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A digital approach for the study of Roman signacula from Syracuse, Sicily

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Abstract

In the last decade the epigraphists have grown a new interest in signacula, a class of artifacts for a long time neglected. This has brought numerous contributions devoted to the different regional contexts, along with reflections on methodological questions, not to mention the momentum towards the digitizing of a corpus which counts at least 3,500 pieces, confirming the great potential of these artifacts in providing information related not only to the economy and to the administration of the "res", both in public and private sphere, but also about the profile of the signacula holders. In this scenario, a specific research question has been inspired by the Sicilian seals - about 60 signacula and a dozen impressions left by seals on mortar in burial contexts: it is possible to identify unequivocally a signaculum through its impression? Given for granted that the use of 3D documentation will bring along effective results in terms of improved readability of signacula and seals, the aim of this contribute is to establish a protocol for a semi-automatic matching between 3D models of seals and 3D models of impressions. As part of a preliminary scanning campaign of Late Roman impressions on mortars and metal seals from the catacombs of Syracuse, two bronze metal seals were digitized with a NextEngine 3D triangulation laser scanner and subsequently 3D printed with liquid resin with a Formlabs Form 2 SLA high resolution printer. The casts obtained, were experimentally used to create a set of impressions on mortar using different degrees and angles of pressure, in order to create similar but still different stamps. During the next step, the impressions were 3D scanned and used as ground truth for the outlined semi-automatic procedure of matching with the seals. In MeshLab environment, the 3d models of seals and impressions were manually aligned and then the distance between two sets of 3D points was measured using the filter Hausdorff distance in order to validate a matching. This successful exercise could open the way to the proposal of creating a virtual edition of signacula with 3D models metadata. Furthermore, a research agenda may include the design of a machine learning algorithm for matching of 3D meshes.

Categories and Subject Descriptors (according to ACM CCS): I.3.8 [Computer Graphics]: Applications—

1. Introduction

The present contribute stems from a wider research concerning ancient bronze seals in Sicily. Over the last decade the epigraphic scholars have grown a new interest in *signacula*, a long neglected class of artifacts. This has brought about numerous contributions focused on different regional contexts, along with reflections on methodological issues, and encouraged the digitizing of a corpus counting at least $3,500$ pieces. However, seals show all the difficulties of other classes of the *instrumentum*: atomized edition of the finds, often scattered in local editions with a poor dissemination; lack of archaeological data and context of finding; lack of accurate graphic documentation and legible photos and a large dispersal on the antiques market. The academia is still looking for a comprehensive, updated study on bronze seals, although a first set of dedicated research has been presented at the recent International conference *Instrumenta Inscripta V* (2012) [BB14].

In this scenario our actual knowledge of the Sicilian seals still remains underdeveloped, waiting for an improvement. A first succinct and partial cataloguing was arranged by Giacomo Manganaro only in 2006 [Man06]. The Sicilian finds, about 60 *signacula* and a dozen impressions left by seals on mortar in burial contexts, confirm the great potential of these artifacts to provide information related not only to the economy and to the administration of the *res*, both in public and private sphere, but also about the profile of the

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signacula holders. An accurate survey of images, forms and textual content of the seals may give insight on ethnic, cultural and social panorama of the Island; for instance, by disclosing the rare case of a *signaculum* belonging to a woman from the senatorial class, or showing a clear prevalence of the Latin language during the imperial period in a basically Greek-speaking territory.

In 2015 a preliminary survey campaign took place into the repositories of the Sicilian museums, starting from the Museo Regionale "Paolo Orsi" and the Antiquarium of the Pontifical Committee of Sacred Archaeology, both in Siracusa. The finds from Siracusa are particularly significant, due to the presence of several impressions on mortar: a unique example in Sicily and an extremely rare one in Italy, where Rome seems to be the only comparable case [Fer86]. The relevance of the impressions is determined by their clear and dated contexts of provenance (Late-Antique hypogea and common cemeteries of the Christian community), as opposed to seals, for which only in very few cases it is possible to determine the origin and even more difficult appears to establish their chronology because of the long duration of use and the limited variations in shapes and paleography. Due to the difficulties in producing a satisfactory photographic documentation of seals, and in order to preserve copies of the fragile and perishable impressions, in the same period a scanning campaign on some selected finds has started, using a NextEngine 3D triangulation laser scanner (Fig. 1).

