Virtual reconstruction and restoration of an uncommon bronze vessel from the Mălăieşti Roman fort

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Abstract:
This paper details the preparation stages and processes for the digital documentation and virtual reconstruction and restoration hypotheses of a heavily damaged archaeological artefact. The presented workflow starts with the immediate actions after the artefact unearthing, going through physical restoration, 3D digitization, virtual restoration (including virtual anastylosis) and a virtual reconstruction hypothesis proposal for the initial shape and looks of the object as when it was created. The artefact subjected to this process is an uncommon bronze vessel found on the premises of the Roman fort from Mălăiești, Prahova County, Romania. The scientific data and archaeological research have already identified with accuracy its dating, chemical composition, and the most probable functionality. All this information was disseminated in a recent study. The authors also discuss the good practice models applied in both virtual and physical restoration and how the two fields intertwine. The digital results are also exhibited in a simple but effective narrative style in the online medium, accessible at https://cercetari-arheologice.ro/materials/ca29.1/malaiestiVessel/, designed for both public and expert scientific groups.

Rezumat:
În această lucrare sunt detaliate etapele pregătitoare și procesele din spatele unei documentări digitale, a reconstrucției virtuale și a ipotezelor de restaurare a unui artefact arheologic puternic afectat. Modul de lucru prezentat începe cu activitățile imediate de după dezgroparea artefactului, trecând prin restaurarea fizică, digitizarea 3D, restauarea virtuală (incluzând anastiloza virtuală) și o propunere de reconstrucție virtuală pentru aspectul și forma inițială a obiectului, așa cum ar fi fost creat. Artefactul supus acestui proces este un vas de bronz neobișuit, descoperit în perimetrul castrului roman de la Mălăiești, județul Prahova, România. Datele științifice și cercetările arheologice au putut identifica cu precizie datarea, compoziția chimică și cea mai probabilă utilizare a sa. Toate aceste informații sunt diseminate într-un alt studiu recent publicat. Autorii discută modele de practică utilizate atât în restaurarea virtuală cât și în ce a fizică și cum cele două domenii pot întrepătrunde. Rezultatele în format digital sunt expue într-un stil narativ simplu dar eficient în mediu online, accesibil la adresa https://cercetari-arheologice.ro/materials/ca29.1/malaiestiVessel/, fiind proiectat atât pentru publicul general cât și pentru grupurile de experți.

Keywords: Virtual archaeology, virtual reconstruction, virtual restoration, 3D digitization, Roman military vessel

Cuvinte cheie: Arheologie virtuală, reconstrucție virtuală, restaurare virtuală, digitizare 3D, vas militar roman

Introduction

The last few years have seen a flood of digital content from the field of virtual heritage emerging in the online medium. Partly due to the increase in speed and quality of telecommunication technologies but also due to the accelerated advances in hardware miniaturization and large data processing. This process is not recent but merely highly accelerated and democratized so that using very few resources any museum, art gallery or other cultural institution can easily digitize and exhibit in virtual mediums their tangible collections. If *2D digitization* was easily achievable for paintings, manuscripts or photographs and is already more advanced in terms of collection digitalization in online repositories for years, in the realm of publishing 3D digitization or reconstructions things are slightly different due to the technological limitations until not far back. But today's available technology allows for similar approaches in building 3D online repositories[1] that meet all the criteria for virtual exhibitions: high

[1] Smithsonian 3D digizitization – prehistoric artefacts.

quality models, metadata, paradata and most importantly a secured local storage and access for the 3D models. Unfortunately, there is a limited number of such existing digitalized collections as most of the institutions usually choose third party publishers like SketchFab, with limited scientific and repository features, to exhibit and even store their digital content.

3D digital content in archaeology is usually referred to as "virtual" and is part of the scientific discipline called virtual archaeology. It is not an independent discipline as it is directly dependent on archaeology. The term was first coined in 1990 by Paul Reilly who used it for the combination of virtual reality (computer-based simulations) and archaeology[2] to try to solve problems like the unrepeatability aspect of an excavation and achieve new ways to document, interpret and annotate archaeological finds and processes. For years, virtual archaeology and virtual heritage were skeptically viewed as merely expensive "fringe" approaches with limited use for archaeology or cultural heritage, usually for visualization. Today things look quite different. The scientific community embraced the virtual archaeology practices, further developed, and refined them, broadening their applications along with the growing accessibility to new means of 3D recording and processing.

The reality of the increased use of digital and computer-based content in cultural heritage highlighted the risk of a multitude of unchecked problems that come with such power: data duplication, poor quality recordings, loss of digital data or obsolescence of data formats that leads also to loss of data, just to name a few. These problems were recognized in the 2003 UNESCO Charter on the Preservation of Digital Heritage[3] and a set of principles were issued in the London Charter in 2009[4] for the computer-based visualization of cultural heritage. In 2017 the theoretical framework set by the London Charter was used as a basis for a new set of principles and practical applications in the Principles of Seville in 2017[5]. This document provides comprehensive definitions for terms like *virtual archaeology*, *virtual restoration*, *virtual reconstruction* or *virtual anastylosis* but also guidelines, based on principles stemmed from the Venice Charter in 1964[6], for any cultural heritage project involving new technologies for research, documentation, conservation or dissemination.

