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METHODOLOGY TO CREATE 3D MODELS FOR AUGMENTED REALITY APPLICATIONS USING SCANNED POINT CLOUDS

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ABSTRACT

Precise digital documentation of cultural heritage assets is essential for its preservation and protection. This documentation increases the efficiency of scientific studies that are being carried out during the restoration and renovation process. Precise digital documentation makes use of different laser scanners technologies.

3D scanning devices usually provide a large amount of point clouds, which require long post-processing times and large storage space.

This paper presents a methodology to obtain simplified 3D models designed to remove redundant points and maintain only representative points, preserving the 3D model aspect and allowing the 3D models to be implemented in different augmented reality application on mobile devices.

The 3D mesh optimization methods that have been analyzed and compared are dedicated 3D mesh optimization software (CATIA and Geomagic Studio), open source tools such (Meshlab) and a numerical computing environment (MATLAB).

The methodology proposes a split step that can be applied to both assemblies and reconstructed objects. In this step the 3D scan is divided into components (for assemblies) or original parts/restored parts (for restored cultural heritage assets).

The efficiency and robustness are demonstrated using different 3D scanned Dacian artifacts.

KEYWORDS: laser scanning, surface reconstruction, geometric deviation, point clouds

1. INTRODUCTION

3D imaging techniques, multimedia applications, virtual reality and augmented reality applications become increasingly used in museums and galleries around the world covering a wide range of areas starting with museums dedicated to nature and natural history (Schultz 2013), human science, religious (Gkion, Patoli et al. 2011), etc.

Due to the wide availability of 3D scanners and other data acquisition systems, many 3D models are obtained through the scanning process of actual objects from the museum collections. The discrete point set obtained is then processed to a continuous surface representation such as spline, volumetric or polygonal.

The increasing availability of low-cost 3D acquisition devices has resulted in the widespread dissemination of 3D point clouds of sampled real-world objects. As a consequence, surface reconstruction from acquired 3D point clouds has become an important problem in computer graphics and computer vision (Seversky, Berger et al. 2011)

Many researches (Bruno, Bruno et al. 2010, Rua and Alvito 2011), create detailed models of historical artifacts and then create simplified versions for various virtual reality and augmented reality applications.

Creating simplified versions of 3D models is a critical task because 3D model simplification leads to a decrease in quality.

As shown in (Meftah, Roquel et al. 2010), reducing the amount of data that is used to generate a 3D model implicitly generates errors and deviations of the shape that leads to "deformed" 3D models thus reducing its quality. Level of Detail (LOD) is an indicator that can be taken as an indicator of the quality of the 3D model.

There are several approaches when creating virtual reality and augmented reality applications for museums and exhibitions that focuses on different domains such as: mixed-reality learning (Wu, Lee et al. 2013), augmented reality in a public space (Barry, Thomas et al. 2012), interactive experiences through a 3D reconstruction (Gkion, Patoli et al. 2011), virtual exhibitions on multi-touch devices, developing serious games for cultural heritage (Anderson, McLoughlin et al. 2010), low-cost creation of a 3D interactive museum exhibition (Monaghan, O'Sullivan et al. 2011), evaluating interaction in an online virtual archaeology site, etc.

The authors propose a methodology that can provide optimize 3D models for augmented reality applications. The 3D models are obtained using laser scanning and thus a large amount of data is acquired. This paper focuses on the creation of 3D simplified content for mobile devices and is focused on Dacian cultural heritage assets.

2. PROPOSED METHODOLOGY

The methodology proposed is illustrated in Figure 1.

