METHODOLOGY TO CREATE DIGITAL AND VIRTUAL 3D ARTEFACTS IN ARCHAEOLOGY

Abstract: The paper presents a methodology to create 3D digital and virtual artefacts in the field of archaeology using CAD software solution. The methodology includes the following steps: the digitalization process, the digital restoration and the dissemination process within a virtual environment. The resulted 3D digital artefacts have to be created in files formats that are compatible with a large variety of operating systems and hardware configurations such as: computers, graphic tablets and smartphones. The compatibility and portability of these 3D file formats has led to a series of quality related compromises to the 3D models in order to integrate them on in a wide variety of application that are running on different hardware configurations. The paper illustrates multiple virtual reality and augmented reality application that make use of the virtual 3D artefacts that have been generated using this methodology.
Keywords: *digital artefacts, virtual artefacts, digitization, 3D laser scanning, archaeology*

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INTRODUCTION

There are multiple both at a European and global level that are aimed at taking initiative in order to digitally preserving cultural heritage assets around the world. Almost all cultural heritage preservation projects have individually developed their own metadata structure for their virtual/digital artefact. This paper proposes a methodology that can be used to create 3D digital/virtual artefact that are documented with a detailed history and traceability information regarding the whole digitization process. This information is very valuable and it can be used both in research (regarding the artefacts) and in the various dissemination processes regarding the cultural heritage assets (using the virtual 3D artefacts). The digitization process can be done using diverse methods and equipment but the end result should be 3D quality model and this quality should be quantifiable in more ways than just through the number of vertices of the resulting model. As a result of numerous case studies conducted in collaboration with the National History Museum of Transylvania and Museum of Dacian and Roman Civilization the authors have identified a series of parameters which should be attached to a 3D model in order to transform it into a digital or virtual artefact.

As presented in Civantos[1], cultural heritage institutions (galleries, museums and libraries) are starting to use more often digital media to present their artefacts to their audience and enable them to immerse themselves in a cultural virtual world.

The terms ”digital” and ”virtual” are attributes that nowadays are

[1] CIVANTOS 2012.

attached to an increasing number of entities in order to indicate their presence in a different from than their normal (physical) form. These types of artefacts are being visualized with the help of different computer vision technologies[2] and are stored within a digital storage system.

Digital cultural heritage and digital archaeology are terms that refer to the utilization of ICT within these domains starting with the digitization and virtual reconstruction of the cultural heritage[3] and stretching towards the dissemination process using different digital media[4] systems.

The objectives of the digitizing process of an artefact or a historical monument can vary and may include the following elements:

Documenting the state of fact for an artefact/ monument;

Digital reconstruction of missing components;

To create real life scale replicas;

To digital preserve the cultural heritage asset.

Through diverse initiatives, a series of digital libraries have been created. These libraries contain a large amount of digital and virtual artefacts, and the majority of these libraries are aimed at preserving and disseminating the artefacts in various accessible formats a wide audience using internet browsers. One of the largest collections of 3D digitized cultural heritage assets can be found on the europeana.eu platform.

DIGITAL AND VIRTUAL 3D ARTEFACT IN ARCHAEOLOGY

According to Oxford English Dictionary, the definition of an artefact is an object made by a human being, typically one of cultural or historical interest, or something observed in a scientific investigation or experiment that is not naturally present but occurs as a result of the preparative or investigative procedure.

A Digital 3D artefact represents a digital replica of a real artefact that has resulted from a rigorous digitization process through the use of different equipment and processing methods[5]. In the authors vision a 3D digital artefact needs to maintain a history of all the operations used to obtain the shape and texture of the artefact and to permit the intervention on this data at any moment in cases different changes would be required. Also all the data acquired in the digitization process must be attached to the digital artefact for long term preservation and future post processing stages.

A virtual 3D artefact is a derivative form of 3D digital artefact but it shows the information strictly related to the form and texture of a 3D model. The information attached to a virtual 3D artefact is presented in an interactive way and can contain animations and simulations. These virtual artefacts can use different user interaction interfaces such as tracking systems or haptic devices. A virtual 3D artefact also represents a model that has been processed in order to establish a good compatibility and portability of the file to ensure that it can be used multiple VR equipment such as 3D projection systems, smart glasses, VR headsets, etc.

