# MACRO PHOTOGRAMMETRY IN INVENTORY OF HISTORICAL ENGRAVINGS AT THE ROYAL CASTLE IN WARSAW

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**ABSTRACT:**

In the community historical objects play the role of witnesses of the past history. This creates an obligation to preserve and reconstruct them for future generations. Photogrammetric methods have been applied for those purposes for many years. In the process of development of inventory documentation, the key aspects related to the selection of appropriate measuring methods for particular objects and the creation of appropriate working conditions. At present, digital measuring techniques allow developing 3D photogrammetric documentation which is particularly valuable both, for conservators of historical objects, as well as for creating virtual museums. Particular attention should be paid to the utilisation of macro photography for that purpose which allows for recreating small fragments of historical details. The objective of this paper is to present possible use of macro photography for inventory of historical patterns engraved in brick walls of one of the cellars of the Royal Castle in Warsaw (Poland); they are called engravings or house marks. The cellar walls were made of bricks (20x10cm) on the stone foundations, where a prison was located in the 17th century. Prisoners left their drawings of signs and crests. Bricks are destroyed, some of them are moss-grown, so many engravings are hardly visible and their depths vary between 3 and 5 mm. The Canon 5D Mark II camera with the 50 mm macro lens was used to inventory engravings together with the shadow-free flash, mounted on the lens and a special frame with bolts, being the photogrammetric control network. To ensure the high quality of the 3D model, a network of photographs were acquired from two different distances; they were processed with the use of SfM/MVS algorithms implemented in Agisoft PhotoScan software. The aim of this paper is to discusses the impact of selection of control points on the accuracy of the orientation process, the impact of the point cloud density on correct projection of the digital surface, the influence of the DSM resolution on details of projection of shapes and selection of orthorectification and mosaicking parameters on the accuracy of orthoimage generation.

## 1. INTRODUCTION

In order to perform documentation and visualization for national heritage objects, close-range photogrammetric methods have been widely used for a very long time. For completing documentation of old buildings, historic walls or other similar objects, image-based as well as range-based techniques are commonly used (Arif and Essa, 2017; Gonizzi Barsanti et al., 2013; Grussenmeyer and Yasmine, 2004; Hatzopoulos et al., 2017; Remondino and El-Hakim, 2006). There are lots of valuable, archaeological artefacts which are just a few centimetres per dimension or even less. Usually documenting such objects based on interpretation and manually drawing shapes and most important features while using magnifying glasses. Most close-range terrestrial laser scanners used in archaeology do not allow to generate products with sufficiently high spatial resolution to obtain the most important features of small objects, such as shape, plasticity, texture or current damage. Due to the fact that techniques based on Structure-from-Motion and Multi-View Stereo approach allow for digital reconstruction of the object with the required accuracy and high level of detail (Bianco, 2018; Chiabrando et al., 2015; Moussa, 2006; Westoby et al., 2012). For the purpose of documenting small objects, macro lenses are usually used that allow taking images with high magnification. However, using such lenses creates problems connected with increased distortions caused by changes in focal length. Because of that, using prime macro lenses is advised in order to prepare documentation of small historic objects (Yanagi et al., 2008). An example of the use of macrophotogrammetry in the preparation of inventory documentation for a heritage object can be the development of documentation for the artefact no. 15441 from the collection of the Museum of Archaeology in Zagreb, Croatia. It is an ancient amber figurine depicting a female profile found in a tomb in Kompolje. The dimensions of the sculpture are 30x20x5 mm. A precise calibration of the camera (NIKON D90 with NIKKOR 35-105mm lens) was carried out, followed by obtaining and developing images with principles of SFM/MVS methods. RMSE errors for image coordinates amounted to approx. 1-2 pixels and the largest field error for the reconstructed checkpoint positions was 0.063 mm. This result shows that it is possible to obtain an accurate 3D model for a small historic object using macro photogrammetry methods.