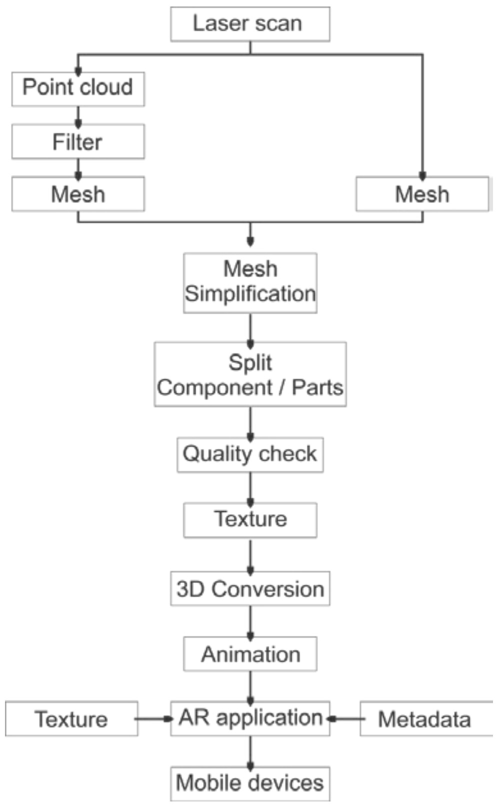

Figure 1 Methodology used to create simplified 3D laser scanned models for mobile augmented reality applications

Technologies and methodologies for the digitization of cultural heritage assets are wide-ranging. Our approach has distinct characteristics and makes use of laser scanners and mesh simplification to implement the 3D scanned model on mobile devices.

2.1 Point Cloud

The first phase of the methodology consists in the 3D scanning and the processing of the acquired data. The objects are scanned from various positions, in order to acquire the full shape. For pots and other vessels, the internal hollow part is also scanned.

There are many methods to acquire 3D data. Each method uses different mechanisms to interact with the surface or the volume of a real object.

During the 3D scanning process, there are certain problems that can appear. Most of them are related to the optical limits of certain laser scanners. Laser scanning give notoriously poor results when shiny surfaces are scanned. These surfaces tend to absorb the light beams, modifying the light environment and in some cases coating the artifacts with a thin sprayed white matte layer improves the scanning.

Using current scanning technologies uniform points clouds (distance between points is constant Figure 2.a) and non-uniform (distance between points is variable Figure 2.b), can be obtained. The proposed methodology can be used for both types on point clouds.

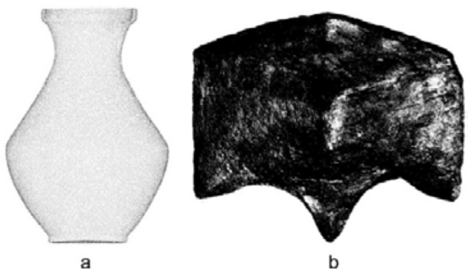

Figure 2 Point clouds type: a – uniform (ceramic vessel) and b – non-uniform (anvil)

As shown in (Savio, De Chiffre et al. 2007, Morovic and Pokorny 2012, OK Rahmat, Ng et al. 2012) scanning small and medium size artifacts can be done with hand held scanners (Figure 3.a), scanners attached to portable coordinate measuring machine (Figure 3.b) or scanners attached to coordinate measuring machine (Figure 3.c). Contact scanning can be used also, but only if the contact between the ruby ball of the touching probe and the artifact surface does not damage the artifact. (Figure 3.d)

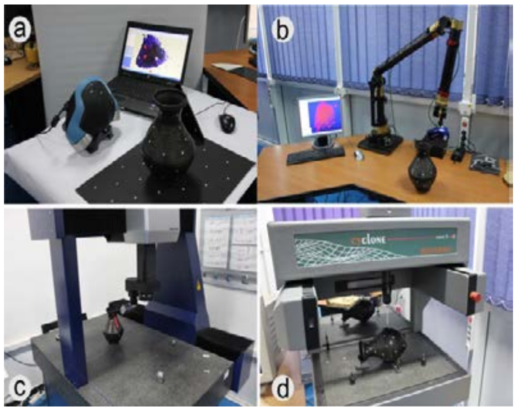

Figure 3 a - hand held laser scanner (ViuScan)
b – laser scanner Zephyr Z-25 attached to portable a CMM (Stinger II)
c – laser scanner attached to CMM(Scope-Check)
d – contact scanning (Cyclone series 2)

The main advantage of 3D laser scanning is its non-invasive mechanism and high speed/good resolution of data record.

