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ABOUT QUALITY AND PROPERTIES OF DIGITAL ARTIFACTS

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ABSTRACT

Any form of use of virtual reality or augmented reality in history and archaeology is based on 3D digitized models that are obtained in various ways (3D modeling, 3D scanning, photogrammetry, etc.). These represent virtual replicas of real artifacts/monuments.

In the authors' vision, a digital artifact is represented by the digitized form of a historical artifact/monument. A virtual artifact is a concept that embodies not only the digital form, but also includes metadata, interactive elements, feedback elements, multimedia files, etc. coupled with stereo vision and the ability to interact with them by specific methods involving VR/AR. The quality of the 3D models used in AR/VR applications is influencing the visual experience of the users, and this represents a property of a virtual artifact that can be defined and quantified.

The authors propose the introduction of the maximum permissible deviation term as the unit of measurement for the fidelity of the digitized 3D model. The quality of a 3D model does not depend only on the precision of the instrument/equipment used in the primary digitization phase and subsequent operations but also on operations prior to this step, such as mesh creation, surface creation, solid generation, optimization etc. The quality of the virtual/digital model is influenced not only by the methods used in order to obtain the 3D model, but also by the purpose for which it will be used (level of details are influenced by the limited amount of storage capabilities on some devices – AR).

Other properties of a 3D model will be defined and exemplified, such as the traceability of the digital/virtual artifact, compatibility, interactivity and portability. The case study presented in this paper concerns the study of Dacian civilization from the Orastiei Mountains (the ancestors of the Romanian people) and represents the effort of an interdisciplinary team's work.

KEYWORDS: virtual artifacts, digital artifacts, virtual reality, quality

1. INTRODUCTION

The terms ″digital″ and ″virtual″ are attributes that nowadays are attached to an increasing number of entities in order to indicate their presence in a different than normal (physical) form – presented with the help of computer based technologies and multimedia, "characterized by electronic and especially computerized technology" [Oxforddictionaries, 2013] and stored in the form of numbers 0 and 1.

As presented in "Tangible culture" [Hecher, 2012], cultural heritage institutions (galleries, museums and libraries) use more and more often digital media to present artifacts to their audience and enable them to immerse themselves in a cultural virtual environment [Bonis, B 2009] .

A series of initiatives exist, both at a European as well as at a world-wide level, aimed at taking inventory and at digitally preserving the cultural heritage in either classical electronic form or in 3D format.

Almost every project individually develops its own metadata structure to accompany a virtual/digital artifact but the initiatives that highlight the process and the method in which an artifact should be digitized in 3D format are most often independent and dispersed, as shown in [Cararae, 2013; Ronzino, 2012; Tien-Yu H, 2012; Popovici, 2008].

In this paper we present a series of properties which can be attached to a 3D digital/virtual artifact to record the creation history and traceability of a digital artifact that can be used both in research (digital 3D artifacts) and for the promotion of cultural heritage (virtual 3D artifact).

Digitizing an artifact/monument can be done using several methods [Pavlidis, G, 2010, (Neamtu, et al. 2011,(a)]. The results vary from case to case, but the 3D model's quality should be quantifiable in more ways than just through the number of polygons.

The quality of a 3D model does not depend only on the precision of the instrument/equipment used in the primary digitization phase [Jakubiec, 2010] and subsequent operations but also the post processing operation such as mesh creation, surface creation, solid generation, optimization etc., which can affect the quality of a 3D model.

Using digital models for digital preservation of cultural heritage should be made to ensure that future generations have access to culture and history [Agosti, M., 2013], but these models are classified so that the correspondence between the physical and the virtual artifact can be emphasized through the metadata or quantifiable parameters.

2. DIGITAL AND VIRTUAL ARTIFACT

In the authors vision the digital 3D artifact is a digital replica of a real artifact resulting from a rigorous digitization process through the utilization of scientific methods and instruments.