## 2. PERFORMED EXPERIMENT

When creating inventory documentation, the key aspect is the selection of an appropriate measurement method to the object and ensuring proper working conditions. When creating inventory documentation, the key aspect is the selection of an appropriate measurement method to the object and ensuring proper working conditions. Bricks with engravings on the walls of the Basement Prison (located in the Justice Court Tower) are a specific object because even though they are located on flat walls of the room, they are 3D objects. Therefore, the only solution that allows to fully reflect the nature of the object was to create a Digital Surface Model for each of the rites and then to make orthoimages. Due to the nature of the object, it was decided to use a photogrammetric SFM (Structure From Motion) and Multi-View Stereo approaches. It was possible to obtain accurate spatial data using the non-metric camera.


Figure 1. A) The Royal Castle in Warsaw with the Justice Court Tower marked in red, B) one of the processed walls, C) examples of photographs of engravings

### 2.1 The subject of analyses

The Justice Court Tower (Fig.1A) is the oldest brick building of the Royal Castle in Warsaw (Poland). The edifice which is almost entirely reconstructed after the destruction it suffered during The Second World War. The number of relics from different historical periods included in the castle buildings is exiguous, these are primarily foundations and basement rooms. This also applies to the Justice Court Tower, which has been dated back to the 14th century. The original cellar located in the basement of the Tower, in the 17th century was adapted to the city prison. From this period come marks carved in bricks, left on the walls of the basement by prisoners. The selection of the object of research and analysis was dictated by conservation reasons. As a result of excessive moisture in the walls, the signs underwent enormous degradation, which in turn, resulted in the slow disappearance of the rites (Markiewicz et al., 2018).

The Basement Prison is located in the bottom part of the Tower. The room size is approximately 4.60 x 4.60 metres and its height is about 3 metres (Fig.1 B). Walls of the basement are made of bricks and the depth of walls reaches about 3 metres. Blowing up the Castle by Germans in 1944 did not completely destroy the Basement Prison. Faces of walls and the ceiling were partially destroyed. In 1961 the Basement was covered by the ceiling and it was preserved. Brick walls of the basement were located on rock foundations. Dimensions of bricks used for the original construction equalled to 92-102 x 115-128 x 262-268 mm (Niepokólczycki and Garus, 1988).

### 2.2 Data acquisition and processing pipeline

The working process was divided into two main stages: data acquisition and processing. The first one included basically acquiring data –taking images of every rite in the Justice Court Tower cellar. In the second part images orientation (SfM approach), dense point clouds (MVS approach), 3D mesh models and orthoimages generation, as well as data analysis, were performed. The whole technological process was shown in the scheme in Fig. 2.

In order to inventory engravings, the Canon 5D Mark II camera with the 50 mm macro lens, the flash mounted on the lens and a special frame with bolts (threaded as the photogrammetric frame) were used.

