-based SfM documentation.

A growing demand for drawn archaeological excavation documentation is driving the increasingly frequent use of photogrammetric SfM methods. Decisive factors in this process are the increased image content density and time saved. These are critical advantages in underwater archaeology – other procedures customary on land, such as tachymetry and laser scanning, are rendered ineffective in our environment by the water barrier. Photographic documentation in this field of research has a long history; George F. Bass ascribes the first photography in underwater archaeology to the Jesuit Pére Poidebard, used during his examination of the port at Tyre from 1935 to 1937 (Bass 1967, 117 f.).

There are a number of factors that impact the quality of the photography. The absorption of light in water – contingent on depth and the distance of the camera from an object, leads to the loss of individual light spectra on the recorded image. When processing the images the colour values must be corrected to avoid any distortion of the documentation. A colour chart placed in the photographed area allows for subsequent control of the image produced (Fig. 4).



Sl. 4 (Lijevo) promjena boje filtriranjem svjetlosti na podvodnoj fotografiji i (desno) ispravak vrijednosti boja (foto: R.Scholz).
Fig. 4 Colour change as a result of light filtration in underwater photography (left), and the correction of colour values (right) (photo by: R. Scholz).

otežavaju izračun slika u 3D model. Zbog toga se ne preporučuje postupak koji se za to koristi prilikom kopnenih iskopavanja.

Sl. 5 Neželjena promjena boje nakon provedene korekcije boja (foto: R. Scholz).
Fig. 5 Undesirable colour change following colour correction (photo by: R. Scholz).

Pokazalo se da uporaba karte spektra boja na svakoj slici nema previše smisla zbog trošenja vremena i napora pri uklanjanju iz svake slike. Prijenos korigiranih vrijednosti na seriju fotografija moguć je samo pri konstantnim uvjetima prilikom fotografiranja. Zbog toga se ne preporučuje vlastoručno korigiranje fotografija, već uporaba tehničkih pomagala.

I uvjeti vidljivosti na nalazištu imaju odlučujući utjecaj na kvalitetu fotografija. Na Baltičkom je moru vidljivost za razliku od Jadranskog mora često ograničena na samo nekoliko metara. Kako bi se stvorile uporabljive fotografije, razmak između objekta i kamere mora se prilagoditi uvjetima vidljivosti. Pritom je potrebno puno pojedinačnih fotografija, kako bi se postigla preporučena podudarnost od 60 do 80 %. To kod većih objekata često dovodi do velikog broja fotografija, što eksponencijalno znači i dulje vrijeme njihove obrade. Za razliku od uobičajenih preporuka korištenja objektiva sa srednjom žarišnom duljinom (Fischer 2015, 2 i dalje), uporaba širokokutnog objektiva je u takvim slučajevima također prihvatljiva.

Pokušaji da se nalazište fotografira tijekom plivanja iz kosih kutova čak je i pri dobroj vidljivosti u Jadranu dovela do manje optimalnih rezultata. Tako je iz 275 fotografija tek nakon korekcija boja mogao biti izračunat oblak točaka. Kako su nizovi fotografija imali krive vrijednosti boja, došlo je do rupa i nedostataka u 3D modelu kao i do nejedinstvene teksture (Sl. 6). Rezultati omogućuju iscrtavanje strukture, no ne ispunjavaju očekivanja suvremene dokumentacije.

Uzroci lošijeg rezultata mogla bi, s jedne strane, biti neoštra mjesta na slikama, koja nastaju zbog kosih

There are other issues associated with the SfM method. Large objects are usually imaged from multiple oblique positions (Fischer 2015, 9). This creates photographs with varying distances from camera to object. There is also the effect of unfavourable spatial depth. Colour correction adapts individual colours, and areas closer to the camera are thus falsely red shifted (Fig. 5). The background remains blue, as there is no red light in this part of the image. The poor lighting conditions means shots are made with reduced aperture, producing blurred areas that complicate translation of the images in a 3D model. The use of this corrective strategy is, therefore, not recommended for on-land excavation.

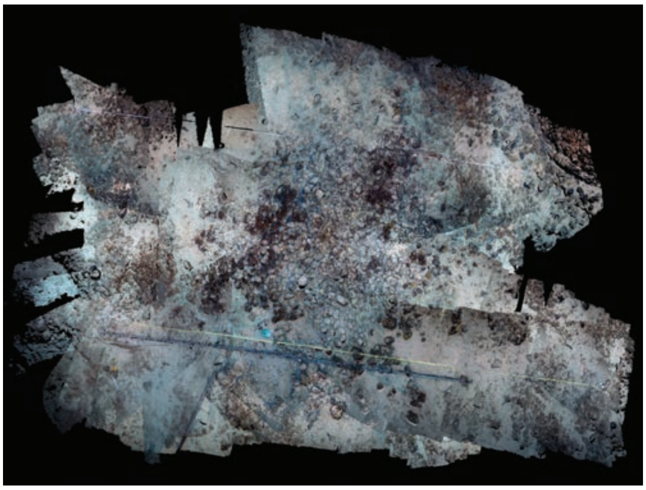
The use of a colour chart on each image was shown to be more or less pointless on account of the loss of time and the effort required to later remove the chart from the image. The transfer of corrected values on a series of images was only possible if the imaging conditions remained constant. Manual correction is thus not recommended and the use of technical aids is advisable.

Visibility conditions at the site also have a decisive impact on the quality of the photography. Baltic Sea visibility for example – contrasted to that of the Adriatic – is often limited to no more than a few metres. The distance between the object and the camera must be adapted to the prevailing visibility conditions if useable images are to be produced. A large number of individual photos will be required if the recommended image overlap of 60 to 80 per cent is to be achieved. With large structures this will often mean producing a large number of photographic images, which exponentially increases the required processing time. Contrary to the customary recommendation to use lenses with normal focal length (Fischer 2015, 2 f.), the use of wide-angle lenses is also acceptable in these situations.

Attempts to photograph the site from oblique angles while free-floating, even with the good visibility afforded by Adriatic conditions, produced suboptimal results. Thus,

Sl. 6 Razlike između slika u SFM nizu fotografija hrpe balastnog kamenja nakon korekcije boja (foto: R. Scholz).
Fig. 6 Post-colour correction image variation in an SfM series of photographs of the ballast mound (photo by: R. Scholz).

snimaka i loše vidljivosti. S druge strane, zbog različitih udaljenosti od objekata i korekcije boja nastaju nepovoljne promjene boja na strukturama.