A 3D digital artifact needs to record a history of all the operations needed for its modeling and to permit the intervention on this data at any moment.

A 3D digital artifact is obtained through digitization that, most of the times, consists of 3D scanning of the real artifact, but other methods can also be employed such as photogrammetry for digitizing an artifact or monument.

The virtual 3D artifact is a 3D model that demonstrates properties specific to virtual reality, that permits interaction by utilizing specific equipment and that can be stereoscopically visualized in an electronically generated environment or in a physical, real-world environment.

A virtual artifact contains attached to the 3D model a series of interactive elements that permit the interaction between it, a virtual or real environment and the user.

This, together with the visualization possibilities, makes the difference between a 3D digital artifact and a virtual one [Neamțu, et al. 2012 (b)].

A virtual artifact should be created starting from a 3D digital artifact that needs to be improved with specific virtual and augmented reality elements.

3. QUALITY OF DIGITAL AND VIRTUAL ARTEFACT

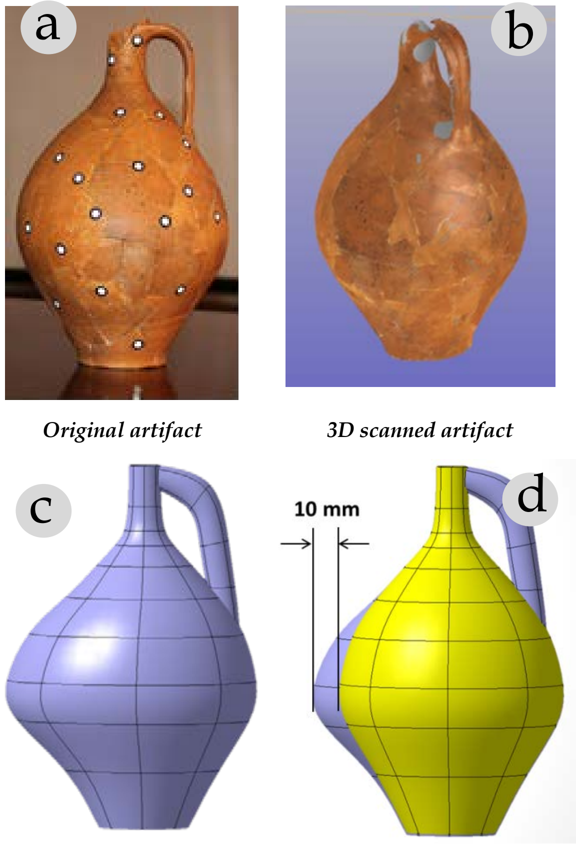
Two wide-spread definitions of quality state that quality is: "proper for use" (Juran, 2010) and "conformity with requirements" (Crosby 1995). If we take the above definition of quality and we try to quantify the quality of a digitized artefact or a virtual artifact we must define what mean "proper for use" and "conformity with requirements". The artifact in digital format can be used in stand-alone applications (VR), VR web based or augmented reality applications. All of them are particular requirement for electronic form of real artifact. Finding a set of descriptors and indicators which can quantify the quality of electronic form of real artifact and store this descriptors / indicators in a set of metadata is a challenge and can be resolved only in a interdisciplinary approach.

The same artifact should be able to be viewed in similar conditions on computers or smart devices using a variety of operating systems (cross-platform).

What does it mean that "conformity with requirements" in case of a digital artifact? What are the requirements and what differentiates an artifact incorrectly digitized from a correctly digitized one? How can digital artifacts be classified based on elements that can remove the subjectivity of the classifier?

These questions and problems can be solved only by identifying a number of parameters of the digitized model that can be uniquely determined and allowing the assignment of a numerical value to the quality of the digitization process.

