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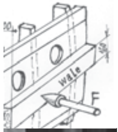
Deutsche Gesellschaft zur Förderung
der Unterwasserarchäologie e.V.

DEGUWA

# Inhalt



Titelmotiv

*Front view (head) of Ram 8.*

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

# Vorwort

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

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

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

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

Winfried Held

# The Significance of Detailed Analysis of 3D Cloud Points Which Include Data that the Human Eye Can Overlook. The Case of a Flat-bottomed Ship from the Ljubljanica River

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

***Abstract*** *– In 2012, a part of a Roman flat bottom cargo ship was researched in the Ljubljanica river near Sinja Gorica. The documentation was based on multi-image photogrammetry. After the initial publishing of the find in 2014, accurate comparative analysis of the 3D point cloud was performed again to find out if any pertinent information on the construction of the ship was overlooked during the fieldwork and the initial post-processing stage. Using different filtering techniques we discovered on the surface of the wooden planks indentations that indicate that the wooden planks were heavily overweighted in a regular fashion which led to the conclusion that wooden containers for bulk cargo were a permanent equipment on the ship from Sinja Gorica. From the discovered indentation marks in the point cloud, one can conclude that details such as these can easily be overlooked if the point clouds are only optically observed.*

***Inhalt*** *– Im Jahr 2012 wurde der Teil eines römischen Flachbodenschiffs im Fluss Ljubljanica bei Sinja Gorica erforscht. Die Dokumentation erfolgte durch Mehrfachbild-Fotogrammetrie. Nach der ursprünglichen Publikation 2014 wurde erneut eine exakte vergleichende Analyse der dreidimensionalen Punktwolke unternommen, um herauszufinden, ob Informationen zur Konstruktion des Schiffs während der Feldarbeit und der anfänglichen Auswertungsphase übersehen wurden. Durch verschiedene Filtertechniken entdeckten wir auf der Oberfläche der hölzernen Planken Eindrücke, die darauf zurückzuführen sind, dass die hölzernen Planken in regelmäßiger Form schwer belastet worden waren. Dies führte zu der Schlussfolgerung, dass hölzerne Behälter für Schüttgut zur dauerhaften Ausstattung des Schiffs von Sinja Gorica gehörten. Aus den in der Punktwolke entdeckten Eindrücken lässt sich schließen, dass Details wie diese leicht übersehen werden können, wenn die Punktwolken nur optisch betrachtet werden.*

In the Ljubljanica river near Sinja Gorica (Vrhnika, Slovenia) an extraordinary Roman flat bottom cargo ship from the first half of the 1st cent. AD is preserved *in situ*. The ship was partially excavated and documented in 2008 and 2012[1]. In contrast to most other flat-bottomed Roman ships from around Europe, the ship from Sinja Gorica stands out by a particularly attractive solution to the strengthening of the ship's construction. It is a previously entirely unknown solution for the structure of the ship in the form of slender bottom timbers hidden in a cross-section groove in bottom planks and continuing through the chine-girder of the ship. Another feature of the ship is that it was almost entirely constructed of beech wood, which was rarely used at that time[2]. The documentation of the excavated part of the ship was carried out using multi-image 3D photogrammetry for which more than 1700 underwater photographs were taken.

Because of one particular detail on the bottom of the ship, which we could not understand and explain, we performed an additional detailed analysis of the 3D point cloud. Using a series of image filters, we discovered between two bottom timbers 180 cm (6 Roman *pedes*) apart on the surface of the wood very shallow, no more than 2–4 mm deep depressions at a distance of ~28 cm from the timber. The depression in the wood then continues for another ~125 cm to the next timber.

From the recognised indentations in the point cloud, it could be concluded that the wooden surface of the bottom planks was heavily overweighted. Therefore, it can be

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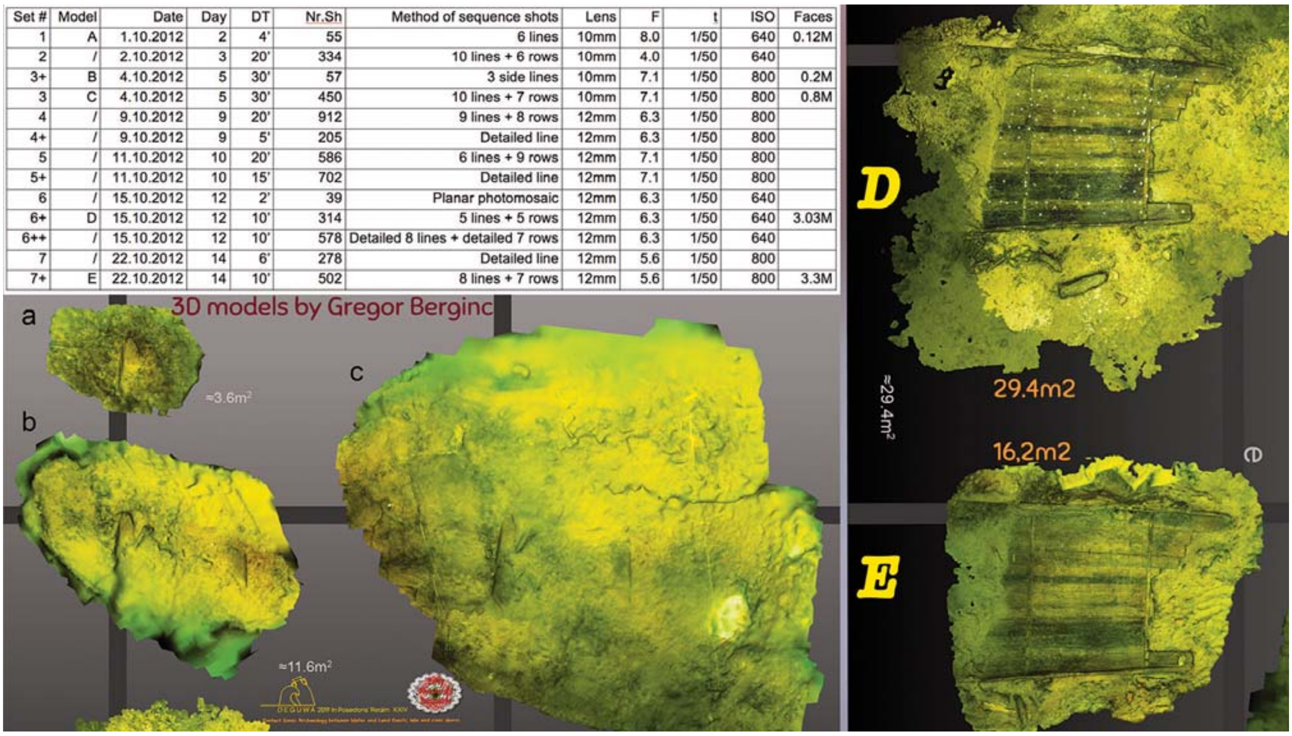
[*] This work was supported by the Slovenian Research Agency, research program Computer Vision (P2-0241), and the Ministry of Culture of the Republic of Slovenia.



