

VIRTUAL PIECE RECONSTRUCTION IN CASE OF CYLINDRICAL GEOMETRY

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ABSTRACT

As time passing the need of immortalization and digitization of ancient pieces is continuously rising. On this basis a method was developed to chronicle objects and a remake of a 16th century piece was created as part of the research. The original geometry and the visualization of a fractioned vase were carried out in CAD system which allows a more precise enquiry of the piece. This article gives an overview, which introduces a complex method of creating real body from a scanned point cloud, on which different virtual simulations can be applied. A method for creating a surface texture with the capability of displaying photo-realistic virtual models was eventually developed. The process itself is innovative and novel in many means; it can not only be used in various circumstances, but it has a perspective of assisting manual restoration procedures as well.

KEYWORDS

Geometry reconstruction, texture mapping, visualization method

NOMENCLATURE

<i>3D</i>	three-dimensional
<i>CAD</i>	Computer Aided Design
<i>gDens</i>	horizontal and vertical distance between the points
<i>g -</i>	number of the levels, the program calculates from <i>gDens</i> and the parameters of the object
<i>zLevel</i>	the value of the <i>z</i> coordinate on a defined level
<i>zMin</i>	the lowest <i>z</i> level/the first level

<i>zMax</i>	the highest <i>z</i> level/the last level, the levels evenly positioned between <i>zMin</i> to <i>zMax</i>
<i>idxMax</i>	exact <i>zLevel</i> and the half of the distance of <i>gDens</i>
<i>idxMin</i>	exact <i>zLevel</i> subtracting the half of the distance of <i>gDens</i>
<i>idxP2Xsorted</i>	points with the largest coordinate „ <i>x</i> ”
<i>P2XYselected</i>	chosen point by coordinate „ <i>x</i> ” and „ <i>y</i> ”

1. INTRODUCTION

In the context of restoration and preservation of ancient pieces arises the need of reconstructing broken parts or making virtual exhibitions for a ceaselessly increasing number of spectators. Such reconstructions are mainly used as scientific measures to remodel objects in the haste of preserving original pieces. Of course it could be used for touristic purposes as well, since a wholly-reconstructed object is always more interesting for laics than bare pieces in disorder. There are tries for automatic reconstruction of incomplete archaeological pieces refers to Antonio Adán's research [1].

The principal motivation of the research is based on a real and general problem of museums. Experts from Hungarian Museum of Applied Arts highlighted their main problems with the recent opportunities of restoration and piece digitalization which revealed new demands of a new technology. There are pursuits in the European Union to have museums' treasures digitalized and available for public via internet. The European Commission found Europeana.eu internet portal which provides a virtual library and great opportunity for museums. Although

international support swept across Europe the quality of these digital copies is not satisfactory in all areas of museums' activity.

Numerous techniques are developed for reconstructions but none of them combined the geometry and the visualization process as precise as this method tries. For instance Akemi Gálvez and Andrés Iglesias' research gives an overview on geometry reconstruction from point clouds using NURBS surfaces [2]. However there are other ideas for rebuilding surfaces. For instance Martin Webera makes geometry reconstruction using photographs [3]. All visualization processes try to correct the distortions what the camera makes during the photography according to Shawn Becker and V. Michael Bove [4]. The reconstruction of an ancient globe is a good example for regular shapes' surface recovery but it isn't a universal idea [5]. Elaboration is also an unsolved problem in texture projection [6].

The developed method is a new and simple reverse engineering technique. The process gives a complex solution to create an accurate solid model and a perfect visualization from a real object that has previously been 3D scanned. The method is considered innovative for it combines the remakes of

engineering software's colour data detection that has previously been used. An essence of the method will soon be introduced. Further automation is needed in order to make the usage of the process suitable for every kind of pieces.

The reconstruction process can be divided into two parts: geometry reconstruction and realistic visualization of the model, however, these two steps are not completely independent from each other. The first step can only be carried out by using scanned points of the existing model, while the second step is based on the geometry and can be prepared along with the first one. Still the abovementioned division is proved to be useful.