These scanning devices usually generate dense cloud points with millions of points which require a large storage space and long post-processing time. The point cloud density is directly proportional with the accuracy of the 3D scan.

Many of the scanners available on the market provide real time automatic generation of the mesh.

The first step of the proposed methodology also involves the processing of the point cloud. This involves removing the points that represent the element that was used as a support for the scanned artifact or noise (Figure 4).

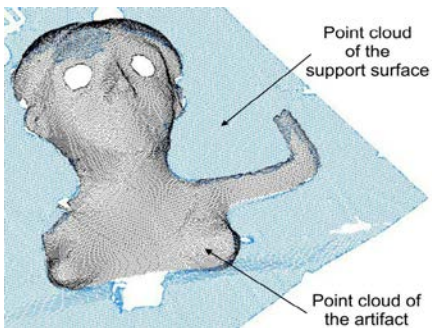

Figure 4 Removing points from Bendis scanned model

Points removal can be made in CAD software using specific tools or software that allow mathematical calculation and removal of points based on the interpretation of XYZ coordinates or RGB attributes.

2.2 *Filter*

The objective of this step is to reduce the number of points so that further processing can be done easier. The higher the number of points acquired is the higher the number of polygons will be. A higher number of polygons will approximate better the real surface of the scanned object.

There are several types of filters (Cignoni, Montani et al. 1998) developed for processing point clouds: Gaussian, uniform, median, morphological, binary, derivatives, etc. These types are being used in CAD software or individual software (e.g. Metro (Cignoni, Rocchini et al. 1998)).

Using adaptive filtering (Figure 5) the areas with a high amount of details will have a denser points cloud mesh, while flat areas or smooth curves have a much lower point density.

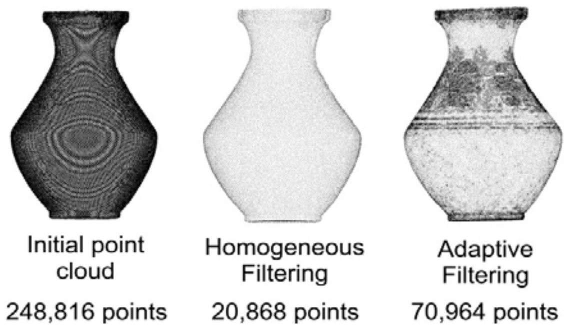

Figure 5 Example of filtering methods

2.3 *Mesh*

A mesh (M) is a discrete representation of geometric model in terms of its geometry G, topology T, and associated attributes A. Were:

G - geometry - nodal coordinates

T - topology - element types, adjacency relationships

A - attributes - color, boundary conditions, etc.

Geometrically a mesh can be classified by the shape of the geometric elements that are used to generate the mesh: triangles, polygons, quadrangles, polyhedral, tetrahedrons or hexahedrons.

AR applications commonly use polygonal and triangle meshes to reduce the number of vertices that has to be processed.

The mesh can be generated using the acquired point cloud or there are some scanning software solutions that can generate the mesh using the scanning software (VX elements, Figure 6).

Figure 6 Mesh generation in VX elements

Bernardini et al. (Bernardini, Mittleman et al. 1999) developed a Ball Pivoting Algorithm (BPA) for surface reconstruction from a given point cloud. The principle is simple: three points form a triangle if a ball of a user-specified radius touches them without containing any other point. Therefore, starting with a seed triangle, the ball pivots around an edge until it touches another point, forming another triangle.

After the mesh has been generated it requires addition processing so that the elements that are manifold, self-intersecting, small and thin can be removed.

Besides these operations that are predecessor to the surface generation process, other operations must be conducted such as: smoothing sharp edges and filling holes.

2.4 *Mesh Simplification*

Most of the simplification methods for 3D models are focuses on polygonal models because all others representations can be converted to a polygonal one.

