3D DIGITIZATION OF MUSEUM ARTEFACTS WITHIN THE INTERREG IRON AGE DANUBE PROJECT

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Abstract

Iron Age Danube project dealt with a wide variety of topics and sites dating back to the Iron age along the Danube river. Primary goals set by the Archaeological museum in Zagreb were the creation of a cultural route for the site of Kaptol, presentation of the site itself and digitization of artefacts from the necropolis of Kaptol – Čemernica. The latter were a part of the permanent museum exhibition in the Iron age section at the Archaeological museum in Zagreb. This paper will present the workflow used to generate image-based 3D models of more than 100 artefacts. The museum itself doesn't have a digitization laboratory or allocated space, a problem which was encountered in other cultural heritage digitization projects, which meant that the setup had to be quickly assembled and disassembled as needed. This paper will present the problems encountered during the entire process, from image acquisition to data processing, as well as the potential solutions. For the purposes of the project we used Agisofts Metashape software which at the time required masks for all photographs involved in the image-based modelling process, in a turntable static camera setup. The newer versions of the software have two additional options one of which ignores the surrounding reference points and uses the markers generated by Metashape to complete the initial camera alignment. The sheer amount of artefacts we aimed to digitize meant that we had to streamline the process of acquiring and processing the photographs and their respective masks. This process was meticulously documented and optimized to take the least possible time while obtaining a satisfactory level of detail on the resulting 3D model. Although the new versions of the software dispense with the need for masking the photographs, the process of removing the unwanted points from the point cloud and aligning different chunks can also be time consuming. This paper will present our results with various photo alignment methods and try to provide an objective comparison. We will also explore the possibilities of utilizing the finished models in computer generated reconstructions of sites, and their usability in promoting the museum and potential exhibitions. Finally, the paper will assess the value of digitizing larger parts of museum collections in light of the recent earthquake in Zagreb which seriously damaged most of the artefacts in the museum.

1. INTRODUCTION

The Archaeological Museum in Zagreb is the most prominent archaeological museum institution in Croatia. The museum's collections, today consisting of more than 450,000 various artefacts and monuments, have been gathered over the years from many different sources (Solter 2016). As a museum, the Archaeological Museum in Zagreb is not only involved in archaeological research and fieldwork but also in the presentation of cultural heritage through exhibitions and projects belonging to the domain of public archaeology and cultural heritage management. The museum also partakes in the implementation of applied knowledge in the fields of 3D digitization of artefacts and monuments, computer visualisations, and virtual reconstructions for specific exhibition projects, both as part of exhibition multimedia displays and as web presentations (Solter 2019). The museum also engages in work on online databases, digital interactive presentations of archaeological artefacts for the general public, as well as the development of digital databases for fieldwork documentation and scientific digital editions of archaeological material.

In recent years, through two Interreg Danube Transnational Programs, the Iron Age Danube and the Danube archaeological eLandscapes projects, the museum initiated and played a vital part in developing new approaches to site presentation of several archaeological sites.

The project "Monumentalized Early Iron Age Landscapes in the Danube River Basin ("Iron Age Danube"), an Interreg Danube Transnational Programme had on board 11 partners and 9 associated partners from 5 countries in the Danube region, and started its 2.5-year implementation on January 2017. The project brought together partners from different institutions dealing with archaeological research, protection and promotion of cultural heritage. The lead partner was Universalmuseum Joanneum from Austria (https://www.interreg-danube.eu/approved-projects/iron-age-danube).

The Iron Age Danube project was focused on monumental archaeological landscapes of the Early Iron Age, characterized by fortified hilltop settlements and large tumulus cemeteries, from the era between roughly the 9th–4th century BC (Hallstatt period).

The project partnership major goal was the development of joint approaches for researching and managing complex (pre)historic landscapes and their integration into sustainable tourism.