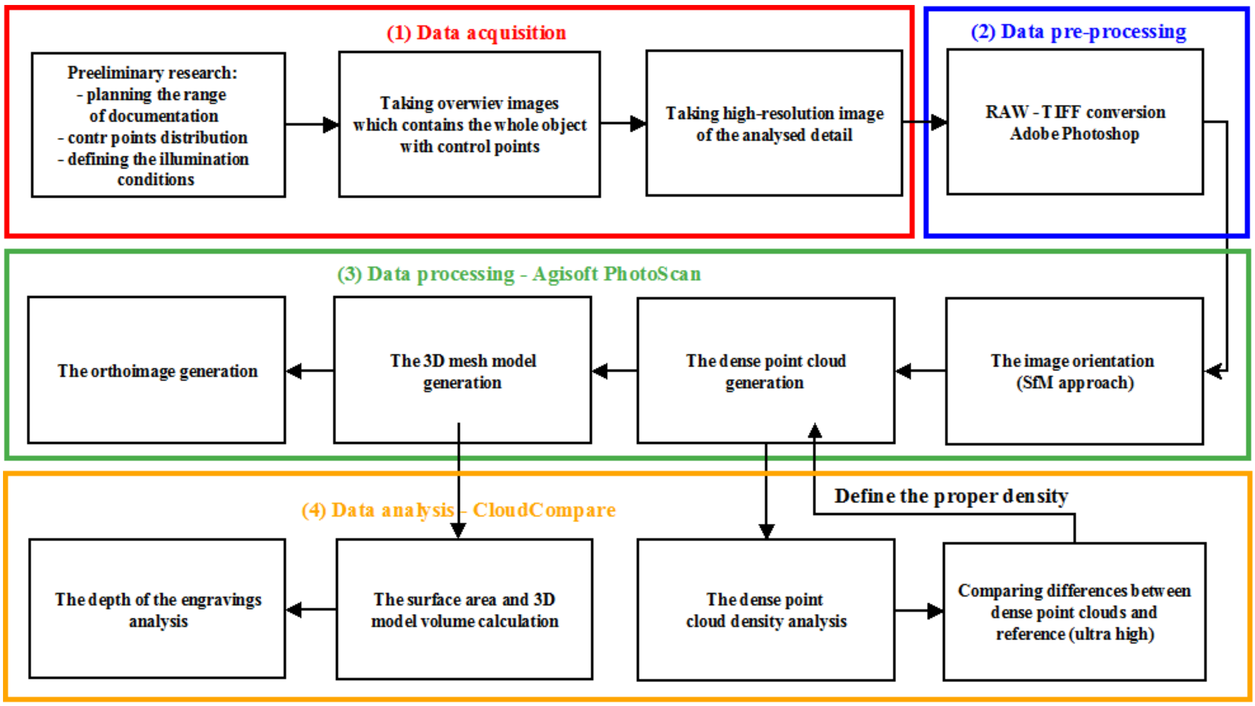


Figure 2. Technological processes of developing engineering documentation for historical engravings

Figure 3. The images acquisition

During the data acquisition, it was decided to perform a specific way of signalizing the ground control points, because it was impossible to mark the control points directly on the walls. For that purpose, the photogrammetric frame was mounted and levelled on the tripod. This allows photographing the frame with an appropriate engraving (Fig. 3). In this case, the proposed control frame should play the role of assigning an appropriate scale to models only. Hence, the data acquisition process was divided into two steps. At the first stage, a fragment of the wall with one or more bricks with engravings was registered together with the photogrammetric frame placed on it. Images were taken with the resolution lower than those which were used for high-resolution documentation generation. At the second step. high-resolution macro photographs of objects were acquired.

In total, about 2400 photographs of 108 bricks with engravings were acquired in the RAW format; then they were converted into the TIFF format using the Adobe Photoshop software. Data acquisition process was presented in Fig. 4.

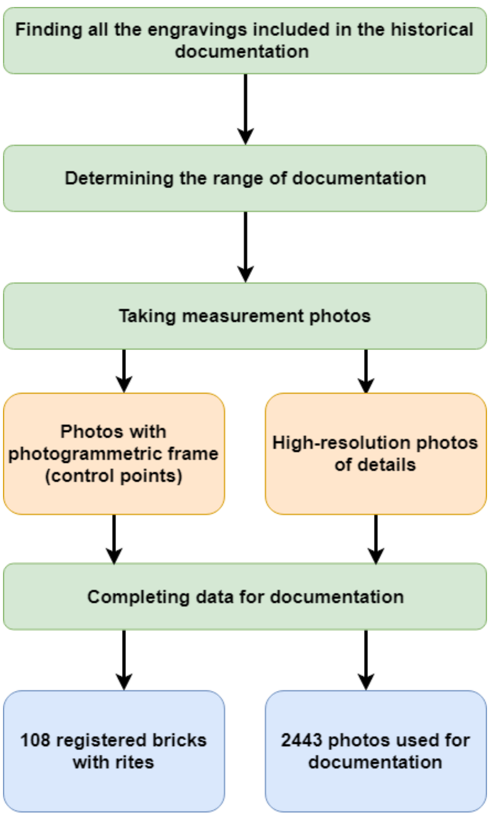


Figure 4. The data acquisition process

## 2.3 The images processing

### The image orientation

In order to image processing the Agisoft PhotScan software was used. Before the image orientation, it was necessary to divide images into two groups: images of entire bricks with the photogrammetric frame attached to them and photographs of details on brick surfaces. The camera self-calibration process was performed separately for each group. Such approach and the appropriate geometry of images allows for correct modelling the interior orientation parameters.