| Set # | Model | Date | Day | DT | Nr.Sh | Method of sequence shots | Lens | F | t | ISO | Faces |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A | 1.10.2012 | 2 | 4' | 55 | 6 lines | 10mm | 8.0 | 1/50 | 640 | 0.12M |
| 2 | / | 2.10.2012 | 3 | 20' | 334 | 10 lines + 6 rows | 10mm | 4.0 | 1/50 | 640 | |
| 3+ | B | 4.10.2012 | 5 | 30' | 57 | 3 side lines | 10mm | 7.1 | 1/50 | 800 | 0.2M |
| 3 | C | 4.10.2012 | 5 | 30' | 450 | 10 lines + 7 rows | 10mm | 7.1 | 1/50 | 800 | 0.8M |
| 4 | / | 9.10.2012 | 9 | 20' | 912 | 9 lines + 8 rows | 12mm | 6.3 | 1/50 | 800 | |
| 4+ | / | 9.10.2012 | 9 | 5' | 205 | Detailed line | 12mm | 6.3 | 1/50 | 800 | |
| 5 | / | 11.10.2012 | 10 | 20' | 586 | 6 lines + 9 rows | 12mm | 7.1 | 1/50 | 800 | |
| 5+ | / | 11.10.2012 | 10 | 15' | 702 | Detailed line | 12mm | 7.1 | 1/50 | 800 | |
| 6 | / | 15.10.2012 | 12 | 2' | 39 | Planar photomosaic | 12mm | 6.3 | 1/50 | 640 | |
| 6+ | D | 15.10.2012 | 12 | 10' | 314 | 5 lines + 5 rows | 12mm | 6.3 | 1/50 | 640 | 3.03M |
| 6++ | / | 15.10.2012 | 12 | 10' | 578 | Detailed 8 lines + detailed 7 rows | 12mm | 6.3 | 1/50 | 640 | |
| 7 | / | 22.10.2012 | 14 | 6' | 278 | Detailed line | 12mm | 5.6 | 1/50 | 800 | |
| 7+ | E | 22.10.2012 | 14 | 10' | 502 | 8 lines + 7 rows | 12mm | 5.6 | 1/50 | 800 | 3.3M |

*Fig. 1: Several phases of capturing site excavation and 3D modelling by multi-image photogrammetry. a., b. and c. were merely testing part. However, D and E we use in further analysis (©Rok Kovačič ; 3D model: ©Gregor Berginc)*

concluded that a wooden container for the bulk cargo was a permanent equipment of the ship from Sinja Gorica. The purpose of the shipping container, therefore, can be compared with similar solutions, such as Arles Rhone 3[3].

## 1. Subsequent detailed analysis of the 3D point cloud of the flat bottom ship from Sinja Gorica

To obtain a 3D model of the flat-bottomed ship from Sinja Gorica under water, we used in 2012 a multi-image photogrammetric recording method[4] for the first time in Slovenia[5]. The reconstruction from a set of photographs is entirely automatic and consists of several stages: identification of discriminative points in individual images, search of stable correspondence among these points in neighbouring images. Automatic calibration of a set of images is following as well to make the construction of a dense cloud of 3D points that best describes the information available in input images. Finally, a triangulated textured network was created. Such 3D models have proven to be extremely accurate, representative and available for further analysis. For hand-operated documentation of the approximatively 8 m² large surface of the barge, at least 25 hours of diving time would be required, while it took only a total of three diving hours to capture the images for documenting five different steps during the excavation of the ship (fig. 1). Sets of images were used to make three different 3D models. A comparison of two of them was made in the Computer Vision Laboratory at the Faculty for Computer and Information Science, University of Ljubljana which confirmed the accuracy of the documentation. The accuracy can also be confirmed indirectly, during the preparation of the graphics documentation from the obtained data. All measurements were also taken with a Terrestrial Laser Scanner (TLS) to have a different double dataset to confirm the process of documentation.

The potential of data acquired in this way is not limited to visualisation of 3D data. In contrast to 2D photographs, where the viewpoint is fixed, and the already interpreted 2D plans, a 3D model enables a simulated observation for study purposes from any virtual viewpoint and of any recorded surface and object. The morphological properties of 3D point clouds, which are a complete recording of the present state, open up countless options for further analysis of the 3D model. That is especially important because the investigation of an archaeological site, in particular an underwater site, is usually physically limited to the duration of the fieldwork and is later, if preserved *in situ*, challenging to access, often also destroyed. 3D models allow us to systematically and in a planned way, study, segment and classify selected surfaces. Using methods from computer vision,

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[1] Erič – Gaspari 2009; Erič et al. 2014.