Mesh simplification aims to reduce the number of polygons and to keep the shape as close to the initial shape, as the number of polygons is reduced the processing time decreases.

In some cases, better results can be obtained if the point clouds are heavily filtered before the mesh is generated.

The simplification of point-based 3D models should satisfy several requirements: (i) the re-sampling of the points from the large point set should be performed efficiently; (ii) the desired reduced number of output samples should be controlled; (iii) the distribution of the output samples can be controlled; (iv) the difference between the original surface and the corresponding surface after resampling should be minimized (Yu, Wong et al. 2010).

2.5 *Split component / part*

In some cases the object cannot be disassembled to allow individual scanning of each component. For artifacts that cannot be disassembled the object can be scanned as a whole and then split in the virtual environment.

In these situations the assembly components can be extracted using geometrical operations. After the components have been extracted they can be reassembled in the virtual environment. These should be reconstructed using CAD software so that the component can be completely reconstructed.

The figure below presents the case of a Dacian iron plier that has been preserved in the open position, without the possibility to close the jaws. Using CAD software the scanned model was divided into three parts as shown in Figure 7.

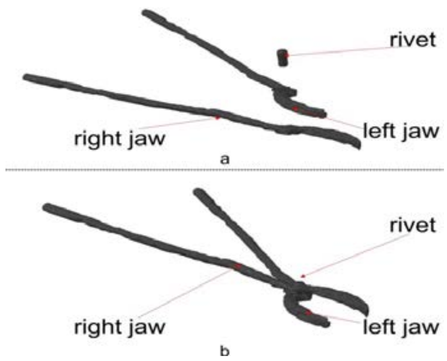

Figure 7 Dacian iron plier virtual restoration

2.6 *Quality check*

The objective of this phase is to determine the maximum deviation between the simplified 3D models and the scanning results. Different tools can be used such as: Deviation Analysis available in almost any CAD solution, Hausdorff distance, or independent solutions tools developed in mathematical computation software (MATLAB, Mathematica, etc.)

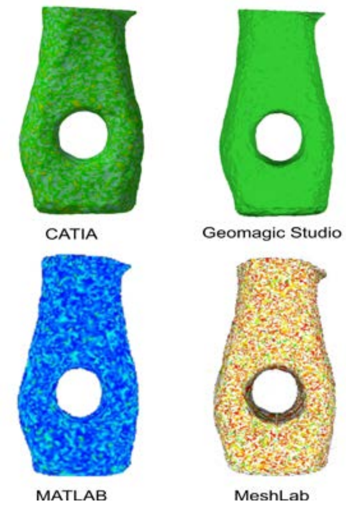

Figure 8 Deviation analyses using four different software

Figure 8 displays four deviations analysis, two were performed in CAD solutions (CATIA V5R21 and Geomagic Studio 2012) and the other two were conducted in MATLAB and Meshlab.

The 3D model is a scanned Dacian hammer, the point cloud obtained using the laser scanning had 140,780 polygons and 70,394 vertices, while the simplified model had 23,463 polygons and only 11,733 vertices.

The geometrical differences between the four methods are different but all the values are in the range of 0.003 mm for the minimum deviation and 0.002 mm for the maximum deviation.

The main advantage of CATIA is that it provides real time interaction with the analyzed object, using the mouse cursor specific points and their deviation values will be overlapped over the 3D model as shown in Figure 9.

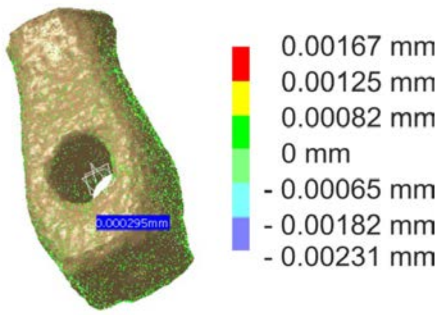

Figure 9 Interactive deviation analyses from CATIA

Figure 10 presents the deviation analyses using the Hausdorff distance tool within Meshlab. The values are similar to the one obtained in CATIA.