In order to perform the exterior orientation, 17 control points, located at the ends of bushes of the photogrammetric frame were measured manually. Seven of them were threaded as check points, i.e. control points which were excluded from the adjustment in order to determine the orientation accuracy. The distribution of points is presented in Fig. 5

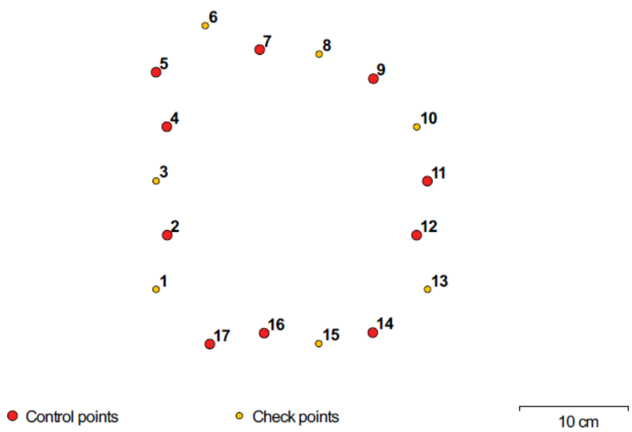


Figure 5. The distribution of control and check points

For the quality assessment, the seven engravings located in the waster wall were chosen. The values of the RMSE (Root Mean Square Error) are presented in Tab. 1.

It can be seen from Table 1 that the accuracy both on control and check points are similar and the total RMSE error is lower than 0.4 mm. This allows for achieving high accuracy shape analysis.

| Engravings | Point type | Number of points | RMSE X (mm) | RMSE Y(mm) | RMSE Z(mm) | RMSE XY (mm) | Total error (mm) |
|---|---|---|---|---|---|---|---|
| W-8-1 | Control | 10 | 0.082 | 0.280 | 0.066 | 0.292 | 0.299 |
| | Check | 7 | 0.127 | 0.234 | 0.167 | 0.266 | 0.314 |
| W-9-1 | Control | 10 | 0.137 | 0.234 | 0.032 | 0.271 | 0.273 |
| | Check | 7 | 0.114 | 0.197 | 0.112 | 0.228 | 0.254 |
| W-9-2 | Control | 01 | 0.126 | 0.263 | 0.118 | 0.291 | 0.314 |
| | Check | 7 | 0.128 | 0.180 | 0.205 | 0.221 | 0.302 |
| W-9-4 | Control | 10 | 0.095 | 0.356 | 0.078 | 0.369 | 0.377 |
| | Check | 7 | 0.193 | 0.229 | 0.182 | 0.300 | 0.351 |
| W-9-5 | Control | 10 | 0.071 | 0.341 | 0.085 | 0.349 | 0.359 |
| | Check | 7 | 0.187 | 0.217 | 0.129 | 0.286 | 0.314 |
| W-9-6 | Control | 10 | 0.103 | 0.322 | 0.037 | 0.338 | 0.340 |
| | Check | 7 | 0.135 | 0.176 | 0.141 | 0.222 | 0.264 |
| W-9-7 | Control | 10 | 0.115 | 0.314 | 0.038 | 0.335 | 0.337 |
| | Check | 7 | 0.130 | 0.172 | 0.150 | 0.216 | 0.262 |

Table 1. The statistic of the RMSE values on control and check points - image orientation

**Generation of dense point cloud**

Due to the characteristics of developed documentation and the huge total number of images it was decided to optimise settings of dense point clouds generation in order to reduce the computation time without reducing the final accuracy. For that purpose dense point clouds were generated at the following pyramid image levels: low (1/16 image resolution), medium (1/4 image resolution), high (1/2 resolution) and ultra-high (full-resolution). Then generated point clouds were exported as LAS files. Figure 6 presents dense point clouds of different density for one selected engraving.