2. Proposed Pipeline

Given for granted that the use of 3D documentation will bring along effective results in terms of improved readability of *signacula* and impressions, a specific research question has been inspired by the Sicilian case: is it possible to identify unequivocally a *signaculum* by its impression? Although seals were produced using a matrix, they cannot be properly defined as serial artifacts because of their close relation to the owner, even in case of *signacula* in multiple copies which are identical or with few variants. Moreover, because of its function, the seal - not by accident in bronze - was meant to endure a long time use, sometimes as long as the (adult) lifetime of the owner; and it was therefore subject to wear and tear effects which in some cases could have left distinctive signs on the artifact. For these reasons it may be extremely gainful to elaborate an identity card of bronze seals via the analysis of detailed 3D models, and to improve matching cases between artifacts and impressions, in order to better identify context of provenance and chronology of the seals. The aim of this contribute is to establish a protocol for a semi-automatic matching between 3D models of seals and 3D models of impressions. We employed several software for different approach, for instance MeshLab for pre-processing, ZBrush to maintain original details of meshes and also to grant manifold allowing 3D printing. The pipeline is detailed in the following.

2.1. 3D print of the seals

The original 3D scan meshes of 2 digitized seals (Inv. SN2 and 16191) were imported to MeshLab [CCC*08] and the holes were filled using the filter *Surface Reconstruction: Poisson*, with the settings suggested for an high definition reconstruction: Octree Depth equals to 10, Solver Divide equals to 8, Samples per Node equals to 20 and the default Surface Offsetting. Using Poisson, we introduced an error by generating missing parts. However, this error is negligible, as non-sampled areas are very small (Figs. 5 (right) and 6). Then, the repaired mesh was imported to Pixologic ZBrush. In ZBrush the original scan was applied as a subtool to the repaired mesh, and the two were merged. This was done to capture as much of the original scan data as possible. Indeed, Poisson may have dropped some detail, hence in this way we restore it. The merged mesh was then made into a unified skin and exported as an OBJ file. The new OBJ mesh was imported into Autodesk Maya, where we created a polygonal model for the seal, and sized it to fit the mesh. When that was completed, we exported out of Autodesk Maya and imported the modeled seal back into ZBrush. Using ZBrush we filled and fit the seal so that there were no gaps. In other words, with ZBrush we check that the post-processed mesh is a 3D printable manifold. Finally, the two parts of the modeled seal have been merged and an unified skin has been generated. Main steps of this preprocessing of the meshes are shown in Fig. 2.

The printing process begin importing the merged mesh into Autodesk MeshMixer. In MeshMixer we separated shells and deleted the interior meshes. We also used planar cut to flatten the stamp sides for easier printing. We exported the final stamp out of MeshMixer as a .STL file for printing (Fig. 3). The .STL was then set up for printing on both a FlashForge – Fused Filament Fabrication (FFF) and Formlabs Form 2 Stereolithography (SLA) printer. The printer settings were layer height equals to $0.1mm$ with 10% infill for the FlashForge and layer height equals to $0.5mm$ with 100% infill for the Formlabs.

2.2. Creation of realistic print replicas

We prepared a mortar as a mixture of gypsum and sand, with a proportion of 50:50. We chose this ratio as it is proved to be worthwhile in order to obtain a mortar not too much sticky and with a reasonable required time to dry. We stamped the seals in two cases filled with mortar (Fig. 4), applying a steady movement ensuring that the print replicas look realistic.

2.3. Digitization through 3D scanning of the print replicas

The digitization of the print replicas has been carried out with two different 3D scanners: NextEngine and Sense. The NextEngine is a 3D laser scanner with an accuracy of $\pm 0.1mm$ in Macro Mode [nex17], while the Sense 3D scanner has an accuracy of $\pm 1mm$ [sen17]. Notice that the accuracy is defined as the minimum dimension distinguishable by the scanner, hence the lower the better. The NextEngine is usually employed for digitization in which an high level of detail is required. The Sense is based on structured light, hence it is way faster to be used, compared to the NextEngine, but as a result the final mesh will have a lower quality. We employed both of them with the aim of comparing the meshes obtained from this two different sources and stating if it is possible to employ low-cost handheld scanners for the scope of the topic presented in this paper.