Sl. 7 Ortogonalni pogled 3D modela hrpe balastnog kamenja na nalazištu oko Verude (R.Scholz).
Fig. 7 Orthogonal view in the 3D model of the Veruda site ballast mound (R. Scholz).

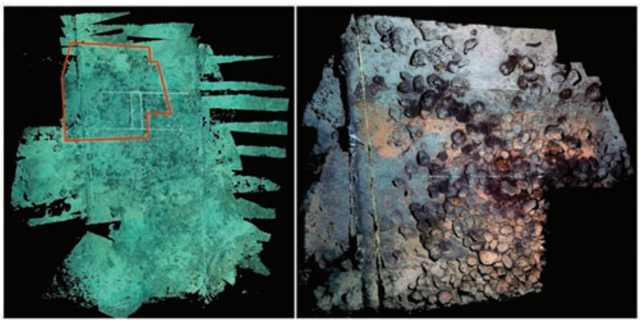
Kako bi iz niza fotografija nastao oblak točaka, a time i 3D model, upotrijebljeni program koristeći SIFT-Algoritam traži točke koje se pojavljuju na više fotografija, takozvane *keypoints* ili *features*. U tome višestupanjskom procesu pikseli jedne fotografije uspoređuju se sa susjednim pikselima na sljedećoj fotografiji. Tako program s određenom vjerojatnošću uvijek iznova razaznaje iste točke na fotografiji te ih koristi u daljnjoj obradi. Što su strukture na fotografijama manje oštre i različitijeg kolorita, to je mogućnost pronalaska dovoljnog broja *keypoints*-a koji su potrebni za daljnju obradu manja. Tako dolazi do toga da veliki broj fotografija ne bude uvršten te program nije u mogućnosti izračunati 3D model. Manje upotrijebljenih fotografija znači i veću nemogućnost preklapanja točaka između fotografija. Rezultat je onda ili nepotpuni oblak fotografija ili oblak fotografija s rupama (Sl. 7).

Kod primjera prikazanog na slici 7 korištene su 193 fotografije za izračun s programom aSPECT3D. Kod fotografija bez korekcija boja nastalo je ukupno 134 zasebnih oblaka točaka. Kod slika s korigiranim vrijednostima boja nastalo je samo 13 zasebnih oblaka točaka. Oba rezultata nisu bila upotrebljiva. Zbog toga je potrebna pouzdana metoda snimanja prikladnih fotografija. Jedno od mogućih rješenja je uporaba višenamjenskog dokumentacijskog mosta, koji je napravljen u tu svrhu (Sl. 9). Na višenamjenskom dokumentacijskom mostu nalazi se mjerno klizište, koje s jedne strane služi za snimanje pojedinih točaka, poput

with 275 photographs, a point cloud could only be calculated following colour correction. False colour values in the image series produced gaps and imperfections in the 3D model and non-uniform textures (Fig. 6). The results did allow for a transformation of the structure, but did not meet the expected standard of modern documentation.

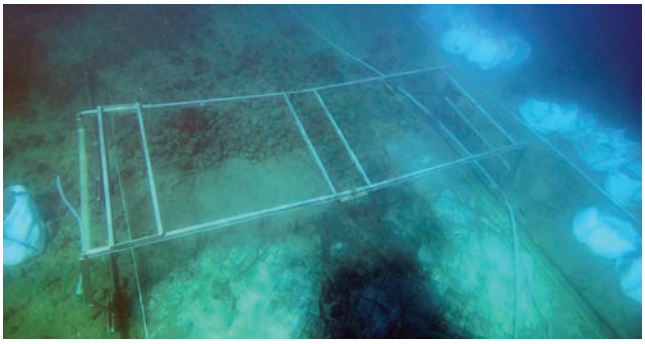
A possible cause of the poor results could, on the one hand, be blurred sections of the individual images, created by the oblique imaging angle and poor visibility. On the other hand the variation in distance from the object and colour correction can also cause unfavourable colour shifts in the structures.

To calculate a point cloud and produce a 3D model from a series of images the software used applies a SIFT (scale-invariant feature transform) algorithm to search for *keypoints* or *features*, i.e. areas that occur in multiple images. In this multistage process pixels in one image are compared with neighbouring pixels in the following image. Thus there is a level of probability that the software will repeatedly identify the same points in two other images and use them in further processing. Higher levels of blurring and differences in colouring will reduce the likelihood that a sufficient number of keypoints will be identified for the next process stage. This, in turn, leads to a significant number of images not being included and rendering the software unable to calculate a 3D model. The drop in the number of images used increases the likelihood that there will not be overlapping points in multiple images. The result is either an incomplete point cloud or a point cloud with gaps (Fig. 7).



Sl. 8 Lijevo: SFM oblak točaka hrpe balastnog kamenja bez korekcije boja, desno: Skica SFM-izračuna istih podataka uz pomoć korigiranih slika, crveni okvir pokazuje poziciju u ukupnoj geometriji (R. Scholz).
Fig. 8 The left image shows an SfM point cloud of the ballast mound without colour correction. The right image shows an SfM estimation of the same data using colour-corrected images; the red frame indicates the position in the overall geometry (R. Scholz).

In the example shown in Figure 7, 193 images were used for an aSPECT3D software calculation. A total of 134 single-point clouds were generated with the nonnalaza ili fototočaka, kao i za montiranje kamere. Tako je moguće snimiti vertikalne fotografije s minornim promjenama udaljenosti i visokom oštrinom fotografija. Također na taj način ne dolazi do izostavljanja nekih parcijalnih područja, a samim time i nedostataka u kasnijoj obradi i 3D modelu. Izbjegava se i izoštravanje kod svake naredne slike, čime se ubrzava cijeli postupak.



Sl. 9 Višenamjenski dokumentacijski most u izvedbi 6 x 2 metra (foto: M.Kaleb).
Fig. 9 The six by two metre version of the multifunctional documentation bridge (photo by: M. Kaleb).