The following flowchart represents the main steps of the reconstruction method (Figure 1).

2. THEORETICAL PRESENTATION OF THE PROCESS

2.1. Recording data

Initial data digitalization is needed to begin the reconstruction process. A real object was used as the source of all detected data acquired from the mapped points of the laser scanner. During the research an ancient piece was appropriated to present this method. To simplify the presentation of the process a cylindrical object was used.

A 3D laser scanner perceived the surface of the piece to get the accurate points of the inner and the outer faces of the original model. Otherwise the points can be reached from photo data but laser scanner detection is more reliable.

The density of the points is important in the process to evince all the surface finish and the accurate geometry. Preciseness is dependent on the distance between the points. It basically means that more frequently used points make better result. The differences between surface finishes on a same area of the surface may have some effects on the detection but it is easily established on the scanned point cloud. Extra points are easily perceptible and reparable into the scanned result. Incorrect and unnecessary points are erased from the point cloud automatically or manually.

Meanwhile the scanning process, photo data recording is needed in studio environment to create the texture. All the settings of the photographing are have to deliberately be predefined and fixed to an accurate solution. The object is placed on a turning

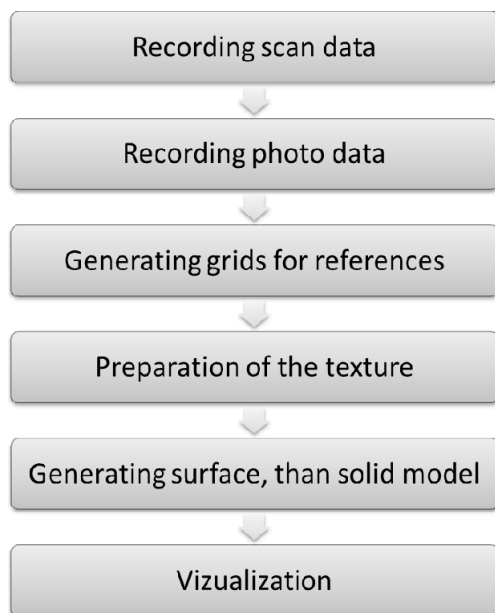


Figure 1 The steps of the developed process

sections in a simple and realistic manner which has not yet been used this accurately. In fact the process is a form of undistorted digitalization technique which is slightly more than 3D scanning. The visualization is based on photograph distortions and gives relevantly better result compared to reverse

table which is suitable for precise rotation by measuring the rotating angle. The piece is rotated about the axis and photographs are taken after every equal angles of rotation. The process can be more precise with denser division of the angles. The aim is to take photographs of the same view using exactly the same light and environment settings.

After the photographing method pictures are generated on computer from digital negatives. Subsequent photo corrections are needed to reconstruct the original colors and directions in every digital picture. Absolute grey card is used as reference to original colours in order to neglect accidental effects of the camera and artificial lights.

2.2. Geometry reconstruction

The purpose is to create a program, which generates NURBS (Non-Uniform Rational Basis Splines) surfaces. They are referred to as the coordinates of scan points. The main idea was to create points on regular arches equidistant around the scanned point cloud. By modifying the point coordinates of on the arches adapted to the coordinates of the point cloud outward surfaces are carried out of the scanned object. As a result by applying this distortion the same features are appeared on the virtual model as on the original piece.

Many different approaches exists in the field of geometry reconstruction techniques [7, 8], but this paper is limited to the usage of arches in case of cylindrical objects as it was previously indicated.

The generating process is controlled by an algorithm, which uses all the detected points sequentially and makes calculations one by one to replace the points on the arches with the selected original scan data.