The acquisition with the NextEngine has been conducted with the following settings: single scan, highest quality, macro mode. Each acquisition required almost 3 minutes. Performing a single

Figure 1: *Group of metal signacula from the Archaeological Museum of Siracusa (on the left). Seals are identified by letters in the figure, while Inv. IDs, written within commas, are the following: A (16192), B (16191), C (33131), D (22478), E (SN1), F (SN2), and G (SN3). 3D scanning of a signaculum D via NextEngine triangulation laserscanner (on the right).*

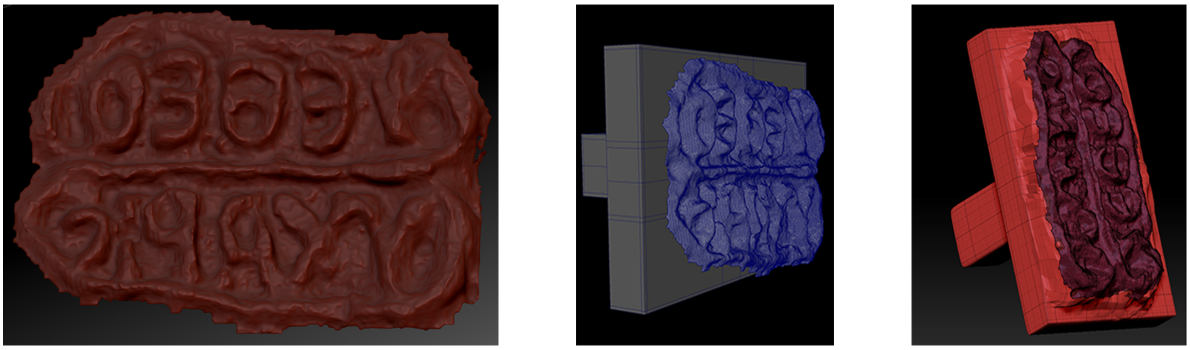

Figure 2: *Preprocess of the 3D mesh of a seal. Original and repaired meshes merged together in ZBrush (on the left). Digitized seal modeled in Autodesk Maya (on the center). Stamp fill in ZBrush (on the right).*

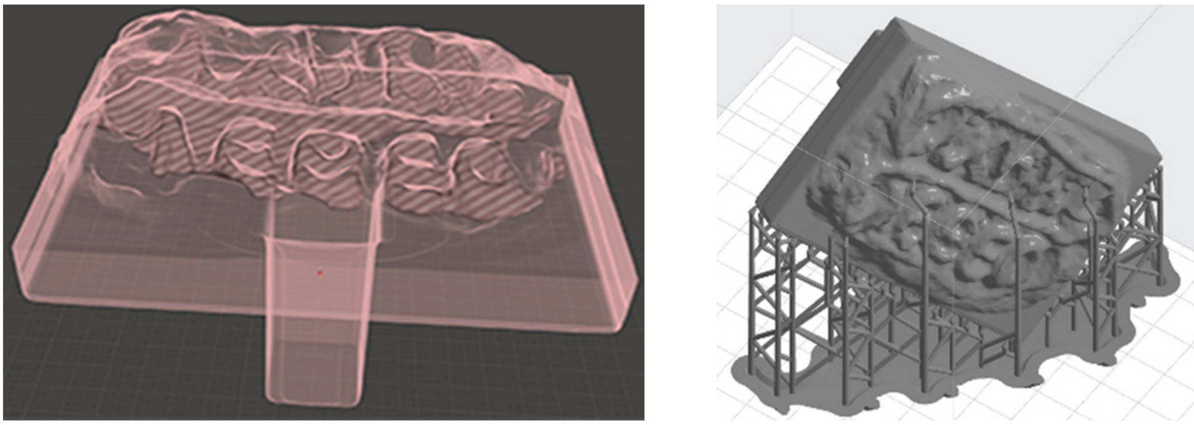

Figure 3: *3D Printing process. Separating and deleting inner meshes for final 3D print (shown on the left) and Form 2 SLA 3D Printing software with STL model (shown on the right).*

scan for each print replica implies that final meshes have some missing part (Fig. 5). Multiple scans could have covered these missing data, but in this case a manual alignment of the scans would have been required instead. We adopted the single scan approach, in order to minimize the manual alignment error. In this way, the only required alignment is the one needed for the comparison between the meshes of the seal and the print replica.