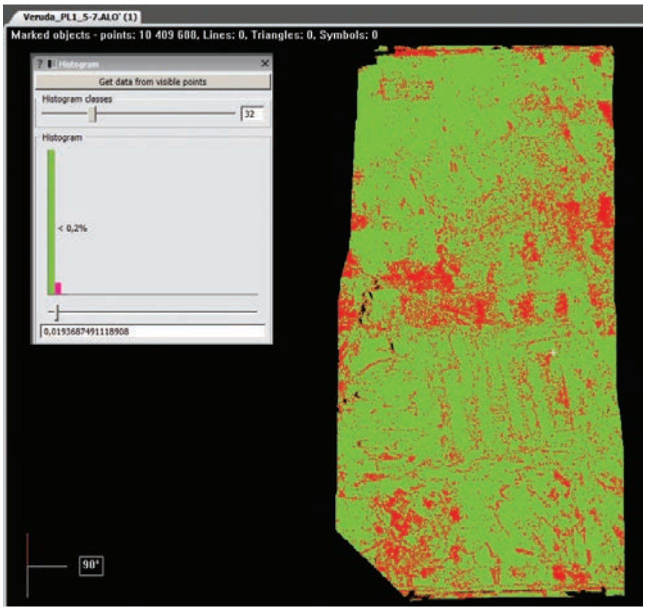
Zbog posebnih uvjeta rada na podvodnim nalazištima gotovo je nemoguće ravnopravno i istovremeno iskopati i dokumentirati neku strukturu. U kratkom roku tanak sloj pijeska prekriva objekte i time otežava fotografsko dokumentiranje. Zbog toga se preporučuje iskopavanje manjih područja i njihovo promptno fotografiranje. Budući da je višenamjenski dokumentacijski most bio pozicioniran 1,6 metara iznad objekta, ronioci su mogli nesmetano raditi direktno ispod njega (Sl. 10). Za SFM dokumentiranje sonda je bila podijeljena u 3 područja širine 2 do 3 metra. U svakom je području snimljeno između 104 do 241 fotografija. Ovisno o tehničkim karakteristikama upotrijebljenih računala proračunati su modeli pojedinih područja ili pak cijele sonde pomoću SFM softvera.

Budući da pri dobroj kvaliteti fotografija po "području" SFM softver producira prosječno 100 milijuna zasebnih točaka, preporučuje se izračun dijela po dijela objekta te georeferenciranje točaka nakon redukcije. Nakon tog koraka mogu se spojiti oblaci točaka čime nastaje tzv. "mesh". Tako je i s prosječnim računalom moguće obraditi tu količinu podataka. Visoka kvaliteta fotografija i konstantni uvjeti njihova snimanja sugeriraju da je difrakcija točaka u postojećoj gustoći niska. Postotak mjernih točaka koje odstupaju najmanje 1,9 cm od izračunskog područja predmeta obično je mala dvoznamenkasta vrijednost, a na ovoj olupini je to maksimalno 0,2% (Sl. 11).

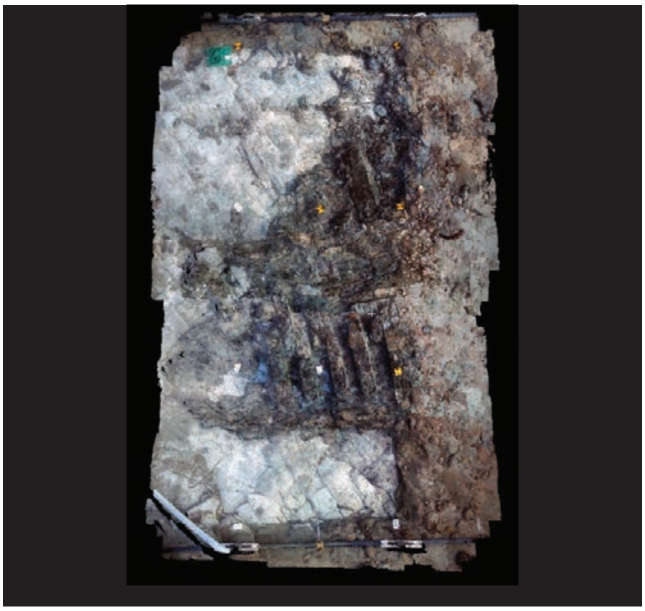
colour corrected images. Only 13 single-point clouds could be determined during the colour-corrected image run. Both results were unusable. What was required, then, was a reliable method of recording suitable images. One possible solution involves the use of the multifunctional documentation bridge that was created for this purpose (Fig. 9). The bridge was fitted with a sliding measuring device, which serves on the one hand to image single points, such as finds or pass points, and as a camera mount. In this manner it is possible to shoot perpendicular images with minor changes in distance and high image sharpness. This also prevents gaps in the imaging area that produces gaps later in processing and the 3D model. This also avoids refocusing for each consecutive image, speeding up the entire process.

The very particular working conditions at underwater sites effectively frustrate any attempt to achieve the uniform and simultaneous exposure and documentation of a structure. The exposed objects are quickly again covered in a thin layer of sand, hampering photographic documentation. As a result the recommended method involves the excavation of a limited area and its prompt imaging. With the multifunctional documentation bridge positioned 1.6 metres above the structure divers were able to work freely directly beneath it (Fig. 10). For SfM documentation the excavation trench was divided into five two- to three-metre-wide strips. From 104 to 241 images were shot in each strip. Contingent on the available processing power, models were calculated with the SfM software either of individual strips or of the entire excavation area.

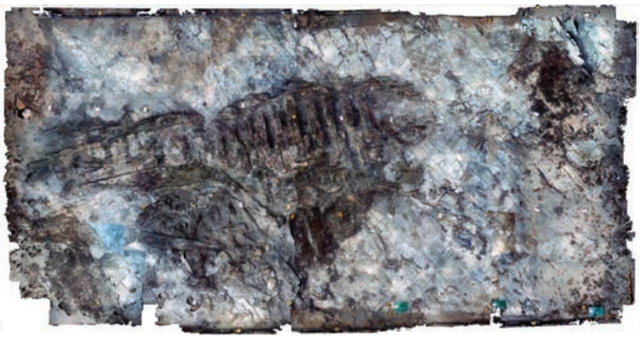
Sl. 10 Iskopavanje drvenih struktura ispod višenamjenskog dokumentacijskog mosta (foto: M. Pešić).
Fig. 10 Excavating the wooden structure beneath the multifunctional documentation bridge (photo by: M. Pešić).



Sl. 11 Lijevo - prikaz oblaka točaka u programu aSPECT3D (R. Scholz).
Fig. 11 To the left is a representation of the point cloud scatter in the aSPECT3D application (R. Scholz).



Sl. 12 Desno - ortogonalni SFM pogled na dio olupine broda (R. Scholz).
Fig. 12 To the right is an orthogonal SfM view of a section of the wreck (R. Scholz).