METHODOLOGY

Based on their knowledge and experience, the authors have developed a methodology for the digitization and reconstruction of archaeological cultural heritage artefacts (Figure 1), which has been validated through a large number of case studies. Within the DACIT project over 500 Dacian artefacts including pottery, iron tools, ceramic tiles and other artefacts have been digitized using this algorithm. The methodology is aimed at obtaining 3D models that can be used both in research activities and in various dissemination digital applications that enables the users to interact with the digital content. The processed artefacts can be used either as standalone 3DPDF files or they can be added to virtual reality and augmented environments. They can be hosted and published to 3D sharing platforms such as 3dvia or Sketchfab.

The first step in creating a digital artefact is the digitization process. This step can be done using different methods and equipment such as: 3D scanning[6], photogrammetry[7] and 3D modeling[8]. A cultural heritage artefact can be digitized using different methods, but the most important aspect in choosing the proper method is related to the precision of the method. The process has to ensure that the 3D digital model represents a digital replica of the real artefact in terms of shape, colour and texture. Every method needs to be carefully chosen and applied in relation to the material and the real artefact's condition. Therefore fragile objects (such as clay, ceramic, glass) will not be scanned using contact scanning; and the scanning process of using positioning targets is not recommended for of painted artefacts.

The digitization method directly influences the results and probably the most important digitization parameter: which is the fidelity of the generated 3D model. Figure 2 presents the case of a ceramic pipe used in the distribution of drinkable water. The pipe was discovered in the Sarmisegetuza Regia archaeological site during the 2012 excavation campaign. For the digitization process, a laser scanning solution from the handheld portable scanner category was chosen. After the digitizing step has been finished, the processed 3D models has been imported within a CAD solution which has been used to determine the inclination and circularity deviation of the four pipe segments. This step has enable the possibility to create the preliminary conclusions related to the fabrication method used for the segments and their joining method, as well as making a FEA analysis of the pipe resistance using the characteristic of the sample material. In the presented case, a CT scanning would have permitted the possibility to obtain the thickness of the wall throughout the whole length of the pipe system and highlighting possible problems with the homogeneity of the material of the pipe. Unfortunately using CT scanners in remote archaeological sites does not

2 OXFORD 2016.
3 ONG 2010; SALONIA *et alii* 2007; OUDATZI 2010; CHOI/YI 2012.
4 GUARNIERI *et alii* 2010; BRUNO *et alii* 2010; ROBLES *et alii* 2012; NÚÑEZ 2012.
5 NEAMTU *et alii* 2014.
6 ONG 2010; SALONIA *et alii* 2007; HINZEN/SCHREIBER/ROSELLEN 2013.
7 LERONES *et alii* 2010.
8 NEAMTU/POPESCU/MATEESCU 2011.