[2] Čufar – Merela – Erič 2014.

[3] Djaoui – Greck – Marlier 2011.

[4] e.g. Canciani et al. 2003; Lowe 2004; Balletti et al. 2015; Agrafiotis – Drakonakis – Skarlatos 2018.

[5] Erič et al. 2014.

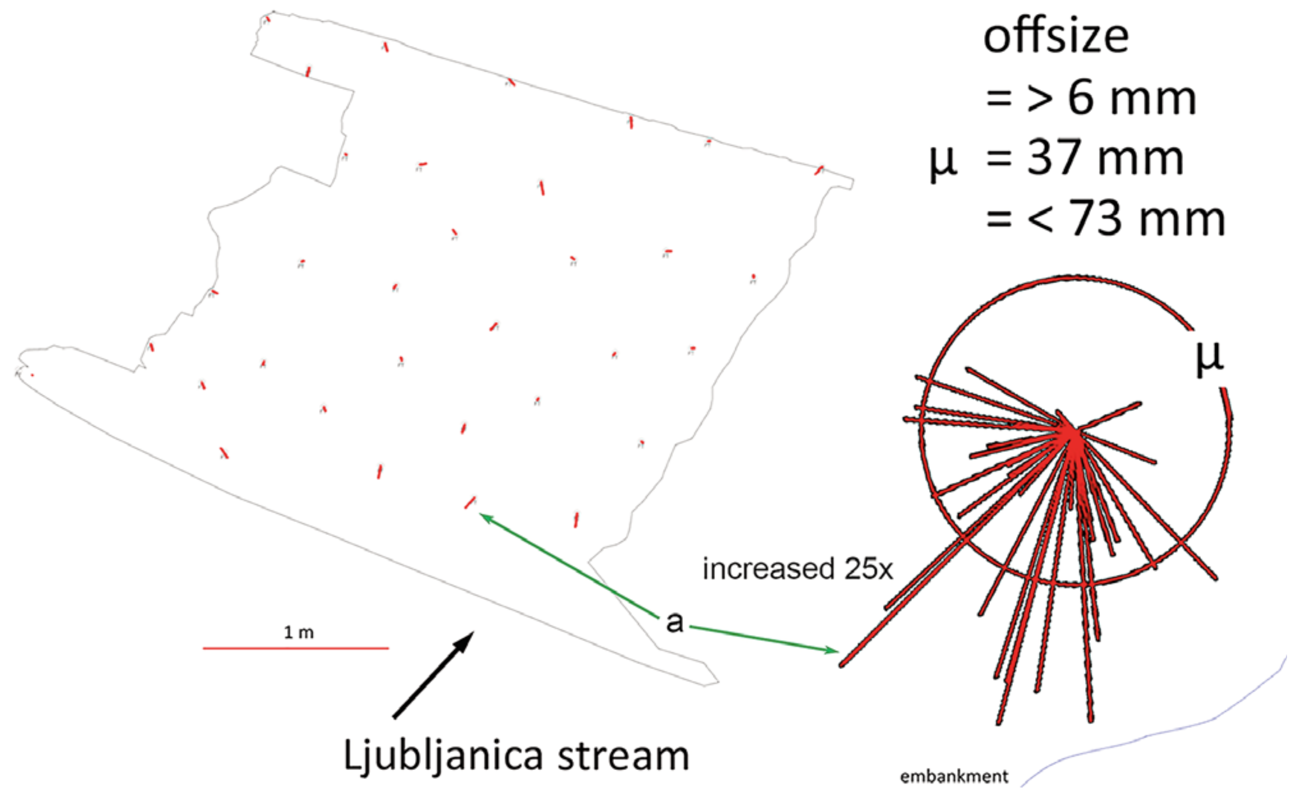

*Fig. 2: Volumetric compare analysis between TLS measurements and 3D model E from fig. 1 (©Miran Erič)*

one can analyse 3D surfaces by searching for specific features that could otherwise be easily overlooked *in situ*. Noteworthy is also the archival sustainability of digital archaeological documentation, which forms the basis for later study, interpretation and promotion.

## Methodology

Beside observing attractive 3D models, the benefit of 3D data are abundant. To interpret and understand 3D point clouds and maybe find some missing information, we try to use several methods. Due to the morphological properties of point clouds which represent the actual state of the artefacts, further analysis of 3D models is possible, which would hardly be possible to perform on actual archaeological sites.

Since we made serious underwater documentation based on multi-image photogrammetry for the first time, we decided to compare the 3D model with measurements taken simultaneously by a Terrestrial Laser Scanner. Next, we made a comparison of two different point clouds of the ship produced by multi-image photogrammetry taken seven days apart. 3D models were appointed into the same coordinate system to simplify volumetric comparative analysis.

Lastly, we decided to use many different filters and shaders which are available in 3D viewers, for example in MeshLab[6] or other applications using filters and shading to analyse 3D models or in many different GIS applications for analysis of terrestrial digital models captured by satellite sensors or ASL measures.

## Results

Differences detected during comparative analysis between the 3D model and the corresponding geodetic measurements indicate the human weakness of using TLS measurements for documenting shallow underwater sites. TLS measurements were influenced by the direction of the water flow in the river since divers performing the measurement were influenced by it. The comparison indicates a non-supervisible error among the datasets between 6 mm up to 73 mm with 37 mm average of deviation in comparison to the 3D point cloud. It was an excellent illustration that human error is unpredictable and, above all, uncontrolled (fig. 2)[7].