Looking at the definitions of these terms, especially for the *virtual reconstruction*, *virtual restoration* and *virtual recreation*, one might think they are only slightly different and could still be easily confused. Actually, the difference is not so subtle. By *virtual restoration* an object or a building is brought back to a former state of existence by using only existing materials, thus the inclusion of *virtual anastylosis*. With *virtual reconstruction* the subject is brought to a former state of existence by using existing materials and creating new elements, with 3D modeling. This aspect must be fully documented and rigorously presented in accord with the authenticity and scientific transparency principles of the Principles of Seville. Usually, the lack of applying of these principles in the virtual reconstruction process leads to a so-called "black box" where the result has no tracing steps for repeatability or even worse, where the original source is no longer distinguishable from the added, and hypothetical, elements. Finally, virtual recreation refers to the complete immersion of the subject in a virtual archaeological context.

In this paper a few areas are discussed, such as: the processes of physical restoration, as the preservation of the materiality of the object, virtual restoration, as the preservation of the information about the object, and virtual reconstruction, as the valorization and dissemination, of a heavily damaged bronze vessel with an uncommon shape and decoration. The virtual restoration stage is based on a detailed 3D digitization step for the accurate documentation of the object and includes a virtual anastylosis hypothesis from its few fragments. The virtual reconstruction stage will consist in two variants: a full reconstruction proposal of the object as it was built and a restoration integration proposal that mixes the 3D digitized model and a virtual prosthetic for the missing areas, with a clear distinction between the original source and the added "material". The final output is a stand-alone online presentation of the object, designed for expert audience with specific scientific tools for interaction but also for the general public that will present all the resulted models in a contextualized virtual environment. The presentation makes use of accessible and open-source technologies for web programming and computer graphics which will be detailed later, and can be integrated in any website within other similar collections.

2 Reilly 1990, 133-139.

3 UNESCO 2003 - Charter on the Preservation of Digital Heritage

4 The London Charter - For the Computer-Based Visualisation of Cultural Heritage 2009

5 ICOMOS General Assembly in New Delhi 2017 - The Principles of Seville - International Principles of Virtual Archaeology

6 ICOMOS 1965 - International Charter for the Conservation and Restoration of Monuments and Sites (The Venice Charter 1964).

Item presentation and previous research

The artefact that is the subject of this paper was discovered during the archaeological research campaigns (2011-2019) carried out at Mălăiești Roman fort. This fort is part of a small group of fortifications built by the Roman army during their conquest campaigns in Dacia at the beginning of the 2nd century A.D, this one specifically being used for a short period of time between 101 A.D.-118 A.D.[7], making the dating of the vessel more accurate.

The object was found buried in the cellar of an officer's apartment, in a corner. It has a globular body, with a rounded shoulder, a wide neck, and a slightly inverted rim. It was provided with a flat base (now detached), made from a different metal sheet. The body preserves a dotted decoration (made by embossing), organized in two registers (one towards the base, the other under the rim – observed only after the 3D scanning), and divided by an undecorated strip on the shoulder. From the point of view of the production process, the vessel was initially cast as a rough cylinder, which was subsequently hammered, to obtain the final shape. Originally, the vessel was very probably provided with a handle, attached to the body with a help of a metal bar (made of iron or copper-based alloy) which was fixed under the rim with the help of the two loops (only one preserved). The existence of a lid held in place by the two loops cannot be excluded.

An important aspect observed and studied is the fact that the inside of the vessel, together with the base, were tinned. The tin coating indicates the fact that the vessel was used in contact with foodstuff, wine or water and excludes its functionality as a cooking vessel, in contact with direct fire or extreme heat[8]. The shape of the vessel is quite uncommon, if one takes into consideration the repertoire of the Roman bronze vessels produced during the 1st century AD (chronology indicated by the context of the discovery).

Figure 1. The Mălăiești bronze vessel, photo after the preliminary cleaning

7 Țentea 2018, 133-137; Țentea, Matei-Popescu 2015; Țentea și Călina 2019, 173; Țentea, Popa and Cîmpeanu 2018, 227–240.

8 Mustață 2017.

The vessel can be considered a variant of the buckets known in the archaeological literature as Östland buckets, possibly the Tingvoll or Westerwanna type. It was produced for a long period of time, from the 1st century BC until the 2nd century AD, in workshops which first functioned in Italy and later moved to the provinces[9]. Only one clear analogy has been identified so far: a bronze vessel preserved in the collections of the Rijksmuseum van Oudheden, Leiden (The Netherlands), which was dredged up from the river Meuse in 1938 and, unfortunately, preserves no information regarding the context of the discovery[10]. The only indication for the production area of the Mălăiești and Leiden vessels is represented by the decoration. It was identified on only two other bronze vessels: an Östland bucket with a slightly different shape, discovered again during dredging works, "downstream from the Roman Rhine – Waal fork", The Netherlands[11] and an ovoid bucket discovered in the river Saône, France[12]. Based on this information it can be speculated that the type was produced in a provincial workshop which functioned in the provinces (in Gallia Belgica or Germania Inferior), during the 1st century AD, most probably during its second half[10].

Methods and processes

Physical restoration

After its discovery, the object was cleaned, restored and treated in the Metal Restoration Laboratory within the National Museum of Romanian History. Before any procedures were started out, a preliminary imaging investigation was carried out in collaboration with INOE 2000 using X-Ray technology on the lump of earth that contained the body of the vessel, to assess the bulk size and structure of the object as well as the existence of any fragile fragments or objects inside the volume of the contents. No other objects were found inside, only that a part of the vessel wall was bashed inwards, and physico-chemical analysis could not find any traces of organic material[13].

Having all these questions cleared out, the first step of the physical restoration could start: the primary mechanical cleaning. In this stage the main purpose was to remove the poorly adherent coatings and soil stains, and in part the soluble corrosive products. Usually, the mechanical cleaning is done with steam-water blasting or manual brushing with either dry brushes or soaking immersions in distilled water with non-ionic detergents. In this case dry brushing was enough to remove all the important soil depositions, especially on the exterior surface. The interior still had a thin soil coating.