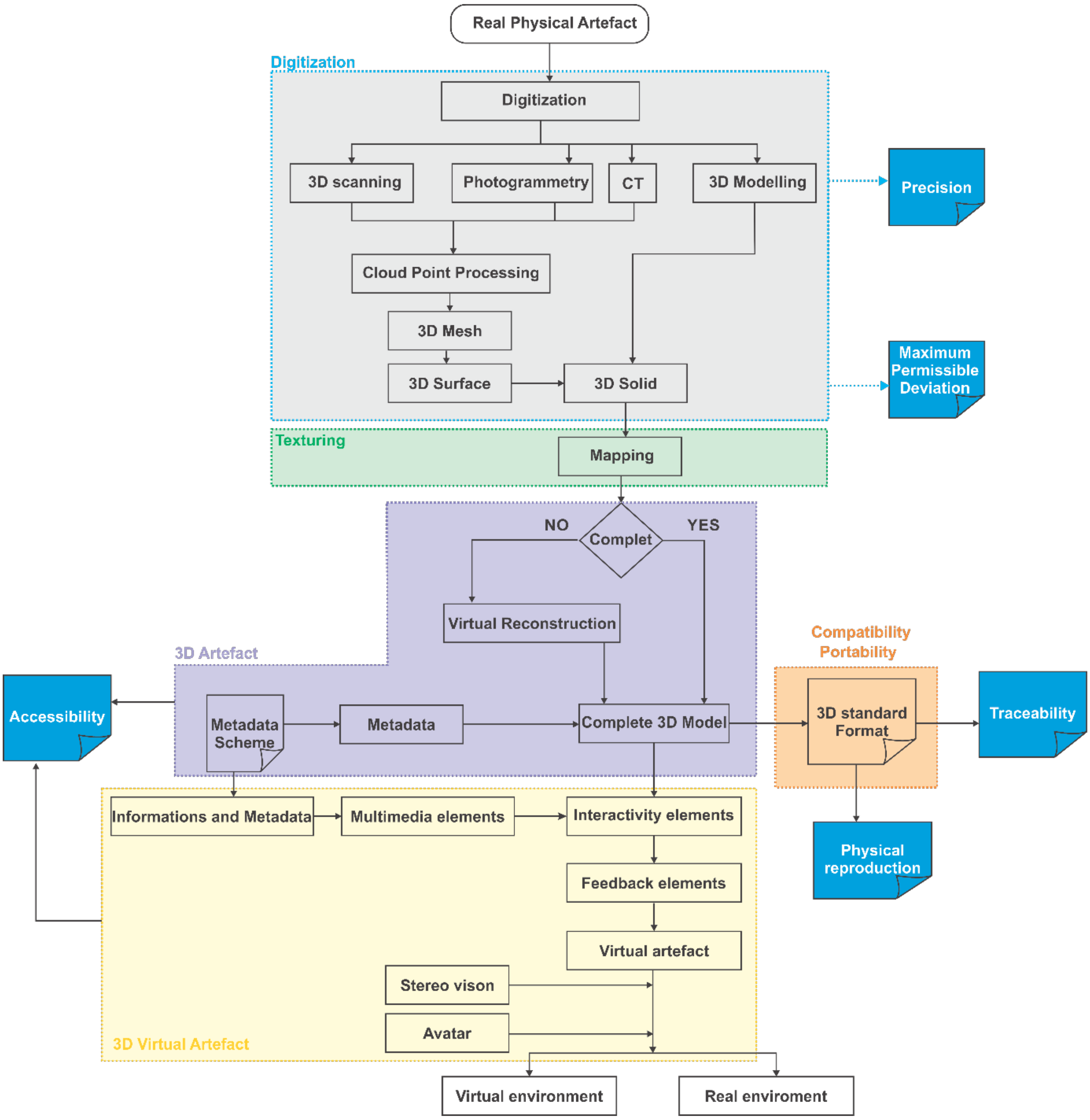

Figure 1. The algorithm used to create digital and virtual 3D artefact.

represent a viable solution using the current state of these scanners.

The result of scanning and photogrammetry consists of a point cloud or a mesh that needs to be processed. The processing consists usually in removing residual points and filtering the point cloud. The filtering can use a number of filters (homogenous, adaptive, etc.) and has the purpose to reduce the number of points in order to ease the subsequent

Figure 2. Laser digitization on site (left) and the resulted 3D model (right).