Sl. 13 Ortogonalni SFM pogled na cijelu olupinu broda (R. Scholz).
Fig. 13 An orthogonal SfM view of the entire wreck (R. Scholz).

Budući da su vrijednosti boja prethodno korigirane na svim slikama, nastaje prirodna tekstura (Sl. 12). Takav 3D model omogućuje visokoprecizan ortogonalni pogled (Sl. 13) koji predstavlja dobru podlogu za kasnije iscrtavanje strukture.

U drugom koraku se ta slika može georeferencirati u GIS ili CAD programu, a strukture iscrtati i interpretirati (Sl. 14). Pozadinski 3D model se tako može koristiti u daljnjoj obradi i rekonstrukciji, no taj razvoj još nije postignut te bi ga u daljnjim radovima trebalo produbiti.

Upotreba ovakvog višenamjenskog dokumentacijskog mosta pokazala se u ovom slučaju neprocjenjivo vrijednom jer je cjelokupan brodolom istražen već u prvoj kampanji sa samo osam ronioca i to u dvadesetak radnih dana. S obzirom na činjenicu da je prikupljeno preko tisuću pokretnih nalaza te da je jedinstven položaj (x,y,z) zabilježen za njih preko pet stotina, a

Given that SfM software generates an average of 100 million individual points per area with good quality photographic input, the recommendation is that the calculations for an object be done section-by-section and that the points be georeferenced post-reduction. This step can be followed by a merger of the point clouds to generate a mesh. Thus this quantity of data can be processed even with average processing (computing) power. High image quality and constant recording conditions indicate low point diffraction in the available density. The percentage of measuring points that deviate at least 1.9 centimetres from the computation object plane will usually have a low two-digit value, in the case of this wreck it never exceeded 0.2 per cent (Fig. 11).

All the colour values were already corrected on all images, which produced a natural texture (Fig. 12). The resulting 3D model allows for a high precision orthogonal view (Fig. 13) that constitutes a good basis for the subsequent conversion of the structure.

In the following step this image can be georeferenced in GIS or CAD software and the structures can be converted and interpreted (Fig. 14). The underlying 3D model can easily be used in further processing and reconstruction, but this process development has yet to be achieved and requires deeper analysis in further work.

This use of a multifunctional documentation bridge of this kind was shown to be of inestimable value in this case, with the entire wreck excavated by the close of the first campaign with only eight divers and in the ujedno je napravljena i vrlo precizna 3D dokumentacija balastne gomile i drvene konstrukcije broda, to je uistinu odličan rezultat. Ubrzavanje rada istraživača te poboljšanje preciznosti dokumentacije doveli su i do smanjivanja troška ovakvog projekta čime se cijeli eksperiment pokazao uspješnim. Stoga je nastavljeno s korištenjem ovog višenamjenskog dokumentacijskog mosta i na istraživanjima drvenih brodova u Wismaru, Njemačka.

Da se kod Verude nalazi brodolom sa sačuvanim drvenim elementima broda ustanovljeno je još u trenutku otkrića. Pretpostavljajući da će se ispod balastnog kamenja pronaći još drvenih konstruktivnih elemenata cijeli je projekt planiran u skladu s tom pretpostavkom. Brodska konstrukcija nije očuvana izvan polja balasta jer tamo nema pijeska koji bi ga pokrio, okolno područje čini vidljiva živa stijena i pokoji prirodni kamen. Pronađeni drveni elementi u pravilu su bili poprilično oštećeni djelovanjem brodskih crva, posebice stoga jer je sloj pijeska na njima bio vrlo tanak. No i dalje su zadržali određenu kompaktnost i čvrstoću. Veći dio drvenih elemenata ostao je *in situ*, pa se mogla napraviti analiza njihovog karaktera. Tom analizom ustanovljeno je da su se od broda djelomično sačuvala rebra, oplata i kobilica (Sl. 14).

Četvrtasta rebra masivnih dimenzija upućuju na zaključak kako je jedrenjak morao biti većih gabarita. Ukupno je dokumentirano 26 djelomično sačuvanih rebara. Debljina rebara varira od 13 do 17 cm, dok im je visina oko 13 cm. Na pojedinim mjestima rebra se udvostručuju, no zbog nepotpune sačuvanosti ne može se ustanoviti u kojoj mjeri. Pojedina rebra prelaze preko kobilice, dok se druga nastavljaju na njih i uzdižu se prema bočnim dijelovima broda.

Na nekim mjestima su u rebrima vidljive oble i četvrtaste rupe, kroz koje su prolazili željezni klinovi i čavli koji su spajali rebro s rebrom i rebra s oplatom. Rebra se pružaju u smjeru sjeverozapad - jugoistok, a njihova gustoća je najveća na središnjem dijelu i na istočnoj strani, dok na zapadnom dijelu nalazišta njihovo postojanje možemo utvrditi tek prema tragovima na oplati. Naime, na oplati se prepoznaju njihovi tragovi u obliku tankog otiska žućkasto-smeđe boje koji imaju širinu kao i rebra, a na tim mjestima su vidljive i četvrtaste rupe koje svjedoče o postojanju čavala koji su tijekom vremena većinom nestali djelovanjem korozije. Na ovim dijelovima je vidljiv i raspored čavala, te se može zaključiti da je oplata u svaku pojedinu gredu bila pričvršćena s dva čavla zabijena uz rub oplatne daske.

Oplata je načinjena od dasaka neravnomjernih dimenzija. Na sjevernom dijelu nalazišta puno je bolje

space of twenty working days. With over a thousand small finds recovered, unique positions (x, y, z) recorded for over five hundred of these finds, and very precise 3D documentation created of the ballast mound and of the ship's wooden structure, this was a truly excellent outcome. The fact that researchers were able to work at a higher pace and that the precision of the documentation was improved, led to project cost reductions, making the entire experiment a resounding success. As a result the multifunctional documentation bridge saw continued use during an excavation of wooden boats at Wismar in Germany.

That a wreck was present with preserved wooden ship elements at Veruda was established during the site's discovery. The expectation that further wooden structural elements would be found beneath the ballast stones informed the entire effort that was planned and grounded in this hypothesis. With no sand there to cover it, the ship's structure was not preserved outside the ballast mound area, and the surrounding area consists of visible bedrock and sporadic natural stones. The wooden elements that were found had, as a rule, seen significant shipworm damage, largely due to the very thin layer of sand covering them. They remain, however, relatively compact and firm. Most of the wooden structural elements were left *in situ*, allowing for an analysis of their characteristics. The examination found that the frames, planking and keel are partially preserved (Fig. 14).