Activities on the project were as follows:

- Archaeological research of landscapes during international research camps
- Development of new digital and analogue tools for tourism use in selected micro-regions
- Development of a digital research database

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- Revitalization of archaeological parks and educational trails
- Creating new museum programs for visitors
- International promotion of the most important landscapes from the Early Iron Age
- Development of strategies for the preservation, research and sustainable development of archaeological landscapes at the regional level

This paper will focus on presenting our workflow for the digitization of Iron Age artefacts, discuss specific methods within the scope of the software we used, and finally comment on the utilization of the generated 3D content.
Based on previous experiences with different types of laser scanners and some limited practice with structured light scanners we settled for the image-based approach to 3D digitization of artefacts. Image-based modelling was used as the most optimal method for this purpose in various digitization projects in other museums as well (Barsanti & Guidi, 2013; Emmitt et. al. 2021)

2. DATA ACQUISITION

In our digitization efforts we aimed to get the best possible results with regards to our equipment and time constraints of the project. A small separate room section on one of the museum floors was set up which was inaccessible to the public and provided us with space to work without interruptions. The room was equipped with a simple table for artefacts, a standing box for the turntable and the standard neutral white backdrop. We also used three photo studio diffuse light sources to illuminate the objects with a 5000K light. The artefacts were brought up to the room from the museum depo or were taken out for a short time from their respective exhibitions. The digitization process was done in baches of up to 10 artefacts and since some of them are similar in shape, colour and size we had to keep a meticulous list of finished items with their respective inventory numbers assigned to them by the museum. To keep up with our work we used simple codes P1, P2, P3, etc. for each individual vessel and we simply noted the museum inventory number next to our name codes on a separate list. This simplified the folder structure and the file naming of our finished artefacts which proved to be important when dealing with a large number of photographs and 3D models.

One of the issues we encountered, was dealing with multiple orientations of the same object in a single dataset. Some of the artefacts have distinct shapes which are sometimes impossible to turn upside down because of the potential damage it could do to the artefact itself. This is mainly a problem with large iron age vessels, usually more than 50cm in diameter. Because of their size and weight, the stress level that would have been exerted on the rim of the vessel, had they been turned upside down, would have surely resulted in compromising the integrity of the artefact. Other objects that fall in this category are the ones with complex ornamentations such as the *askos* vessel (P98_inv11549). Our goal was to get a digital representation of the artefacts which would be as complete as possible, for this reason most of the objects were photographed twice, once in their normal orientation, and once upside down. Additionally, the pots that have narrow necks but a wide diameter in the body were also photographed with a mobile phone camera in an attempt to reproduce the surface inside the vessel as well as the outside. Turning the pots upside down was not done solely for the purpose of reconstructing the base of the vessel, some of the artefacts are very large and their bottom halves break at steep angles which we found are extremely hard to photograph properly without turning the artefact itself.

2.1 Hardware

As was previously mentioned our setup included 5000K diffuse studio lights, a turntable on a box and a uniform backdrop. The turntable was a sturdy wooden one fitted with a white cover which made the turntable surface less slippery. Agisoft Metashape markers were printed and fixed on the turntable surface. A Nikon D7100 mounted with a 18-35mm Sigma lens was used for image acquisition along with a tripod, a remote control for the shutter release and a tape measurer for determining the distance from the object. All photographs were taken in maximum quality .jpg with 6000x4000pix. The f/stop value varied from artefact to artefact but was mostly kept in the f/8 to f/10 range, ISO value vas set at 100, and with a few exceptions the lens was fixed with a tape at 18mm. Since some of the artefacts were coated with a glossy finish during the conservational process, a polarization filter was used on a limited number of objects. This proved to be essential as the light sources, although diffused, were visible on the glossy surface coating of the vessels. When these images were fed into the pipeline the cameras failed to align because of the static points the lights made on the artefact.

Additionally, a Samsung S9 mobile phone was used to gather as much data as possible for the interior on some of the artefacts. The S9 produced images also in .jpeg format with the resolution of 3264x1836pix. The phone was chosen as a quick and easy solution for this task as most of the vessels couldn't fit a larger camera inside. By the end of our photography sessions, we had 24 848 photographs of artefacts, with an average of 120 to 150 photographs per artefact. On average the image acquisition phase for each artefact took between 30min – 45min.