Digitizing a 3D monument / artifact can be done using several methods but laser scanning is probably the most accurate and wide-spread method that can be used today. Obviously, other methods such as modeling or photogrammetry cannot be ignored, but each may introduce a number of errors that are generated by the methods themselves which are known in the literature. In figure 1 and figure 2 are presented two different types of artifacts: a small one (ceramic vessel) and a bigger one (a landscape with an ancient sanctuary). In case of the ceramic pot presented in figure 1 (a) the dimension of the artifact are 250mmx170mmx170mm and this artifact was digitized using laser scan (figure 1 b)



Original artifact *3D scanned artifact*

3D modeled artifact *Comparison between scanned and modeled artifact*

Figure 1 Digitization of a ceramic vessel

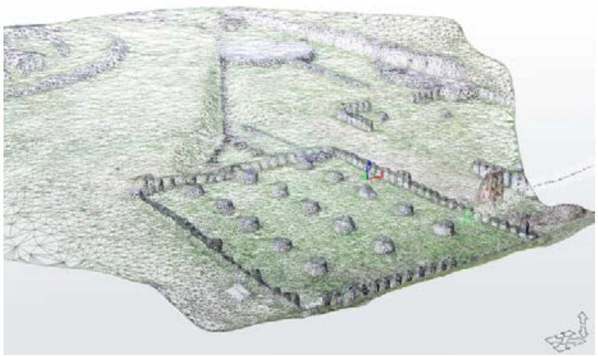


Figure 2 Large landscape digitization (sanctuary of Sarmisegetusa Regia)

The landscape was digitized using photogrammetry. For understand why the precision is important in figure 1 (c), the 3D model of the ceramic pottery was exaggerated deformed and the deviation is presented in figure 1 (d). For this vessel a deviation of 10 mm is visible but for the landscape, 10 mm deviation may be the best result that can be obtained if we take into consideration its dimensions: 80mx20m.

We propose the following set of parameters for quantify the quality of a digital artifact which describes the following properties:

- accuracy and uncertainty of digitization
- traceability
- compatibility and portability
- texture accuracy

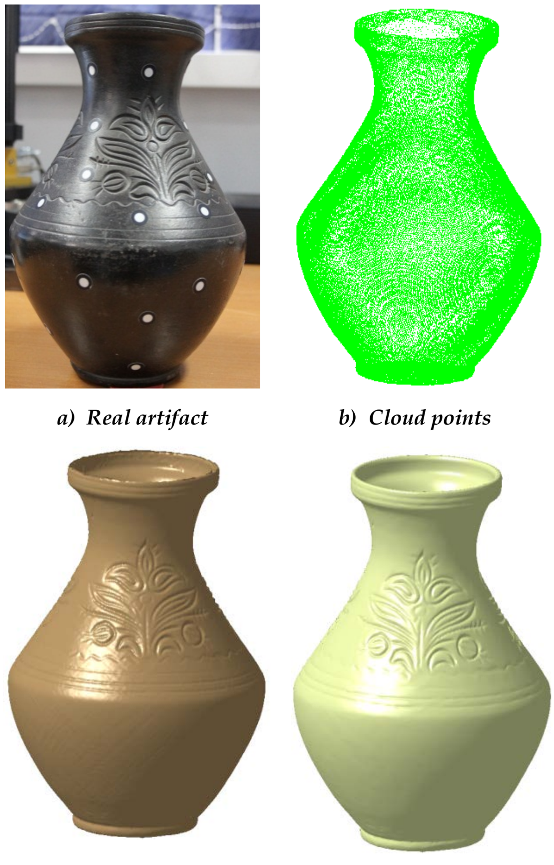
3.1 Accuracy and uncertainty of digitization

In order to measure the accuracy and uncertainty of the digitization process (degree of fidelity), the authors propose the introduction of the term maximum permissible deviation (MPD): a value that highlights the maximum accepted deviation of the digital artifact compared to the real object.

This can be done by comparison between the 3D model and the real artifact through CMM measurement or through scanning.