The massive dimensions of the frames, rectangular in section, indicate a large sailing vessel. Twenty-six partially preserved frames were documented. The frames are sided (thickness) from 13 to 17 centimetres, and moulded (depth) to about 13 centimetres. The frames are doubled at places, but the incomplete level of preservation does not allow us to establish the extent of this doubling. Some of the frames cross over the keel [floor timbers], while others continue off them and rise towards the sides of the vessel [futtocks].

At places we see round and squared holes in the frames through which iron spikes and nails passed to join frame-to-frame and planking to the frames. The frames stretch northwest to southeast, and their density is greatest at the central area and the east side, while at the west end of the site we can only deduce their existence from the traces on the planking. The traces are identified on the planking in the form of a thin yellowish-brown residual impression about as wide as the frames. Also visible at these points are squared holes that testify to the presence of nails that have for the most part entirely corroded away. At these sections we also see the distribution of

Sl. 14 Radna skica elemenata drvene konstrukcije broda; žuto: oplata, smeđe: rebra, ružičasto: otisci rebara, sivo: kobilica, bijelo: neodredivi drveni dijelovi, crveno: željezni čavli i klinovi (foto: M. Pešić, R. Scholz).

Fig. 14 A sketch of the ship's wooden structural elements; yellow: planking, brown: frames, pink: residual impressions of frames, grey: keel, white: indeterminate wooden parts, red: iron nails and spikes (photo by: M. Pešić, R. Scholz).

sačuvana i tu se može raspoznati 6 redova, dok je s južne strane očuvana u 3 reda. Na nekoliko mjesta se vidi uzdužni spoj dasaka oplate koje se nastavljaju jedna na drugu čineći jedinstvenu cjelinu. Ustanovljeno je da se radi o vanjskoj brodskoj oplati, koja je željeznim klinovima bila povezana s rebrima. Debljina oplate iznosi 5 - 7 cm. Osim donje oplate, na južnom dijelu nalazišta pronađeni su i dislocirani drveni elementi, za koje se pretpostavlja da bi mogli biti dijelovi gornje oplate, odnosno palube. Daske oplate smještene su u smjeru sjeveroistok - jugozapad.

Pronađen je i drveni element za koji se pretpostavlja da se radi o ostatku kobilice broda. Debljina joj varira, a visina joj iznosi 10 cm. Uzrok neravnomjerne debljine oplate je uništenost uslijed propadanja drvene građe. Pruža se u smjeru sjeveroistok - jugozapad i dosta je oštećena tako da je na jugozapadnom dijelu djelomično raspuknuta u dva dijela.

Dokumentirani su svi nalazi željeznih klinova i čavala, koji su nažalost vrlo korodirani, ali će se njihove dimenzije otkriti rendgenskim pregledom. Brod je bio nakrcan balastom koji čini veće zaobljeno kamenje, različite vrste i očito potječe iz sedimenta neke rijeke. Iskopavanjem nalazišta pronađeni su i usitnjeni komadi građevinskog otpada, žbuke, opeka, crjepova, te također vrlo usitnjeni ulomci keramike, stakla i životinjskih

nails from which we can conclude that the planking was attached to each timber by two nails hammered near the edges of the planks.

The hull planking is comprised of planks of non-uniform dimensions. It is much better preserved in the north section of the site and we can identify six strakes here, with three strakes preserved on the south side. At several places we see the lengthwise joint of the hull planks, extending one from the other and forming a complete section. This is the ship's hull, attached to the frames with iron spikes. The hull thickness ranges from five to seven centimetres. Identified along with the lower planking, at the south end of the site, were dislocated wooden elements, presumably sections of the deck planking. The planks are oriented northeast to southwest.

A wooden structural element was found that we presume is the remnant of the ship's keel. Its thickness varies, and its depth is 10 centimetres. The variation in thickness is due to degradation caused by decomposition of the wood. The keel lies northeast to southwest and is significantly damaged and has partially split into two parts in the southwest end.

All finds of iron spikes and nails were documented. They are, unfortunately, highly corroded and their dimensions will be ascertained applying radiographic imaging. The kostiju. Ovaj otpadni materijal je dokaz da je brod nekada koristio i otpad kao balast.

Od svih elemenata konstrukcije uzeti su uzorci i u tijeku je analiza kojom će se odrediti vrste drveta. Iz jednog većeg komada pokušat će se napraviti i dendrokronološka analiza. Za sada je s uzorkom drva iz brodske konstrukcije napravljena AMS c14 analiza u laboratoriju u Poznanu u Poljskoj. Rezultat uzorka Poz-57874 je 320 ± 25 BP što kalibrirano iznosi calAD 1566 ± 51. To bi otprilike ukazivalo na doba izgradnje broda, jer je drvo posječeno oko te godine.

Brodolom ne sadrži dovoljan broj ključnih elemenata da bi se na prvi pogled mogao rekonstruirati njegov izgled, ali će se daljnjom analizom i usporedbama s drugim nalazima ovog doba pokušati saznati više o njegovom originalnom izgledu i dimenzijama. Za sada možemo reći kako se čini da je riječ o trgovačkom brodu, dužine preko 20 metara.

Pred početak istraživanja, kao i tijekom istraživanja, između balasta mjestimično su se pronašli pokretni arheološki nalazi. Uglavnom su to metalni komadi raznih oblika, ali očito namjerno rastaljeni, razbijeni ili spljošteni pa je vjerojatno riječ o otpadnom materijalu izrađenom od raznih talina bakra, mjedi, bronce, kositra itd. Većina ih je sasvim rastaljena u neprepoznatljive oblike (Sl. 15).

Sl. 15 Rastaljeni komadi kositra, bakra i drugih talina (foto: L. Bekić).
Fig. 15 Melted pieces of tin, copper and other alloys (photo by: L. Bekić).

Drugi su djelomično rastaljeni, ali neki su tek prikupljeni kao metalni otpad, poput namjerno spljoštenog kotla (Sl.16:1). Također se pronalaze i poluproizvodi, polovice brončanih okruglih ingota (Sl.16:11) te bakrenih traka (Sl.16:3,4).

Porijeklo metalnog otpada je različito. Od oštećenih metalnih predmeta brodskog tereta valja izdvojiti

boat was loaded with ballast consisting of large rounded stones of various kinds and evidently extracted from river sediment. Excavation of the site also yielded fragmented bits of construction rubble, plaster, bricks, roof tiles and highly fragmented potsherds, glass and animal bones. This refuse material indicates that the ship at times used refuse as ballast.