We performed a volumetric comparison between two 3D models recorded during underwater excavation, which were taken seven days apart (fig. 1, D and E; fig. 3). Red colour represents areas where the two models differ the most. Such visualisations and comparisons of 3D data should be performed regularly already during the excavation and later for the monitoring of artefacts and entire archaeological sites. On fig. 3a, we see a negligible deviation indicated by the orange colour – a part of chine-girder exposed to the water stream – possibly related to the weakness because of excavation processes.

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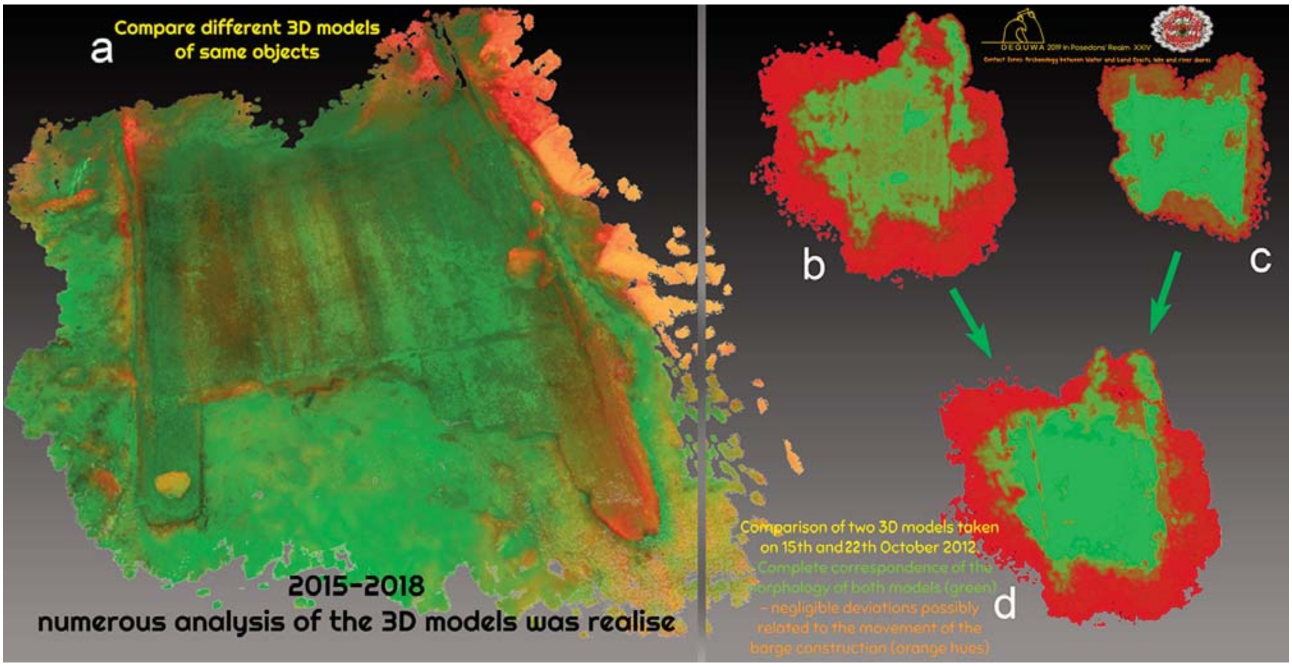
[6] Cignoni et al. 2008.

[7] Erič et al. 2013; 2016a.