The acquisition with the Sense 3D has been conducted with the standard settings [sen17]. The scans were performed using the Sense 3D with an handheld approach and keeping an average dis-

Figure 4: *Cases A (shown on the left) and B (shown on the right) filled with mortar. On the upper part of the images seals are shown, while on the bottom part their related print replicas are clearly visible.*

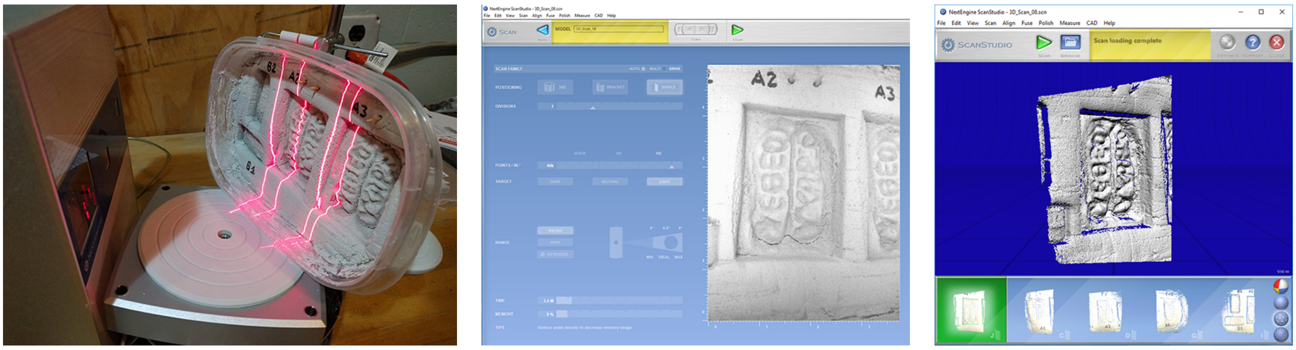

Figure 5: *3D scan with NextEngine. Physical setting of the 3D scan (on the left). Acquisition settings of NextEngine (on the center). Example of digitized print replica after 3D scan through NextEngine (on the right).*

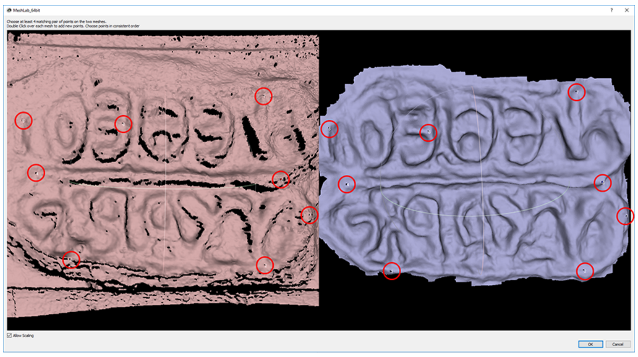

Figure 6: *Manual alignment in MeshLab environment (matching points have been highlighted with red circles to make them more visible).*

tance of 30*cm* (the minimum possible distance for this device is 20*cm*). Each acquisition required almost 20 seconds.

2.4. Comparison between 3D model of the seal and 3D scanned mesh of the print replicas

Once the print replicas have been acquired with a 3D scanner, we firstly define on the mesh a region of interest (ROI) around the print replica, removing the meaningless parts. We process the meshes on MeshLab [CCC*08]. The ROI is manually defined through the *Select Vertexes* and *Delete Vertices* tools.

It has been seen that the print replicas are smaller than the seals. This is due to autogenous and drying shrinkage phenomena that are very common in materials like concrete and gypsum [YSK05]. For the same phenomena, the surface of the mortar may be cracked in some parts. We empirically measured this shrinkage on the mortar used in our experiments comparing several shrinking factors, properly from 0% to 15%, as [YSK05] suggested. We found that the shrinkage affecting our seals is approximately of the 5% of the initial size. Hence, every mesh of the print replicas is rescaled using a scaling factor equal to 1.05 in any dimension.