Samples were taken of all structural elements and an analysis is ongoing to determine the species of wood used. One large piece will be used to attempt a dendrochronological analysis. An AMS 14C analysis has been conducted on a sample of wood from the ship's structure at a laboratory in Poznan, Poland. The result of sample Poz-57874 is 320 ± 25 BP, which yields a calibrated result of calAD 1566 ± 51. This indicates the date of the felling of the timber and the approximate date of the construction of the boat.

There are an insufficient number of key elements at the wreck site to reconstruct its appearance from an initial examination, but further analysis and comparative analysis opposite other finds from this period may lead to greater insight into its original appearance and dimensions. For now we can say that this appears to have been a merchant ship with an overall length in excess of twenty metres.

Sporadic recoveries of archaeological finds were made ahead of and in the course of the excavation among the ballast. These are for the most part metal artefacts of various forms, but evidently deliberately melted, broken or flattened, such that this is likely scrap consisting of various alloys of copper, brass, bronze, tin and other metals. Most are melted beyond recognition (Fig. 15).

Other pieces are partially melted, while others still were simply collected as scrap metal, including a deliberately flattened cauldron (Fig.16:1). Also recovered were intermediate goods, halves of round bronze ingots (Fig. 16:11) and copper strips (Fig.16:3,4).

The origin of the scrap metal varies. Noteworthy among the damaged metal items from the ship's cargo is the damaged upper section of a luxurious cauldron (Fig. 16:1) bearing a geometric decoration and the Arabic inscription "La ilahe illallah, Muhammedun resulullah". The inscription is in a graphic style specific to the sixteenth/seventeenth century, and the artefact clearly comes from Asia Minor.[1] This section of the cauldron was deliberately flattened in order to take up less space. Also recovered was a handle with dragon's heads, likely

[1] We wish to thank Oğuz Aydemir, Chairman of the TINA Board of Directors, and Dr Önder Bayır, Director of the Ottoman Archives in Istanbul, for their reading of the old Arabic inscription.

oštećeni gornji dio luksuznog kotla (Sl. 16:1), koji je uz geometrijske ukrase imao arapski natpis "La ilahe illallah, Muhammedun resulullah". Natpis je pisan specifičnim grafičkim stilom 16. / 17. st. i očito potječe iz Male Azije.[1] Ovaj dio kotla je namjerno spljošten, kako bi zauzimao manje mjesta. Također je pronađena ručka sa zmajskim glavama, vjerojatno od posude za svetu vodu koja bi prema nekim analogijama mogla biti proizvod južnonjemačkih radionica. Nađeno je mnoštvo oštećenih i zasada nedostatno identificiranih metalnih predmeta (Sl. 16:2,5). Među svim tim komadima ipak se prepoznaju razne mjedene ručke, držači, ljudska figurica, kositrene zdjele (Sl.16:10), dijelovi kositrenih tanjura, bakrenih kotlova itd.

Vrlo korodirani željezni čavli i klinovi vjerojatno su pripadali samoj brodskoj konstrukciji. Pronađene su i brojne brončane četvrtaste podloške raznih veličina (Sl. 16:9), koje inače služe za spajanje dugih brodskih klinova, a za koje za sada ne možemo znati da li su pripadale konstrukciji ovog broda ili su također dio metalnog tereta. Dvije sačuvane kositrene zdjele, spremljene jedna u drugu, vjerojatno su ipak pripadale brodskoj opremi (Sl. 16:10).

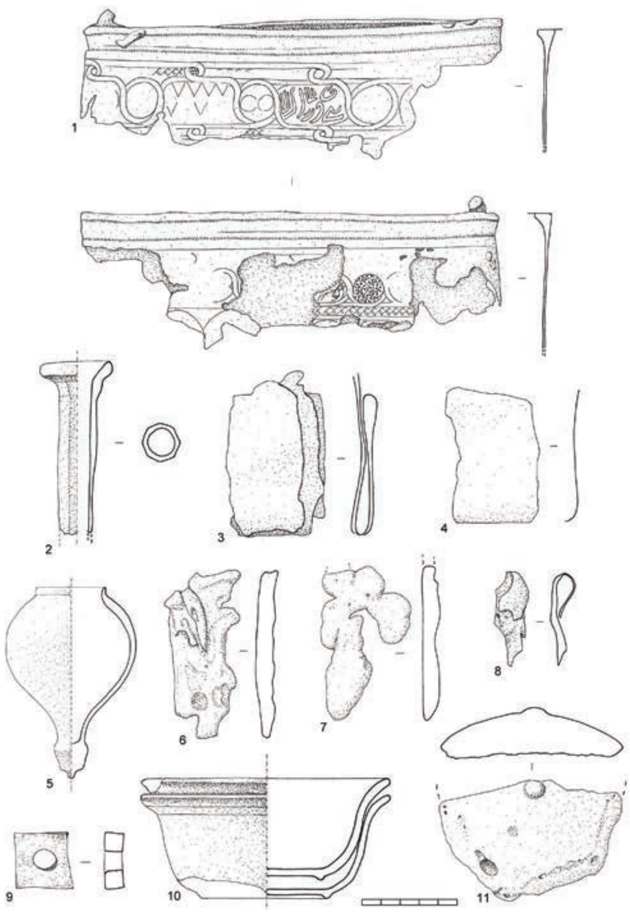
Uz to pronađena su i zrna koja pripadaju puškama arkebuzama ili mušketama, te male željezne topovske kugle. Puščane kugle pronađene su na ostacima broda i oko njega, dvije čak i oštećene udarom u tvrdu podlogu, pa je moguće da su to tragovi borbe za brod. Uglavnom su to okrugle olovne kugle kalibra od 14 do 16 mm te dvije željezne od 17 i više mm. Kalibar kugli od 16 mm pripadao bi lakoj mušketi zvanoj Caliver, koja je zapravo poboljšana arkebuza i u širu uporabu ušla je sredinom 16. st. Sveukupno je dosada izdvojeno 6 puščanih kugli s ovog brodoloma.

Topovske kugle pripadaju kalibru 55-58 mm, mada neke još neočišćene imaju promjer od 62 mm. Takve male kugle mogle su služiti u palubnim, tzv. okretnim topovima tipa smirilj (Esmeril). Da su kugle pripadale naoružanju potonulog broda potvrđuje i činjenica da je nađeno 5 kugli naslaganih jedne uz druge. Vjerojatno su bile spremljene u nekoj košari, koja ih je nakon brodoloma držala dovoljno dugo zajedno da ih korozija spoji u jedan konglomerat (Sl. 17). Osim tih pet, pronađeno je još nekoliko topovskih kugli samostalno ili u korozijskom konglomeratu s drugim predmetima.