For such products accuracy analyses were performed aiming at finding the optimal solution, meeting, at the same time, the requirements of the minimum required accuracy and the rational processing time. For that purpose, the Cloud Compare tool was used (Fig. 6 E-G). The dense point cloud of the highest (ultra-high) density was assumed as the reference cloud; all other point clouds (low, medium, high) were then compared with that cloud. Distances between closest points of clouds in the directions of all axes (XYZ) and the total distance as the resultant distance of those three values were calculated. Maps presenting locations of the biggest differences in a point cloud (Fig. 6 E-G).

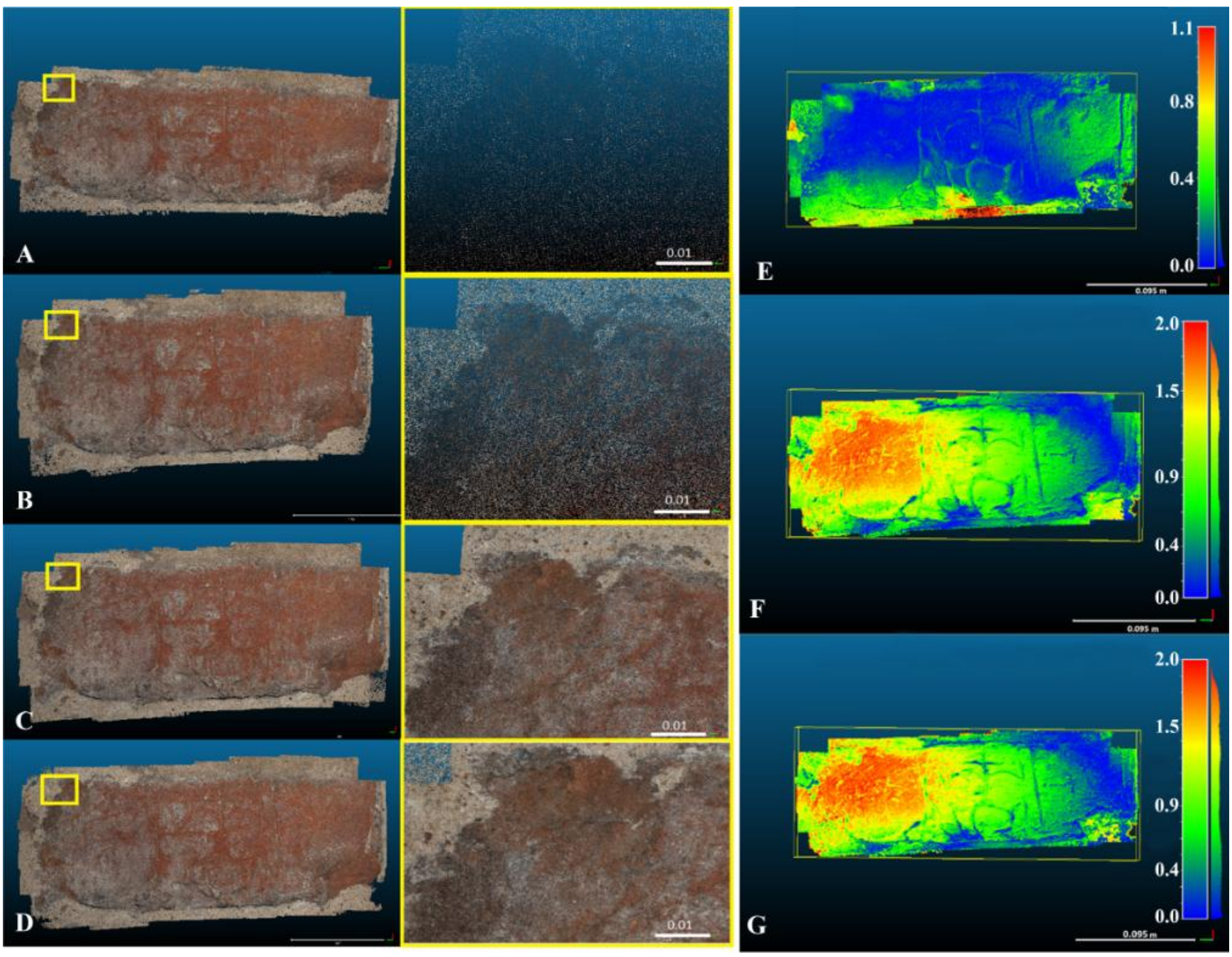


Figure 6. Generated point clouds at different levels of the image pyramid: A) Low (1/16 of the photograph resolution), B) Medium (1/4 of the photograph resolution), C) High (1/2 of the photograph resolution), D) Ultra high (the full resolution of the photograph). Comparison of distances between point clouds of different densities with the ultra-high cloud (in millimetres): E) High, F) Medium, G) Low.


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Figure 6 E-G presents the results of the comparison of particular point clouds of different densities with the ultra-high cloud (from the top: high, medium and low clouds). Using a colour scale, inconsistencies in relation to the densest point cloud were presented. Zero deviations were marked in blue. For the first case (the high point cloud; Fig. 6E) the range of scales was set to the distance of 1.1 mm, since the maximum deviations reaching only this value were observed there (the range of scale was assumed in order to increase the visibility of changes); for remaining two cases changes up to the distance of 2.0 mm may be observed, therefore the range of scale for those cases equals to 0-2.0 mm (Fig. 6F and G).