In order to compare the ROI with 3D model of the seal we emulate the physical action to put near each other the model and the print, trying to fit them. This procedure of physical fitting is usually difficult to be performed due to various factors, e.g., shrinkage,

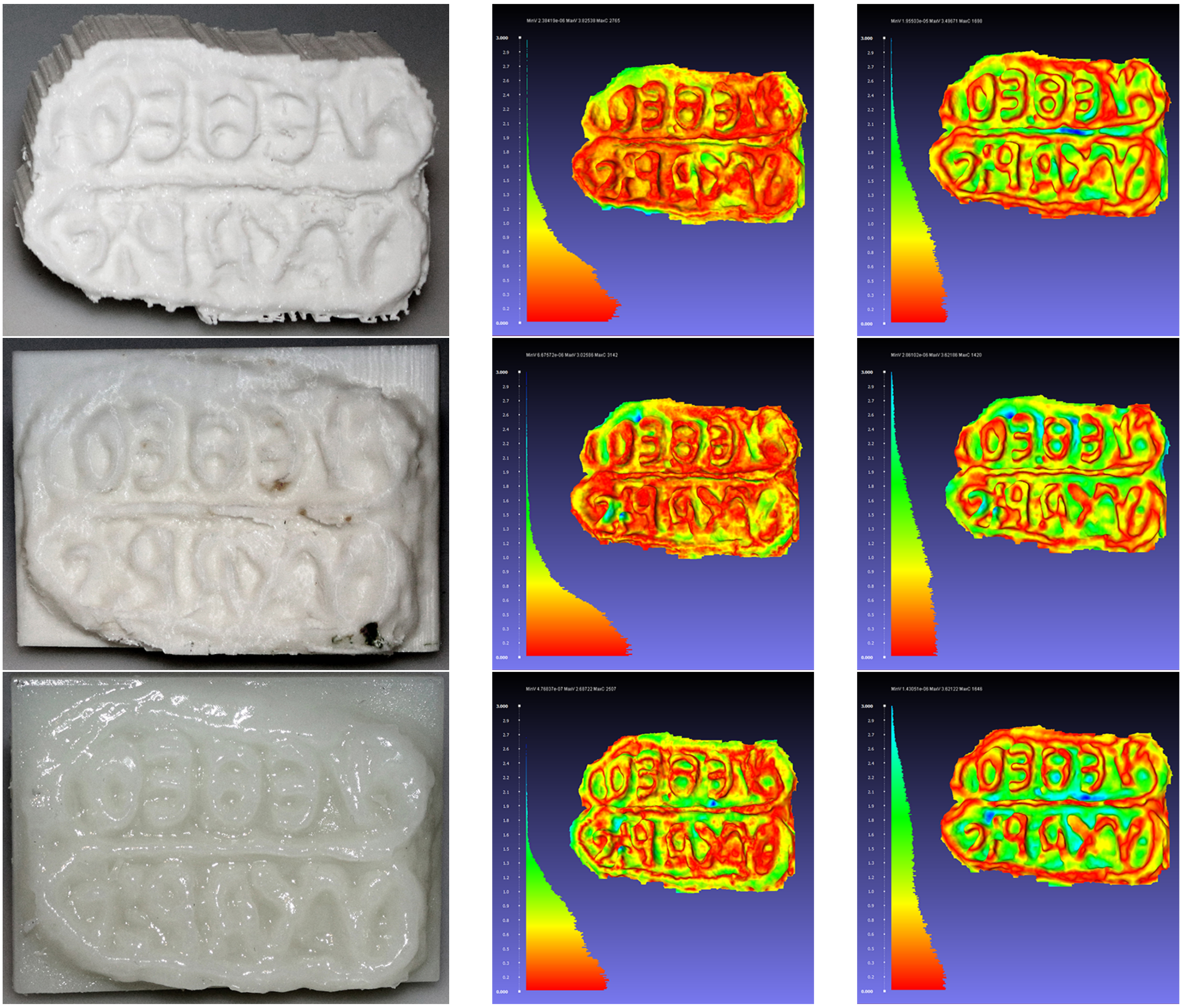

Figure 7: *Computation of Hausdorff distance on print replicas in case A. Photos of the seals are shown in the first column, while the Hausdorff distance between the model of seal and digitization through NextEngine and Sense 3D are shown in the second and third columns, respectively. All the histograms have the same fixed setting: only the Hausdorff distance values from* 0 *to* 3 *are shown, with 256 bins; the width of the bins is normalized between* 0 *and* 3142 *(the highest number of element in a single bin for this experiments).*

missing parts or unknown orientations between seal and print. The digital fit of the meshes is done with the manual alignment tool (for pre-alignment) and Iterative Closest Point (ICP) procedure (for final alignment) through selection of points that look very similar in both models. The search for this kind of matching point represents a more reliable task, if compared to the physical fitting. Potentially, just 3 points are needed for the alignment. However, if more points are found, then alignment will be more accurate. In our experiments we selected 8 matching points for each alignment (Fig. 6). Since these 8 points are manually selected, notice that they may be taken in different parts of the seals than the one depicted in Fig. 6. Whereby it was possible, we preferred points on the boundary of meshes as in real cases details in the middle are often deteriorated and less reliable, while the silhouette of seal is more clearly distinguishable. Indeed, it is easier to say that a circular print cannot be made by a rectangular seal, even if details in the inner part may be very similar.