2.2 Software

The tape measurer was used in tandem with a DoF Droid mobile app to help determine the best setup with regards to the depth of field and the sharpness of each image. Adequate depth of field (DoF) is specific to each artefact in respect to their size, and has to be calculated by taking into account the distance between the artefacts centre point and the sensor. The Depth of Field (DoF) is defined as the range of distances in which the object appears acceptably sharp in a photograph (Verhoeven 2018). If properly set up the resulting images should have no blurred areas which considerably affect the image-based modelling process and often result in noisy 3D reconstructions (Farella et al. 2022). Good data organization was necessary to successfully complete the goals of the digitization project. All artefacts were assigned with a "P" number, which was also the name of the folders. The folders contained images from the DSLR and images from the phone camera, masks for DSLR photographs, Metashape save files in .psx format, exported 3D models and their respective texture maps in .obj and .tiff formats. Adobe Photoshop CS6 was used to generate masks for all the photographs. Although masking tools are available in Agisoft Metashape, we opted out for Photoshop as a quicker solution for the large amount of masks necessary for our project.

The process of 3D model generation through Agisoft Metashape, or as it was earlier called Agisoft Photoscan, has already been proven to produce adequately precise and detailed models for the purposes of museum artefact digitization. (Barsanti & Guidi, 2013; Emmitt et. al. 2021) The software works with SfM and dense multi-view stereo-matching algorithms (Barsanti & Guidi, 2013). It is semi-automatic in nature, but allows the user to tweak the settings for alignment accuracy, implement reference and control points, utilize masks, and influence the final polygon count, as well as the resolution of the texture. By the end of the data processing phase, we had 123 complete 3D models of iron age artefacts.

3. DATA PROCESSING

3.1 Masking

Once we ascertained that most of the artefacts will have to have at least two positions, and sometimes three, we quickly realized that we need an efficient way for the separate sets of data to merge into one. There are two options available, the processing of different artefact orientations in separate chunks and then aligning them separately, or masking everything but the artefact and the turntable and then processing the images jointly (Farella et al. 2022). The masking option was chosen as the preferred method, because it reduces the time of processing the 3D model, and with it we avoid the problems with image orientation. Still given the final number of photographs the masking option represented a daunting task. The masking process in Adobe Photoshop has been used in other digitization projects (Marziali & Dionisio 2017), and the following workflow represents our version of the procedure.

The masks were created by a simple and quick workflow which utilizes the “curves” adjustment to overexpose the white background and enhance the contrast between the artefact and the background. After that, a simple stroke with a “quick selection tool” and a right click of the mouse enable us to fill the first portion of the image with a completely white color. An inverse selection tool gives us the option of selecting the background and filling it with a completely black color. The file is then saved as a .png with the extension of “_mask” after the photograph name/number (Figure 1). Eg. DSC_2582_mask.png. Using various shortcuts and with a lot of practice we managed to streamline the process down to 25sec per mask.

Figure 1: An example of a .png mask created in Adobe Photoshop

The photographs for each artefact were imported into the Agisoft Metashape software where masks were applied, and a quick overview of the masked photographs (in thumbnails mode) is available in the photos panel. This is a good validation process, as it can often happen that some of the masks were not properly saved or have been skipped altogether, and they have to be reloaded. In the settings for the alignment process the option “apply masks to key points” should be selected.

The process from this point on was pretty straightforward, for the purposes of our project we used high settings for the image alignment phase and the dense point cloud generation, while the settings for the mesh generation varied between medium and high depending on the artefact and the details on its surface. All of the textures were produced in 4096x4096pix resolution.

3.2 Modelling the inside of the large narrow necked vessels

The only exception to the standard workflow, were the large vessels with narrow necks, where we used the mobile phone camera to try and capture the inside of the artefact. As expressed in Farella et al. (2022), all museum digitization projects should strive to: *“a faithful, complete and precise reconstruction of the object's shape and geometry, limiting occlusions and avoiding loss of information”.* Although mobile phone cameras were successfully tested in image acquisition for the purposes of digitization projects in museums (Apollonio et. al. 2021) this is to our knowledge the first time that DSLR data sets and mobile phone camera datasets were combined to document the inside of the artefact with the outside surface to get a more complete reconstruction of the object (Figure 2).