**3D model generation**

Based on the generated high-density point cloud, the 3D model (Fig.8) was textured. The average size of an individual triangle of this model equalled to 0.008 $mm^2$. The size of the entire model equalled to 35618.80 $mm^2$ and its volume was 70 $cm^3$. In case of big zooming imperfections are visible on the model surface in the form of unnatural bulges, however, they are smaller than 1 mm, so they can be considered insignificant.

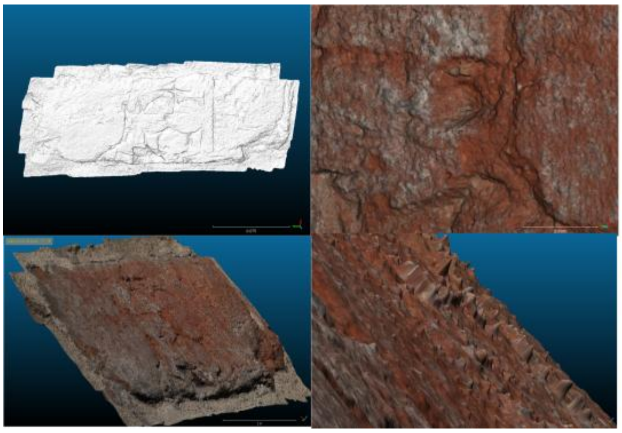

Figure 7. The 3D mesh model of the W-9-3 engraving generated based on the high point cloud (without and with textures)

For the needs of comparing, models from other clouds of the lower density were also generated (the medium and low point clouds, Fig. 8). Due to the low accuracy, those models were rejected from further works. However, those models are discussed in the presented work in order to allow for visual analyses. Despite the considerably worse quality, the shape of engraving and other important elements are still visible, their visual interpretation is also possible. Depending on the purpose of works and the efficiency of the measuring station the worse quality products may become an alternative for products which require more computer power. Digital surface models (DSM) generated from the medium and low point clouds together with imposed textures are presented in Fig. 9.

## 3. CONCLUSIONS

Development of engineering documentation for such objects as historical engravings on bricks of the walls of the Basement Prison was a challenge due to the high care required for the entire process. Measurements must be performed with the extreme attention and care not to destroy anything. The documentation must be carefully developed with the possible highest accuracy since it may be used in the future as the basis for the reconstruction of the destroyed object, for any analyses or as materials for education.