Then, we apply the filter *Sampling - Hausdorff Distance* between the ROI and the mesh of the seal. The Hausdorff distance is defined as the set of Euclidean distances between paired points of two meshes. In MeshLab this distance is implemented through a sampling of the meshes, in order to obtain paired points [CRS98]. The

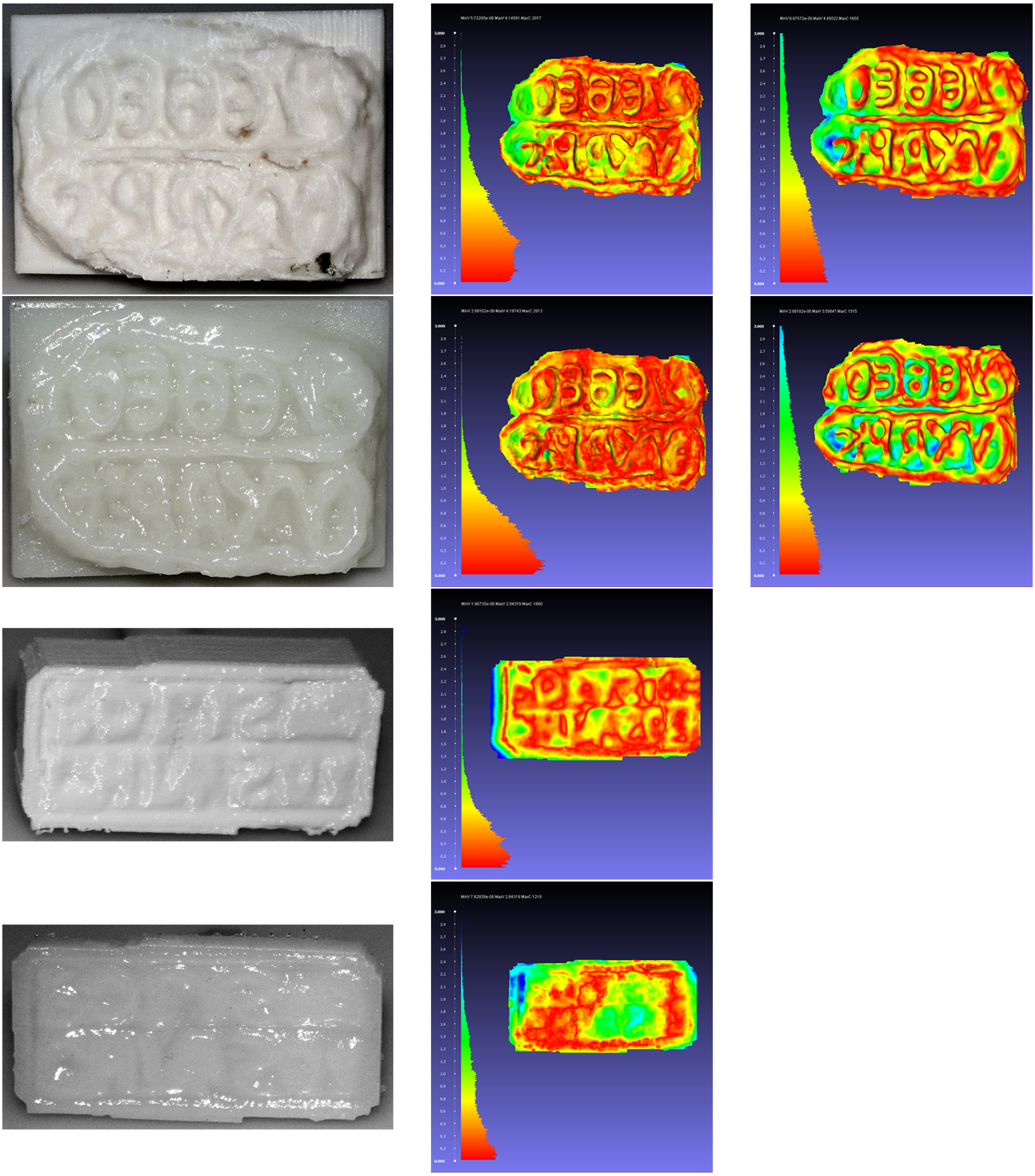

Figure 8: *Computation of Hausdorff distance on print replicas in case B. Photos of the seals are shown in the first column, while the Hausdorff distance between the model of seal and digitization through NextEngine and Sense 3D are shown in the second and third columns, respectively. The last two seals have not been compared with Sense 3D as the digitized meshes have too low quality. All the histograms have the same fixed setting: only the Hausdorff distance values from* 0 *to* 3 *are shown, with* 256 *bins; the width of the bins is normalized between* 0 *and* 3142 *(the highest number of elements in a single bin for this experiments).*

result of the distance computation is named in MeshLab *Quality Vertex* and can be visualized through the *Colorize by Vertex Quality* filter. It is also possible to compute and visualize an histogram of the Quality Vertex values.

One can expect that two meshes that are very similar should obtain an histogram with a peak in the very low-valued bins. In Meshlab a jet color palette is used to represent the normalized Quality Vertex values, with red and blue colors used for high and low values, respectively. We recall that higher Quality Vertex values are obtained where Hausdorff distance is lower, and viceversa. The comparison between 3D models of the seals and 3D scanned meshes of the print replicas is shown in Fig. 7 and 8. However, the Sense 3D scanner has an accuracy that is not capable to acquire the so small details on the surface of print replica of our second seal, hence we were not able to compute the Hausdorff distance of these meshes.

2.5. Discussion about the meshes comparison and Hausdorff distance

In Fig. 7 and 8 we have shown the Hausdorff distance values using histograms colored with a jet colormap (from red to blue colors). All the reported histograms show only the values within the range from 0 to 3, with 256 bins. The width of the bins is normalized between 0 and 3142 (the highest number of elements in a single bin recorded in our experiments). In this way, the histograms are easily visually comparable.

Firstly, we stress the highest Hausdorff distance for meshes acquired by Sense 3D. This is an expected behaviour due to its accuracy equals to $\pm 1mm$. The histograms of the meshes acquired with Sense 3D compared with the ones of the NextEngine are wider and with a lower number of elements in the low-ranked bins.