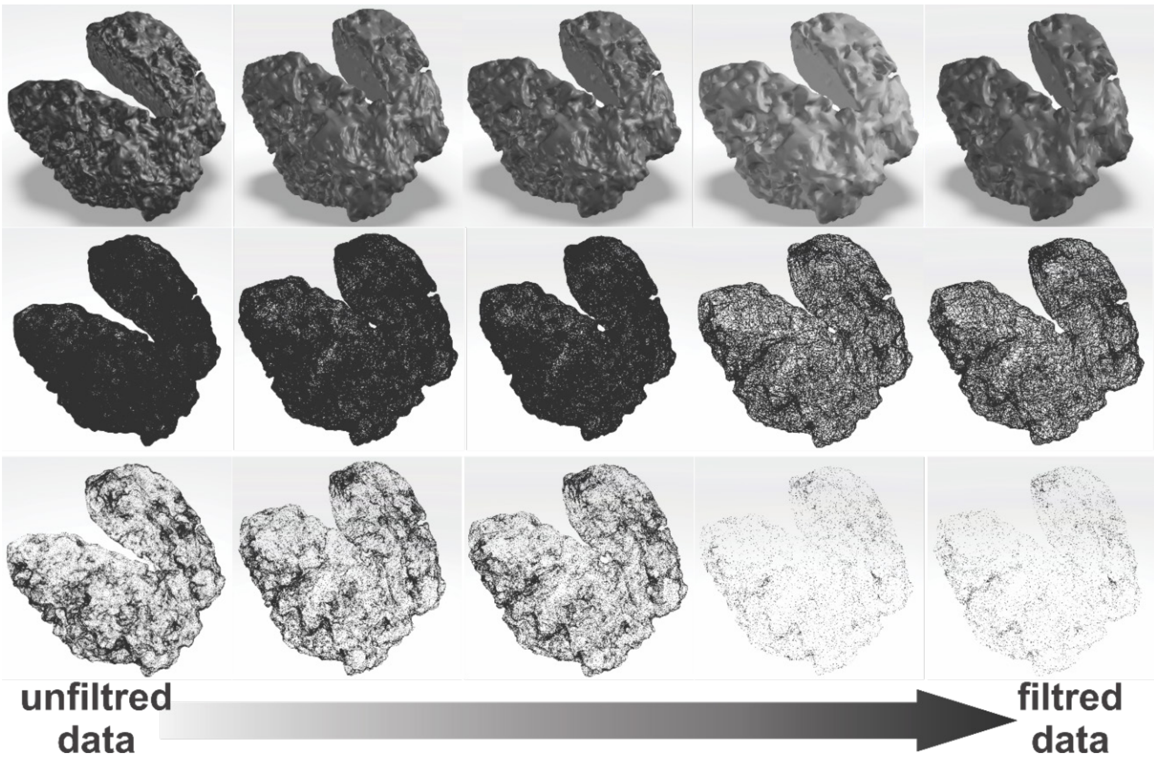

Figure 3. Cloud point filtering and their different results.

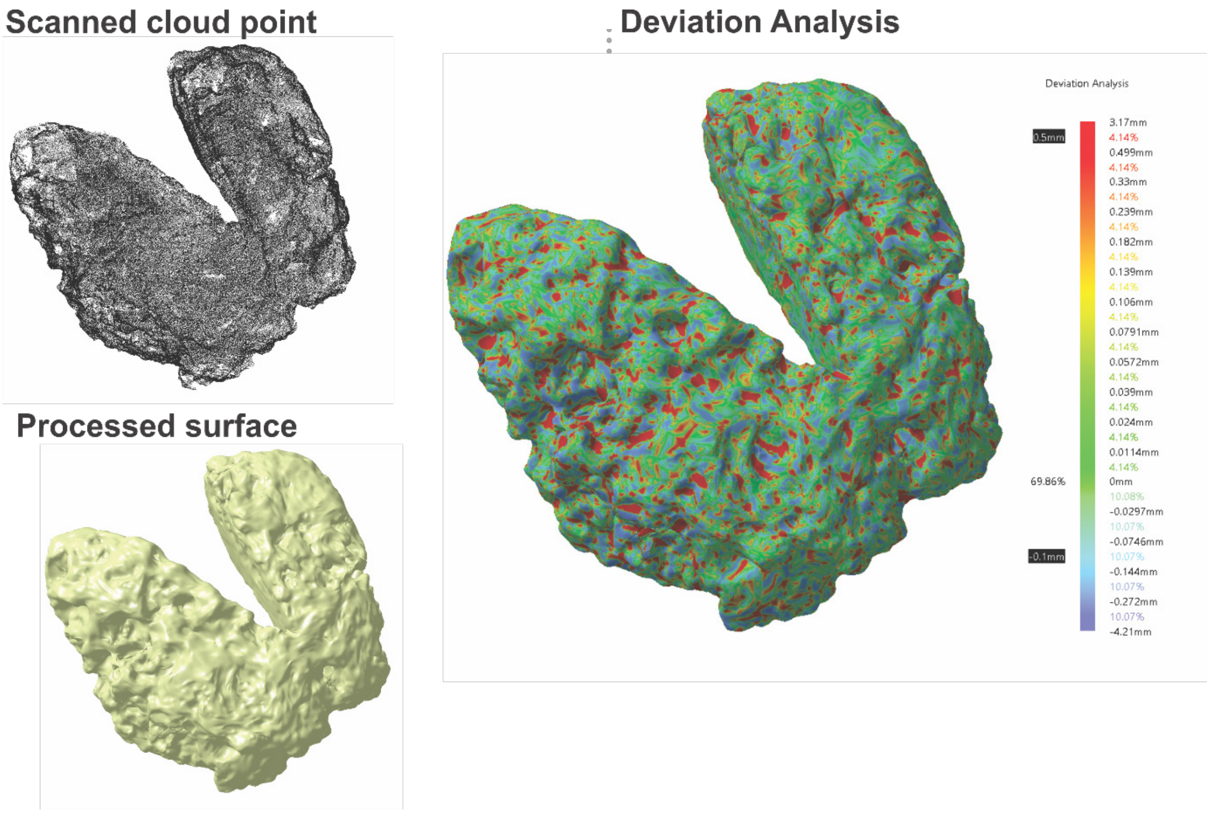

Figure 4. Deviation Analysis between the processed and initial scanned models.

processing. Choosing incorrectly the filter can result in the decrease in fidelity of the 3D model. Figure 3 illustrates the same artefact that has been filtered using different parameters. The details regarding the surface of the heavy filtered 3D model are significantly reduced.