Chronologically, after this stage the object was subjected to a series of physicochemical investigations summarized in L. Angheluță et al 2022. The second stage in the physical restoration process was the detailed proper mechanical cleaning of adherent soil marks and crust protrusions from corrosion products. In this case steel chisels (or tungsten carbide) profiled as needed, were used for manual scraping.

Figure 2 Left: the vessel before preliminary cleaning; Right – during the proper cleaning

9 About this type see: A. Koster 1997, 61-68.
10 Mustață and Țentea 2022.
11 Koster 1997, 62-63, no. 78.
12 Baratte 1984, 39-40, no. 72, Pl. XXVIII/72. XLIV/72.
13 Angheluță et al. 2022, 185-198.

Once these cleaning steps were finished, the object was ready for a detailed 3D digitization stage, as detailed further.

The final steps of the preservation measures consist in the chemical stabilization treatment and the consolidation of the corrosion products, after which the object also gains a protective coating on the surface which slightly changes its appearance but also its interaction with light.

3D Digitization

This process is an important step in the early stages of the artefact life as it can serve as an instance of its early conservation state and could also be used to help against illicit trafficking practices or improper cultural goods management (damage during transport, storage, etc.). It also has an important value for both scientific and public dissemination deliverables. It must be stated that this type of documentation cannot replace the historical value of any artefact, monument, or other real element it represents. It does not save nor preserve the object any other way than as digital information that can easily serve for further studies[14]. The importance of the digital information a correct 3D digitization carries, has been emphasized for years and has become a critical aspect in the global and European policies regarding the way the museums operate (with a highlight on the digitalization aspect), especially after the terrible events in Brazil[15] and France[16].

Laser/structured light scanning and photogrammetry are largely the accepted methods of 3D digitization that pose no risk to the conservation state of the digitized objects[17].

In this case, the aim of 3D digitization was on one hand to document the object's surface before the final physical restoration stage by scanning the main body and its biggest fragments for both geometrical and chromatic properties, and on the other hand to use the digitized 3D model further in the virtual reconstruction processes and finally to have it published in an online virtual medium for general public and scientific expertise access.

After assessing the goals of this 3D digitization and the resources available it was decided that the best method to use, in this case, was photogrammetry. The available laser scanning equipment (NextEngine HD) although provides an accurate 3D scanning of the surface, its color rendition has a quite poor quality. Photogrammetry is a passive image-based processing method used for the determination of the shape and metric parameters of a surface from one or more photographs of that surface[18]. Due to its versatility, photogrammetry is used in many fields of industry and research, and in Cultural Heritage and Archaeology it can successfully be used for subjects ranging in size from small coins to entire architectural complexes or landscapes using the same equipment. In this specific case, a special attention was given to the reflective characteristic of the exterior surface of the vessel. Shiny, reflective, translucid, and transparent materials usually pose great difficulties in extracting the 3D geometrical reconstructions with both active scanning (laser or structured light) and photogrammetry methods. Adapting some of these surfaces can be successfully recorded with photogrammetry[19].

Data acquisition was done using an automated rotating table synchronized with the photo camera through wireless infrared technology. The rotating parameters (speed and number of steps) were setup through a mobile app that controlled the whole syncing process. Lighting was ensured with LED lights in a special photography tent with a white background. The accuracy of the colors and color temperature was corrected using color and white balance witness cards. The images were recorded using a Sony A7RIII mirrorless camera with 42 megapixels (7952x5304 pixels), in RAW format, and a Canon L 24-70 mm f/4 lens with a Sigma adapter for Sony mount, at the focal length of 35 mm. The lens were covered with a circular polarizing filter for strong reflection reduction. The camera was fixed on a tripod at 0.5 m working distance (between the sensor and the focus point) with f/22, exposure of 1/50s and ISO 4000. These parameters were calculated to have a balance between the smallest working distance (resulting in best details on the sensor) and the range of the depth field (0.263 m) so that both the exterior and the visible interior surface on the opposite side of the vessel would be in good focus (maximum width: 0.19 m). A total of 395 images were recorded with 48 images per rotating cycle (8 cycles) and another few images for specific angles and details.

The difficulties of this object were posed by the bashed in wall fragments that made impossible the access to some of their interior sides.

[14] Tasić et al. 2017.
[15] Greshko 2018.
[16] Blakemore 2019.
[17] Stampouloglou et al. 2019, 1073–1080.
[18] Luhmann et al 2014.
[19] Angheluță and Rădvan 2020, 1–12.

With the image sets recorded in RAW format, additional adjustments could be performed. Using the color checker image shot in the *in-situ* conditions, a camera profile was generated and applied to the whole image set. Other edits were the white balance and shadow/highlights slight adjustments. The images were exported in JPEG format at full resolution for the 3D processing part.