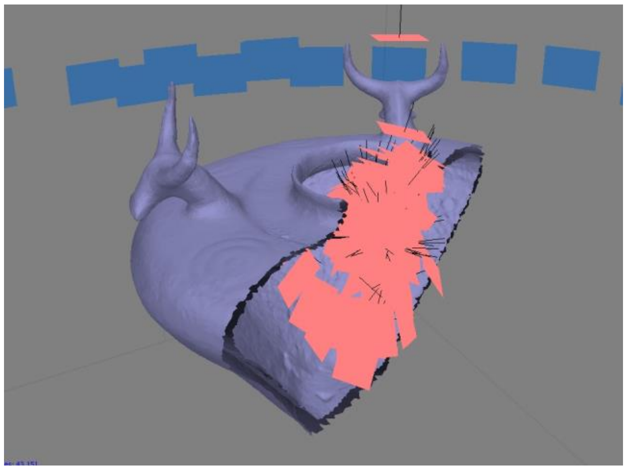

Figure 2: Aligned mobile phone images on the inside of the artefact

The process included all of the masking steps for DSLR photographs outlined in the previous section. After masking and alignment, the camera calibration data was exported, and then the process was repeated for the mobile phone data in a separate project. Once we obtained both calibration files for these two very different cameras all the photographs were loaded into a single project, and separate calibration files were applied to different sets of photographs. Since we weren’t sure how well the image alignment phase would work, we placed additional Agisoft markers on the inside of the artefact. An important distinction was made during the image acquisition process between the strategy of acquiring the photographs. The DSLR ones were taken with a tripod and by rotating the turntable with the artefact, while in the case of the mobile camera the images were taken from the hand after the first phase of DSLR photographs, but before rotating the object upside down. The mobile phone camera photographs were taken with the flash option turned on, as it was necessary to ensure that the images weren’t blurred and a light source was needed to cover the inside of the vessel.

These images were taken by moving the camera over the neck of the vessel and gradually entering the inside of the vessel, taking the images all the way in. Once inside the vessel a 360 degree turn of the camera provided us with a full view of the inside of the artefact. The only part that was reconstructed poorly was just below the neck of the vessel where the space is narrow and the flash from the camera caused parts of images to become blown-out. It is also crucial to mention that during the texture generating process the mobile phone images covering the outside surface of the object should be disabled, because otherwise they affect the quality of the DSLR texture taken on the outside. Using this method, we managed to reconstruct most of the inner surface of the artefact, adding another layer of detail to our 3D models (Figure 3).

Figure 3: Cross-section of a 3d model of one of the artefacts; P0_inv19700

3.3 "Apply masks to key points" vs. "new" methods

The data collection and processing took place in 2018, since then the software was updated and two new options to deal with photograph alignment in a fixed camera with a turntable scenario were introduced. We used one of the artefacts from our digitization project to test and compare various methods of aligning the photographs on a single dataset. The aim was to present the most optimal method for proper camera alignment in cultural heritage artefacts where at least two different orientations of the object are necessary to reach a satisfactory level of a faithful, complete and precise digital representation of the artefact.

3.3.1 "Apply masks to tie points" method

The first new method was "apply masks to tie points" which enabled suppression of the background related points based only on one or two masked photographs. It was introduced in the 1.4.1. build in 2018, the software manual states: *"Apply mask to tie points option means that certain tie points are excluded from alignment procedure. Effectively this implies that if some area is masked at least on a single photo, relevant key points on the rest of the photos picturing the same area will be also ignored during alignment procedure (a tie point is a set of key points which have been matched as projections of the same 3D point on different images). This can be useful to be able to suppress background in turntable shooting scenario with only one mask"* (Agisoft LLC 2021). The method stipulates that a proper alignment of both orientations of the artefact can be achieved by masking a single photograph. In our experiment it was shown that by increasing the number of masked photographs better alignment results are achieved, and sometimes not even three masked photographs are enough to produce a correct alignment. Using the "intelligent scissors" tool to mask the photographs (as suggested by the manual) can be pretty time consuming, so all the masks were once again created in Adobe Photoshop, and subsequently imported to Metashape. It seems the best approach is to make a mask for each single row of photographs, basically each time a camera changes position with respect to the object. This significantly reduces the amount of masks needed for a single artefact from on average 130, to on average 10, while maximising the possibility of proper alignment (Figure 4). It should be noted that in some cases and with some artefacts we weren't able to get a satisfying alignment even after using 10 or more masks, so the method has a failure component which should be taken into account and explored further.