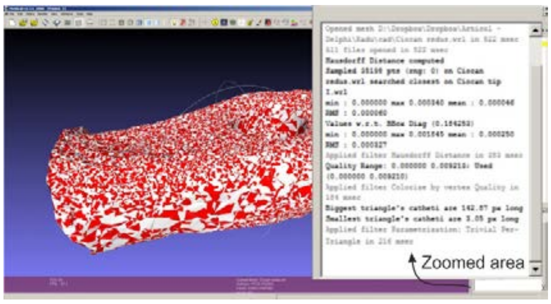

Figure 10 Hausdorff distance analysis within Meshlab

Figure 11 presents the deviation analyses using MATLAB, the values are similar to the ones obtained in the other software.

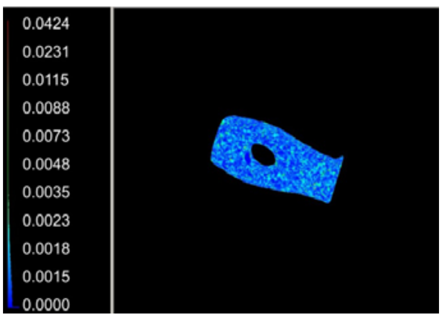

Figure 11 Deviation analysis using MATLAB

Since the deviations are so small, the authors consider that the 3D simplified model is suited to be used in augmented reality application. But if the artifact is intended to be used for different research activities, the 3D model that hasn't been optimized should be used.

2.7 Texture

Texture is the operation that offers visual esthetic skin to 3D models so that the virtual object will be similar to the real object. Texturing can be done in several ways, both in CAD software solutions and in software solutions that are used in the gaming and animation industry (3ds max, Maya, Blender, etc.). This operation can be done in two distinct moments of the methodology: right after the quality check or directly in the software to create the AR application, if the application support texturing.

2.8 3D conversion

The most commonly used format used in the AR applications are *.obj, *.vrml, *.3dxml and .dae, since these formats can contains additional information, such as texture.

There are scanning solutions that are able to provide *.obj file format directly, but the most common scanners offer standard CAD formats such as *.stl, *.igs, *.stp, *.ascii. In most cases mesh processing is done in other formats than those mentioned above, because of this 3D conversion is required to be able to use them in AR applications. 3D conversion can be done using specialized software (Deep exploration), directly in applications that were used to process the scan mesh, web converting solutions, or solutions developed in different programming software.

During the conversion of 3D scanned operation, the geometry may suffer some changes. In these cases additional operations are required to ensure the correct conversion of the 3D models. One of these operations involves the generation of a surface created on top of the initial processed mesh. This surface will be exported instead of the processed mesh.

The alternative to this solution is to generate solid bodies and then convert them to avoid geometry changes.

2.9 Animation

3D animated models provide a better visual experience compared to a static 3D model. In the case of simple objects, automatic rotation around z axis provides an overview of the object and eliminates the need for manual manipulation. In the case of complex assemblies or components, animation can provide additional information to the user.

2.10 Metadata

Metadata represents all the additional data that will be added to the 3D model to provide a more enjoyable 3D experience to the user. These can be text file, audio files, 2D images or video files. These metadata are intended to provide additional information when the user requests them, while viewing the 3D model in the augmented reality environment. The metadata helps users to better understand the virtual artifacts.

2.11 Testing on mobile device

The authors used three different mobile devices (two smartphones and one tablet) to test the augmented reality application. The VaD AR application has been created using Metaio Creator and it contains 15 different 3D scanned models.

VaD AR uses only 2D image tracking at the moment, but the authors will extend the application to use different 3D objects and environment tracking system such as SLAM instant tracking and visual search.

5. RESULTS

In order to validate the methodology a case study was conducted. A scanned Dacian pliers (Figure 12) is illustrated below, the artifact was scanned using a laser scanner that provides an accuracy of 15 μm. The laser scanning generated a point cloud of about 340.000 points.