In order to correctly apply the SFM/MVS methods its assumed principles must be met. Appropriate settings of the camera with respect to operating conditions must be obeyed, the appropriate geometry of photographs should be ensured and the non-invasive establishment of the control should be planned. However, when all requirements are met, the SFM/MVS methods applied in macro photogrammetry allows achieving products which reflect the reality with the high accuracy. Performed works may be significantly simplified by partial automation of processes of the orientation of images and complete automation of processes of generation of point clouds and the 3D DSM mesh models. However, some difficulties may result from the required long time of waiting for the generation of final products of works and the high equipment requirements of the Agisoft PhotoScan tool.

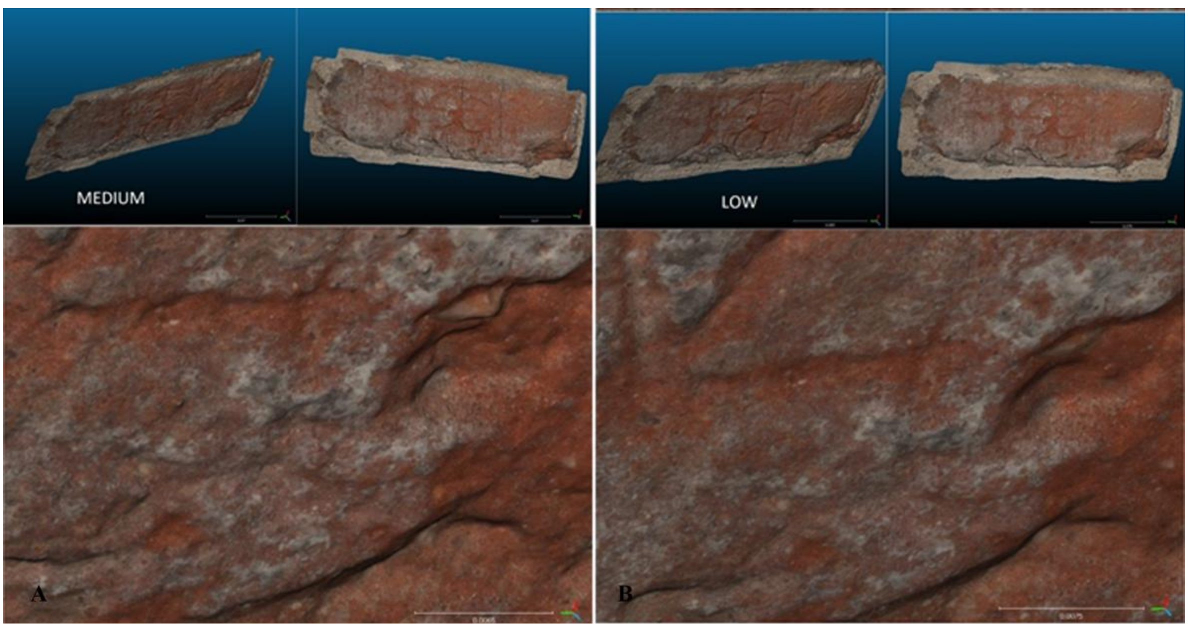


Figure 8. Mesh 3D models of the W-9-3 engraving generated basing on medium and low point clouds

After initial optimisation of settings aiming at the acceleration of works, products of sufficient accuracy were generated within a short time. This work may be considered as a proposal to solve the task of development of inventory documentation for historical objects at small scales.

Resuming the results of this work concerning the inventory of historical engravings by means of macro photography and the use of Agisoft PhotoScan, it is recommended to assume the following parameters:

- Defining the photogrammetric network special designed frame with well know measured points,
- Acquiring images in two scenarios: images which contain the reference network and those for shape reconstruction,
- For finding the tie points and exterior orientation process the full resolution of images is required,
- In order to achieve the required accuracy of works, it is necessary to generate the dense point cloud at the level 1/2 or a full resolution photographs which resolution depends on the level of details of the analysed engraving. The resolution at the third level of the pyramid of images does not allow generating of a correct 3D model, what results in incorrectly generated orthoimage.
- In order to generate the 3D model, it is worth to apply the number of triangles which corresponds respectively, to 1/5 or 1/15 of the number of points included in the dense point cloud.

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