The photogrammetric 3D processing was performed with Agisoft Photoscan v1.8 PRO. The workflow is straight forward: image alignment, scale adjustment and object repositioning, mesh generation using depth maps and finally textures generation for diffuse, normal and occlusion maps. Before texture generation, the scene is cleaned

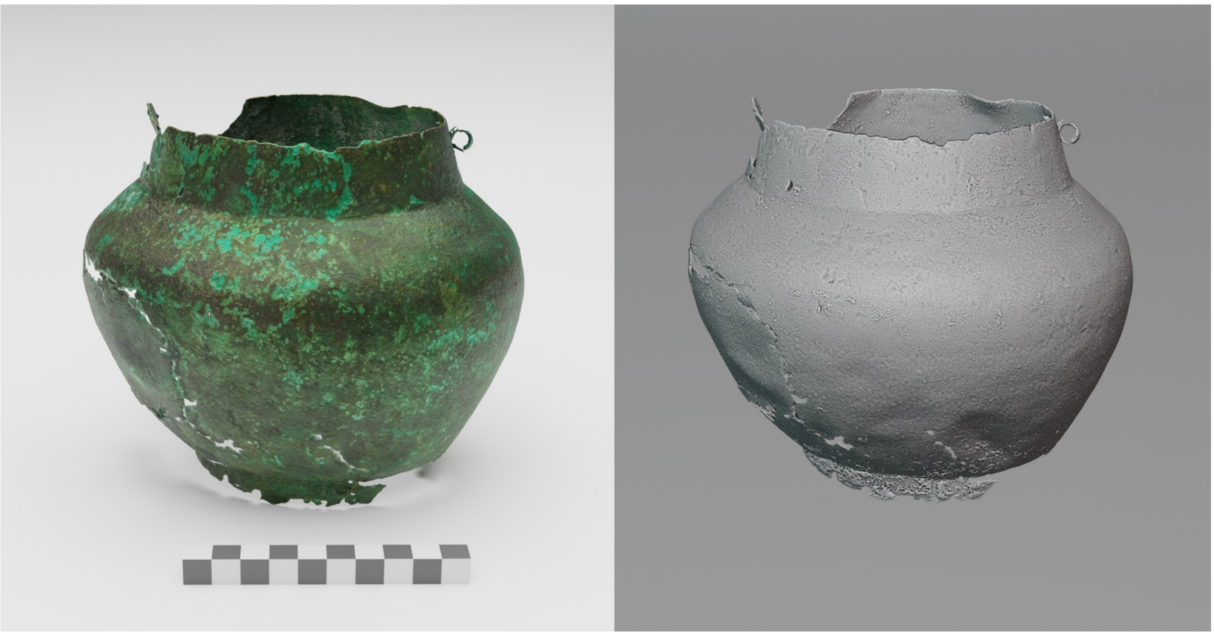

Figure 3 3D digitization results: Left – textured render; Right – Matcap surface render

for any residuals or elements that are not part of the subject.

The next step was preparing the mesh for further uses. After it was generated, the mesh was constituted in millions of polygons (45.5 million) which are not best suited for any kind of visualizing or processing application, especially for online use. Therefore, a simplification process was required. In this case, the mesh was reduced to 500.000 polygons with the Decimation tool in Agisoft Photoscan software, followed by the generation of textures (diffuse map, normal map and occlusion map) based on the high poly mesh.

Two meshes were exported: the decimated one and the original raw result, both in OBJ format. The simplified model was first used for profile extraction (Figure 4) and other precise measurements like volume, areas, decoration spots diameters or wall thicknesses along the profile, while the raw result (also much bigger in terms of disk storage) was used for retopology.

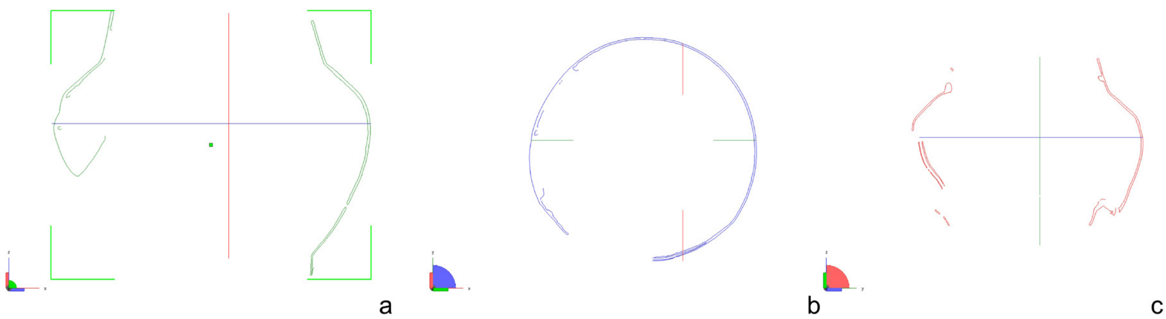

Figure 4 Extracted profiles of the 3D digitized bronze vessel: a- Y axis (green); b- Z axis (blue); c- X axis (red)

Virtual restoration and virtual anastylosis

The first step in the *virtual restoration* stage was to prepare the source digital model for editing. After the generation of the 3D digitized model, the polygon structure of the mesh is not organized and almost impossible to edit with accuracy. This is one of the reasons behind one of the most important steps in 3D asset preparation in videogame, VFX and animation industry: *retopology*. Retopology is a process of recreating an existing 3D digital surface with a more optimal geometry, usually a clean quad-based mesh. In our workflow we used one of the free software solutions available, Instant Meshes[20].

The source material used was the raw mesh, exported in the previous step. The retopology was set to simplify the mesh to 500.000 uniform quad polygons (polygons with four edges). This structure was much easier to manually edit in the following steps. A retopologized mesh is a new object, which keeps many of the original's details, but it is not the original scan result. It is an important aspect to keep in mind. The new retopologized model is further used for alterations, deformations and other edits in the virtual restoration and virtual reconstructions stages. At this stage the new model has no texture attached to it, because all the information regarding the surface has been modified. There are many ways to re-texture the retopologized 3D model, and our approach was to bake the texture from the old model into the new one using a 3D modeling software.