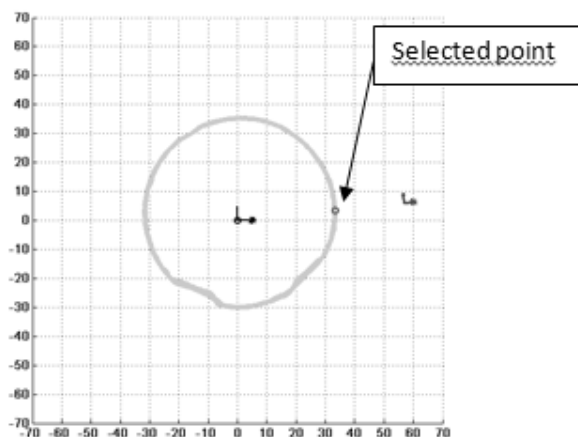


Figure 2 A selected point

The base of the process is given by this distortion.

The scanned data usually provides the base for the surface reconstruction [9]. In this method the modified surface generates the final solid geometry.

The operation of the algorithm is presented in the following few illustrations step by step:

Point selection is made as the first step (Figure 2).

Point selection on a same level is used with every chosen point. The required accuracy is depended on the number of the levels (Figure 3).

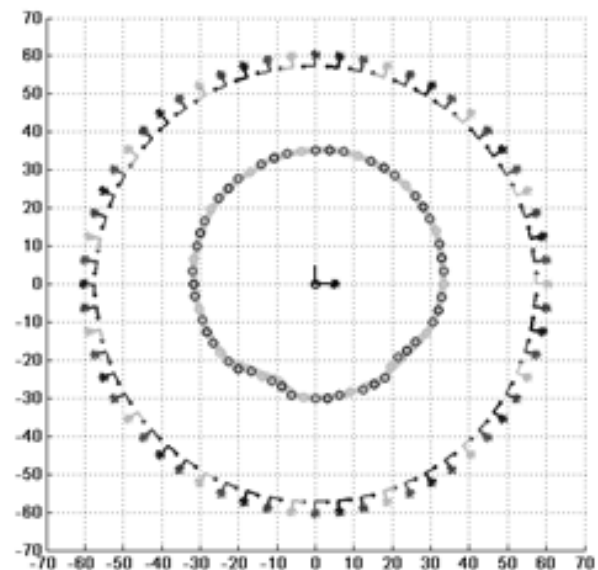


Figure 3 Selected points on a chosen level

Every chosen scan point is used as the reference of the distortion method (Figure 4).

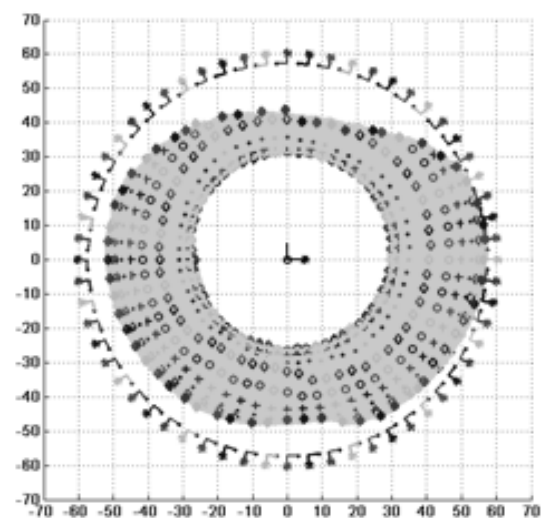


Figure 4 How the program makes the narrowing calculations

The same calculation is repeated while the algorithm runs (Figure 5). The next figure presents the process.