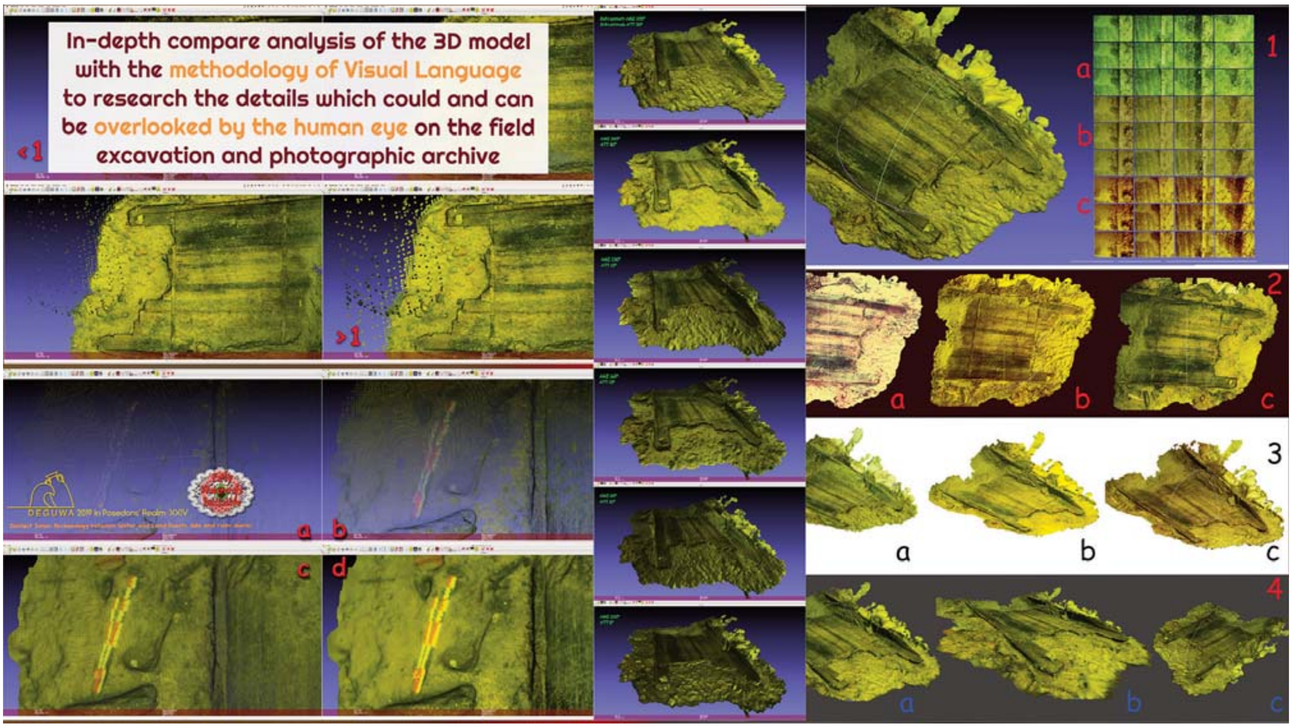


Compare different 3D models of same objects

2015-2018
numerous analysis of the 3D models was realise

Comparison of two 3D models taken on 15th and 22th October 2012
Complete correspondence of the morphology of both models (green) – negligible deviations possibly related to the movement of the barge construction (orange hues)

*Fig. 3: Changes in a comparison between 3D models D and E (©Mitja Pugelj)*



In-depth compare analysis of the 3D model with the methodology of Visual Language to research the details which could and can be overlooked by the human eye on the field excavation and photographic archive

*Fig. 4: In-depth compare analysis of the texturised 3D model by the methodology of Visual Language (©Miran Erič)*

Finally, we decided to analyze the point cloud model using several filters and shaders which are mainly used in remote sensing for recognising anthropogenic changes in a cultural landscape which are in its basic form shallow reliefs. All processes of analysis by visual language methods are based on understanding form, colour processing, shape, etc. which art theory operates with. We made an in-depth visual comparison analysis of 3D models and tried to understand the 3D model as a profound relief by finding the best sharpening, filtering and shading tools from different 3D modelling applications. Several methods and techniques were used to recognise the best filtering and shading to analyse 3D models. However, just some of them were useful in the 3D model without image texture (fig. 4. 5).

## Interpretation

We obtained the most desirable results with Dimple and Cook-Torrance shaders[8], where we surprisingly discovered some crucial details which we overlooked during the underwater excavation and examination (fig. 5). By switching between several different azimuths (50°, 70°, 140°, 310°) and altitudes (10°, 15°, 25°, 35°) for shading and

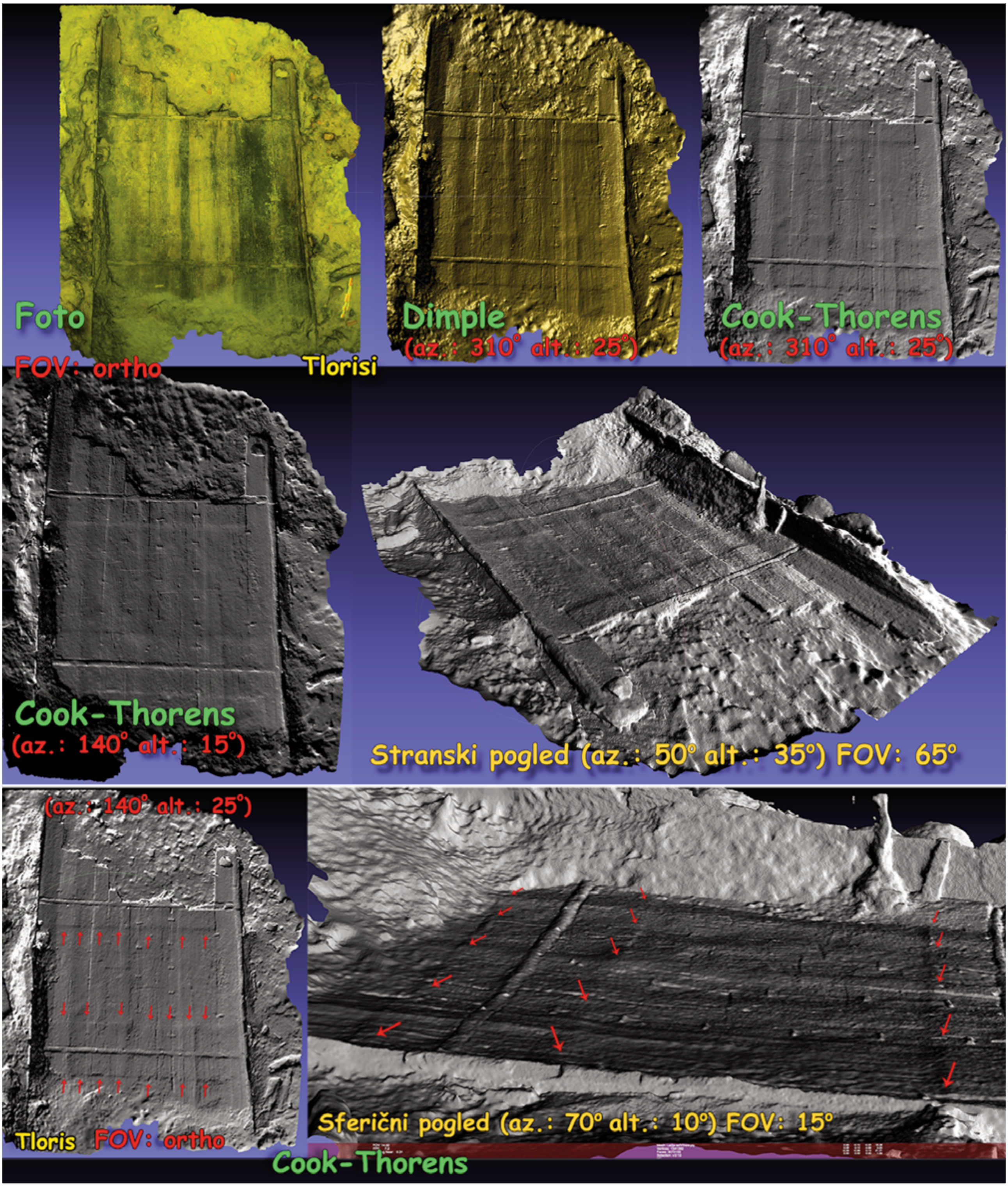


*Fig. 5: In-depth compare analysis of the 3D model by filtering, lightening, shaping, and shading using the methodology of Visual Language with different filters and shaders (Top: ground plan; Middle: side view; Bottom: spheric view) (©Miran Erič)*