Secondly, we notice a slight difference between the seals printed in plastic and the ones printed in resin. In particular, the resin seals are more sticky and when used in the process of making print replicas a bit of mortar remains attached on them. This results in print replica being less accurate.

At this point, a discussion about Hausdorff distance is needed. There are several works in literature employing a similar pipeline w.r.t. the one proposed in this work [Rem11, GRAB16, RM15, AGI*16]. We employed this kind of distance in order to assess of what are the parts of a print that are more similar to a seal. The way in which the distance should be used is more oriented to a visual evaluation of the obtained Quality Vertex values. Indeed if the whole mesh has a reddish colorization, then one is able to asses that the two compared meshes are alike (i.e., the match between seal and print is very good). However, the Hausdorff distance should not be used to ensure a match without any other cue. Instead, it should be used to reject clearly mismatch, since it is very unlikely that mismatching prints and seals could obtain the same low-ranked distance values, as the one shown in the reported experiments. For instance, the last model of seal shown in Fig. 8 obtained a nice Quality Vertex colorization of the meshes and some low-ranked values in its histogram. However, it looks hard to assess from a match of this kind if it should be treted as a correct match or a mismatch, but it is possible to state that there is a partial match, at least.

3. Conclusions

The archaeological implications derived from the application of such innovative digital approach for the study of Roman *signacula* are rather significant. However, the test of the protocol on two specimens, even with promising outcomes, requires an extend experimentation period on a larger selection of artifacts. The main goal of creating a virtual edition of *signacula* with 3D models metadata still remains an open option at the top of our research agenda, where extremely important becomes to design a machine learning algorithm for matching 3D meshes automatically in order to drop the manual exercise via the use of the Hausdorff Distance. As future works, we are planning to test and compare other technologies (i.e, RTI imaging) different from the 3D scanning, which has been proved to be difficult for handling data and expensive for needed devices. Another promising way for further investigation is represented by the employment of image processing and visual feature matching techniques based on depth-maps, which may substitute the more complex machine learning approach.

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