Figure 12 Dacian pliers a- real photo b- point cloud

The first hypothesis was to reduce the number of points using filtration and then generate the mesh. The second one was to generate the mesh using all the points and then reduce it gradually using different filters and software solutions.

The table bellows (Table 1) provides the reports about the number of points and polygons obtained by the two methods.

Table 1 Simplified 3D models

Level of detail	Cloud point		Mesh	
	Vertices count	Polygons count	Vertices count	Polygons count
90%	157,013	325,707	156,758	313,180
80%	135,652	282,458	135,819	271,595
70%	118,721	247,152	118,844	237,647
60%	101,990	211,843	101,867	203,696
50%	84,866	176,537	84,892	169,748
40%	68,007	141,232	67,916	135,799
30%	51,088	105,923	50,938	101,849
20%	33,972	70,616	33,961	67,900
10%	16,969	35,308	16,983	33,950

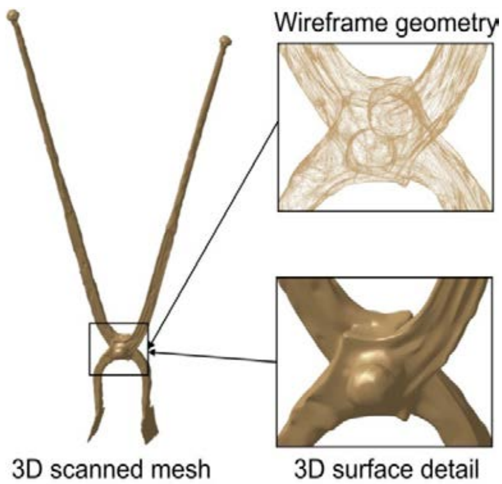

Figure 13 Information regarding the scanned Dacian pliers

In order to check the quality of the 3D simplified models (Figure 13), the simplified meshes were compared with the initial mesh that was generated using the initial data acquired by the laser scanner.

Table 2 Simplified 3D models

Level of detail	MATLAB		CATIA V5	
	Min	Max	Min	Max
90%	-0.0010	0.0011	-0.0011	0.0010
80%	-0.0028	0.0021	-0.0021	0.0027
70%	-0.0040	0.0044	-0.0043	0.0039
60%	-0.0097	0.0073	-0.0071	0.0094
50%	-0.0133	0.0118	-0.0114	0.0128
40%	-0.0172	0.0243	-0.0234	0.0166
30%	-0.0301	0.0340	-0.0327	0.0290
20%	-0.0477	0.0554	-0.0533	0.0459
10%	-0.0972	0.1404	-0.1005	0.0935

The results from CATIA V5 R21 and MATLAB are presented in the table 2. The values obtained are similar.

But if we compare this deviations with the ones presented for the digitized hammer in Figure 9, we see that the deviations are constantly increasing very rapidly along with the 3D model simplification.

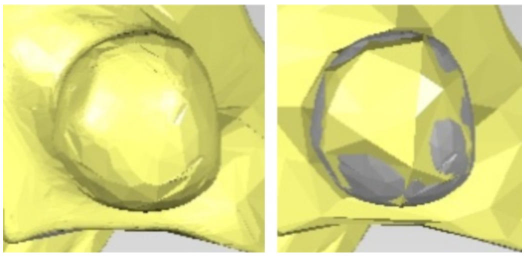

Figure 14 Rivet visual deviations

The highest deviations are located near the round rivet that keeps the two pliers jaws together. The difference between the original mesh and the 10% simplified model can be seen in Figure 14. The rivet roundness has been deformed.

A balance between the degree of fidelity of a 3D model details and file size must be made, so that the 3D model can be loaded fast on mobile devices such as smartphones or tablets.

Even more simplified 3D models have been created such as the LOD 1% (Figure 15). This 3D model has only 1,701 vertices and 3,396 polygons. Because this object has been simplified too much, many details are missing.