To determine the deviation of the digitized model from the actual object the steps below must be followed:

- The scans of the actual artifact;
- The point cloud (Figure 3b) is converted into 3D mesh (Figure 3c) and then in surface (Figure 3d) using a CAD software;
- The CAD model is imported into the CMM's (Coordinate Measuring Machine) software for measurement (Figure 4);
- Using the CMM's software the real and the digital models are aligned with the help of established methods (PLP (point – line - plane), best fit, etc.);
- Using the CMM's touch probe and its software points of interest on the real artifact's surface are recorded;



a) Real artifact *b) Cloud points*

c) 3D Mesh *d) 3D Surface*

Figure 3 Ceramic pottery digitization steps

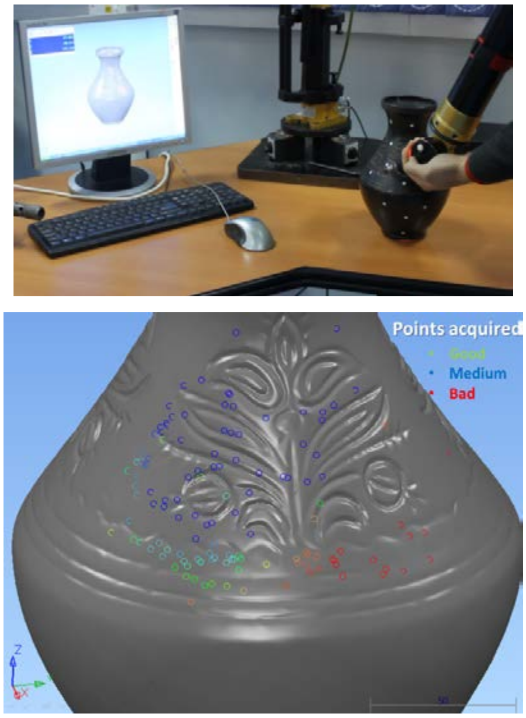


Figure 4 Comparison of real model with CAD model: top – procedure of points acquisition using CMM, bottom – graphical display of deviation

- Using the CMM's software the standard deviation is calculated between the real and the digital artifact (Figure 5).

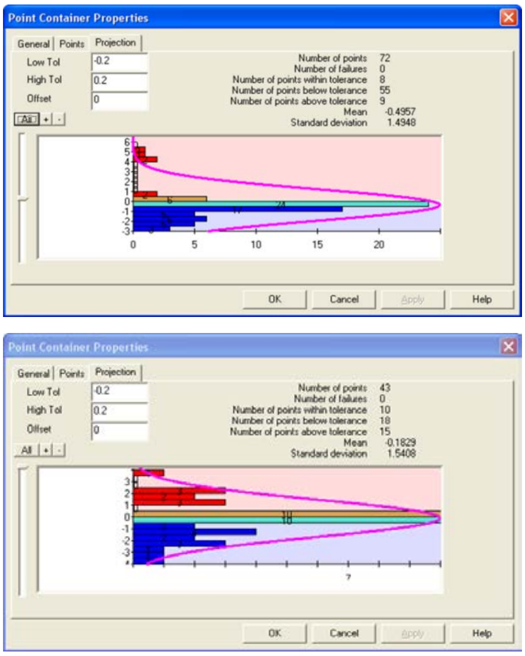


Figure 5 Graphic representation of point's deviation using Histogram

After comparing the CAD model to the real one, the value for the standard deviation is obtained. Next using a CAD tool (Deviation Analysis) we can check deviations recorded in each stage of the process of obtaining the CAD model.

Thus the comparison of the two CAD models (e.g. the point cloud and mesh / surface) results in a deviation color map as presented in figure 6.

Using the same instrument (Deviation Analysis) the differences between 3D models obtained by various methods of digitization can be determined, as shown in the figure 7.

3.2 Traceability

The authors define traceability of the 3D digital artifact as its property to keep track of all operations that led to its creation and also of initial elements in their unaltered state - from point cloud to final model generation.