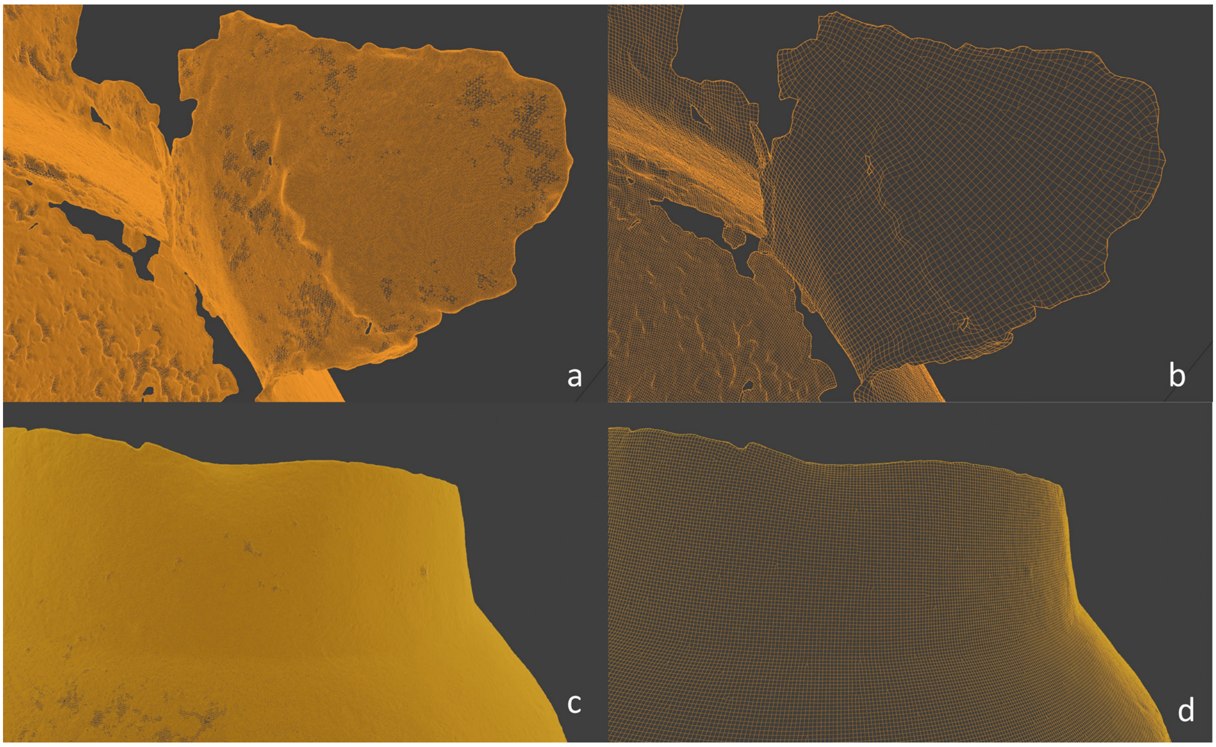

Figure 5 Retopology result: a and c -raw 3d scan result at 45.5 million polygons; b and d – simplified and retopologized mesh at 0.5 million polygons

The first goal in this *virtual restoration* process was to bend the bashed-in walls and align them to a hypothetical original position in the effort to virtually restore the vessel at its original shape, using the existing pieces. This whole process was realized in Blender 2.93 LTS. Using the extracted profiles of the vessel, an ideal, complete, shape was modeled in 3D and used as virtual reference for repositioning of the bended elements.

In Figure 6 are depicted several experimental results regarding a virtual restoration proposal method using hard surface modeling as a tool for "fixing" bended areas by bringing them to their original position. With green color are marked successful tests. With red color is marked a rather complicated area where the vessel wall was heavily contorted, and its surface was twisted into itself. The process here, in the given time frame, was not very successful and also, incomplete. The twisted area could not be fully corrected and the areas that were corrected showed too many errors (as seen in Figure 6 red mark). In the end the method proved very useful for simple deformations but time consuming and required great skills for the twisted and complicated areas.