3.3.2 "Exclude stationary tie points" method

The option "exclude stationary tie points" was introduced in build 1.7.0 in 2021. The option was designed to take advantage of the fact that if you're working with reference points on the turntable you can force the alignment process to calculate the camera positions by only taking into account the pre-detected reference points. The software manual states: *"Excludes tie points that remain stationary across multiple different images. This option enables alignment without masks for datasets with a static background, e.g. in a case of a turntable with a fixed camera scenario. Also enabling this option will help to eliminate false tie points related to the camera sensor or lens artefacts"* (Agisoft LLC 2021). During our experiments with the new feature, we noticed that while using this option it is wise to increase the number of reference points and their visibility in all angles, because sometimes cameras can get misaligned. Non the less, the process works very well in most cases and seems to dispense with the need for masking large batches of photographs. However, the forced camera alignment also produces a significantly higher amount of noise in the dense point cloud data. Luckily the noise in the data can be handled with relative ease by utilizing the option to select and delete the points by color. The process also demands that different positions be modelled in separate chunks and aligned afterward. This doubles the amount of time it takes to process the data and finish the model, not to mention the fact that it takes a considerable input from the operator to finalize the process, whereas in both masked methods ("apply masks to tie points", and "apply masks to key points") once the alignment is complete and checked all the data is processed in a single chunk.

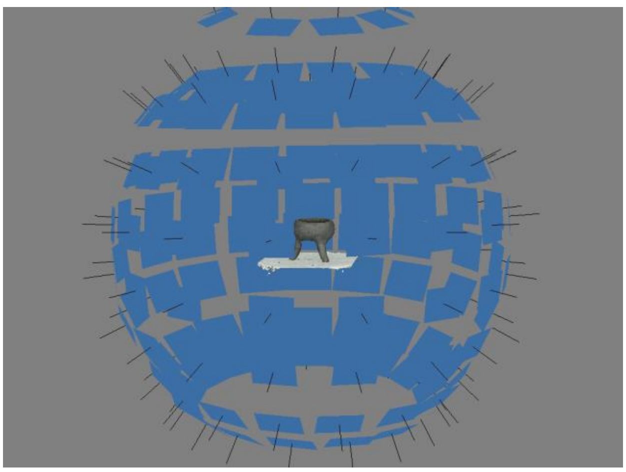

Figure 4: A snapshot of properly aligned photographs using the "apply masks to tie points" method; P45_inv11550

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3.3.3 Conclusions on the best approach to the alignment of photographs

After assessing the three available methods for processing the artefacts which require at least two different orientations to be captured we concluded the following:

Method	Nmr. of mas ks	Single chunk or multiple chunks	Processing time (finished 3D model	Time engagement of the user
"Apply masks to key points"	130	Single	105min	60%
"Apply masks to tie points"	10	Single	116min	15%
"Exclude stationary tie points"	/	Multiple	90min	22%

Table 1: Comparison of different methods for the photo alignment process

The method of "apply masks to tie points" gives us best results in the photo alignment phase because the time engagement of the human processing the data is the smallest. Masking all of the photographs for each artefact is a tedious task despite the fact we were able to streamline the process and bring the time of processing for each mask down to 25 seconds. When we review the data, we can see that masking all the photos is actually the quickest method of producing the desired result if we want a single chunk dataset. But when we consider the amount of artefacts usually involved in these types of projects the time engagement of the user becomes the most important column. The method "exclude stationary tie points" is by far the quickest, but is still plagued by the fact that different orientations of the same item have to be processed separately and subsequently they have to be merged through the chunk alignment process. The method therefore produces an inferior model as opposed to the first two methods which integrate all the photographs from both orientations into the same photo alignment process.