If a digitized artifact keeps a documented history of operations used to generate it, any operation can be analyzed later and can be optimized in order to improve them with new technologies and algorithms for generating 3D models.

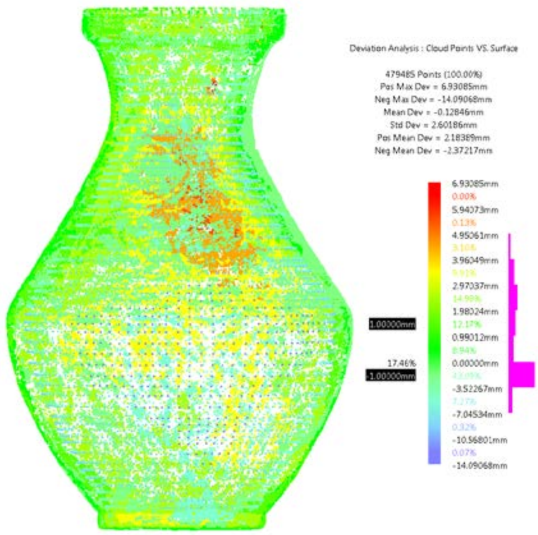


Figure 6 Deviation Analysis for two CAD models: point cloud and surface

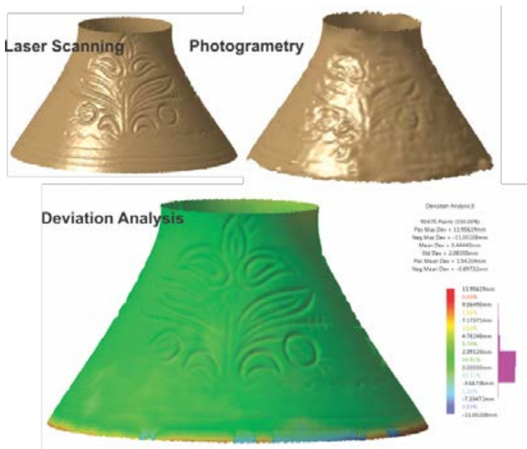


Figure 7 Deviation Analysis for two CAD models: point cloud and surface

In general CAD software allows operation history preservation [Neamțu, et al. 2012], in the form of an organized tree, in Parent - Child structures (figure 8), in some situations, the operations can be sorted according to type, and not only in the order of their occurrence.

Figure 8 shows the reconstruction of a ceramic vessel, in which the digitized fragments are clearly highlighted in both the textured and CAD model. For each scanned fragment distinct groups of wireframe elements (symmetry axis, boundary), surfaces or solids are created.

Universal 3D formats (*.igs, *.stp, *.stl, *.u3d, etc.) are not capable of preserving the history of all necessary operations for 3D model creation, but they ensure the compatibility between different software platforms. But the 3D digital artifact model should be made available in these formats, in order for it to be used in applications, other than the ones in which it was built.

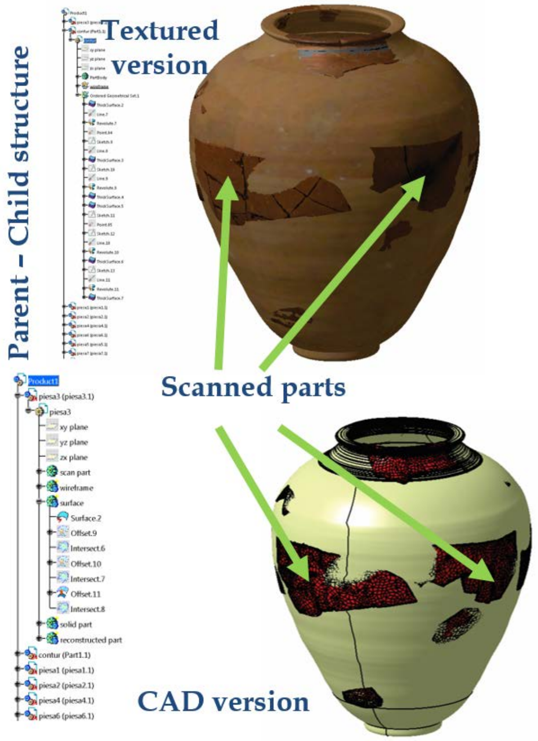


Figure 8 Reconstruction of a Dacian storage vessel (chiup)