20 Jakob 2015, 1-15.

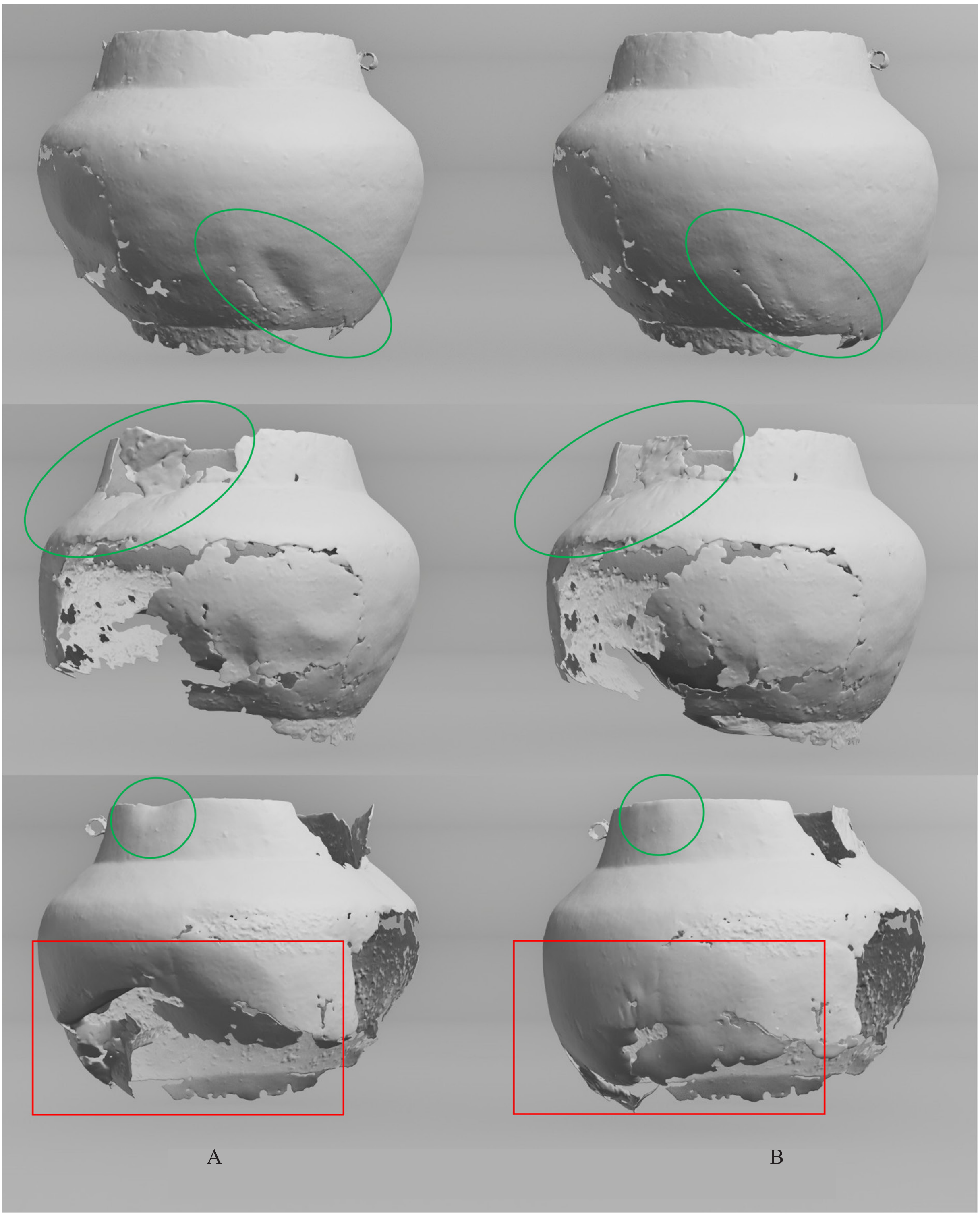

Figure 6 Before (A) and after (B) virtual restoration using hard surface modeling the original digitized model

For *virtual anastylosis* the result of the previous step could not be used, as it was incomplete. The virtual approach is extremely useful as it does not require the manipulation of the physical objects. The digitized fragments were virtually positioned, using the same software program, considering the clues for their original position. These clues usually come from closely investigating any possible connection points, process much eased by inspecting the 3D digitized model, and studying the shape, curvature of the surface and the decoration (if any). The latter clues help to approximate the register the fragments are most likely to have been part of, in lack of any information regarding their connection areas to the main body. Heavy corrosion usually deforms these connection points making this process really complicated.

In this case, the most important fragment was a 9x11cm piece coming from the base of the vessel. After its physical cleaning one side showed clear tin coating, indicating the fact that it was the interior side of the base. Other fragments were too small to be considered for anastylosis in this stage but could be integrated in future works.

For *virtual anastylosis*, usually, you need the digitized fragments you want to put together. One way to obtain them is to scan the fragments and use the results. But there are situations, such like this case, where the fragments can pose problems due to their size. The thickness of the base was similar with the walls of the vessel, under 2 mm. Such size is not a problem for macro-photogrammetry[21], but combined with the large area – like a sheet of paper - of the fragment made the 3D digitization of it a small problem because the two sides of the object could not be connected during processing. Instead, a workaround method was used. Benefitting of the fact that this fragment was perfectly flat, scaled images for both sides were used as textures with transparency to model two basic 3D panels for each side, representing the base fragment.

Figure 7. Left: virtual anastylosis of the vessel main body and the base fragment; right – hypothetic original shape as a translucid virtual prosthetic

Once the fragments are in their original or the suggested positions, the virtually restored model can be used as it is or it can be improved by filling the missing areas with a virtual prosthetic volume represented in distinguishable color and optical properties. We opted for a white translucid aspect. More detailed research would be required for the materials and the design of a 3D printed prosthetic that would be compatible with the physical object in real world or even completely replicate the materials and looks of the original[22].

Virtual reconstruction

This multidisciplinary field is usually met with skepticism and criticism because often it delivers incomplete or unusable results by scientific standards, because with great power comes great responsibility. The great power of virtual reconstructions is the ability to visually represent realistic reconstructions or interpretations of movable and immovable heritage elements, elements that no longer exist or are in an advanced state of ruin or barely recognizable. The polemic around this practice is usually seeded in some of its bad examples of implementation, many of them quite similar with bad practices in real life physical restorations. By bad practices we understand virtual restoration processes that do not follow the basic principles of conservation and restoration[23] usually resulting in so called „*black boxes*" where the original or source material cannot be distinguished from the added material or in the case of virtual reconstructions, where there is no distinction between known or hypothetical

[21] Angheluță 2019, 101-107.
[22] Shengyu 2022, 1–14.
[23] Petzet 2004, 7-29.

builds. Also, the lack of scientific transparency regarding the documentation used for reaching the concluded hypothesis contributed to this issue. In this regard, Clark[24] and others suggested the use of terms like „models" or „visualizations" rather than „reconstructions", as these results are merely interpretations, not the „truth". With the hybridization of digital media in Cultural Heritage, many fields like video gaming, cinematography, computer programming and virtual reality are intersecting, each bringing its own language and rules, resulting in new and useful means for dissemination and experience, but also contributing and inflating this issue of scientific transparency and authenticity.