In order to measure the degree of fidelity of a digitization process, the authors propose the introduction of the term maximum permissible deviation (MPD): a value that highlights the maximum accepted deviation of the digital artefact compared to the real one. This term

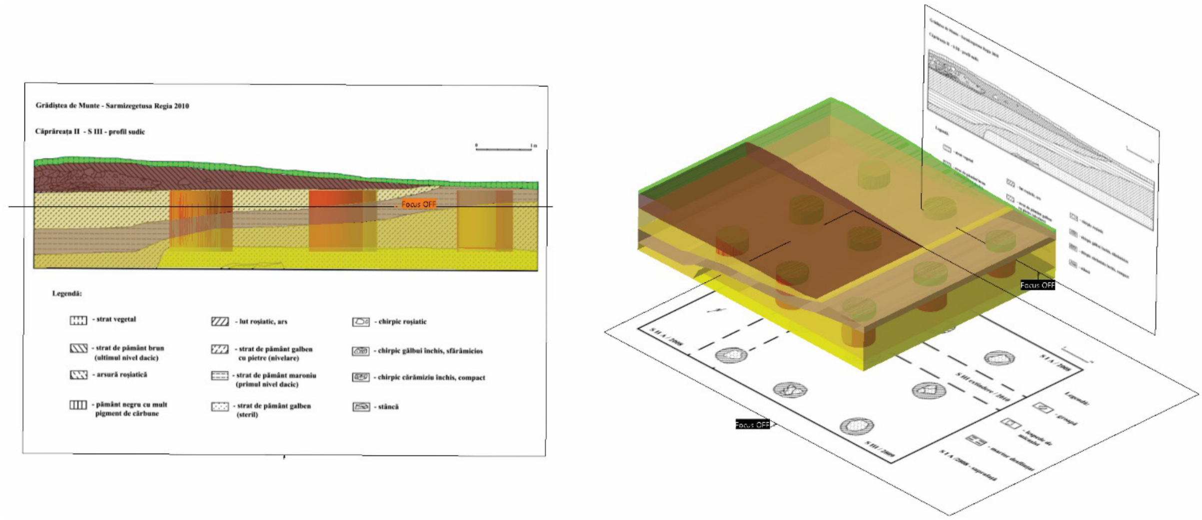

Figure 5. Using 3D modeling as a tool to digitize archaeological excavations.

Figure 6. Roman ceramic pottery photograph (a), digitized model (b), parametric UV Map (c).

was presented in[9] as a tool for describing the quality of a digital artefact. In order to obtain the value of the MPD parameter a comparison has to be done between the 3D model and the real artefact through the use of a CMM measurement equipment or through scanning and utilizing a CAD model (CAD deviation analysis). Figure 4 illustrates two comparative analyses between CAD models that were obtained after using different 3D mesh filtering parameters and the CAD models obtained from the initial point cloud without filtering. The deviations are illustrated using a colour map and numerical values.

When using 3D modelling as a digitizing method, the quality of a 3D model is directly proportional to the quality and quantity of information used during the modelling process. Therefore when dealing with simple artefacts, traditional measuring instruments such as callipers and micrometres can be used to measure the artefact or monument and add those values to the 3D model.

3D modelling is the only viable solution that can also be used to digitize elements that are no longer available. Their current availability is influenced by different reasons such as damaged/incomplete artefacts, stolen artefacts or older excavations that are no longer available. Figure 5 describes the digitization process of an archaeological excavation; the high or low fidelity of the CAD model mainly depends on the precision by which the field drawings were measured and created.

The 3D texturing represents the next step within the proposed methodology. Many texture mapping techniques can be used[10]; but lately the 3D scanning systems have the capacity to simultaneously scan 3D shapes and their texture at the same time. Texturing is not only aesthetic, it also provides artistic information regarding an artefact, and that is why it should be given special consideration. Figure