To assess the traceability of a digital artifact the authors propose using a set of descriptors associated with this property. The ranking of these descriptors was establishing using AHP method (Analytically Hierarchy Process) – figure 9.

In table 1 is presented the ranking of descriptors resulted from AHP, classified in five categories: cloud points, mesh, wireframe, surface and solid.

3.3 Compatibility and portability

Compatibility and portability of a 3D digital artifact can be defined as the properties that enable the model to be viewed and modified at all times, in a cross - platform way.

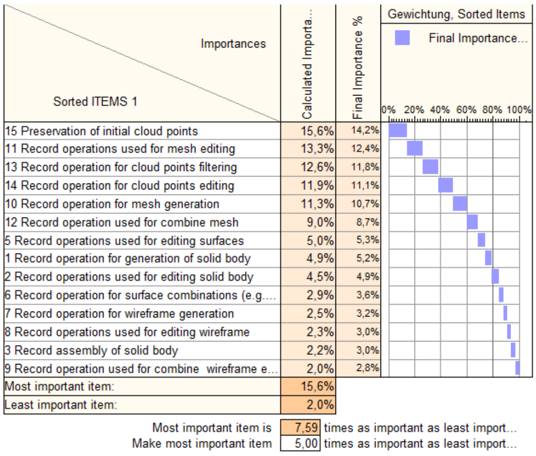


Figure 9 Using AHP method for establishing the degree of importance for descriptors of traceability

Table 1. Descriptors for traceability

Element	Descriptor	Points
Solid	Record operation for generation of solid body	4.9
	Record operations used for editing solid body	4.5
	Record assembly of solid body	2.2
Surface	Record operation for generation of surfaces	5
	Record operations used for editing surfaces	5
	Record operation for surface combinations (e.g. Split, Join, etc.)	2.9
Wireframe	Record operation for wireframe generation	2.5
	Record operations used for editing wireframe	2.3
	Record operation used for combine wireframe elements	2
Mesh	Record operation for mesh generation	11.3
	Record operations used for mesh editing	13.3
	Record operation used for combine mesh	9
Cloud Points	Record operation for cloud points filtering	12.6
	Record operation for cloud points editing	11.9
	Preservation of initial cloud points	15.6

Cross – platform means using different operating systems and hardware configurations for both computers (Figure 9 top) and for smart devices (Figure 9 bottom).

Thus, a 3D digital artifact should ensure the possibility to be viewed (and edited if it is possible), by using different software from the one it was created in, even if the history of all necessary operations for its creation cannot be preserved (when transferring the 3D model, using standard CAD formats).