Therefore, all virtual heritage/archaeology projects require a very well-structured workflow and usually involves experts coming from different fields. In this case-study, the virtual reconstruction project followed a bottom-up strategy: 3D digitization, research and documentation, data processing and finally the 3D reconstruction hypothesis. The 3D digitization result was used as a starting point in determining/categorizing the shape and decoration typologies of the vessel. An extensive research effort was carried out in finding analogies for this type of vessel. The results were scarce as only a few largely similar objects have been reported in some catalogues, rendering the typology of the vessel as uncommon.

Comparing the shapes of the similar objects found it was concluded that the shape of the vessel was globular and that the missing parts did not contain elements with a different shape profile from the rest of the body that is not damaged. In this regard, the profile of the undamaged area of the vessel (Figure 3-a) was used as the shape for the full vessel virtual reconstruction hypothesis. The thickness of the walls was also extracted from the 3D digitized model (1.77 mm for the upper neck area and 2.37 mm for the area in the vessel's the largest diameter). For the virtual reconstruction, considering the small difference between these values (0.5 mm) it was decided for an average value of 2 mm for the whole vessel wall thickness.

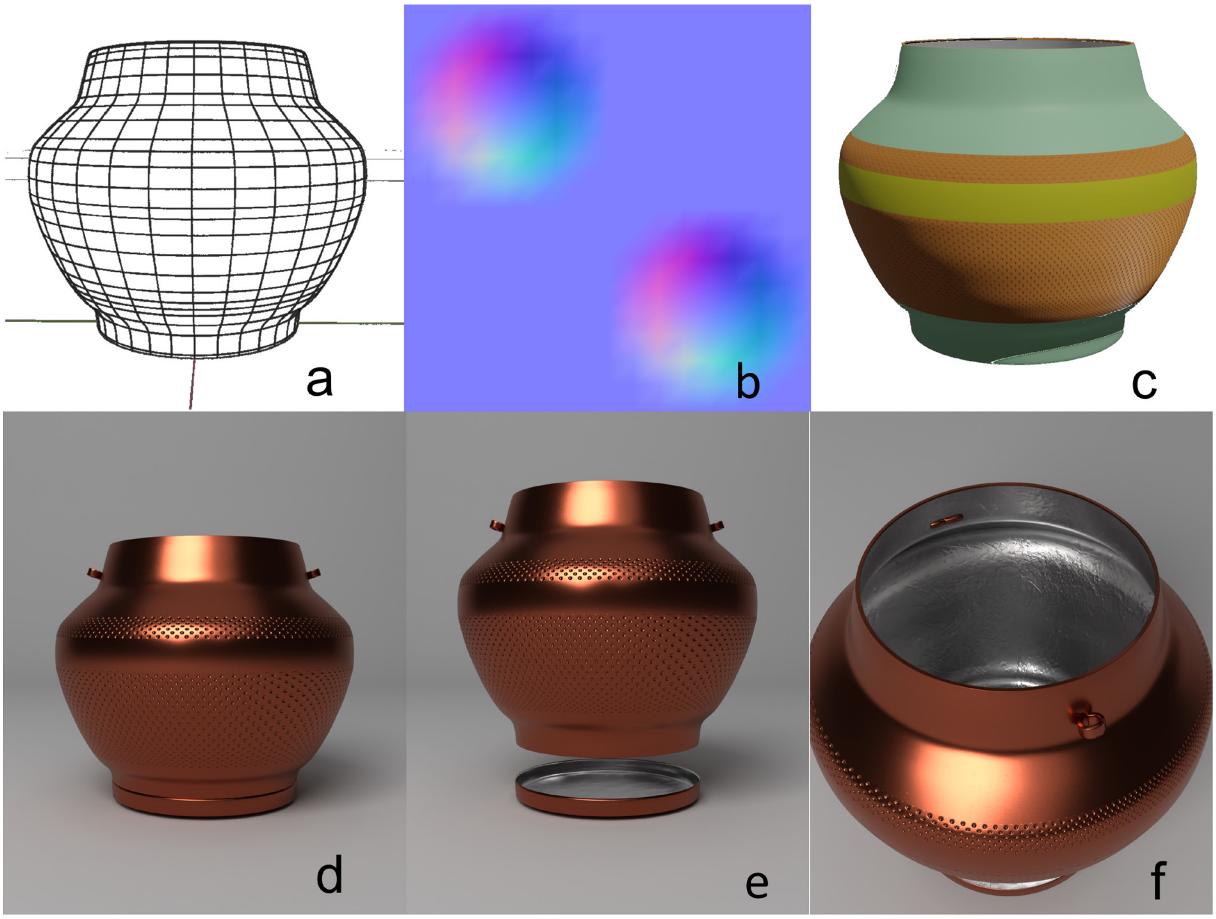

Figure 8 Stages of the virtual reconstruction: a-hard surface modeling (wireframe view); b- normal map texture for the decoration; c- UV mapping of areas with different properties of the object (interior, exterior, decoration, polished median band); c-f - rendered views of the final reconstruction

[24] Clark 2010, 63-73.

Of the two hooks for the supposed handle only one ring still exists, so it was used as model for the design to virtually replace the missing one, as there was no better suggestion for that part. As we had no details regarding the handle, the range of hypothetical possibilities was too large to propose a reconstruction solution.

From the base was found a large fragment with no distinguishable connection points to the rest of the vessel, except the tinned side which suggests it was the interior side. The most solid hypothesis, considering the Leiden vessel analogy, was that the base was no part of the main body, but „welded" on. There were no technological marks on the vertical walls for this proposal, only a wearing mark at the start of the bottom rim, which might indicate a friction with the bottom vertical wall over the vessel bottom rim.