9 NEAMTU 2014.

10 TRINCHÃO ANDRADE/BELLON/SILVA/VRUBEL 2010.

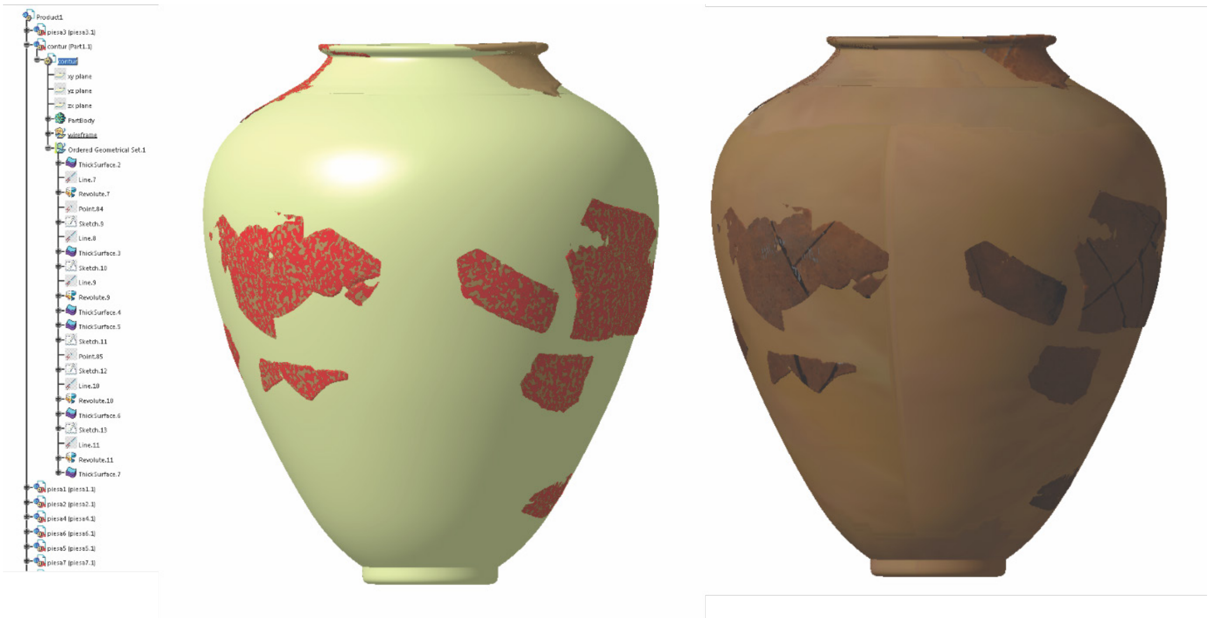

Figure 7. Traceability using the history of operation of the 3D model (left), the 3D digital model of Dacian ceramic vessel without texture to highlight the difference between the original parts and reconstructed parts (middle) and the final reconstruction with texture (right).

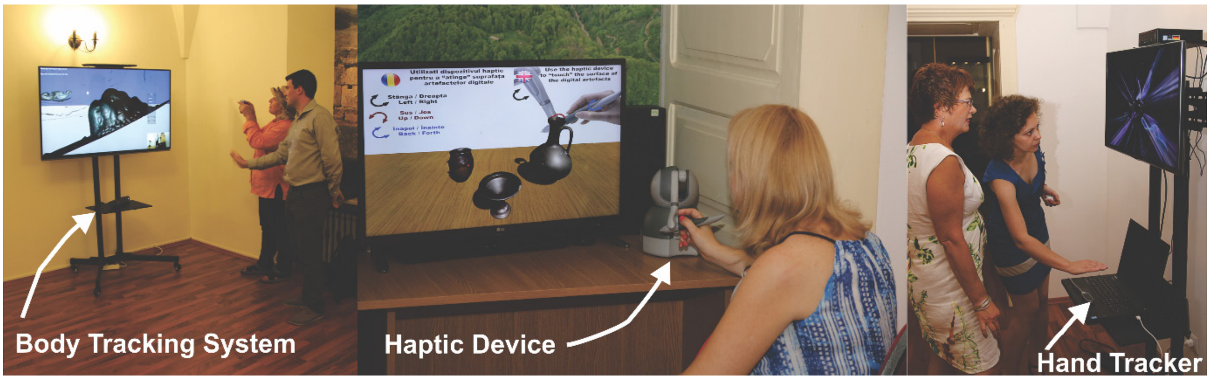

Figure 8. Interaction possibilities with a digital artefact.

6 illustrates a photograph of a ceramic pot (a) and the 3D model (b) resulted during the 3D scanning process that can acquire the texture as well as the geometry of a real life object. The laser scanning solution used is capable of generating a parameterized UV map (c) of the digitized object.

The next step of the proposed methodology in this paper involves generating a 3D model. A 3D model can be directly generated from the data acquired by the scanner for artefacts that are not fragmented. The fragmented / incomplete artefacts are required to enter in an additional digital reconstruction phase.