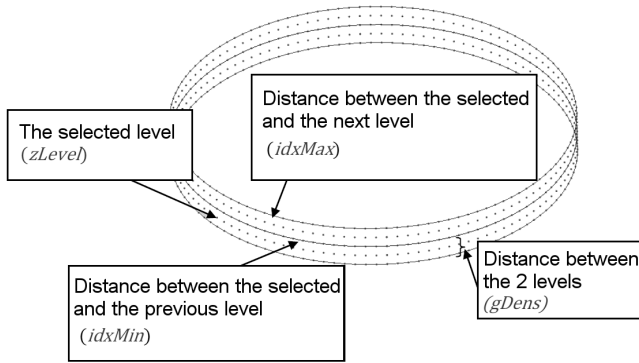


Figure 5 The tested area

All these steps need programming abilities. Homogeneous coordinate transformations are the base of the transformation method to find the location of the correct scan point. Homogeneous coordinate transformations used to modify the points:

$$T_1 = \begin{bmatrix} \cos(\theta) & -\sin(\theta) & t_x \\ \sin(\theta) & \cos(\theta) & t_y \\ 0 & 0 & 1 \end{bmatrix}$$

$$T_2 = \begin{bmatrix} \cos(\theta) & \sin(\theta) & 0 \\ -\sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & -t_x \\ 0 & 1 & -t_y \\ 0 & 0 & 1 \end{bmatrix}$$

$$t = \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix}$$

Location of the correct scan points:

$$idxMin = [s(:,3) \geq zLevel - \frac{gDens}{2}]_1$$

$$idxMax = [s(:,3) \geq zLevel + \frac{gDens}{2}]_1$$

$$idxP2Xsorted = [P2Xsorted(:,1) \geq -1 \cdot radius]_n$$

$$P2XYselected = \begin{bmatrix} P2Xsorted(1) \\ \vdots \\ P2Xsorted(idxP2Xsorted) \end{bmatrix}$$

2.3. Visualization

To prepare a realistic texture, distortions are needed. This is necessary because the texture is based on the side view of the rotated photographs. In the developed method, a flat pattern is needed with linear matching on the cylindrical surface. Sphere surface

texture is created in the article of Alberts [9]. Later in the process this cylindrical face will shrink on the previously gained data of the point cloud.

After the photo data registration photographs are generated from the digital negatives. During this step sensor noise was attended, the Anti-Aliasing filter, the MOIRE effect and the colour temperature. These inaccuracies may have an effect on the generated pictures, but they are not relevant in this case; they may need to be checked during the actual process, but they were neglected during the calculations.

The following flowchart represents the main steps of generating texture (Figure 6).

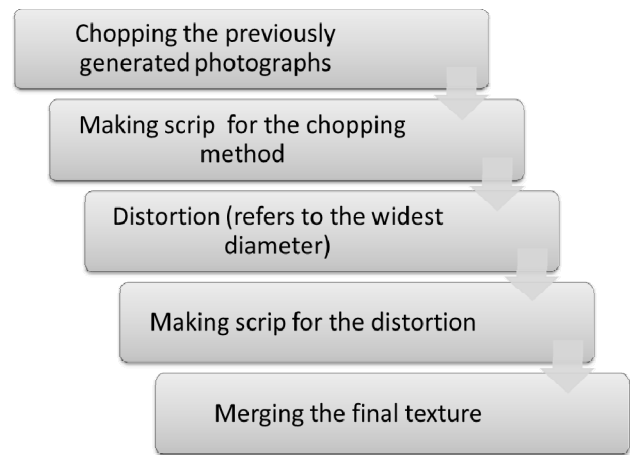


Figure 6 The process of generating texture

At the first step slices are chopped from the photographs. A previously selected area is chosen by the total height and diameter of the object. These slices are distorted in horizontal way from the generated photographs based on the diameter of the vase. All of the calculations are based on the pixels of the photographs. The distortion is made on all slices in selected diameters. The lamination is referred to the largest diameter of the vase. Then the slices are merged by panorama-maker software in linear merge type. The transparency is set to generate a more realistic physiognomy.

Original studio settings are finally to be reconstructed in the render module of the CAD software. All the previously measured dimensions are remodelled and the object is put in the original place as in the photo studio. In this environment rendered pictures and videos are made from the solid model. All the settings of the material and the lightings are adjusted until the same visage what can be seen the originally taken picture.