different angles for field of view (FoV: Ortho, 15°, 65°) we visually detected a tiny change in the depth of the bottom between two bottom timbers, which was on order between 2 to 4 mm. After a detailed examination of the edge of depression and its range on the bottom of the ship, one can conclude undoubtedly that we are faced with a rectangle-like depression of dimensions around 209 cm × 119 cm ± 5% which loosely equals the dimension of seven by four Roman *pedes*. The distance between the recognized edge of the depression **e1** and **e2** is around 60 cm, and this is loosely a distance of two Roman *pedes* (fig. 6). We can with high confidence conclude that this depression could unquestionably not be recognised by eye during the underwater excavation. Even if the wood would be transferred from the *in situ* position underwater to the process of conservation, this tiny detail could hardly be recog-

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[8] Cignoni et al. 2008.

*Fig. 6: The significance of a detailed analysis shows the data that the human eye can overlook (©Miran Erič)*

*Fig. 7: The bottom planks got pressured on this recognised rectangle deformation and exposed, that a kind of wooden boxes was used to transport material (3D modelling ©ArtRebel9; ©Miran Erič)*

nised. The process of deterioration and deconstruction of wooden surface starts immediately after lifting soaked wooden artefacts out of the water, and such surface details would completely disappear.

After this analysis of the 3D point cloud, we can assume that one part of ship equipment was a wooden container for bulk material which caused the beechwood[9] of the bottom planks to get the newly identified rectangular impressions. During the Roman time, such

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[9] More about properties of beechwood in Čufar et al. 2017.

wooden boxes were often used to transport material between Nauportus and Emona (**fig. 7**).

## 2. Challenge

New computer technologies and methods offer archaeology[10] a historic opportunity to increase efficiency in the treatment and protection of cultural heritage artefacts. Rapidly developing areas such as computer vision[11], artificial intelligence[12], neural networks[13], block sequencing technology, 3D modelling, AR / MR / VR / XR[14], gamification[15], new clustering algorithms, algorithms for image processing, segmentation[16] and comparison of 3D point clouds (ICP; SIFT; SfM), automatic generation of 3D point clouds and 3D surface models from image data[17] etc., have great potential for improving the professional work of archeology and preservation of cultural heritage[18]. The speed of change and the development of new technologies also in the field of underwater documentation is remarkable[19]. Furthermore, they can move directly from laboratories to excavations of archaeological remains. 3D point clouds are a *de facto* standard for 3D documentation and modelling in the last several years[20].

Constant improvements in the performance of internet and computer technologies combined with rapid advancements in computer vision algorithms now make it possible to efficiently and flexibly reconstruct the 3D geometry of objects. Objects of different sizes can be modelled using image sequences from commercial digital cameras[21] that can be processed by web services and freely available software packages, forming low-cost systems for numerous applications (restoration, historical care of monuments, visualisation, analysis of the artefacts etc.). The potential of this technology enables automatic generation of 3D point clouds or surface models (as 3D polygons) with photo-realistic texture from image data. These so-called low-cost systems[22] represent an efficient alternative to expensive terrestrial laser scanning systems for the as-built documentation of 3D objects in cultural heritage and archaeology.

Nevertheless, in archaeology, we are still talking about the digital divide. It is becoming increasingly clear that classical archaeological methods are no longer suitable and efficient. The treatment of the remains of cultural heritage is still facing many open and unresolved issues[23]. Traditional evidence (drawings, photographs, subjective descriptions and comparisons with similar archaeological remains), which were created at the discovery of the remains, raise several open and unanswered questions. The knowledge of the archaeological artefacts remains incomplete and often lost forever by the methods of preservation or further archaeological treatment. Subsequent and repeated research is no longer possible. Very often, artefacts remain only dead archaeological material, which otherwise promotes speculation and guesswork, but it does not provide explicit scientific explanations.

Entirely disposed of analytical and research treatments, remains of underwater cultural heritage[24] and cultural heritage is stored *in situ*[25]. Traditional archaeological, museum or conservation methods and techniques do not allow for a more comprehensive understanding of the significance of certain archaeological remains, nor give the possibility of further analytical and scientific research and comparison. With new technologies such as photogrammetry, TLS, LiDAR, MSS, ALSM, 3D modelling, 3D scanning, 3D documentation, storage of triangular data networks into cloud points, virtualisation, visualisation, algorithms for processing and comparison, technology enriched and virtual reality, artificial intelligence, neural networks, etc., this practice varies considerably. The remains are no longer dead and disappeared objects. It becomes a living organism with sufficient information that we can research, compare, analyse and evaluate[26]. At the same time, the scope of this information enables the production of 3D replicas and virtual presentations. The results become accessible to all. With AR / VR / MR / XR technology, for example, 3D models (triangulation cloud points) enable optimal understanding of the artefacts, their location in time and space, operative use, etc., within the shortest possible time.

Unexploited and unused immeasurably deep data beyond the beauty of the dance of 3D models and it is visual fascination allow us to develop new tools for analysing point clouds[27]. The profusion of visual data follows the pictorial turn paradigm[28] of 3D models analysis with several methodolo-

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[10] Reilly – Rahtz 2003.

[11] Verhoeven 2011; Drap 2012.