All generated 3D models must come with a history of all necessary operations that have been done in order to obtain them and should create a clear distinction between the original scanned elements and the reconstructed elements. It is important to have the 3D model generated in a CAD solution that allow to record and store all operations that have been done within the software solution to the 3D model (Figure 7). Transforming a point cloud model acquired by a scanner into a solid model involves operations which make use of a series of approximations that involve the transformation of a 3D point clouds into surfaces. Within CAD software solutions each operation is editable at any time, therefore after the 3D model has been processed it is possible to change the parameters used to define the shape of the 3D model. The operation described above can be grouped under the traceability name tag and are stored within the 3D model in the CAD application.

Portable 3D file formats such as .igs, .stp, .stl and u3detc are not equipped with the capacity to preserve history of all necessary operations within the same 3D file format, but they ensure compatibility between different software platforms. **Compatibility and portability** of a 3D digital artefact model can be defined as the properties that enable the model to be imported and modified anytime between multiple cross-platform software solutions.

The **availability** of a 3D digital artefact refers to the possibilities of visualizing the same shape and texture even when different hardware and software solutions and systems are being used.

There are multiple Metadata (“data about data”)

Figure 9. Virtual artefact multimedia interactivity elements.

schemes that can be used such as: Europeana[11], Dublin Core Metadata[12], Encoded Archival Description[13], etc. Based on the metadata information there can be created various auxiliary support materials which then can be used to create the virtual artefact. The main difference between a digital and a virtual artefact is the presence of multimedia, interactivity and feedback elements. Thus a virtual artefact can provide additional information to a user either on request using various digital elements such as text, images, animations, simulations, multimedia clips, etc. The user can interact with a virtual artefact using classical devices (mouse, 3D mouse, keyboard) but also through natural gestures using tracking systems or using haptic devices (Figure 8).

The **interactivity** of a virtual artefact refers to the possible interaction elements that can be done by a user to interact with the digital content. There are multiple interactive elements that can perform the following two functions:

- Informational - provides additional information and metadata when the user is requesting this
- Feedback - virtual artefacts have the ability to offer feedback through haptic devices and other devices specific to virtual reality environments (trackers, glove, etc.).

The figure below highlights a 3D model of virtual artefact (ancient anvil) located in a digitally reconstructed virtual environment. The 3D Model generated using laser scanning technology is enhanced with the following elements (Figure 9):

- visual interaction elements - Transparency, Rotate, Exploded View
- Multimedia: Video, Animation, Presentation, Audio.
- Resources: Annotation, Quizzes, Hyperlink.
- Stereo 3D: Interleaved, Top and Bottom, Frame Sequential.

Besides the items listed above a virtual artefact can be prepared for force-feedback simulations, in the case presented above it is possible to manipulate the objects using a VR glove, and to touch the 3D digital model using haptic device and obtaining some additional information from an avatar (Figure 10).

A virtual artefact can be placed in either a virtual reality application or in mixed augmented reality application, these types of applications are currently being used in different cultural institutions as shown in CHOI[14]. The most popular augmented reality applications are used on touch screen devices such as smartphones or tablets. Because the processing capabilities of these devices are limited, the 3D models are being optimized by reducing the number of vertices that defined the shape of the 3D model.

RESULTS

Using the methodology presented in this paper more than 500 artefact were digitized using laser and structured light scanners. The digital and virtual artefacts are used in various applications and they are stored in online databases such as Europeana and Sketchfab. The Digitized artefacts can be accessed within the DACIT project database (dacit.utcluj.ro). All the models are available as standalone 3DPDF files and 3D models embedded from the Sketchfab platform. The models have metadata information attached to each individual model in accordance with the EDM model system (Europeana Data Model). The 3D models obtained have a very precise dimensional resolution and detailed texture maps as illustrated in Figure 11.

The Virtual artefacts have been used in virtual reality applications developed in Unity software solution for different types of hardware equipment such as haptic device, full body tracking systems or hand tracking devices. Within the project an online virtual tour has been developed,

[11] EAD 2016.
[12] DCMI 2016.
[13] PAPATHEODOROU 2011.
[14] CHOI/YI 2012.