3. CASE STUDY: RECONSTRUCTION OF A 16TH CENTURY VASA

3.1. Recording scan data

In the beginning of the reconstruction laser scanner is used for point data detection. The real object was used as the source of the research. A 16th century vase is used to introduce the process. The cylindrical surface of the ancient piece is scanned with 3D laser scanner. The inner and the outer faces are detected in rotary scan type. During the substantial demonstration the outward scan points are enough to create the correct faces. The suiting of the inward faces is potential.

The density of the points is important. The points are detected in 0,2 [mm] x 0,2 [mm] density (Figure 7). The brightness of the coated areas didn't have effect on the final result of the scanning. The difference between bright (coated) and matt finish areas of the surface may have an effect on the detection but it will easily establish on the scanned point cloud. The scanned point cloud was homogeneous and precise. Extra points were erased from the borders and the overlapping areas.

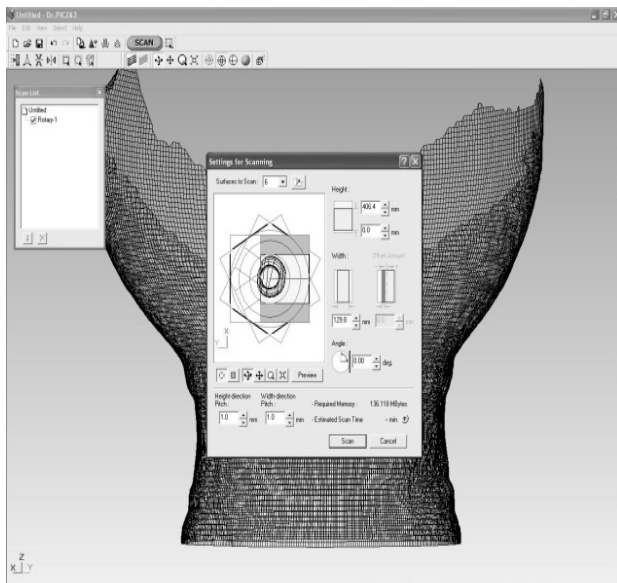


Figure 7 Computer presentation of the point cloud and the settings of the 3D laser scanning

3.2. Recording photo data

The usage of the photo data is a cost effective way in the reconstruction of the ancient pieces [10]. In this method the photographs of the vase play main role in the visual reconstruction as well. After the scanning process, photographs are made in studio environment. The settings of the photographs are

calculated previously and measured precisely. The vase is placed on a turning table which is suitable for precise rotation and able to level. The piece is rotated about the axis normal to the table and photographs are taken in every 10 degree. After the works the results are 36 different photographs from the same view with the same light and environment settings. Photographs are generated from the digital negatives (.raw format to .jpg). Corrections are needed on the generated photographs to reconstruct the original colours and directions in every digital picture. Absolute grey card is the reference of the original colours (Figure 8). Other previously mentioned effect didn't make any inaccuracy needed to be corrected.



Figure 8 The positioned in the studio environment and the absolute grey card for the subsequent colour corrections

3.3. Geometry reconstruction

Geometrical and visual data unite during post processing. Post processing is able to manage scan data and fit continuous surface on it. During the fitting the visual data processed as texture. This provides the complexity of the method.

In this step the process uses unique strategy for post pre and post processing which indicates the need of a special program because commercial CAD systems' abilities are not enough to perform in the required way. Reprogramming of existing CAD software is more suitable for the previously invented strategy. As a result reconstruction of the real body of the vase is started in parallel using CAD software called PTC Creo.