[1] Na čitanju starinskog arapskog natpisa zahvaljujem kolegama Oguzu Aydemiru, direktoru TINA-a te Dr. Önderu Bayiru, direktoru Otomanskog arhiva u Istanbulu.

from a holy water vessel that some analogies indicate could be the product of workshops in southern Germany. An abundance of damaged and not yet unambiguously identified metal objects were discovered (Fig. 16:2,5). Among these items we do recognise various brass handles, knobs, human figurines, tin bowls (Fig.16:10), sections of tin plates, copper cauldrons, and other objects.

Highly corroded iron nails and spikes were likely parts of the ship's structure. Also found were numerous square bronze washers of various sizes (Fig. 16:9) used when connecting long ship spikes – we do not presently know, however, if they were part of the ship's structure or part of the metal cargo. Two preserved tin bowls, set one into the other, were likely part of the ship's equipment (Fig. 16:10).



Sl. 16 Izbor karakterističnih metalnih nalaza (crtež: L. Bekić).
Fig. 16 A selection of characteristic metal finds (drawing by: L. Bekić).

Also found were round balls for use in harquebuses or muskets, and small iron cannonballs. The musket balls were found at the remnants of the ship and around it, with two damaged by impact into a hard surface, from which we deduce a possible struggle for control of the

Sl. 17 Veliki željezni konglomerat u kojem se nalaze topovske kugle. (foto: L. Bekić).
Fig. 17 A large iron conglomerate containing cannonballs (photo by: L. Bekić).

Što se tiče keramičkih nalaza, najveći broj ulomaka je sasvim usitnjen i pronađen u kontekstu balasta otpadnog materijala. Stoga se za samo nekolicinu većih ulomaka keramike predmnijeva da je vlasništvo posade broda, za sve ostale porijeklo treba tražiti u nekoj od luka gdje su takav balast krcali. Ti keramički ulomci mogu se tipološki datirati u drugu polovinu 16. ili početak 17. st., a uglavnom pripadaju sjevernotalijanskim radionicama, što su uobičajeni nalazi na sjevernom Jadranu.

Stakleni nalazi su također vrlo usitnjeni i stoga također vrlo vjerojatno pripadaju balastu, no pronađena su i dva veća ulomka staklenog pehara koji je morao pripadati posadi. To su dijelovi pehara s reljefnim prikazom lavljih glava, za koji se može reći da je mletačkog porijekla i to iz 16. st. (Sl. 18).

Sl. 18 Dio pehara s reljefnim lavljim glavama (foto: M. Kaleb).
Fig. 18 Part of a goblet with a lion head relief (photo by: M. Kaleb).

ship. For the most part these are round lead balls with a calibre of from 14 to 16 millimetres and two iron balls of 17mm or greater calibre. A 16mm calibre ball would have been used in the Caliver musket, actually an improved harquebus that saw widespread use in the mid-sixteenth century. To date six musket balls have been recovered from the wreck.

The cannonballs are of 55 to 58mm calibre, with some not yet cleaned having a diameter of 62 millimetres. Small cannonballs of this type would have been used on deck-mounted swivel guns of the *esmeril* type. That the cannonballs were from the sunken ship's armament is confirmed by the fact that five balls were found stacked in a pile. They were likely stored in some form of basket that was preserved following the sinking of the ship long enough for corrosion to form a single conglomerate (Fig. 17). Besides these five cannonballs, several others were found as isolated artefacts or forming a corrosion conglomerate with other artefacts.

With regard to the ceramic finds, the majority of sherds are highly fragmented and found in the context of the refuse material ballast. Only a few larger sherds are presumed to have been the property of the ship's crew, while for the remainder the origin should be sought in any of the ports at which ballast of this kind was loaded. These potsherds can be dated by typology to the second half of the sixteenth or early seventeenth century. The provenances of most are the northern Italian workshops and these are common finds in the north Adriatic.

Glass finds are also highly fragmented and thus also very likely from the ballast, but two larger sections were found from a goblet that must have been from the crew's property. These are sections of a goblet with a lion's head in relief, likely a sixteenth century Venetian piece (Fig. 18).

Organic finds aside from the ship's wooden structure include a small section of unravelled coarse cordage. Also found was a large quantity of small animal bones, many of which are scorched and were presumably part of the refuse ballast.

Initial analysis places the date of the ship's cargo and its equipment in the second half of the sixteenth and early seventeenth century, while the analysis of the wood's age indicate that the ship was built a few decades earlier.

Large and small fragments of scorched and carbonised wood were found across the whole of the site, in all layers, which leads us to conclude that the ship may

Od nalaza organskog porijekla, osim same drvene konstrukcije broda pronađen je i manji dio rasukanog grubog brodskog konopa. Također je pronađeno i mnoštvo sitnih životinjskih kostiju, od kojih su brojne spaljene, te ih valja pripisati balastu otpadnog porijekla.

Početne analize datiraju teret broda kao i brodsku opremu u razdoblje druge polovine 16. i početka 17. st. dok analiza starosti drva ukazuje da je brod građen nekoliko desetljeća prije.

Na čitavom nalazištu u svim slojevima pronalaženi su veći i manji komadi nagorenog i pougljenjenog drva, što navodi na zaključak da je brod nastradao u požaru, za vrijeme dok je bio usidren. Brod je u trenutku potonuća najvjerojatnije prevozio metalne poluproizvode. Oni su mogli biti namijenjeni daljnjoj preradi, čemu u prilog ide činjenica da je većina metalnog brodskog tereta gotovo u potpunosti rastaljena ili na sebi nosi tragove taljenja.

Mali broj nalaza koji se može pripisati teretu ali i brodskom inventaru upućuje nas na mogućnost da je brod opljačkan ili da je taj materijal naknadno izvučen s brodoloma brzo nakon njegovog potonuća. Tako nedostaje potencijalni vrjedniji teret i brodska oprema poput sidara i topova.

Dosadašnjom analizom nalaza, prvenstveno ostacima brodskog tereta, inventara broda te keramičkih ulomaka iz balasta, zasada smatramo da je brod građen sredinom 16., a potonuo početkom 17. st. Opširnije analize moći će se provesti tek kada se obradi sva terenska dokumentacija i konzerviraju pokretni nalazi.