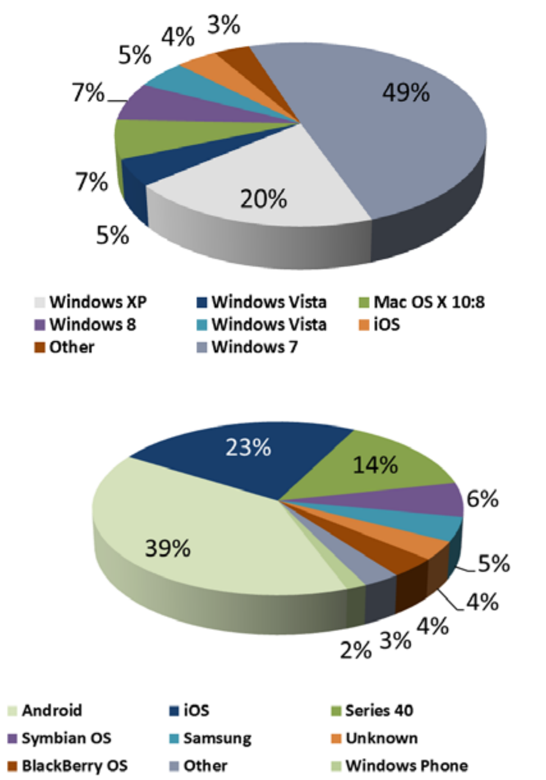


Figure 10 Distribution of operating system (OS) for computers (top) and for smart devices

Using standardized formats for 3D models it is possible that the digitized artifact can be viewed on various hardware and software configurations. Another problem to be solved is how to view a model with older or newer versions (of software) than the one that created the initial file. For example the files with the extension *.IGES (Digital Representation for Communication of Product Definition Data), which began to be standardized in 1980 (U.S. National Bureau of Standards - NBSIR 80-1978), can be used for 3D data manipulation on most common OS and CAD software and maybe is the most used 3D format for sharing 3D models between CAD platforms.

To assess the compatibility and portability the authors propose a quantitative assessment based on the number of CAD formats in which the 3D model can be exported, directly from the application in which it was generated.

3.4 Texture accuracy

Texture is the element that gives the visual appearance of digital artifacts. Texturing a 3D model can be done by mapping or when scanning using a color laser during the digitization process. Faithful representation of the texture can provide important information not only about color, pigment or painting technique but also in terms of the method with which the vessel was created, the quality of the material or the burn process.

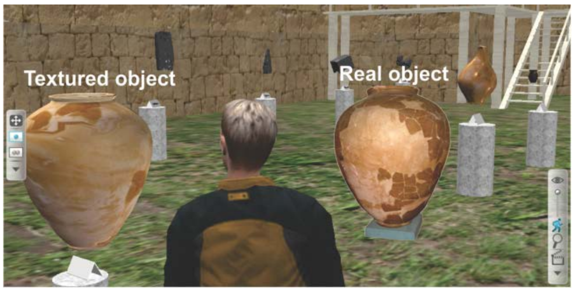


Figure 11 Difference between real and digital textured model (top) and UV map texture for pottery (bottom)

Mapping a simple photograph onto the 3D model may not lead to the best result (Figure 11). Using a more advanced method like UV texture mapping (Cube mapping, MIP maps, etc.) which associates each pixel to each physical area of the artifact can lead to better results.

Another method for automatic association between the 3D model and texture is laser scanning of the artifacts. This method usually creates automatic mapping using UV or UVW methods. Also photogrammetry techniques can yield satisfactory results as shown in Figure 12.

Figure 12 Melancholic Roman (Delphi Archaeological Museum): digital model obtained using photogrammetry (left) and real artifact (right)

Evaluation for the texture in terms of quality is quite difficult because, its quality is directly influenced by the method of acquisition, lighting conditions, or equipment used in the process.

For an objective evaluation of this, the authors believe that a minimum number of parameters must be known so that subsequent processing of color can be made on the basis of measured parameters during data acquisition.

Table 2. Descriptors for texture accuracy

Parameter	Value
Equipment type	Cannon D550
Software version	1.0.9
Lens	18-55mm
Exposure Time	1/30sec
Resolution	18Mpx
Luminous intensity	18600 lux
ISO	160

Because in both cases, for laser scanners that can acquire texture and other equipment, the texture is acquired through an optical sensor. The parameters describing the acquisition of a texture should reflect its quality and the environmental conditions in which the data acquisition was made as shown in Table 2.

4. CONCLUSION AND FUTURE WORK

In this paper the authors propose a set of metadata that help define and establish the technical quality of digital artifacts.

The notion of quality of a historical or cultural artifact in the approach of this paper refers only to the quality of digitization and digital processing of the artifact and does not consider their historical or artistic qualities.