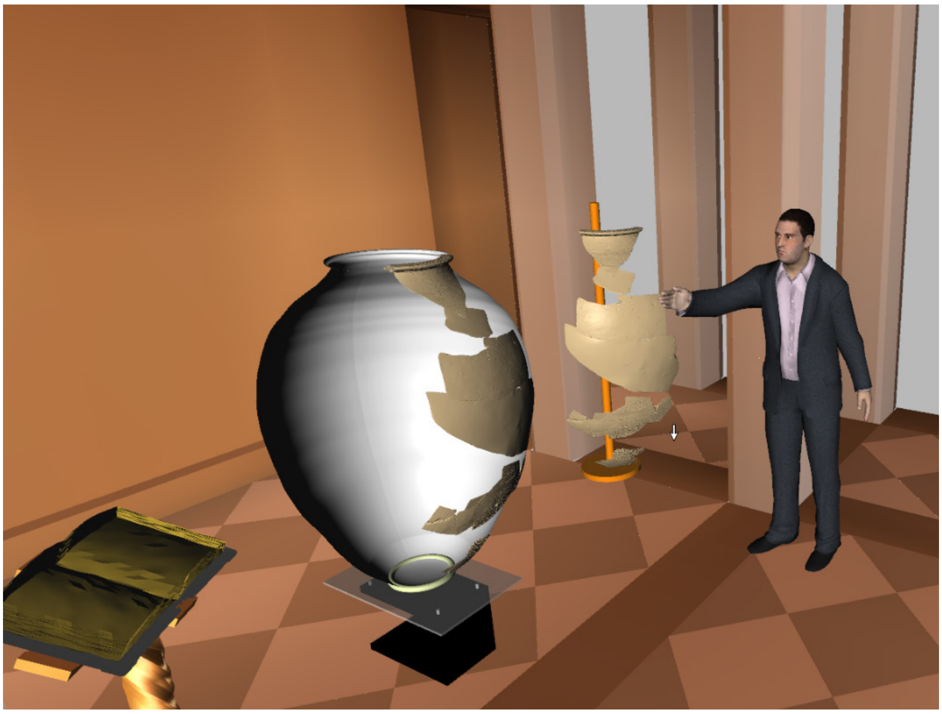

Figure 10. Virtual environment with an avatar and haptic interaction.

Figure 11. The 3D model on an artefact from the DACIT project.

Figure 12. Virtual tour application – interactive metadata for the virtual artefacts

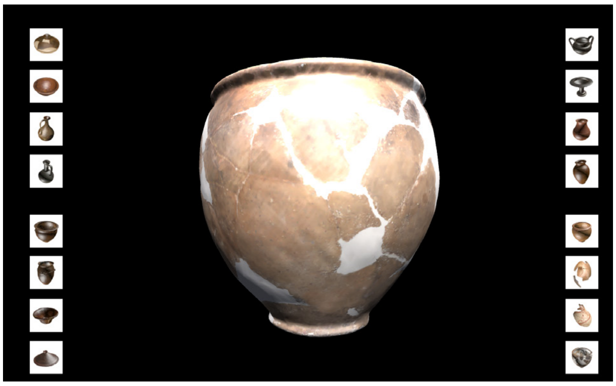

Figure 13. AR and VR application that make use of the virtual artefacts.

this virtual environment is accessible online through a web browser and this application integrates the artefacts metadata within a virtual environment (Figure 12).

Digital artefacts have also been integrated in standalone VR and AR application that are available in the museum exhibition area. Figure 13 illustrates an augmented reality application that enables real time annotation directly on real artefacts and a VR application that allows the user to interact with the digital assets using different tracking systems.

CONCLUSIONS

The methodology use to obtain 3D digital / virtual artefacts presented in this paper has been validated by numerous case studies developed by the authors. The authors introduce and define some of the properties of 3D digital and virtual artefacts that are required to obtain "high quality" digital / virtual artefacts. The quality of these models is directly influenced by the Fidelity, Traceability, Compatibility, Interactivity and Portability parameters presented in the paper.

The article introduces the term of Maximum Permissible Deviation, a term that can be used to classify the digital / virtual artefacts based on a mathematically determined parameter that can be used to numerically express the quality of an artefact. Based on this parameter, one may differentiate between digital artefacts that can be used in research activities and the ones used for dissemination activities of the cultural heritage assets. In the case study presented in this paper this parameter is presented both numerically and as a colour map applied on the digitized 3D shape of the object.

The 3D Digital preservation methodology can be used to preserving cultural heritage assets. Even if the amount of processing steps and metadata that is required by this methodology is high, the quality of the resulted 3D models is very important. The accuracy of the digitization process along with the digitization uncertainty are terms borrowed from the industrial metrology field and they are very important parameters that should define each 3D digitization process.

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