First of all manipulation of the point cloud is needed along the borders to neglect extra parts. Afterwards cylindrical faces are generated with points on regular arches on previously specified distances (Figure 9). They will lead the narrowing method. During the

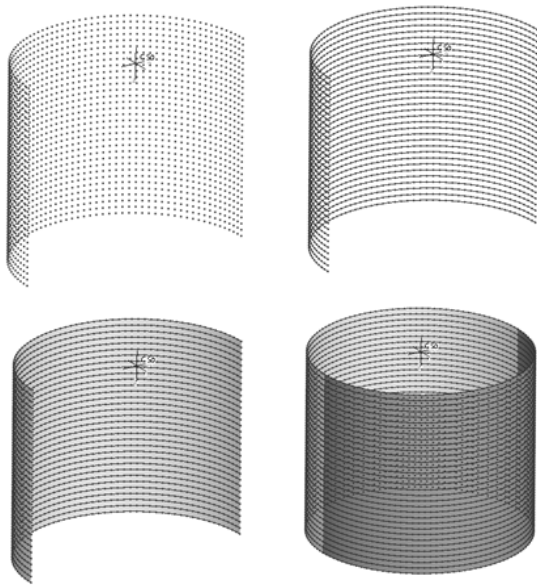


Figure 9 The cylindrical faces with the generated points on the arches

research 34 arches were selected as a reference of the cylindrical surface.

After the cylindrical surfaces are created around the point cloud with the selected referring points the algorithm starts the narrowing method point by point. The points on the surfaces are migrated to the selected points on the scan data.

The NURBS surface was reconstructed in the CAD system using the point data coordinates gathered from the MATLAB program. A .txt formatted file of the counted coordinates was then read into the CAD system which generated the surface automatically. MATLAB was used to apply homogeneous

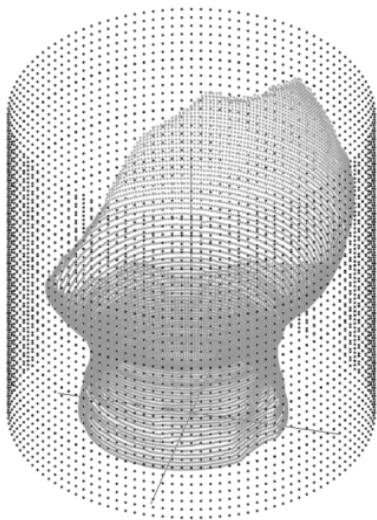


Figure 10 The point cloud and the generated points

coordinate transformations. Scan points were modified into observer coordinate systems by homogeneous coordinate transformations. The program selects the nearest scan point from the observer coordinate system level by level to transform the previously generated cylindrical surface into the outward face of the vase (Figure 10).

On those parts where scan data is not found the algorithm follows the last detected point and repeats it until the last examined level. This makes the end of the program (Figure 11).

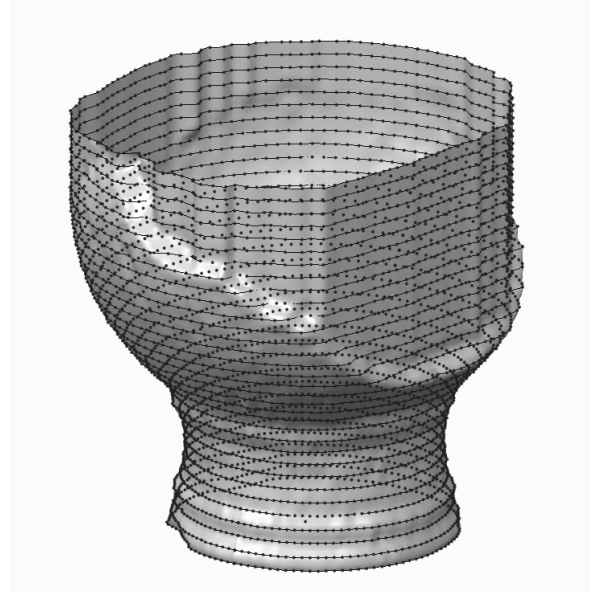


Figure 11 The modified generated surface and points on the point cloud

The linear texture is suited on the generated surface adapting to the half parts of the model and the scanned geometry (Figure 12). Ultimately the final surface is generated by narrowing the cylindrical surface on the point cloud using as a reference the points on the previously created arches. Then the extra parts of the surface which extends over the border of the point cloud were cut (Figure 13). With this method a surface model of the vase is created.