Documenting the technical quality of a historical artifact is very important in terms of long-term preservation, so that in the long-term the digitization of a historical artifact ensures the preservation of accurate information about it even if the actual artifact suffers degradation or irreversible damage.

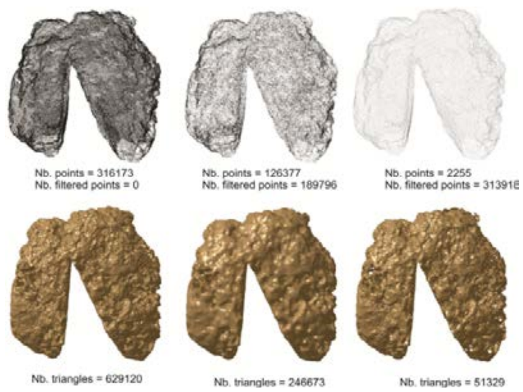


Figure 13 Points filtering and mesh generation, versus CAD Deviation Analysis in case of Dacian iron artifact

Parameters chosen by the authors to describe the technical quality of a digital artifact are descriptors that can be calculated mathematically (standard deviation where accuracy and uncertainty of digitization) or can be physically determined (traceability or texture accuracy).

The term of maximum permissible limit of deviation (MPD) is inserted: a value that highlights the maximum accepted deviation of the digital artifact compared to the real one and two methods are presented which permit the determination using measurement with CMM or with Deviation Analysis with a CAD instrument (Figure 13).

From the point of view of long-term preservation techniques we can attempt to determine some parameters that describe the technical quality of a digitized artifact.

The number of points and triangles can provide an overview regarding the fidelity of the digitized surface (Figure 12) but how can the size of those triangles affect the quality of the artifact and the file size space required.

The authors identified a number of issues which still need to be researched and for which they are still seeking solutions. One of the research directions is trying to answer the questions: How to measure texture mapping?

How to measure the quality of a texture in comparison with the real texture of an artifact?

The authors try to establish a procedure or a formula in the form of:

$Q= (R_{eqp} + \mu + S_{tdev} + \ldots) / (\ldots)$

where:

- R_{eqp} - resolution of equipment,
- μ - uncertainty of digitization process,
- S_{tdev} - standard deviation of the final model from scan result,
- ….. – other parameters.

This approach attempts to determine a mathematical formula to comprise more parameters and to provide a single score for the technical quality of an artifact.

From the point of view of the traceability of a digital artifact, the recording of all the necessary operations needed for its creation will allow in the future the reinterpretation of this data using new algorithms to generate the 3D models.

Ensuring the compatibility and portability should be a requirement for digital artifacts because modern technology (hardware and software) is very diversified and has a rapid rate of development.

The availability in digital format of an artifact for researchers and general public is an objective which must be bore in mind when digitization is fulfill. As shown in [Forte, M. 2011], there is a strong gap between data capturing and data accessibility, which in our opinion can be decreased if we define compatibility and portability as property of digital artifact. This two property can be evaluated and measured and can be an indicator for accessibility to the digital and virtual form of an artifact.

The texture of a digital artifact is probably as important as the 3D shape when it transmits artistic or historical information. The digital preservation and the correct overlay over on the 3D model are very important considering the time and the conditions of exposure or storage of historical artifacts which invariably affects the texture over time.

Attaching some information regarding the acquisition manner of the texture in digital format and properties of the sensor used may allow subsequent preparation of the digital texture in a way in which the *.raw format (called also digital negative) allows intervention on light intensity and color of the scene.

The measurement of digitization precision of the texture can be a very laborious and expensive process that at this time is practically impossible to do for each digitized artifact.

Therefore, the authors propose attaching a data set that allows recreating the conditions in which the texture was digitized in the idea that in the future these conditions could be recreated in the virtual environment and the texture will be corrected if necessary.

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