[12] Puyol-Gruart 1999; Chanda 2019.

[13] Slabanja et al. 2018.

[14] Unger – Kvetina 2017.

[15] Breuer – Bente 2010; Silcock et al. 2018; Dubbels 2019.

[16] Stopinšek 2012; 2016; Stopinšek et al. 2013.

[17] Software packages and/or web services use: open-source software: Bundler/PMVS2 and VisualSFM, web services: Autodesk 123D Catch beta, and low-cost software: Agisoft PhotoScan.

[18] Antlej et al. 2011; Neumüller et al. 2014.

[19] Remondino et al. 2012; Seinturier et al. 2013; Erič et al. 2016b.

[20] Lobb et al. 2010.

[21] Canciani et al. 2003; Yamafune – Torres – Castro 2016.

[22] Canciani et al. 2003; Remondino et al. 2012; Erič et al. 2016b.

[23] Ioannides et al. 2010; Scopigno et al. 2017.

[24] Diamanti – Georgopoulos – Vlachaki 2013; De Reu et al. 2014; Schmidt-Reimann – Reuter 2015.

[25] Erič – Poglajen 2014.

[26] Manders 2011; Gregory – Manders 2015.

[27] Mahiddine et al. 2013; McCarthy 2014; McCarthy – Benjamin 2014; Menna – Agrafiotis – Georgopoulos 2018.

[28] Mitchell 1994; Erič – Solina 2016.

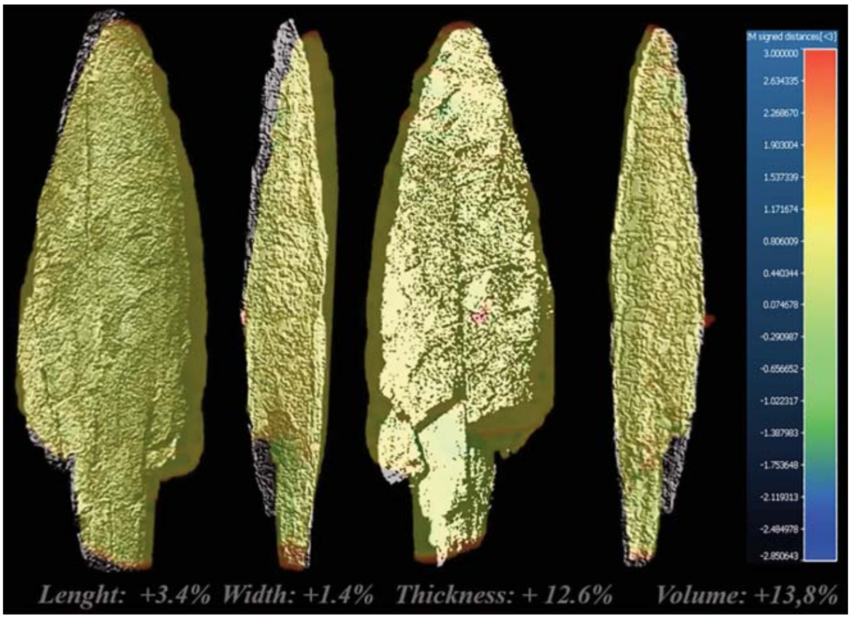

*Fig. 8: Volumetric 3D compare analysis of a palaeolithic wooden point (see Erič et al. 2018) (3D modelling ©Intri, Ljubljana; ©i3mainz; ©Enej Guček Puhar)*

gies as a visual language, remote sensing, computer vision, neural networks and big data analysis.

## Visual Language Analysis

Visual language as a system of communication using visual elements was established by Johannes Itten[29] and Rudolf Arnheim[30] with significant emphasis to the perception, imaging in mind, meaning and expression, innate structure in the brain, visual thinking and education. Visual thought processes are diffused, interconnected and are cognitive at a sensory level. This process forms images in the mind's eye, manipulating and evaluating ideas before, during and after externalising them, and constitutes a cognitive system comparable with, but different from, the verbal/written language system. Human beings have an innate capacity for cognitive modelling, and its expression through sketching, drawing, construction, acting out, and so on, is fundamental to human thought[31].

Visual language analysis of 3D models is a way to analyse many visual elements, principles and rules, to think about tiny changes of texture and surface of the 3D model by colour, shape, contrast, light and shadow, gestalt principles, symmetry, and many others (**figs. 4. 5. 8**). A visual language analysis requires us to find out in the point cloud some information that was overlooked during the fieldwork or throughout the post-processing of data.

## Volumetric models in Computer Vision

Psychologists who study human visual perception agree that at some point, the apparent structure of the physical world should be reflected in the perceptions that are formed in our mind. Irving Biederman[32], a perceptual psychologist, proposed a theory, recognition-by-components, that a modest set of volumetric components called geons can support most recognition tasks by humans. This idea to construct more complex structures from a small set of basic elements is very powerful and is the foundation principle in many other scientific fields. Research in computer vision focused, therefore, from the beginning on the search of possible volumetric models that could be recovered from images by a computer. Superquadrics were identified as suitable part-level models[33], and we have developed an iterative optimisation method of their re-