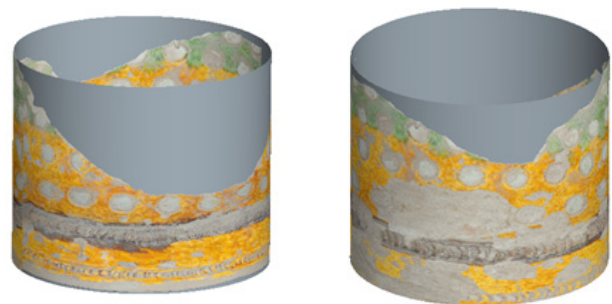


Figure 12 The generated texture placed on the cylindrical surface

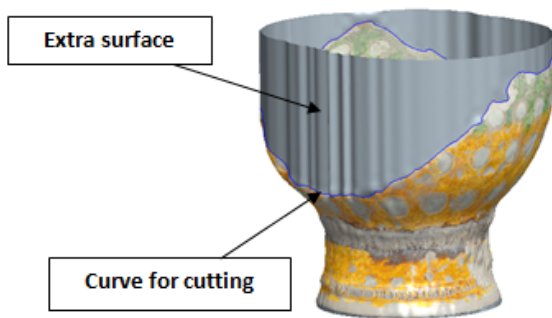


Figure 13 Extra parts of the surface have to be divided and removed after the narrowing method



Figure 14 The reconstructed outward surfaces of the vase

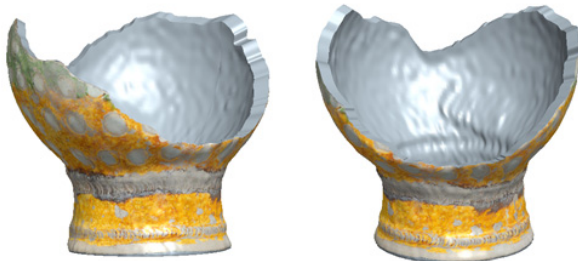


Figure 15 The solid model of the vase after the thickening

Solid model was generated by thickening the surface.

After the cut the outward faces represented the surface of the original model (Figure 14). In this method the inner scan data isn't used. The solid model is generated by thickening (Figure 15).

3.4. Visualization

After the geometry reconstruction visualization is needed to present the outward spectacular parts of the vase and to give a natural presence of the ancient materials.

Distortions are needed to create a flat pattern which can be fit on the cylindrical surface as a decal before the narrowing distortions. Modifications are necessary because the texture is based on the side view of the rotated photographs. The distortions are indicated by this process according to the diameters of the piece. Levels are selected to make references for the horizontal stretching.

First slices are cropped from the photographs. Every slice is created with the same pixel coordinates and measurement. All the 36 slices are distorted according to the measured diameter (in pixel) at each selected level. On those places where the diameter of the vase is larger the deformity is more conspicuous (Figure 16).

Using these modified slices the whole texture is merged in panorama maker software to get a linear merged flat pattern. According to the solid model the decal is cut into two parts adapting to the half spaces. This dividing process is based on calculations with the pixels of the texture referred to the main views in the software.

The transparency is set in those places where the cover of the vase is pitted. On those places where the coated areas are missing the original material of the vase appeared. It is helpful to generate a more



Figure 16 Distortion of the slices and the flat pattern of the texture

realistic physiognomy (Figure 17).



Figure 17 The textured solid model. The uncovered parts appear on the texture.

At the end of the project the original studio settings are reconstructed in the render module of the PTC Creo, called Photolux. All the previously measured dimensions were remodelled and the vase was put in the exact place as it was in the studio. In this environment rendered pictures and videos were made from the solid model (Figure 18).