5. UTILIZATION OF DIGITIZED ARTEFACTS AND RESULTS OF OUR PROJECT

During the project, the Archaeological Museum in Zagreb digitized the Early Iron Age artefacts from its collection, with special emphasis on the Kaptol site. A part of the artefacts from the old research campaigns is in the Archaeological Museum in Zagreb, while the artefacts from the contemporary archaeological excavations is in the City Museum in Požega, the digitization of the material and its presentation in a virtual environment enabled a unique presentation of grave units that are otherwise physically separated and thus inaccessible to visitors. The final result of our digitization efforts are 123 3D models of Iron Age artefacts from the museum collection, most of the artefacts are pottery vessels, with a few bronze objects, all found within a burial context. For now, a selection of 3D models is presented at the online sketchfab platform on a public museum profile, where anyone can view the results of our digitization efforts (Figure 5).

Figure 5: A 3D model of the askos vessel uploaded on sketchfab platform; P98_inv11549

The 3D models of artefacts enabled us to create faithful reconstructions of the funeral custom established by archaeological research at the Kaptol – Čemernica Iron Age necropolis. In 2016 a revision excavation was completed on the site of tumulus IV which revealed additional data on the context of the finds in the museum, and provided more information on the structure of the tumulus itself, as well as on the funerary practices of that period (Potrebica, Rakvin 2019) (Figure 6). The reconstruction of the funeral custom was completed as a VR animation in Unity game engine (Unity®), which will at a later date be incorporated as a part of the museum's presentation of the artefacts. This will provide the museum with a chance to evaluate how the VR content is utilized by the visitors, as numerous projects in other museums have already begun to do (Kersten et. al. 2018; Schofield et. al. 2018) The 3D models were optimized and exported in .obj formats and were incorporated into the virtual reconstruction of the tumulus.

Figure 6: A still frame from the VR animation of the possible funerary ritual at Tumul IV on Kaptol-Čemernica site; note the 3D models of artefacts in the foreground of the bonfire

Game engines have a particularly interesting role in the presentation of cultural heritage digital content. The applications range from simulating a photo studio for the presentation of material, to recreating entire scenarios such as the afore mentioned burial at Kaptol. These visualizations were developed within the scope of the Danube's archaeological eLandscapes project, which is a continuation of the previous Iron-Age-Danube project. Virtual archaeological landscapes of the Danube region (Danube´s Archaeological eLandscapes) is a project co-financed by the Interreg Danube Transnational programme, which lasts from mid-2020 till the end of 2022.

The project´s major goal is to regionally, nationally and internationally increase the visibility of the cultural heritage, and in particular the archaeological landscapes of the Danube region, making them more attractive for integration into the region's tourism offers (Balen et. al. 2021).

6. REMARKS ON ARTEFACT PRESERVATION THROUGH DIGITIZATION

Apart from the importance of use of 3D models of artefacts in creating and presenting a faithful way of life in ancient times, 3d models proved to be extremely important for communication with the public during the Covid-19 pandemic when museums, including the Archaeological Museum in Zagreb, were closed (Guberina et. al. 2020). In addition to the pandemic, the Archaeological Museum in Zagreb was hit by two devastating earthquakes in 2020, which destroyed not only the building but also part of the museum artefacts, so the museum is still closed to visitors.

Figure 7: Earthquake damage in the Prehistoric section of the museum in 2020

Virtual content has thus become the only way to communicate with the audience and the general public. The Museum is currently working on the renovation of the building as well as on the conservation and reconstruction of the museum artefacts, which will be followed by the return of the museum's permanent exhibitions, where special attention will be paid to better earthquake countermeasures. Until then, the Museum has an active role in working with the public in various, direct ways, through workshops and exhibitions in other venues. The Museum has paid great attention to the creation of archaeological routes, like Iron Age Danube Cultural Route, but also various virtual contents accessible through museum web pages (https://www.amz.hr/hr/virtualni-muzej/).
3D models of museum artefacts have proven to be extremely important not only as a tool for creating virtual content and for communication with the public, but also in the restoration and production of replicas of museum artefacts. Finally, the museum has included the 3D digitization of its category "A" artefacts and other valuable objects in its core strategy documents.

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