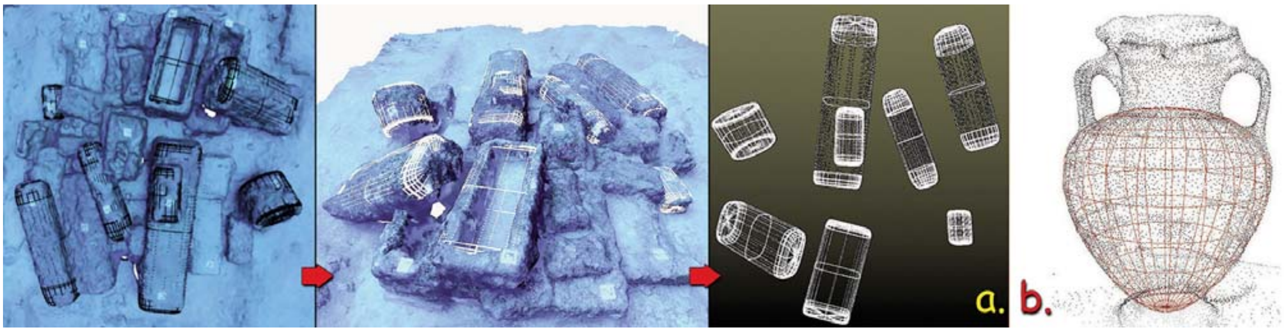

*Fig. 9: Use of superquadrics in case of underwater culture heritage. Left a.: sarcophagi and stone blocks of the Roman Age shipwreck near Sutivan on island Brač modelled by superquadrics (©Žiga Stopinšek; Jaklič et al. 2015). Right b.: 3D model of amphora modelled by superquadrics (©Žiga Stopinšek; Stopinšek – Solina 2017)*

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[29] Itten 1970; 1974.

[30] Arnheim 1970.

[31] Wikipedia s. v. Visual language <https://en.wikipedia.org/wiki/Visual_language>.

[32] Biederman 1987.

[33] Pentland 1986.

covery from range images[34]. We are now developing a convolutional neural network (CNN) solution to this problem to achieve nearly real-time performance[35]. Such volumetric modelling provides compact and perceptually relevant information about the 3D structure of a given scene, which others will be able to build upon and use them, for example, for an interpretation of an underwater archaeological site.

Reducing unessential bits, superquadrics help us to clarify information and enable a higher level of abstraction. The expressive power of superquadrics can be additionally enlarged by applying global parametric deformations such as bending and tapering or local deformations as an additional layer of details[36].

Superquadric modelling is used for modelling of a variety of natural and human-made objects. Recently, we used superquadrics for 3D documentation of archaeological sites and artefacts to model stone blocks on a Roman shipwreck[37] (fig. 9a) and amphorae[38] (fig. 9b) from dense 3D point clouds. Such models can simplify the computation of the volume of the ship's cargo, and hence its tonnage and size.

## 3. Discussion

Analysing the 3D model of remains of the Roman ship from the Ljubljanica River pointed out that the point cloud contains information that cannot be detected by classical research methods and techniques or only with the human eye. However, they can be observed, detected, researched and evaluated using tools of computer vision[39].

The use of 3D technology and the point cloud analysis in the interpretation of the remains of the early Roman wooden boat from the beginning of the 1st century AD confirmed greater accuracy (volumetric, graphic, textural, visual, statistical etc.) of underwater documentation, faster and more efficient data capture, shorter diving time and consequently increased safety at work, the possibility of further analytical processing and data research, both directly in the field and in the laboratory, and lower costs of underwater fieldwork. However, we can expect the possibility of creating new interactive databases and collections of 3D models, the possibility of 3D modelling and replication, the possibility to obtain information from 3D documentation, which can not be established by classical techniques and methods of archaeological treatment of cultural heritage items, reconstruction of artefacts by combining several 3D models of artefact parts and finally the possibility of visualisation and virtualisation of discovered objects.

After processing the data, it was possible to establish that the documentation is exceptionally accurate, and the 3D model of the ship, in contrast to the analogue documentation that contains only 2D layouts, plotting, cross-sections and, if necessary, details (e.g. individual construction elements), allows almost identical study as during the field excavation. This very edge cannot compete with an extraordinarily high-quality archival photography, which is still necessary today as an excellent tool, or manually guided stereo-photogrammetric programs (CAD and GIS), which somehow tried to cover the lack of quality and accuracy in post-processing procedures.

The potential of 3D data in archaeological documentation is beyond the attractive appearance of virtual 3D models[40]. In contrast to a 2D photograph that permanently defines the direction and view as well as the interpreted 2D floor layout, a 3D model allows a simulated virtual view into documented surfaces or objects that can be studied almost precisely like *in situ*. More importantly, because of the morphological characteristics of 3D clouds of spatial points, which provide a perfect image of the current state, the possibilities of further analyses of the 3D model are entirely open, which could not be performed even in real terms on the original surfaces of archaeological sites. Systematically and carefully, it is possible to study, segment or classify selected areas on a 3D model. With automated search and analysis of surfaces, it is possible to find on the model elements that would otherwise be overlooked due to limited time in the natural environment. The archival sustainability of digital archaeological documentary material is necessary as a basis for studying, promoting, interpreting and sustainable use. Separate activities are essential for the gradual replacement of traditional documenting with digital documentation. In this context, the implementation of the recommendations of international projects, such as ARIADNE and PARTHENOS, is significant, providing data from cloud points of the 3D model. The Computer Vision and Visual Language analysis of the cloud points from the 3D models must become the standard of permanent treatment and evaluation of cultural heritage objects excavated by archaeological methodology[41].

What is the message of the 3D point cloud analysis of the Roman cargo ship from the river Ljubljanica? New information was found that could not be obtained with traditional archaeological methods. The validity of new technologies was confirmed both for field excavations and for further laboratory treatment. Data and

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[34] Solina – Bajcsy 1990.

[35] Oblak et al. 2019.

[36] Jaklič – Leonardis – Solina 2013.

[37] Jaklič et al. 2015.

[38] Stopinšek – Solina 2017.

[39] Guček Puhar et al. 2018.

[40] Molloy – Milić 2018.

[41] Gilissen – Hollander 2017.

information from 3D point clouds are open for new interpretations, although artefacts are protected *in situ* or *ex situ* or have been damaged or even permanently destroyed after the initial examination.

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