No, paralelno s arheološkim istraživanjima vode se i povijesna istraživanja pa je otkrivena mogućnost koja bi ovaj brodolom mogla povezati s jedinstvenim povijesnim događajem. Tako se rezultati dosadašnjih arheoloških istraživanja poklapaju s podatkom da su Uskoci 1597. g. kod Verude napali, opljačkali i zapalili mletački trgovački brod dok je bio na sidrištu (Novak 2004). Nakon kraja restauratorsko-konzervatorskih zahvata na pronađenim predmetima i svih predviđenih analiza, uključujući dubinsku analizu povijesnih izvora, ustanovit će se da li je uistinu riječ o tom brodu.

S obzirom na dostupnost ove lokacije za sve rekreativne ronioce, uključujući ronioce na dah, te činjenicu da je nalazište položeno uz turistički najposjećeniji otok kod grada Pule, bilo je vrlo bitno čim prije obaviti dokumentiranje strukture broda te prikupiti pokretne nalaze kako bi se spriječila devastacija. Tijekom istraživanja kvalitetno su dokumentirani ostaci drvene brodske konstrukcije te su prikupljeni brojni sitni nalazi

have been sunk by fire while at anchor. The ship was most likely transporting metal intermediate products when it sank. They may have been destined for further processing, supported by the fact that the majority of the ship's metal cargo was almost entirely melted or bore traces of melting.

The small number of finds that can be attributed to the ship's cargo and its inventory points to the possibility that the ship was likely either looted prior to sinking or that the material was salvaged not long after the shipwreck. Thus there are no traces of possibly more valuable cargo or ship's equipment like the anchors and cannon.

The analysis of the finds made so far, primarily the remnants of the ship's cargo, its inventory and the ceramic sherds from the ballast lead us to the tentative conclusion that the ship was built in the mid-sixteenth and that it sank in the early seventeenth century. A more comprehensive analysis will only be possible following the complete processing of all field documentation and the conservation of small finds.

Historical research ran parallel to the archaeological excavation and identified data that points to the possibility that this wreck may be associated with a specific historic event. The results of the excavations to date, namely, are consistent with the records of an Uskok force attacking, looting and burning a Venetian merchant vessel at anchor off Veruda in 1597 (Novak 2004). Completion of the restoration and conservation interventions on the recovered artefacts and all planned analyses, including deeper analysis of the historical sources, should resolve this proposed identity of the ship.

Given the easy accessibility of this location to all recreational divers, including breath-hold divers (freedivers), and the fact that the site lies next to the most frequently visited island tourism destination near the city of Pula, it was critical that the structure be documented as quickly as possible and that small finds be recovered to prevent devastation. The excavations saw quality documentation of the remnants of the ship's wooden structure and the collection of numerous small finds that will assist in shedding light on the identity of the vessel and the historical background. The remnants of the ship were carefully protected after the excavation. The ship's wooden structure was first covered with a layer of sand over which geotextile was placed in overlapping strips. A second layer of sand was placed over the geotextile and the ballast stones were placed on top of it, such that the entire protective layer was further secured and the wreck site remained visible. Divers visiting the site in koji će pomoći razotkrivanju ovog broda i povijesnog događaja. Ostatci broda su nakon istraživanja pomno zaštićeni. Prvo je drvena brodska konstrukcija zasipana pijeskom, zatim su preko nje položene preklapajuće trake geotekstila. Preko geotekstila ponovno je nasipavan pijesak, a balastno kamenje vraćeno je preko geotekstila, tako da je cijela ova zaštita dobila dodatnu čvrstoću, a mjesto brodoloma ostalo vidljivo. Ronioci koji će ubuduće posjetiti ovo mjesto, ugledat će gotovo istu situaciju kao i 2013. godine, kada je nalazište po prvi puta prepoznato. Ali s velikom razlikom u tome što su istraživanja razotkrila tajnu kamene gomile.

Prijevod / Lektura s njemačkog na hrvatski: Sandro Stojić, Melani Podgorelec
Prijevod s hrvatskog na engleski: Neven Ferenčić

the future will see almost the identical situation as was found in 2013 when the site was first identified – with the major difference, of course, that the excavation unveiled the secret concealed by the mound of stones.

Translation / copyediting (German to Croatian): Sandro Stojić, Melani Podgorelec
Translation (Croatian to English): Neven Ferenčić

LITERATURA / LITERATURE

BASS, G. F. 1967. *Archäologie unter Wasser*, 2. Auflage, Bergisch Gladbach.

BEKIĆ, L. 2013. Archaeological Survey of the Seabed in the Broader Rovinj and Pula Areas in 2013; Rekognosciranje šireg podmorja Rovinja i Pule 2013, *Submerged Heritage / Potopljena baština* 3, Zadar. 46– 50.

BEKIĆ, L. 2017. Il mercantile depredato dagli Uscocchi a Veruda, u: Auriemma, R. (ed.) *Nel mare dell'intimita. L'archeologia subacquea racconta l'Adriatico*. Roma 248.

BEKIĆ, L., SCHOLZ, R. 2017. Veruda Shipwreck Investigation Wraps Up / Završetak istraživanja brodoloma kod Verude, *Submerged Heritage / Potopljena baština* 7, Zadar. 24–27.

BEKIĆ, L., SURIĆ, R. 2016. Shipwreck Investigation off the Islet of Veruda / Istraživanje brodoloma u podmorju otočića Veruda. *Submerged Heritage / Potopljena baština* 6, Zadar. 9–16.

FISCHER, L. 2015. Structure from Motion in der Praxis, 3D-Visualisierung mittels Digitalfotos, Netzpublikation zur Grabungstechnik, Nr. 6, Jg. 2015, herausgegeben von der Kommission Grabungstechnik <http://www. landesarchaeologen.de [22. 10. 2018.]>

JANSA, V. 2013. *Probleme und Lösungsansätze beim Monitoring unterwasserarchäologischer Fundstellen am Beispiel des UNESCO - Weltkulturerbes Pfahlbauten*, Diplomarbeit Universität Wien.

NOVAK, G. 2004. *Jadransko more u sukobima i borbama kroz stoljeća* II. Split.

SCHOLZ, R., BEKIĆ, L., PEŠIĆ, M. 2016. Fotobasierte Dokumentationsmethoden in der limnischen und maritimen Archäologie, *Skyllis* 16/1. 9–19.