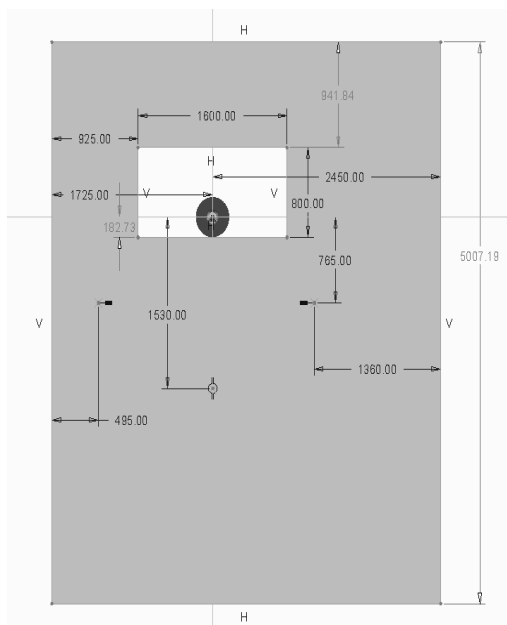


Figure 18 The reconstruction of the photo studio in CAD system

The virtual vase is placed on a dais and in the settings all the previously measured amounts are re-established (Figure 19). The clay parts of the piece got matt finish and the coated ones got bright. The reflections of the previously set lights (soft boxes) on

the vase showed similar reflections than the original photographs (Figure 20).

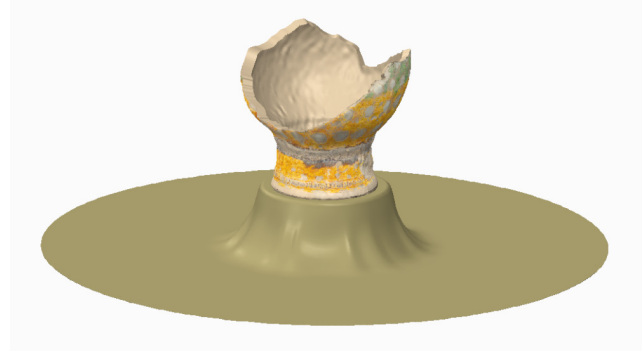


Figure 19 The model during the rendering process

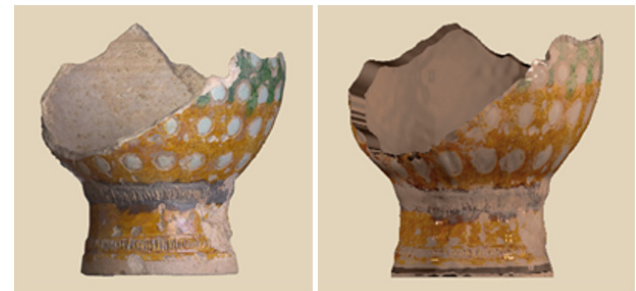


Figure 20 The original and the rendered picture

4. CONCLUSION

Motivation of the research originated in a global aim to manage the museums' relics together and set up a virtual inventory of all their pieces. Moreover it would help the restoration process. According to the previous research in the topic unmined fields appeared among the quality of the final models. In general the integrated management of visualization isn't appeared in any case of research. Solid models require continuous surfaces to generate; and the post processing of the detected scan and visual data needs complex programing which haven't used before.

Obvious simplifications were made in this representation of the method. The aim is to eliminate these in order to extend the technique for free-form surfaces. Development of resolution would provide better results on the geometry and on the visualization as well. Picture distortion indicates the biggest deviation from the original model; this result preannounces the need of another photography process which able to detect the alternation of the surface.

As a consequence of the method validations were made relative to the solid model to substantiate the results on the geometry and the texture mapping. (Figure 7) Verifications were created to certify the relations between the scanned point cloud and the

solid geometry as well as the photographs with the rendered pictures.

The usage of the technique is very extensive. The reconstructed pieces can be demonstrated in virtual exhibitions where the user can see the objects placed in original environment during a walk through ancient or medieval times. It will be useful not only in restoration but in prosthesis and industry as well.

On the other hand missing parts could be supplement to help and simplify the restorations. Exact calculations can make to create the perfect replacement for any pieces. Computer aided simulations on the virtual models could detect weak and critical parts to avoid further damage.

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