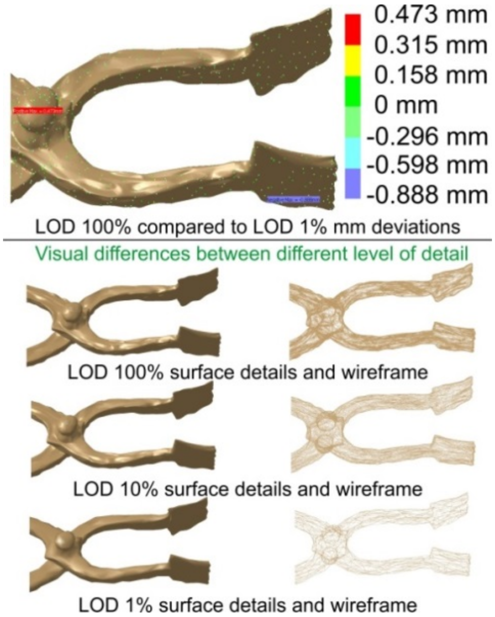

Figure 15 Optimized 3D models surfaces

The table below presents the file size in KB for three common 3D file formats, the stereolithography (*.stl), the wavefront technologies (*.obj) and the 3DVIA (*.3dxml). These files describe the surface geometry of a 3D model. The *.stl file format has no texture, while *.obj and *.3dxml can support texture or other common CAD model attributes. (Table 3)

The most common 3D file format for mobile devices is the *.obj file format.

Recently augmented reality applications have started to use *.fbx files, the main advantage of this file format is that the animations are embedded within the same file.

Table 3 File format and file size in KB

Level of Detail	*.STL	*.OBJ	*.3DXML
LOD 100%	16,577	34,256	4,862
LOD 90%	14,929	30,361	4,394
LOD 80%	13,262	26,774	3,921
LOD 70%	11,604	23,189	3,449
LOD 60%	9,947	19,606	2,970
LOD 50%	8,289	16,272	2,493
LOD 40%	6,631	12,977	2,010
LOD 30%	4,974	9,683	1,528
LOD 20%	3,316	6,389	1,043
LOD 10%	1,658	3,096	558

The simplified 3D models have been tested on three applications. Two applications are free to use from Google play store: 3D AR and AndAR. The other application is VaD AR (Figure 16).

Figure 16 VaD AR augmented reality application

The table below (Table 4) presents the initial loading time (in seconds) of the 3D simplified LOD 10% model of the Dacian pliers using different AR applications.

Table 4 LOD 10% 3D model of the Dacian pliers average loading time (seconds) on mobile devices

Mobile device	3D AR	And AR	VaD AR
Asus TF300T	14	15	12
Samsung Galaxy Note II N7100	12	13	11
Samsung I9300 Galaxy S III	15	16	15

After the models are loaded the user can focus the camera on different markers and the application will display the correct model instantly with no loading time.

A total of 15 simplified 3D models have been added to the VaD AR application. The mobile devices can load the proper models and overlap them correctly. In order to make the application viable for a much higher amount of 3D models, the management system within the application requires more fine-tuning.

5. CONCLUSIONS

Creating simplified 3D models from data acquired with different laser scanning techniques is not a simple task. The simplification method needs to be carefully analyzed so that the simplified model deviation analyses are not high.

The methodology presented in this paper can be used to obtain simplified 3D models that can be loaded into commercial and custom made AR applications.

Reducing the polygons number of a 3D model entails a lower level of detail, and in some cases a loss of detail of the scanned object. Polygon reduction can be done in different CAD software application or in custom applications created specifically for this purpose. After testing two CAD software solutions (CATIA V5, Geomagic Studio 2012) and a software solution that uses a Gaussian reduction algorithm implemented in MATLAB, no significant differences have been recorded between the deviation values of the 3D optimized models.

The VaD AR application with 15 simplified 3D models and 15 different markers has been presented with the occasion of the Night of Museums cultural event in Cluj-Napoca. The public enjoyed interacting with 3D scanned artifacts using augmented reality.

6. ACKNOWLEDGMENTS

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