The decoration was a bit complicated. A seemingly uniform pattern of embossed dots covers the lower register of the vessel. Upon a closer surface inspection of the digitized model, with the virtual racking light tool, important details were observed: the decorated register was not spread all the way down to the base, but only for 5.2 cm below the undecorated median band (2.3 cm) and actually another decorated register was found above the median band for 1.3 cm. Measuring the dots' diameters and the distances between them, also in virtual environment, resulted that these were made with the same tool (1.8 mm dot diameter) but not so uniform in pattern (distances between them ranging between 0.5 to 1.5 mm). The modeling of the decoration was done using textures, namely the normal maps, rather than hard-surface modeling. In Figure 8-c the mesh of the object was split into areas with different material properties, each with a different color: teal color for the usual exterior material, orange for the decorated areas, green for the uniform median band and gray for the silvery coating in the interior (not visible in the figure). This way it was easier to manage the different materials applied on the same object. In Figure 8-b is depicted the normal map texture used for imitating the dotted decoration.

Based on the physico-chemical investigations carried out in the previous studies which resulted in the characterization of the bulk metal of the vessel as a Cu-Sn alloy, the color of the diffuse material for the exterior surface was chosen. The interior was determined in the study that it was coated with tin, so the material for this side was set accordingly with a silvery aspect.

Visualization and archiving

Virtual content needs virtual environment to be fully experienced. In this regard, one of the main purposes of this endeavor was to develop an environment suitable for an immersive and participative exploration of an archaeological find, in this case the Mălăiești bronze vessel. The most accessible medium for this approach is a tool in form of a public online web page which can present text, images and interactive 3D content. The purpose of this tool is to offer an alternate way for narrative in virtual archaeology. In this case the presentation contains: artefact general presentation, a summary of previous scientific studies and investigations, the 3D digitization process, and results with full paradata, scientific 3D viewer with features like measuring, raking light inspection, profile extraction, virtual restoration and anastylosis 3D viewer, virtual reconstruction proposal 3D viewer.

To achieve these goals, a web page was designed using simple HTML code with minimal resources, split several sections, each dedicated to specific type of information. The first section contains the general presentation of the vessel and its discovery and the archaeological context. The second section is dedicated to previous scientific investigations while the third being dedicated to the process of 3D digitization with all the recording and processing details. The fourth part will present the visitor three options for interactive visualization: scientific view, virtual restoration and third, the virtual reconstruction. Each will open different 3D viewers with different purposes and features.

The 3D viewers used, although different in concept, are all based on the same technology: WebGL. The first one, the viewer with scientific features, is an open-source resource developed by the Visual Computing Lab of ISTI-CNR[25] and requires a few adjustments before use, like converting the 3D model into a proprietary format. The other viewers are simpler and were developed using ThreeJS and are designed only for simple inspection of the 3D models.

All the 3D content is stored locally with the web page and loaded in the virtual environment of the 3D viewers. This offers an increased security and control in the long run versus third party hosting solutions. The presentation page is available at *https://cercetari-arheologice.ro/materials/ca29.1/malaiestiVessel/*.

25 Potenziani 2015, 129-141.

Discussion and conclusions

With a good strategy and discipline, while documenting each step, a truly transparent process of virtual restoration and virtual reconstruction can be achieved. The tools and methods used in this process were chosen based on quality and cost-effective criteria. The workflow presented in this paper can be split into several main steps, each with specific tasks. Following the artefact discovery and the scientific investigations on the bulk material and corrosion compounds, a physical restoration process was carried out. Once the cleaning step was completed, the first objective was to digitize in 3D the vessel and its biggest fragments, before the final stage of the restoration. The method used for the 3D digitization was photogrammetry. The resulted mesh was prepared (cleaning, retopology, texture baking) for both online publishing and for further processing in the next steps. For virtual restoration, the digitized and retopologized 3D model was used. Retopology of the polygons structure (quads) helped for an easier editing of the mesh in bringing the bended walls to a hypothetical original position. This process requires high skills in 3D modeling and its results are also depending on the complexity of the original object. Digitized fragments (only the base in this case) were also positioned in hypothetical positions. Finally, using a translucid material the remaining gaps were virtually filled to complete a full virtual restoration proposal. The virtual reconstruction process also made use of the digitized model, more specifically the axis profiles extracted from it. Based on these profiles the shape, thickness, and symmetry of the body of the vessel, a new 3D model was designed and produced in 3D to an ideal original shape. The new 3D model was textured using gaming industry standard methods for efficient 3D assets in online environments.

All these resulted models were integrated in a presentation web page as a model for a complete and immersive narrative that would serve both general and expert public requirements. This presentation includes comprehensive data about the archaeological research that lead to the discovery of the bronze vessel, the scientific investigations carried out for the material and conservation state characterization and finally customized 3D viewers for different purposes: analytical study of the 3D digitized model, virtual restoration, and virtual reconstruction inspection. Each model opens in a separate window that also contains all the data regarding its production/design. This approach was meant to solve any possible “black box” issues regarding the processes that led to the final results.

The cost-effective criteria in regards of replicating the process for other items or collections was met. The web development process and 3D viewing capabilities were realized using open-source resources while the 3D digitization was carried out using photogrammetry, that is much cheaper and more versatile than its alternatives (laser or structured light scanning), yielding similar if not better results (considering the color aspects).

This process can be further replicated for an entire collection and included in an online repository or database for public access.

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